# A letter of Response to Anonymous Referee #1

Manuscript Number: acp-2011-907
Manuscript Title: Development and uncertainty analysis of a high-resolution $NH_3$ emissions inventory and its implications with precipitation over the Pearl River Delta region, China

**Referee comments**

**1 Overall Comment:**

*This manuscript addresses an important issue air quality, ecosystems, and understanding the composition of the atmosphere. They present an ammonia emission inventory for China with high spatial resolution and a representation of temporal variability. This is an important step forward and is within the scope of "Atmospheric Chemistry and Physics". However, I have very serious concerns about the quality of the analysis and the interpretation of the results. In order to gain acceptance, I strongly recommend that the authors make these substantial changes and improvements.*

**Response:** We appreciated it very much for the referee's positive comments especially for recognizing the advantages of our inventory. In the revised version, we have carefully addressed these comments and incorporated the suggestions from all reviewers and interactive discussion. We are confident that the revised version has been greatly improved with these valuable comments.

**Referee comments**

**Specific Comments:**

*1.1 Analysis of the trend in precipitation concentrations*

*About the precipitation samples how frequently are the samples retrieved from the field and analyzed? Does the time in the field change the $H^+$ balance? How accurately are the concentration of sulfate, nitrate, and ammonium measured? These are likely to be more stable than $H^+$.*

**Response:** In this paper, the precipitation data were collected from officially operated acid rain monitoring stations in the PRD region. Samples were collected by using an automatic precipitation sampler equipped with a polyethylene bucket at each rainfall event. In order to keep the $H^+$ balance, the pH values of the rainwater samples were measured immediately at the end of a rain event at sampling sites with a portable pH analyzer. Then, they were filtered through 0.45μm pore size membrane filters to remove the insoluble particles, and stored in a refrigerator at about 3-5 °C prior to chemical analysis. The anions $F^-$, $Cl^-$, $NO_3^-$ and $SO_4^{2-}$ were measured by ion chromatography, and the cations of $K^+$, $Na^+$, $Ca^{2+}$ and $Mg^{2+}$ were measured by atomic absorption spectrometry. $NH_4^+$ was determined using the Nessler's reagent colorimetric method. The collection and analysis of precipitation samples in laboratory strictly followed the technical specifications required for acid deposition monitoring in China (HJ/T165-2004, State Environmental Protection Administration of China, 2004) to assure the analytic quality of precipitation samples. In the revised version, we added a brief introduction about the above-mentioned contents in Section 2.2 and Section 2.7.

**Reference:**

State Environmental Protection Administration of China, 2004. Technical Specifications for Acid Deposition Monitoring. State Environmental Protection Administration of China, Beijing (in Chinese).

Wang, H., and Han, G. L.: Chemical composition of rainwater and anthropogenic influences in Chengdu, Southwest China, Atmos. Res., 99, 190-196,2011.

Zhang, M. Y., Wang, S. J., Wu, F. C., Yuan, X. H., and Zhang, Y.: Chemical compositions of wet precipitation and anthropogenic influences at a developing urban site in southeastern China, Atmos. Res., 84, 4,311-322, 2007.

*"In Table 7, the mean long-term trend of the ratio $Ca^{2+}+NH_4^+$ /$SO_4^{2-}$ +$NO_3^-$ (NP/AP) was around 0.94 during 1998-2006, which was lower than that of some northern Chinese cities (e.g. Beijing) (Yang et al., 2004). This indicates that more inputs of alkaline species like $NH_3$ into the precipitation in Beijing than that in the PRD region." I don't think you can make this conclusion, because many relevant cations are excluded from Table 7. Beijing also has more dust, while the coastal cities in the south likely have more sea salt.*

**Response:** Thanks for comments. In order to address the comment, we re-did an extensive review of articles about the soluble ionic compositions of wet precipitation. It is true that researches in this way are currently scarce to assess the balance between acidity and alkalinity, but Tang et al. (2005) indicate that the equivalent ratio of NP/AP could be used as an index for evaluating the degree of the anthropogenic activity. Therefore, we revised our previous viewpoints and details please find the revised version in the new Section 3.6.1. We added all quantitatively measured concentration of ions of $F^-$, $Cl^-$, $NO_3^-$ , $SO_4^{2-}$, $K^+$, $Na^+$, $Ca^{2+}$ , $Mg^{2+}$ and $NH_4^+$ in Table 9. To ensure the reliability of these ion data, the ionic balance of total anions (Σ−) with total cations (Σ+) for each precipitation sample was checked. The results showed that the correlation coefficient between them was 0.99, within the range of 1.00±0.25, indicating that the data qualities for these precipitation samples were acceptable (Zhang et al., 2000).

