Response to Referee #2

We thank the Referee for the careful reading of the manuscript and helpful comments. According to the suggestions of the referee, the comments have been carefully addressed, and the paper is carefully revised. We believe that the revised paper has been significantly improved after addressing the comments of the referee. We respond to each specific comment below. The original comments by the Referee are shown in bold italics. Our reply is shown in blue.

General comments:

1. ***This paper conducts a numerical study to investigate the impact of crop field burning and topography on haze pollution in the North China Plain. This is an interesting study and potentially will be useful for air quality management in this region. However, there are several important points need to be appropriately addressed before it can be accepted for publishing in Atmospheric Chemistry and Physics.***

   We thank the referee for the careful reading and the valuable comments that helped improving our paper.

Detailed comments:

1. ***The impacts of biomass burning and topography on air quality in the North China Plain certainly are interesting topics for policy makers. However, because modeling results are sensitive from case to case, from policy perspectives, such kind of study should be conducted for a longer period. For the crop filed burning, this paper only conducted a case study for one week in October. According to Figure 2 of this paper and other previous studies in China, the most intensive period of biomass burning in the eastern China is June. It's a little bit strange that the authors selected a case in October. In fact, from the results presented in Figure 5, it is quite clear that in this case the crop field burning activities didn't play an important role on air quality in both NNCP and SNCP if it was compared with an overall broad peak of anthropogenic pollution. For suck kind of non-typical case, I don't know whether it is meaningful to make many statistics to compare the relative contributions in several tables (e.g. Tables 3-6). With such a short-term case, I would like suggest conducting more in-depth analysis to understand specific scientific questions other than a calculation of numbers.***

   We thank the referee for the thoughtful comment. This comment deals with several issues, and our responses are as follows:

a. We selected a case study in October rather than in June, because the air pollution was extremely high (with maximum concentrations larger than 300 μg/m^3) in NNCP, including Beijing, the capital city of China. It is important to understand the CFB contribution to the heavy air pollution in the incident.

b. We agree with the referee that in order to get a solid conclusion from policy perspectives, multiply case studies are needed. We clarify that the purpose of this study is to get some insights of how could CFB affect the air quality in NNCP and Beijing under heavy haze condition. However, in order to get quantitative analysis, more and longer studies are needed.

> Line 461-463**,** **"**We get some insights of how could CFB affect the air quality in NNCP and Beijing under heavy haze condition, though more and longer studies are needed to get more representative conclusions.**"**

c. The selected study period is under a heavy aerosol pollution period. The relative daily average contributions reach to a maximum of 34% and 32% in SNCP and NNCP, respectively. However, by considering the heavy pollution (> 300 μg/m^3) in this period, a little over 30% is prominent.

> Line 351-355, **"**Indeed, the CFB pollution plume go through a long-range transport to NNCP can cause an obvious increase to $PM_{2.5}$ concentration, with the maximum daily average contribution of 32% (**Table 5**). Such a high transported contribution indicates that the CFB is not only one of the significant local pollution sources, but also a considerable regional pollution source.**"**

d. According to the referee's suggestions, we added more statistical results in Table 6, including the regional average changes in mass (μg/m3) and percentage (%), and the lag-time of CFB pollution of NNCP from SNCP.

> Line 370-388, **"**The pattern comparisons between simulated and observed near-surface $PM_{2.5}$ concentrations (*$TPM_{2.5}$*) perform well (**Fig. 9 Left Panels**). Meanwhile, the regional average CFB contributions are shown in **Table 6**, including mass concentration and related percentage as well as the related lag-time of NNCP corresponding to SNCP. At T1, massive local pollutants are emitted from CFB in SNCP and the CFB plume had not yet been largely transported to NNCP (see ***$CPM_{2.5}$* of Fig. 9 T1**). The CFB contribution is high in SNCP with 72.6 μg m^{-3}, accounting for 71% of the total $PM_{2.5}$, whereas the CFB contribution is low with 8.1 μg m^{-3} in NNCP, only accounting for 21%. At T2, high CFB contribution occurred in both SNCP and NNCP with 37 μg m^{-3}, suggesting that plenty of CFB pollutants

emitted from SNCP and had been transported to NNCP (see ***$CPM_{2.5}$* of Fig. 9 T2**). At T3, CFB contribution rapidly reduced in SNCP with 20.2 μg m^{-3} (13%). It is worth to note that the high CFB contribution with 50.4 μg m^{-3} (58%) is still remained in NNCP (see ***$CPM_{2.5}$* of Fig. 9 T3**). At T4, the CFB contribution largely decreased in both SNCP and NNCP (no more than 6%) (see ***$CPM_{2.5}$* of Fig. 9 T4**). The lag-time of NNCP to SNCP are 7-12 hours, and gradually increase from T1 to T4, implicating that the effect of CFB remains in longer time in NNCP than in SNCP. The highest $PM_{2.5}$ concentrations are along the foothill of the Taihang Mountains (**Left panels of Fig. 9**), which may be related to the mountain effects.**"**

