Authors' Responses to Reviewer Comments

Manuscript: A comprehensive biomass burning emission inventory with high spatial and temporal resolution in China (Ref. No.: acp-2016-560)

Reply to comments from Anonymous Referee #2:

General comments:

Review of "A comprehensive biomass burning emission inventory with high spatial and temporal resolution in China" This study addresses what the authors believe are key weaknesses of current biomass burning emission inventory for China: 1. Missing sources (in particular firewood), 2. Incomplete or source specific EF, 3. Estimates of crop straw utilization and it's variability across regions/provinces, 4. Province level resolution of available inventories is not appropriate for modeling / evaluation emission impacts of atmospheric chemistry, climate or health.

Response:

We thank you very much for your careful and insightful review. We have taken the following comments into consideration in revision. Please see the following point-by-point responses.

Specific Comments:

P1, Ln 25-26 "Corn, rice and wheat represent the major crop straws, with their total emission contribution exceeding 80% for each pollutant." Please clarify for which pollutants ("each pollutant") crop straw combustion accounts for 80% of total emissions. Do they refer to SO_2, CO, CH_4, and Hg? Or all pollutants listed in lines 20-21? Do the authors mean that the combined emissions of corn, rice, and wheat account for 80% of the inventory total emissions of specific pollutants?

Response:

We thank you very much for your comment. We are truly sorry for the confusing sentence. In this sentence, each pollutant refers to all pollutants listed in lines 18-19.

We have revised this sentence in the revised version in Lines 26-27 on Page 1:

"Corn, rice and wheat represent the major crop straws. The combined emissions of these three straw types account for 80% of the total straw burned emissions for each specific pollutants mentioned in this study. "

Statements regarding emissions of EC and NH_3 are contradictory, please clarify / correct: P1, Ln 24-25 "...firewood contributes most to EC and NH3 emission." P1, Ln 26-27: "Corn straw burning has the greatest contribution to EC, NOx and SO_2 emissions; rice straw burning is dominant contributor to CO_2, VOC, CH_4 and NH_3 emissions.

Response:

We thank you very much for your comment. We are truly sorry about this unclear description. This sentence means that firewood contributes most to EC and NH_3 emission compared with other sources (indoor straw, In-field crop residue, livestock excrement, forest and grassland fire). As for the various crop straw types, corn straw burning has more contribution to EC, NOx and SO_2 emissions, and rice straw burning has more contribution to CO_2, NMVOC, CH_4 and NH_3 emissions compared with other straw types. We have revised this sentence in the revised version in Line 27 on Page 1 and Lines 1-2 on Page 2:

" As for the straw burning emission of various crops , corn straw burning has the largest contribution to EC, NOx and SO_2 emissions; rice straw burning has higher contribution to CO_2, NMVOC, CH_4 and NH_3 emissions; wheat straw burning has higher contribution to CO and Hg emissions."

P1, Ln 31: "The temporal distribution shows that higher emissions occurred in April, September, and October during the whole year." This statement is unclear. Do the authors mean that the combined emissions from April, September, and October exceeded emissions for the remainder of the year? Please clarify

Response:

We thank you very much for your comment. We are truly sorry for the confusing sentence. This sentence means that as for the emission from each month, these months have higher emission. According to our calculation, April, May, June and October are the top four months with higher emissions, due to the in-field crop residue burning. While as for EC, the emission in February, January, October and December are relatively higher due to the biomass domestic burning in heating season. We have made the corresponding revision in the revised manuscript in the P2L6-7:

"…April, May, June and October are the top four months with higher emissions, due to the in-field crop residue burning. While as for EC, the emission in February, January, October and December are relatively higher due to the biomass domestic burning in heating season."

P2, Ln3: "haolocarbon" important to secondary chemistry?

Response:

We thank you very much for your comment. We are truly sorry for the confusing description. Haolocarbon is unimportant to secondary chemistry. Ethylene, propylene, toluene, mp-xylene and ethyl benzene are major species of NMVOC, which are important to secondary chemistry. We have made the corresponding modification in the revised manuscript in Lines 10-12 on Page 2, Lines 18-25 on Page 18 and Lines 18-19 on Page 21:

Lines 10-12 on Page 2*: "The species with relatively higher contribution to NMVOC emission include ethylene, propylene, toluene, mp-xylene and ethyl benzene, which are key species for the formation of secondary air pollution."*

Lines 18-25 on Page 18: "The total NMVOC emission is 3474 Gg in this study. The alkenes are the major contributor of biomass burning NMVOC emissions. The contribution of alkenes to the total NMVOC emission is approximately 34%, more than that of alkane (28%), aromatics (24%), alkynes (13%) and others (1%). Among these species, ethylene, acetylene, propylene and 1-butylene are the major species of alkenes and alkynes, with the total contribution accounting for 40.1%. Ethane, n-propane, n-butane, and n-dodecane are the main species of alkanes, with the total contribution accounting for 14.0%. Benzene, toluene, styrene, mp-xylene and ethyl benzene are the major species of aromatics, with the total contribution of 16.6%. Several species *mentioned above are key for the formation of secondary air pollution, such as ethylene, propylene, toluene, mp-xylene and ethyl benzene (Huang et al., 2011). It illustrates that the biomass burning emission control is urgently needed for the air quality improvement. Detailed NMVOC species emission is shown in the Supplement (Fig. S5)."*

Lines 18-19 on Page 21: "Several species with higher contribution to NMVOC (e.g., ethylene, propylene, toluene, mp-xylene and ethyl benzene) are key species for the formation of secondary air pollution."

P2, Ln17 change "critical" to "significant"

Response:

We thank you very much for your suggestion. We have made the revision in revised manuscript in Line 24 on Page 2:

"...Biomass burning is also a significant source of greenhouse gases such as methane (CH_4) and carbon dioxide (CO_2) ..."

