Reply to Anonymous Referee #3

We thank the reviewer for the careful reading of the manuscript and helpful comments. We have revised the manuscript following the suggestion, as described below.

General comments

This manuscript presents a WRF-CHEM modeling study using to evaluate the contribution of regional emissions to the air quality in Beijing during a summertime pollution episode using the FSA analysis. This study comes timely as there have been debates over whether local emissions play the major contribution to the air pollution in Beijing. The methodology is sound, and the results are well presented and organized. I would recommend it for publishing with a few minor revisions.

Specific comments

1 Comment: P1 line 27-28 and p21 lines 462-463, it is a big jump to extrapolate the results from an episode to the whole summer season. You need to prove that the episode studied is representative of the summertime situation in Beijing. In addition, air quality"primarily determined by the trans-boundary transport" may only be applied to $PM_{2.5}$, not O_3, since background O_3 accounts for 46% of the afternoon O_3 (line 338). Maybe I have a misunderstanding in here, which is related to the comment below.

Response: The description of the study episode has been added in Section 2.2 as follows: *"The maximum of O_3 concentration is higher than 350 μg m^{-3}, and the maximum of $PM_{2.5}$ concentration can reach a high level exceeding 150 μg m^{-3}. SI-Figures 1a-c show the daily averages of the temperature, relative humidity, and wind speed in Beijing during the summer of 2015. The minimum air temperature is 18.7 ^{o}C, and the maximum air temperature is 40^{o}C during the summer, with average of 25.7 ^{o}C. The average relative humidity is 63.8%. The southeast or southwest wind is prevailing over NCP due to the influence of East Asian summer monsoon (Zhang et al., 2010), with the average wind speed of 5.6 m s^{-1} in the summer of 2015. During the study period, the average temperature, relative humidity, and* *wind speed are 28.4 °C, 51.7% and 6.3 m s^{-1}, respectively, indicating typical summertime meteorological conditions. During the summer of 2015, the average $PM_{2.5}$ concentration is 56.1 μg m^{-3} and the average O_3 concentration in the afternoon is 216.4 μg m^{-3} (SI-Figures 1d-e). The high O_3 and $PM_{2.5}$ event occurs frequently during the summertime of 2015, so the study period can well represent the summertime O_3 and $PM_{2.5}$ pollution in Beijing, and provides a suitable case for observation analyses and model simulations to investigate the effect of trans-boundary transport on the summertime air quality of Beijing. "*

We have changed "primarily determined by the trans-boundary transport" to "*generally determined by the trans-boundary transport*", considering the important O_3 contribution of background in the abstract.

2 Comment: Confusions on some concepts. To my understanding, the "trans-boundary transport" term refers to the transport of regional anthropogenic emissions (i.e., $\boldsymbol{f_S}$), and it does not include "background" ($\boldsymbol{f_0}$). Am I right? In addition, in the FSA analysis, which term include the biogenic emissions? Are the interactions between anthropogenic and biogenic emissions accounted? Does the trans-boundary transport include the impacts of biogenic emissions?

Response: The "trans-boundary transport" defined in this study does not include the contribution of background ($\boldsymbol{f_0}$). In the study, we have not differentiated the individual effect of anthropogenic and biogenic emissions, and the biogenic emissions have been regarded as background considering that the biogenic emissions provide natural O_3 precursors and cannot be anthropogenically controlled.

3 Comment: In both the abstract and summary sections, besides considering the uncertainties in emissions and meteorology, simulations for more pollution episodes should be addressed to "evaluate trans-boundary transport contributions to the air quality in Beijing for supporting the design and implementation of emission control strategies".

Response: We have added the sentence in the Conclusion: "*In addition, simulations for more pollution episodes should be investigated to evaluate the contribution of trans-boundary* *contributions to the air quality in Beijing for supporting the design and implementation of emission control strategies.*".

4 Comment: P2-3, lines 55-56, "daily average of up to 110...", daily average or daytime average?

Response: According to Wang et al. (2016), the maximum O_3 concentration during the polluted episode in summer of 2014 can exceed 300 μg m^{-3}, so it should be "daily average" in lines 55-56.

5 Comment: P5 lines 111-113, more descriptions of the episode are needed, including meteorological conditions, which may help to add information whether or not the episode is representative of the summertime air pollution in Beijing. Also, what does the "mean daily" mean here? episode average?

Response: Please refer to the response of Comment 1. The "mean daily" can be interpreted as episode average.

6 Comment: P9 line 191-193, the differences in CO, SO_2, NO_x and $PM_{2.5}$ between 2013 and 2015 are attributed solely to the emission change. Are the meteorological conditions similar between these two periods?

Response: We have clarified in Section 2.5: " *The rainy days during summertime in Beijing are 43 and 46 days in 2013 and 2015, respectively, showing the similar meteorological conditions between the two years. Therefore, in general, the air pollutants variations between 2013 and 2015 can be mainly attributed to implementation of the APPCAP.*"

7 Comment: P10-11 Section 3.2, $\boldsymbol{NO_3^-}$ and $\boldsymbol{NH_4^+}$ are shown in Figure 3, but there are no discussions or descriptions of these two components. Point comparisons may also contribute to the biases.