2. In the second part of this paper, the authors conducted an interesting numerical experiment by removing topography in specific regions in WRF-Chem model. However, such kind of treatment may cause some inconsistency in the initial conditions of meteorological parameters and the terrain data, which need more spin-up time because WRF uses a terrain-following vertical coordinate. However, according to the modeling description of this paper, the spin-up time for the WRF-Chem simulation is only 12 hours. Since the authors aim to give a quantitative understanding of the topographic effects, a longer spin-up time, for example several days, is needed. In addition, same as the Comment #1, as a case study for several days, the quantitative results here will have large uncertainty for policy makers. I would like suggest giving a more in-depth discussion by touching some scientific questions related to mountain, such as the impact of mountain-valley breezes on the accumulation of air pollutants etc.

a. To address the comment of the referee, we extended the model spin-up time from 12 hours to 3 days (Line 178), and updated related results. We also added some shortcomings of the model study in the **Section 4.5 Impact of mountains**. As we stated in the above, we cannot give a quantitative analysis by the case study from policy perspectives, more cases and longer studies are needed.

Line 396-405, **"**In this study, we utilized the differences between the simulations with or without mountains to represent the effect of the topography on $PM_{2.5}$ concentration, which were calculated based on Eq. (9). As an on-line dynamical model, the topography changes in WRF-CHEM can lead to dynamical changes, such as the wind speeds at the foothill of the mountains. This is a useful and traditional sensitivity analysis method for numerical model to quantify the mountains effects, but with some shortcomings, which are to bring uncertainties to the sensitivity experiment. Firstly, the impact of topography is complicated to be completely quantified only by the altitude remove behavior. Secondly, the initial NCEP FNL data with mountains is treated as "real" in scenarios without mountains.**"**

b. The guiding effect is treated as part of the mountain blocking effect. We modified and added the description in the revised paper.

Line 31-34, "…through the blocking effect. The mountains block and redirect the airflows, causing the pollutant accumulations along the foothill of mountains. This study suggests that the prohibition of CFB should be strict not just in or around Beijing, but also on the ulterior crop growth areas of SNCP."

Line 418-423, "Here, it is attributed to the mountain blocking effect, which has two categories of influences. Firstly, the mountains block the airflows, causing pollutant accumulation and resulting in high $PM_{2.5}$ loading at the foothill of mountains (Influence-1, block). Secondly, the mountains redirect the airflows, causing the pollutants move toward the downwind foothill areas (Influence-2, redirect)."

Line 486-491, "Another major finding is that the mountains, surrounding the NCP in the north and west, play significant roles in enhancing the $PM_{2.5}$ pollution in NNCP through the blocking effect. Mountains block and redirect the airflows, causing the pollution accumulation along the foothill of mountains. The Taihang Mountains had greater impacts on $PM_{2.5}$ concentration than the Yanshan Mountains."

Supplementary data of Fig. S3, "**Fig. S3** The schematic pictures of mountains effect along with the topography of the NCP region. (a) Mountains block the airflows and cause pollutants accumulated at the foothill of mountains. (b) Mountains redirect the airflows, and cause pollutants move toward the downwind foothill areas (Influence-2, redirect)."

3. The authors didn't give appropriate literature review for the both topics of biomass burning and topographic effect. In the model description part, the authors gave too many (more than 15) unnecessary references related to some common model schemes in WRF-Chem with some of them published several decades ago. However, in the main results part (Sect. 4), only two references (Cao et al., 2008 & Huang et al., 2012) are cited in the first paragraph but there is a lack of some comparisons of the results and conclusions with previous works done by other scientists for similar topics.

To address the comment of the referee, we added several revisions.

a. A comprehensive summary of biomass burning emission topographic effect have been added in Line 52-66 and Line 80-91, respectively.