P2, L2: "The amount of straw outdoor burning in China in 2009 is 0.215 billion tons (MA, 2011)." This should statement should be qualified e.g. change: "is" to "was estimated as". Also, please provide a couple lines describing the data and the source of data, since the citation is not readily accessible.

Response:

Thanks very much for your comment. We have made the corresponding modification in the revised manuscript in Lines 11-12 on Page 3:

"...The amount of in-field crop residue burning in China in 2009 was estimated as 0.215 billion Mg. The data is obtained from the government report on the investigation and evaluation of crop straw resources in various provinces in China (MA, 2011)."

In addition, we have added the sources of the report in the reference list in the revised manuscript:

"MA: Investigation and Evaluation Report on Crop Straw Resources in China, Ministry of Agriculture, 2011, available at http://www.kjs.moa.gov.cn/, (in Chinese)."

P4 L3: Please provide a citation for the "energy statistical yearbook" and provide a brief (1 sentence) description of the yearbook. P4, L7 "statistical yearbook" is this the "energy statistical yearbook"? Please clarify. P4, L11 "yearbook" is this the "energy statistical yearbook"? Please clarify.

Response:

We thank you very much for your comment. We have added the corresponding citation, description and clarification. Detailed content in the revised manuscript was listed below.

Lines 20-23 on Page 4: "Moreover, because of the lack of firewood consumption record in the China Energy Statistical Yearbook (NBSC, 2009-2015), few studies have developed a comprehensive biomass burning emission inventory in China in recent years. China Energy Statistical Yearbook provides official information on the energy construction, production and consumption, including the detailed firewood consumption in various regions. However, the firewood consumption data is no longer contained in the NBSC (2009-2015) since 2008."

We have added the corresponding citation in the reference list in the revised manuscript:

"National Bureau of Statistics of China (NBSC): China Energy Statistical Yearbook 2009−2015, China Statistics Press, Beijing, 2009−2015, available at http://www.stats.gov.cn/tjsj/tjcbw/, (in Chinese)."

P4, L7 Here "statistical yearbook" refer generically to all statistical yearbook. Actually, the detailed firewood consumption could be not obtained from any other yearbook in addition to energy statistical yearbook.

P4, L11 Here "yearbook" refer generically to all statistical yearbook (e.g. China Statistical Yearbook, China Rural Statistical Yearbook, etc.) in China.

We have made the corresponding revision in Lines 25-28 on Page 4 and Lines 1-3 on Page 5:

"...First, not all biomass burning sources have been included in recent years, especially since 2008, because of the lack of firewood consumption data in the various statistical yearbooks (e.g. China Energy Statistical Yearbook, China statistical

yearbook, China rural statistical yearbook). Second, the source-specific EFs used in emission estimation need to be updated based on the systematic combing of local tests in the latest research. Third, the proportion of crop straw domestic burning and in-field crop residue burning, which could reflect the recent conditions of different provinces in China needs to be investigated. Fourth, the current biomass burning emission inventory for China is generally at province resolution because detailed activity data cannot be directly obtained from the various statistical yearbooks in China…"

P5, L1 delete "including" before "domestic combustion" The authors use the term "field burning" to refer to burning of crop residue in the field, and grassland and forest fires. The widely used terminology in biomass burning research refers to in-field crop residue burning, grassland, and forest fires as "open burning". The author should use this terminology not "field burning" when referring to the combined crop residue, grassland, and forest burning. The use of "field burning" by the authors is inconsistent with accepted terminology and is confusing, a forest is not a "field".

Response:

We thank you very much for your comment. We have made the corresponding modification:

"The biomass burning considered in this study is mainly divided into two categories, domestic combustion and open burning. Domestic combustion mainly involves crop straw, firewood and livestock excrement (mainly used in pastoral and semi-pastoral areas) burning. Open burning includes in-field crop residue burning, forest and grassland fire."

Similar description has been revised through the full text in the revised manuscript.

P5, L11 What is the unit "a" in Mg/a?

Response:

We thank you very much for your comment. We have changed the unit "Mg/a" to "Mg/yr" in the manuscript. In addition, all the "a" in the unit have been changed to "yr" through the full text in the revised manuscript.

P5, L23: Please clarify the source of data in Figure S1 (statistical yearbook?) and note that it is prefecture level.

Response:

Thanks very much for your suggestion. The source of data in Figure S1 is from China Statistical Yearbook (NBSC, 2013b). We have added the corresponding content in the revised manuscript in Lines 24-26 on Page 6 and Lines 1-2 on Page 7, and in the supplement in Figure S1:

Lines 24-26 on Page 6 and Lines 1-2 on Page 7*: "There are currently no statistics on the amount of each crop yield at the county resolution ($P_{i,k}$) in various yearbooks in China. Therefore, in this study, we conducted a correlation analysis between grain yield and crop yield at prefecture resolution, and found a good correlation (R = 0.747, detailed analysis is provided in the Supplement, Fig. S1). The grain yield at prefecture resolution was summarized from China Statistical Yearbook in 2012 (NBSC, 2013b). The crop yield at prefecture resolution was summarized from statistical yearbooks edited by National Bureau of Statistics in 2012 for each province.…"*

Figure S1 in the revised supplement:

"S1 The correlation between crop yield and grain yield at prefecture resolution.