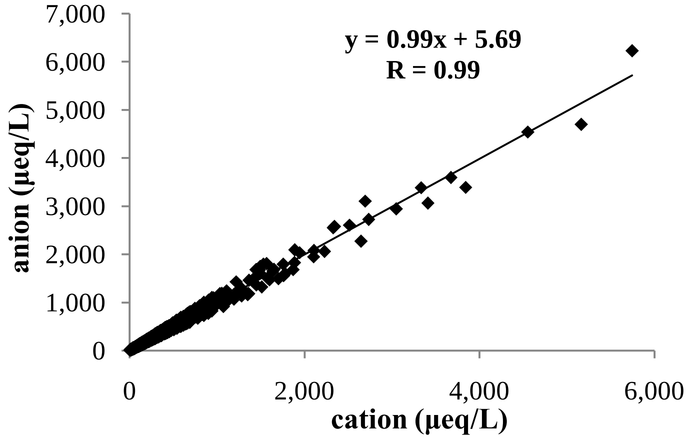


**Fig. 1.** Relationships between the sum of cations and that of anions.

**Reference:**

Tang, A., Zhuang, G. S., Wang, Y., Yuan, H., and Sun, Y. L.: The chemistry of precipitation and its relation to aerosol in Beijing, Atmos. Environ., 39, 3397-3406, 2005.

Zhang, J., Chen, N., Yu, Z., and Zhang, J.: Ion balance and composition of atmospheric wet deposition (precipitation) in Western Yellow Sea, Mar. Environ. Sci., 19, 10-13, 2000.

*I recommend removing this discussion of acidity and Figure 9, as they are a distraction from the main purpose of this paper which is ammonia.*

**Response:** Accepted! Thanks for the valuable suggestion. It is true that the main purpose of our paper is to conduct an investigation of the characteristics of major ammonia emission as much as possible, and to build an initial attempt to assess the relationship between precipitation concentrations and ammonia emissions. In the revised version, we have removed these related discussions of acidity in Section 3.6.1 and the previous Fig. 9.

**Referee comments**

*1.2 Analysis of the temporal trends*

*I find Figure 8 very difficult to understand. After pondering this for a while, I determined that the blue line must be plotted on the left axis. This is very confusing. Please plot this as a stacked bar chart.*

**Response:** Accepted! We followed the comment and a stacked bar chart was presented in the revised manuscript (See Fig. 9 in the revised version).

*The temporal trends in fertilizer seem reasonable. But please provide more information about how this is calculated in the methods section. However, I'm not sure that the livestock monthly variability is reasonable. Is it based on consumption of livestock? This is what is described in the text, but we would expect livestock animal population to be out of phase with consumption, because the animals have to be raised for several months before they are consumed. The emissions should be more* *closely tied to temperature, which is the most important factor affecting volatilization. This is alluded to, but it is not clear how this is incorporated in these estimates. Please include a discussion of how the temporal variability is calculated.*

**<u>Response:</u>** We appreciate the positive comments and valuable suggestions from the referee. Being different from $SO_2$, $NO_X$ and CO, which are mostly from the fuel combustion of power plant, industrial boiler, on-road mobile and non-road mobile sources, $NH_3$ emissions are mainly from agricultural source like livestock and nitrogen fertilizer application. By using some surrogates like energy consumption, electricity production, industrial product yields, traffic flows and fire count, the temporal variations of non-agricultural emission sources could be relatively easily characterized (Zheng et al., 2009). However, seasonal characteristics in agricultural source emissions depend strongly on both local human farming activities and climate conditions (Pinder et al., 2006), characterization of their temporal variations is more challenging. We totally agree the referee's concern of the detailed process for temporal trends. Nevertheless, it must be pointed out that currently, under the circumstances of lacking detailed agricultural registers and practices, reliable input parameters in the function of process driven description, and field $NH_3$ measurement data in the air quality monitoring network widely existed in China, sound temporal profiles are hard to develop. In this study, temporal profiles mainly referred to other similar studies (Streets et al., 2003; Chinkin et al., 2003; Meng et al., 2010), considering the seasonal characteristics of agriculture activities and meteorological conditions in the PRD region.

For livestock, theoretically, an accurate temporal profile should conduct by measuring the emission rates from each source, but it is not feasible obviously (Pinder et al., 2006) at the current stage. Hence, in our study, the scanty statistical data in agricultural register (housing, storage, spreading and grazing) lead to require simplifying assumptions at different times by data mining or referring the recommended profiles in other studies (Streets et al., 2003; Chinkin et al., 2003). We collected production information of animal husbandry in Guangdong province (Statistical Reports of Guangdong Province, 2007) and ambient meteorological data to aid the development of temporal profiles of ammonia emissions in PRD region.