Line 52-66, **“**However, CFB have adverse impacts on traffic conditions and ecology environments (Shi et al., 2014;Zhang, 2009), and release plenty of pollutants, such as CO, SO_2, VOC, NOx and $PM_{2.5}$ (Koppmann et al., 2005;Li et al., 2008). According to Guan et al. (2014) and Lu et al. (2011), annual CFB contribute about 13% of the total particulate matter (PM) emissions in China (Zhang et al., 2016). And it is more prominent during the harvest periods due to its strong seasonal dependence. Numerous studies have quantified the contribution of biomass burning and CFB to PM pollution in China. According to Yao et al. (2016), Cheng et al. (2013), Wang et al. (2009; 2007) and Song et al. (2007), biomass burning has important impacts on the ambient $PM_{2.5}$ concentrations (15-24% in Beijing and 4-19% in Guangzhou). Yan et al. (2010) captured a heavy pollution with PM_{10} concentrations higher than 350 μg m^{-3} in some CFB locations. It is reported that CFB may contribute more than 30% of the PM_{10} increase during CFB incidents (Zhu et al., 2012; Zha et al. 2013;Su et al., 2012). Cheng et al. (2014) report a summer case that CFB contributed 37% of $PM_{2.5}$ concentrations in the Yangtze River delta.**”**

Line 80-91, **“**Yanshan and Taihang Mountains surround the NCP in the north and west (**Fig. 1c**). Such topography affects air pollution though PBL in complex ways (Miao et al., 2015b;Sun et al., 2013;Liu et al., 2009). Hu et al. (2014) have reported that the Loess Plateau and NCP result in a mountain-plains solenoid circulation, exacerbating air pollution over NCP. Chen et al. (2009) have founded that a mountain chimney effect is dominated by mountain-valley breeze, enhancing the surface air pollution in Beijing. The mountain-plain breeze develops frequently in Beijing and may play important roles in modulating the local air quality (Miao et al., 2015b;Hu et al., 2014;Chen et al., 2009). Miao et al. (2015a) founded that the mountains played a significant role in the sea-land aerosol circulation and the pollutants could be transported and accumulated in the NCP areas along the mountains, which is treated as the blocking effect (Zhao et al., 2015).**”**

b. A more detailed model description was added in **Section 3.1 Model description**.

Line 153-160, “The specific version of WRF-CHEM model is developed by Li et al. (2010; 2011; 2012), with a new flexible gas phase chemical module and the CMAQ (version 4.6) aerosol module developed by US EPA

(Binkowski and Roselle, 2003). The wet deposition follows the CMAQ method and the dry deposition is parameterized following Wesely (1989). The photolysis rates are calculated using the FTUV (Li et al., 2005;Tie et al., 2003), in which the impacts of aerosols and clouds on the photochemistry are considered (Li et al., 2011)."

Line 162-166, "Meanwhile, the ISORROPIA Version 1.7 (http://nenes.eas.gatech.edu/ISORROPIA/) is utilized to simulate the inorganic aerosols, which is primarily used to predict the thermodynamic equilibrium between the ammonia-sulfate-nitrate-chloride-water aerosols and their gas phase precursors of H_2SO_4-HNO_3-NH_3-HCl-water vapor."

Line 184-185, "The biogenic emissions are calculated on-line with the WRF-CHEM model using the MEGAN model (Guenther, 2006)."

c. We modified and added explicit statements of provincial CFB emission inventory processing in Line 192-197 and Line 210-221. And we updated the provincial statistical data and related results. The detailed results and related references were added i n supplementary data of Table S1, Table S2 and Table S3.

Line 192-197, "This situation may be resulted from the limitation of local enforcement of regulation despite CFB have already been banned (Zhang and Cao, 2015;Shi et al., 2014). The CFB have a seasonal pattern due to the post-harvest activities with two distinct peaks in summer and autumn, especially in June (33-59%) and October (6-19%) (**Fig. 2b**). The strong seasonal dependence character suggests that the CFB emissions during October are much larger than annual averages."

Line 210-221, "where i stands for each province and k for different crop species of rice, corn and wheat. $E_{i,co}$ stands for CO emission from CFB of *i-th* province in gigagrams [Gg]. $P_{i,k}$ is the yield of crop in Gg. F_i is the proportion of residues burned in the field. D_k is the dry fraction of crop residue (dry matter). R_k is the residue-to-crop ratio (dry matter). CE_k is the combustion efficiency and EF_{co} is the emission factors of CFB. The $P_{i,k}$ values were taken from an official statistical yearbook (NBS, 2015) (**Table S1**), and the F_i on a provincial basis were taken from Wang and Zhang (2008) and Zhang Yisheng (Unpublished doctor thesis-in Chinese) (**Table S1**). The parameters of D_k, R_k, and CE_k are listed in **Table S2**. The EF_{co} from CFB was summarized range from 52 to 141 g kg^{-1} in China (**Table S3**). In this study, we used 111 g kg^{-1} as the average EF_{co} of crop residue, which was used to estimate the emissions from global open burning (Wiedinmyer et al., 2011)."