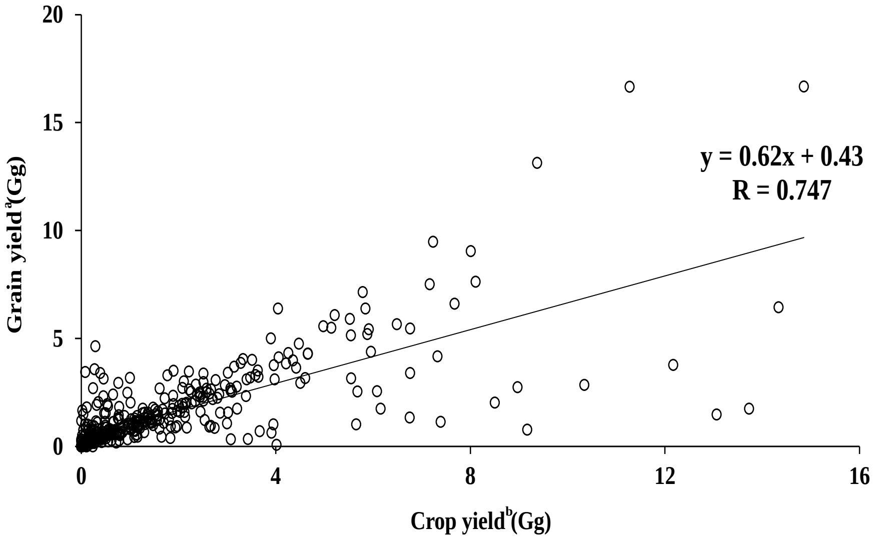

Figure S1 The correlation between crop yield and grain yield at prefecture resolution.
Note: [a] NBSC (2013); [b] a range of statistical yearbooks edited by National Bureau of Statistics in 2012 for each province.

Table 3. Are the superscripts denoting reference for N_k also the references for D_k and CE_k? Please clarify.

Response:

Thank you very much for the comment. We are truly sorry for the missing reference of D_k and CE_k. The reference for D_k and CE_k is He et al. (2015). We have add the corresponding reference in Table 3 on Page 38:

Table 3 Residue-to-production ratio (N_k), dry matter fraction (D_k) and combustion efficiency (CE_k) of crop straw used in this study.

Crops	N_k	D_k [f]	CE_k [f]
Corn	1.269[a]	0.87	0.92
Wheat	1.3[b]	0.89	0.92
Cotton	3[b]	0.83	0.9
Sugar cane	0.3[c]	0.45	0.68
Potato	0.5[d]	0.45	0.68
Peanut	1.5[b]	0.94	0.82
Rapeseed	1.5[d]	0.83	0.9
Sesame	2.2[d]	0.83	0.9
Sugar beet	0.1[b]	0.45	0.9
Hemp	1.7[e]	0.83	0.9
Rice	1.323[a]	0.89	0.93
Soybean	1.6[d]	0.91	0.68

[a] Zhang et al. (1990). [b] Bi et al. (2010). [c] Han et al. (2002). [d] NATESC (1999). [e] Gao et al. (2009). [f] He et al. (2015).

Section 2.2.2 Firewood. Please clarify exactly which regression equation(s) were used to predict firewood consumption.

Response:

Thanks very much for your comment. According our correlation analysis between firewood consumption and other factors that may have a relationship with the firewood (rural population, gross agricultural and timber yield), we found that the rural population and firewood consumption have the best correlation relationship. Because the regression equation is various for the different historical years (Figure 1, 1998-2007), the regression analysis results was used to find the main factor which could be applied to calculate the detailed firewood consumption. Then the detailed firewood consumption was estimated based on the rural population.

P6, L26 What is the unit "a" in ton/a? Is a = "annum"? If so I recommend using year ("yr") instead. Also, is this metric ton?

Response:

We thank you very much for your suggestion. We have changed the "a" to "yr" in the units through the full text in the revised manuscript. In addition, we have changed the "ton" to "Mg" in the units through the full text.

P6, L26: "damaged area" = "burned area"? I assume by "damage area" the authors mean burned area. I recommend the authors use "burned area" instead of "damaged area" for consistency with biomass burning literature and accepted terminology. From an ecological standpoint a burned forest or grassland is not generally "damaged" since fire is a natural part of many if not most ecosystems.

Response:

We thank you very much for your suggestion. We are truly sorry for the confusing description. In fact, the "damaged area" in the original manuscript means "burned area". We have made the corresponding modification through the full text in the revised manuscript.

P6, L29: More details are needed on the data used and the method used to determine the spatial and temporal distribution of burned area. 1. Describe the "damaged area" data from NBSC (2013c) and NBSC (2013d). a. Is the data county level, prefecture level, province level? b. What is the time resolution of the data (annual, monthly, daily)? c. How was the data collected, e.g. is it based on administrative reports from local land management agencies? d. Does the dataset include both wildfires and fires used for ecosystem management, e.g. clearing logging debris or rangeland burning for grazing? 2. Provide a web link to where the references NBSC (2013c) and NBSC (2013d) can be accessed.

Response:

We thank you very much for your comment.

1. The response about the "damaged area" data from NBSC (2013c) and NBSC (2013d):

1.a. The data of damaged area from NBSC (2013c) and NBSC (2013d) is at provincial-level;

1.b. The time resolution of the data is annual resolution;

1.c. The data was collected from the China Statistical Yearbook published by National Bureau of Statistics of China;

1.d. This dataset did not include the fires used for ecosystem management.

Considering the low temporal and spatial resolution of statistics data for burned area, we have updated our methods and data employed in this study, and have re-calculated the pixel-based emission of forest and grassland fire using the bottom-up method. The daily burned area data is derived from the moderate-resolution imaging spectroradiometer (MODIS) direct broadcast burned area satellite product (MCD64A1; http://modis-fire.umd.edu) with a primary spatial resolution of 500 m. Detailed description about the methodology employed for the estimation of the biomass burning emission owing to forest and grassland fire was listed in Sect. 2.2.3 of the revised manuscript**:**

"2.2.3 Forest and grassland burning

The burning mass of forest/grassland can be calculated from the annual mass of forest/grassland burned (Mg/yr) as Eq. (3):

$$A = \left(\sum_{j=1}^{10} BAx,j \times FLx,j \times CFj\right) \times 10^{-6}, \quad (3)$$

where subscripts j, and x represent the land cover type, and location, respectively, $BA_{x,j}$ is the burned area (m^2) of land cover type j at x, $FL_{x,j}$ is the biomass fuel loading (the aboveground biomass density in this study; g/m^2) of land cover type j at x, and CF_j is the combustion factor (the fraction of burned aboveground biomass) of land cover type j.