Response: We have added description of $\boldsymbol{NO_3^-}$ and $\boldsymbol{NH_4^+}$ as the referee suggested in Section 3.1.2 as follows: *"The model reasonably well reproduces the observed temporal* *variations of SOA, nitrate, and ammonium, with IOAs exceeding 0.75. The model also replicates well the peak concentrations of SOA, nitrate and ammonium at the rush hour, but generally underestimates the measured SOA, nitrate, and ammonium concentrations, with MBs of -1.1 μg m^{-3}, -0.7 μg m^{-3}, and -0.5 μg m^{-3}, respectively. For nitrate and ammonium aerosols, the underestimation occurs mainly on 8 July 2015."*

8 Comment: Figures 10 and 11, regarding the contributions from total emissions, emissions from Beijing, and emissions outside Beijing. As I understand, the last two terms are calculated as $f'_B + f'_{BS}$ (or $f_{BS} - f_S$) and $f'_S + f'_{BS}$ (or $f_{BS} - f_B$), but how is the first term (contribution from total emissions) calculated? $f_{BS} - f_0$? or sum of the last two terms? Captions in Fig. 10 and 11 are a bit of confusing: f_B, f_S, and f_{BS} represent simulation results, not contributions.

Response: We performed four simulations in this study: (1) f_{BS} with all the emissions; (2) f_B with Beijing emissions alone; (3) f_S with non-Beijing emissions alone; (4) f_0 without all the anthropogenic emissions. Therefore, the contribution of only-Beijing emissions is represented as $f_B - f_0$ (f'_B), and the contribution of the non-Beijing emissions is represented as $f_S - f_0$ (f'_S). The pollutant level in Beijing is determined by the contribution of only-Beijing emissions (f'_B), the trans-boundary transport of non-Beijing emissions (f'_S), emission interactions (f'_{BS}, $f_{BS} - f_B - f_S + f_0$), and background (f_0).

We have changed the captions of Figures 10: *"Temporal variations of the average near-surface (a) O_3 and (b) $PM_{2.5}$ concentrations from f_{BS} with all the emissions (black line), f_B with Beijing emissions alone (blue line), and f_S with non-Beijing emissions alone (red line) in Beijing from 5 to 14 July 2015."*

9 Comment: P15 line 337, 45.6%, but in table 2, the number is 46.1%.

Response: We have changed "45.6%" to "46.1%".

10 Comment: Table 3 is shown and is not discussed.

Response: We have changed the original Table 3 to Table 4 in Section 3.2.2 in the present study. We have discussed as follows: "*Table 4 shows the average $PM_{2.5}$ contribution in Beijing from only-Beijing emissions, non-Beijing emissions, emission interactions, and background. During the study episode, the average $PM_{2.5}$ contribution from local emissions is 13.7%, which is much lower than the contribution of 61.5% from the emissions outside of Beijing, further showing the dominant role of the trans-boundary transport in the Beijing $PM_{2.5}$ pollution. The emission interactions enhance the $PM_{2.5}$ level in Beijing on average, with a contribution of 5.9%. The background $PM_{2.5}$ contribution to Beijing is 18.9% on average, lower than those for O_3. The $PM_{2.5}$ contribution caused by the trans-boundary transport is about 67.4% of $PM_{2.5}$ concentrations in Beijing, indicating that the cooperation with neighboring provinces to control the $PM_{2.5}$ level is a key for Beijing to improve air quality. Previous studies have also demonstrated the dominant role of non-Beijing emission in the $PM_{2.5}$ level in Beijing. Based on CMAQ model, Streets et al., (2007) have reported that average contribution of regional transport to $PM_{2.5}$ at the Olympic Stadium can be 34%, up to 50%—70% under prevailing south winds. Guo et al. (2010) have provided a rough estimation that the regional transport can contribute 69% of the PM_{10} and 87% of the $PM_{1.8}$ in Beijing local area using the short and low time resolution data in the summer. Combining the $PM_{2.5}$ observations and MM5-CMAQ model results, regional transport is estimated to contribute 54.6% of the $PM_{2.5}$ concentration during the polluted period, with an annual average $PM_{2.5}$ contribution of 42.4% (Lang et al., 2013). Using the long-term measurements of $PM_{2.5}$ mass concentrations from 2005 to 2010 at urban Beijing, and trajectory cluster and receptor models, the average contribution of long-distance transport to Beijing's $PM_{2.5}$ level can be approximately 75.2% in the summer (Wang et al., 2015)*".

Technical corrections

1 Line 25, the word "more" has been replaced by "higher".

2 Line 32, "reasonably" has been changed to "better".

3 Line 134, Stein et al. (1993) has been revised as Stein and Alpert (1993).

4 Line 189, the word "hourly" has been deleted.

5 Line 227, “the failure of ” has changed to “biased”.

6 Lines 533-538, the two references have been added in the manuscript.