Burned area data for 2012 were derived from the moderate-resolution imaging spectroradiometer (MODIS) direct broadcast burned area product (MCD64A1;

http://modis-fire.umd.edu). This product employs an automated algorithm for mapping MODIS post-fire burned areas, and deriving the approximate burn date within each burn cell combined with surface reflectance, land cover products, and daily active fires. The MCD64A1 product has a primary spatial resolution of 500 m and a temporal resolution of 1 month. The extent of burning over a Julian day and its temporal uncertainty are specified for each burn cell. The burned areas within an approximate Julian day can be extracted from the original 500 m resolution map.

Earlier research on the estimation of FL values for forest and grassland typically employed an averaged value of aboveground biomass density. However, these values do not well reflect the spatial variations of FL for each vegetation type. In this study, numerous local FL were collected for each province and vegetation type. The type of vegetation burned in each pixel was determined by the 1 km resolution MODIS Land Cover product produced by Ran et al. (2010). We considered 10 vegetation types as forest and grassland (i.e., evergreen needleleaf forest, evergreen broadleaf forest, deciduous needleleaf forest, deciduous broadleaf forest, mixed forest, closed shrublands, open shrublands, woody savannas, savannas, and grassland). The values of FL employed in this study are listed in Table 4. As for CF, it has usually been set as a constant in previous literature. In our paper, CF values were collected for each vegetation type, and the CF in each pixel was determined by the MODIS Land Cover product and the CF of typical vegetation. The CF of forest, closed shrublands, open shrublands, woody savannas, and grassland were set as 0.25, 0.5, 0.85, 0.4, and 0.95, respectively (Michel et al., 2005; Kasischke et al., 2000; Hurst et al., 1994).”

2. The web link of the references NBSC (2013c) has been added in the reference list in the revised manuscript. The references NBSC (2013d) have been deleted in the revised manuscript:

“*National Bureau of Statistics of China (NBSC): China Statistical Yearbook 2013, China Statistics Press, Beijing, 2013c,* ***available at http://www.stats.gov.cn/tjsj/ndsj/****, (in Chinese)*.”

P6, L31: A more detailed description of the forest and grassland biomass and combustion efficiency data is needed: 1. Provide a web link to where the references

Tian et al. (2003), Lu et al. (2011), and EPD (2013) can be accessed. If they are not accessible, the work is not reproducible. 2. What forest components does the biomass number listed in Table 4 include? Organic soil/duff, litter, down dead wood, understory herbs and shrubs? 3. Is the forest biomass derived from forest inventory data? 4. The combustion efficiency of forests is 0.1 – 0.2. Is this because much of the forest biomass numbers include boles and branches of live trees which do not burn? 5. Does grassland category include shrub lands? 6. Please comment on how the biomass loadings and consumption estimates used in this study compare with those used in previous global emission inventories (e.g. GFED, van der Werf et al., 2010; FiNN, Wiedinmyer et al., 2011) and surveys of fuel consumption (e.g. van Leeuwen et al., 2014) and studies of grassland biomass in China (e.g. Ni, 2004; Ma et al. 2016; Zhao et al., 2014) 7. The value of 1800 kg/ha (180 g/m^2) used in this study compares reasonably well with Ni (2004) study of northern China Northern (325.5 g/m^2).

Response:

Thanks very much for your comment.

Considering the coarse resolution of statistical data and the lack of fires used for ecosystem management, we have changed the dataset and method employed in this study, and we re-calculated the pixel-based emission of forest and grassland fire. Detailed description could be found in the response to the comment mentioned above..

Besides, we further elaborate on the biomass fuel loadings and combustion factor data. As the values of biomass fuel loadings are various from vegetation types and provinces, in this study, numerous local biomass fuel loadings were collected for various vegetation types and provinces (Fang et al., 1996; Fang et al., 1998; Pu et al., 2004; Hu et al., 2006). Combustion factor of various vegetation types were derived from Michel et al. (2005), Levine et al. (2000), Kasischke et al. (2000), and Hurst et al. (1994).

Detailed description about the methodology employed for the estimation of the biomass burning emission owing to forest and grassland fire was listed in Sect. 2.2.3 of the revised manuscript. Please see the response to the comment mentioned above.

In addition, the specific responses to the comments are listed below:

1. The web link of the references Tian et al. (2003), Lu et al. (2011), and EPD (2014) has been added in the reference list in the revised manuscript

   "Tian, X. R., Shu, L. F. and Wang, M. Y.: Direct Carbon Emissions from Chinese Forest Fires, 1991−2000, Fire Safety Science, 12, 6−10, 2003, http://hzkx.ustc.edu.cn/ch/reader/view_abstract.aspx?flag=1&file_no=200312002&journal_id=hzkx, (in Chinese).

   Lu, B., Kong, S. F., Han, B., Wang, X. Y. and Bai, Z. P.: Inventory of Atmospheric Pollutants Discharged from Biomass Burning in China Continent in 2007, China Environmental Science, 31, 186−194, 2011, http://manu36.magtech.com.cn/Jweb_zghjkx/CN/Y2011/V31/I2/186, (in Chinese).

   EPD: Guide for compiling atmospheric pollutant emission inventory for biomass burning, Environmental Protection Department, 2014, http://www.zhb.gov.cn/gkml/hbb/bgg/201501/t20150107_293955.htm, (in Chinese)."

2. The forest components in the revised manuscript include trunk, branch and leaves of trees.
3. The forest biomass in the revised manuscript is not derived from forest inventory data. The forest inventory data only provides the trunks biomass of the forest. In addition, the data used in our paper also involves branches and leaves biomass of trees.
4. The combustion efficiency of forests in the revised manuscript was set as 0.25 according to Michel et al. (2005).
5. Grassland category in the revised manuscript including woody savannas, savannas and grasslands. shrub lands are included in the forest category.
6. The detailed description on the estimation of biomass loadings and consumption in this study could be found in the response to the comment mentioned above (Sect. 2.2.3). The biomass fuel loadings data are collected from the research made in China (Fang et al., 1996; Fang et al., 1998; Pu et al., 2004; Hu et al., 2006), and the data is often used in recent studies on the estimation of biomass burning emission and proved to be credible. (Song et al., 2008; Qiu et al., 2016).

7. In revised manuscript, the biomass fuel loadings of grassland are different from province and vegetation type.

P7, L1 Units for grassland biomass are kg/ha while other quantities are listed as kg/hm^2. While these units are equivalent, please be consistent by using either ha or hm^2 throughout the manuscript.

Response:

Accepted. We have made the corresponding modification through the full text in the revised manuscript.

Table 4. Note the units for forest biomass.

Response:

Accepted. The unit of forest biomass is g/m^2, which has been added in Table 4 in the revised manuscript.

P7, L10: Provide a web link to where the references EOCAIY (2013) and NBSC (2013b) can be accessed

Response:

Thanks very much for your comment.

The web link of NBSC (2013b) has been added in the reference list in the revised manuscript:

"National Bureau of Statistics of China (NBSC): China Statistical Yearbook for Regional Economy 2013, China Statistics Press, Beijing, 2013b, available at http://www.stats.gov.cn/tjsj/tjcbw/, (in Chinese)."

China Animal Industry Yearbook (EOCAIY 2013) is edited by the editorial committee of Chinese animal husbandry, which is a reference about the information of animal husbandry and veterinary medicine, feed and forage industry. It is widely used in recent research, such as Kang et al. (2016) and Huang et al. (2012). However, it is not publicly available online.

Section 2.3 EFs The VOC emissions factors for forest, grasslands, open residue burning, and feces burning seem quite low compared to those reported in extensive reviews such as Akagi et al. (2011). I imagine the difference is that the VOC category in Table 5 & 6 include only a subset of VOC present in biomass smoke and measured in other studies. Please comment in the differences.

Response:

Thanks very much for your comment. The NMVOC emission factors were updated based on a systematic combination of localized measurements conducted in China. According to our examination about the references selected for In-field crop residue burning and feces burning in this study, NMVOC emission factor include alkane, alkene, alkyne and aromatics with C2-C12. In the revised manuscript, the EF for forest and grassland fire was selected from Akagi et al. (2011) due to the lack of localized measurement. The emission of NMVOCs species has been revised according to the species corresponding to emission factor.

Section 2.4 Spatial Distribution Is the land use data of Ran et al. (2010) publicly available? If so, please provide a web link where it may be accessed.

Response:

Thanks very much for your comment. The spatial distribution of the land use data is MODIS land cover data which is processed by Ran et al. (2010). The web link of the reference has been added in the reference list in the revised manuscript:

"Ran, Y. H., Li, X. and Lu, L.: Evaluation of four remote sensing based land cover products over China, Int. J. Remote Sens., 31, 391−401, available at http://www.tandfonline.com/doi/abs/10.1080/01431160902893451, 2010."

Figure 2 is not very useful. It should be replaced with or augmented with table that provides the total emissions and percent of each species by source.

Response:

We thank you very much for your suggestion. As the total emissions of each species have already been mentioned in the manuscript and in the Table 7, we marked the percent of each species by source in the Fig. 2.

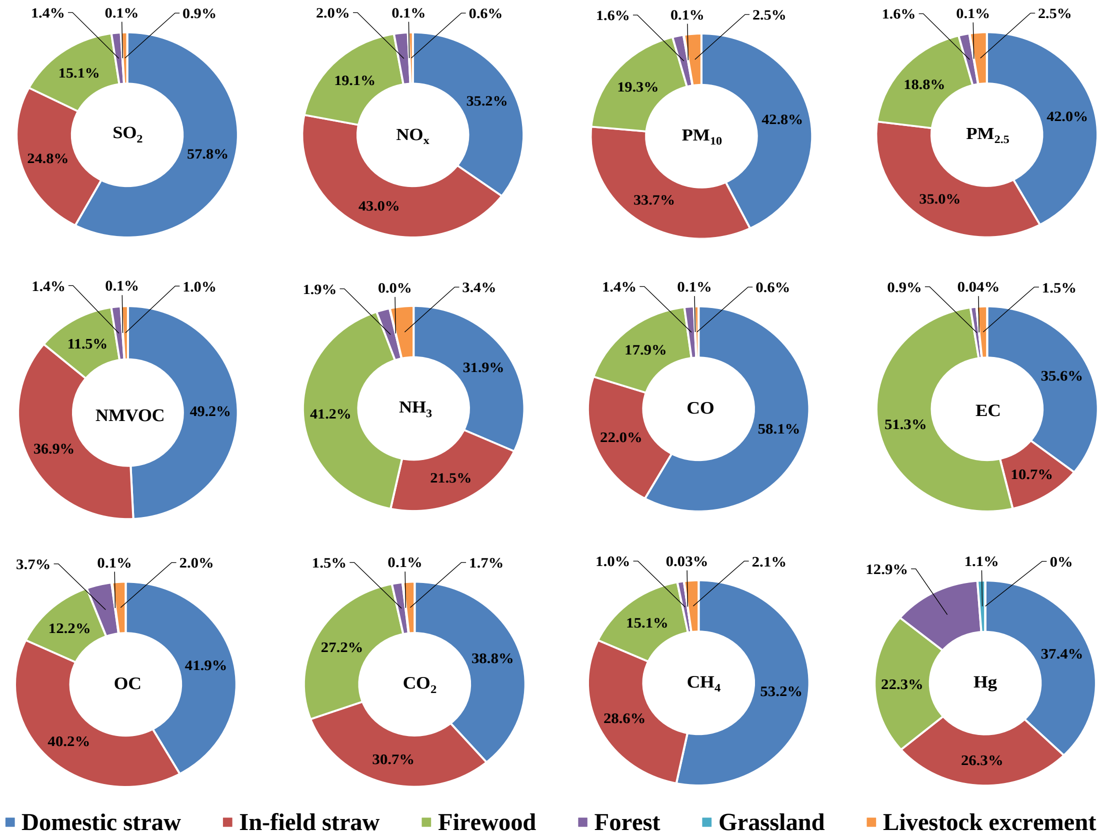

Figure 2. Contribution of different source to the total biomass burning emissions in China, 2012.

Results and discussion. Please include a table providing total annual fuel consumption and emissions for the 12 species in Table 7 by source. This will is needed to compare current paper to previous studies that may have focused on only a subset of sources.

Response:

We thank you very much for your suggestion. We have added the total annual fuel consumption by source in order to discuss the result (Sect. 3.1.1 in lines 15-25 on Page 11 and lines 1-13 on Page 12). The emissions for the 12 species by source can be calculated through the total emission in Table 7 and the percent of each species showed in Fig. 2.

lines 5-8 on Page 12*: "…In addition to the sources mentioned above, the contribution of livestock excrement burning, forest and grassland fire is relatively small. It is mainly due to the small amount of biomass fuel consumption. The biomass fuel consumption of these three biomass sources are 10614 Gg, 6647 Gg and 505 Gg, respectively, which is* *significantly lower than that of straw domestic combustion (201582 Gg), in-field crop residue burning (147178 Gg) and firewood combustion (127250 Gg)…"*

P9 L15-16 Please note the total annual burned area of forest and grasslands.

Response:

We thank you very much for your comment. The total burned area of forest and grasslands are 3587 and 4241 km^2, respectively. As the discussion content in P9 L15-16 in the original manuscript is about the contributions by each biomass burning sources. The fuel consumption has more direct influence on emission estimation compared with burned area of forest and grasslands. Therefore, we gave the fuel consumption here:

"…In addition to the sources mentioned above, the contribution of livestock excrement burning, forest and grassland fire is relatively small. It is mainly due to the small amount of biomass fuel consumption. The biomass fuel consumption of these three biomass sources are 10614 Gg, 6647 Gg and 505 Gg, respectively, which is significantly lower than that of straw domestic combustion (201582 Gg), in-field crop residue burning (147178 Gg) and firewood combustion (127250 Gg). The contribution of livestock excrement burning to PM10, PM2.5, NH3, EC, OC, CO2 and CH4 is 2.52%, 2.47%, 3.44%, 1.52%, 1.96%, 1.67% and 2.10%, respectively. The contribution of forest and grassland fire to biomass burning emissions to most chemical species in China is small (0.9–3.7%), except for the contribution of forest fire to Hg emissions (14.0%)."

Figures 4 & 5 are difficult to read and the data would be better presented as tables, perhaps in the supplement.

Response:

Thanks very much for your comment. Considering the occupied space of many information in Figures 4 & 5, the result is more suitable to present through figures. A furthermore quality improvement of the Figure 4 and Figure 5 has been made. The data in the figures could be read. In addition, the reader can get the detailed data freely through contacting us after the paper acceptation. Considering the importance of the result, it is better to present it in the main body of the manuscript.

P13, L13-14: Are specific crops typically burned harvest season, sowing season, or both? Or does it vary by region and practice?

Response:

Thanks very much for your comment. The specific crops typically burned in harvest season or sowing season, and it varies according to the burning habit in different regions. For example, wheat crop straw in the north often burned in its harvest season while rice crop straw in the south often burned in its sowing season to clear the cultivated land and increasing the soil fertility for the next sowing. In addition, due to the difference of climate conditions, the harvest and sowing season vary in various regions. Therefore, we discussed the temporal variation in biomass burning emission in different regions. We have revised the explanation in Lines 5-8 on Page 17:

"Burning activity mainly occurs in the harvest season (crop residue burning) or crop sowing season (clearing the cultivated land and increasing the soil fertility for the next sowing), and it varies according to the burning habit in different regions. In addition, the sowing and harvest seasons vary in different regions because of the climate conditions. Because of the differences in burning activity and climate conditions in various regions, monthly emission features vary regionally and to consider this, we divided China into seven areas…"

Section 3.6 Please describe how parameters were estimated for the PDFs used in the Monte Carlo simulation.

Response:

We thank you very much for your comment. We have made the corresponding modification in Lines 2-10 on Page 19:

"The Monte Carlo method is used to analyse the uncertainty of this emission inventory, which was used in uncertainties estimation for many inventories studies (e.g., Streets et al., 2003; Zhao et al., 2011; Zhao et al., 2012). Activity data (Zheng et al., 2009) and EFs (Zhao et al., 2011) are assumed to be normal distributions. The coefficients of variation (CV, the standard deviation divided by the mean) of activity

data and emission factors were obtained from literature review. CV of activity data for firewood and crop straw burning were set as 20% (Zhao et al., 2011; Ni et al., 2015). As the data source of activity data for livestock excrement is same as the crop straw burning (i.e., government statistic data), CV is also set as 20%. MCD64A1 burned data products has been shown to be reliable in big fires (Giglio et al., 2013), and the CV of burned area of forest and grassland fire is from the reported standard deviation (Giglio et al., 2010). The biomass fuel loadings (Saatchi et al., 2011; Shi et al., 2015) and combustion factor (van der Werf et al., 2010) of forest and grassland fire were within a CV of approximately 50%. The CV of EF for each pollutant for each biomass burning type is shown in the supplement S8 and S9."

Supplement S8 and S9 have been added in the revised supplement:

S8 CV (coefficients of variation) of biomass domestic burning emission factors.

	Material	SO_2	NO_x	PM_{10}	$PM_{2.5}$	NMVOC	NH_3	CO	EC	OC	CO_2	CH_4	Hg
Domestic burning	Corn	0.5[*]	0.02[a]	0.5[*]	0.27[b]	0.5[*]	0.5[*]	0.85[a]	0.34[b]	0.44[b]	0.04[a]	0.5[*]	0.05[c]
	Wheat	0.5[*]	0.16[a]	0.5[*]	0.23[b]	0.5[*]	0.5[*]	0.89[a]	0.76[b]	0.29[b]	0.07[a]	0.5[*]	0.12[c]
	Cotton	0.5[*]	0.5[*]	0.5[*]	0.26[b]	0.5[*]	0.5[*]	0.5[*]	0.39[b]	0.55[b]	0.5[*]	0.5[*]	0.33[c]
	Cane	0.5[*]	0.5[*]	0.5[*]	0.26[b]	0.5[*]	0.5[*]	0.5[*]	0.63[b]	0.45[b]	0.5[*]	0.5[*]	0.32[c]
	Potato	0.5[*]	0.5[*]	0.5[*]	0.26[b]	0.5[*]	0.5[*]	0.5[*]	0.63[b]	0.45[b]	0.5[*]	0.5[*]	0.53[c]
	Peanut	0.5[*]	0.5[*]	0.5[*]	0.26[b]	0.5[*]	0.5[*]	0.5[*]	0.63[b]	0.45[b]	0.5[*]	0.5[*]	0.03[c]
	Rape	0.5[*]	1.21[d]	0.5[*]	0.15[b]	0.26[d]	0.5[*]	0.26[d]	0.63[b]	0.45[b]	0.5[*]	0.5[*]	0.3[c]
	Sesame	0.5[*]	1.78[d]	0.5[*]	0.26[b]	0.24[d]	0.5[*]	0.29[d]	0.63[b]	0.45[b]	0.5[*]	0.5[*]	0.3[c]
	Beet	0.5[*]	0.5[*]	0.5[*]	0.26[b]	0.5[*]	0.5[*]	0.5[*]	0.63[b]	0.45[b]	0.5[*]	0.5[*]	0.3[c]
	Hemp	0.5[*]	0.5[*]	0.5[*]	0.26[b]	0.5[*]	0.5[*]	0.5[*]	0.63[b]	0.45[b]	0.5[*]	0.5[*]	0.3[c]
	Rice	0.5[*]	0.05[a]	0.5[*]	0.29[b]	0.5[*]	0.5[*]	0.06[a]	0.65[b]	0.5[b]	0.01[a]	0.5[*]	0.46[c]
	Soybean	0.5[*]	1.78[d]	0.5[*]	0.26[b]	0.76[d]	0.5[*]	0.44[d]	0.63[b]	0.45[b]	0.5[*]	0.5[*]	0.74[c]
	Firewood	0.5[*]	1.42[d]	0.5[*]	0.16[b]	0.15[d]	0.5[*]	0.39[d]	0.46[b]	0.35[b]	0.5[*]	0.5[*]	1.17[c]
	Feces	0.8[*]	0.8[*]	0.8[*]	0.8[*]	0.8[*]	0.8[*]	0.8[*]	0.8[*]	0.8[*]	0.8[*]	0.8[*]	0.8[*]

Table S1 CV (coefficients of variation) of biomass domestic burning emission factors.

Note: Lowercase letters indicate the data source.

*Sources are from the following: [a] Zhang et al. (2008). [b]Li et al. (2009). [c] Chen et al. (2013). [d] Zhang et al. (2013). * Expert judgment data from Wei et al. (2011).*

S9 CV (coefficients of variation) of biomass open burning emission factors.

	Material	SO_2	NO_x	PM_{10}	$PM_{2.5}$	NMVOC	NH_3	CO	EC	OC	CO_2	CH_4	Hg
Open burning	Corn	0.45[b]	0.42[b]	0.5[*]	0.09[b]	0.53[b]	0.76[b]	0.08[b]	0.33[b]	0.39[b]	0.01[b]	0.22[b]	0.05[a]
	Wheat	0.67[b]	0.52[b]	0.5[*]	0.54[b]	0.25[b]	0.38[b]	0.41[b]	0.32[b]	0.26[b]	0.03[b]	0.25[b]	0.12[a]
	Cotton	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.33[a]
	Cane	0.5[*]	0.32[d]	0.19[d]	0.16[d]	0.71[d]	0.5[*]	0.61[d]	1.57[d]	0.2[d]	0.18[d]	0.5[*]	0.32[a]
	Potato	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.53[a]
	Peanut	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.03[a]
	Rape	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.3[a]
	Sesame	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.3[a]
	Beet	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.3[a]
	Hemp	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.3[a]
	Rice	0.5[*]	0.8[d]	0.88[d]	0.17[d]	0.75[d]	0.5[*]	1.19[d]	1.38[d]	1.53[d]	0.14[d]	0.5[*]	0.46[a]
	Soybean	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.5[*]	0.74[a]
	Evergreen Needleleaf Forest	0.3[c]	0.39[c]	0.25[d]	0.25[d]	0.31[e]	0.66[e]	0.38[e]	1[f]	0.62[f]	0.08[e]	0.52[e]	0.52[g]
	Evergreen Broadleaf Forest	0.4[e]	0.54[e]	0.25[d]	0.25[d]	-	1.58[h]	0.29[e]	0.6[e]	0.57[e]	0.04[e]	0.39[e]	0.52[g]
	Deciduous Needleleaf Forest	0.3[c]	0.23[c]	0.25[d]	0.25[d]	0.31[e]	0.66[e]	0.38[r]	1[f]	0.62[f]	0.08[e]	0.52[r]	0.52[g]
	Deciduous Broadleaf Forest	0.3[c]	0.46[e]	0.25[d]	0.25[d]	0.79[e]	0.27[e]	0.19[e]	0.33[e]	0.52[e]	0.02[e]	0.18[e]	0.52[g]
	Mixed Forest	0.3[c]	0.46[e]	0.25[d]	0.25[d]	0.62[e]	0.27[e]	0.19[e]	0.33[e]	0.52[e]	0.02[e]	0.18[e]	0.52[g]
	Closed Shrublands	0.44[e]	0.21[e]	0.25[d]	0.25[d]	0.48[e]	0.33[e]	0.25[e]	0.4[f]	0.18[f]	0.02[e]	0.35[e]	0.74[h,g]
	Open Shrublands	0.44[e]	0.21[e]	0.25[d]	0.25[d]	0.48[e]	0.33[e]	0.25[e]	0.4[f]	0.18[f]	0.02[e]	0.35[e]	0.74[h,g]
	Woody Savannas	0.44[e]	0.21[e]	0.25[d]	0.25[d]	0.48[e]	0.33[e]	0.25[e]	0.4[f]	0.18[f]	0.02[e]	0.35[e]	0.52[h]
	Savannas	0.63[e]	0.29[e]	0.25[d]	0.25[d]	0.25[e]	0.8[e]	0.29[e]	0.5[e]	0.46[e]	0.02[e]	0.6[e]	0.52[h]
	Grasslands	0.63[e]	0.29[e]	0.25[d]	0.25[d]	0.25[e]	0.8[e]	0.29[e]	0.5[e]	0.46[e]	0.02[e]	0.6[e]	0.52[h]

Table S2 CV (coefficients of variation) of biomass open burning emission factors.

Note: Lowercase letters indicate the data source.

*Sources are from the following: [a] Chen et al. (2013). [b] Li et al. (2007). [c] Andreae and Rosenfeld (2008). [d] Song et al. (2009). [e] Akagi et al. (2011).[f] McMeekin et al. (2008). [g] Friedli et al. (2003). [h] Streets et al. (2005). * Expert judgment data from Wei et al. (2011).*

Figure S4. Please note the data sources used to derive the non-carbon PM components.

Response:

We thank you very much for your suggestion. The $PM_{2.5}$ speciation is obtained from Li et al., (2007) and Waston et al., (2001), which have been described in Sect. 2.6 in the original manuscript. In addition, we have added the data sources of the $PM_{2.5}$ speciation in Figure S4.

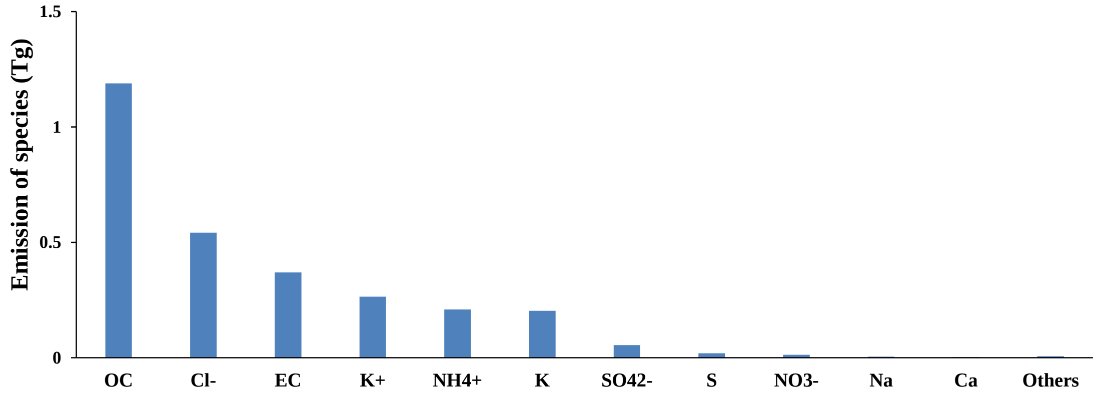

Figure S4 Emission of $PM_{2.5}$ species from biomass burning.

Note: Species in others include Al，Si，Mg，Fe，Pb，Zn，Ba，Ti，Ni，Cr，Mn，Sr，V，Cd，As，Zr，Se，Ag，Sb，Sc，Mo，Ga，Tl，Co and Hg. $PM_{2.5}$ speciation profile is obtained from Li et al., (2007) and Waston et al., (2001).

TECHINCAL The manuscript contains many minor grammatical errors, here are a few: P13, Ln3-4: Change “This is because the main contribution of these species emission sources is from straw outdoor burning” to “This is because straw outdoor burning is the main source for these species” P13, Ln 4: change “The outdoor burning straw mainly occurs in...” to “The outdoor burning of straw occurs mainly in...” P13, L19 insert “a” between “have” and “relatively” and change “peak” to “peaks” P13, L20: change “discrepancies” to “differences” P13, L28: change “while” to “where” P14, L7: change ‘peak” to “peaks” P14, L14: Change “Besides” to “Additionally” P16, L23-25 Sentence beginning “More localized EF of...” is jumbled and must be rewritten.

Response:

We thank you very much for your helpful suggestion. We have made the corresponding modification in the revised manuscript.

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