For N fertilizer application, we investigated the farming seasons of different crops in the PRD region based upon the database of farming seasons for different crops, such as wheat, corn, nice, sugarcane, vegetables, and others, which are available at http://www.zzys.gov.cn/ (China's planting information network). With these seasonal characteristics of agriculture activities and meteorological conditions, a preliminary temporal profile for agriculture source was established.

As shown in the Introduction part of this paper, studies on highly resolved temporal and spatial ammonia emissions lagged behind other precursor pollutants like $SO_2$ and NOx, especially in the PRD region. We realized that the temporal variations of agricultural $NH_3$ emission are still highly uncertain. We will continue to do further study for improving the estimates of ammonia emissions, and their temporal and spatial characteristics. In the revised version, based upon above materials, we clarify how monthly variations in the agricultural sources were characterized (See the added Section 2.5 and Section 3.3 in the revised version) and recommended future research by considering the other referee's comment and the short comment in the Interactive Discussion (See Lines 10-18 on Page 25 in the revised version).

**Reference:**

Chinkin, L. R., Ryan, P. A., and Coe, D. L.: Recommended improvements to the CMU ammonia emission inventory model for use by LADCO, U.S. Lake Michigan Air Directors Consortium, 2003.

Meng, Z. Y., Xu, X. B., Wang, T., Zhang, X.Y., Yu, X. L, Wang, S. F., Lin, W. L., Chen, Y. Z., Jiang, Y. A., and An, X. Q.: Ambient sulfur dioxide, nitrogen dioxide, and ammonia at ten background and rural sites in china during 2007–2008. Atmos. Environ., 44, 2625-2631, 2010.

Pinder, R. W., Adams, P. J., Pandis, S. N., and Gilliland, A.B.: Temporally resolved ammonia emission inventories: Current estimates, evaluation tools, and measurement needs, J. Geophys. Res., 111, D16310, doi:10.1029/2005JD006603, 2006.

Streets, D. G., Bond, T. C., Carmichael, G. R., Fernandes, S. D., Fu, D., Klimont, Z., Nelson, S.M., Tsai, N. Y., Wang, M. Q., Woo, J. H., and Yarber, K. F.: An inventory of gaseous and primary aerosol emissions in Asia in the year 2000, 108, D21, 8809, doi:10.1029/2002JD003093, 2003.

Zheng, J. Y., Zhang, L. J., Che, W. W., Zheng, Z. Y., and Yin S. S.: A Highly Resolved Temporal and Spatial Air Pollutant Emission Inventory for the Pearl River Delta Region, China and its Uncertainty Assessment, Atmos. Environ., 43, 5112-5122, 2009.

**Referee comments**

*1.3 Analysis of the trend 1998-2006*

*The conclusions state: "A significant long-term correlation between agricultural $NH_3$ emission and pH value was observed reflecting the fact that the local $NH_3$ emissions influence the precipitation characteristics."*

*This is not correct. I could find no such statistically significant correlation described in the results. Furthermore, looking at the data in Table 7 and Figures 11-13, there does not appear to be any trend in the cation ratio or $NH_4^+$ in precipitation.*

**Response:** We accepted the comments from the reviewer. It may be true that it is weak to conclude that local $NH_3$ emissions may influence the precipitation characteristics based upon the comparison between the long-term trends of them. In the revised version, we have revised the statement (See Lines 7-9 on Page 25 in the revised version). However, we tried to make preliminary analysis of the potential correlations between $NH_3$ emissions and pH values owing to that ammonia is the only alkaline gas in atmosphere. Also, we can see that the long-term trends of the ratio $Ca^{2+}$+$NH_4^+$/$SO_4^{2-}$+$NO_3^-$ were consistent with pH values during the study period (Fig.12 in previous version). We did some new analysis, which was shown in the revised Section 3.6.1.

*The analysis of the trend 1998-2006 is not useful and should not be presented. According to the emission estimates, there is relatively small trend in emissions over this period. According to the $NH_4^+$ concentration data, there is no trend over this period. There are some very high values reported in 1999 and 2005. From this, it is not possible to conclude that there is a meaningful relationship between the measured $NH_4^+$ at this estimate of $NH_3$ emissions. The best is that there is no real trend in either dataset. The authors should simply state this and move onto a different approach for the analysis.*

**Response:** We appreciate the careful comments and valuable suggestions from the referee. In the previous version, we revealed the relevance by showing the annual variation between $NH_3$ emissions and $NH_4^+$ in precipitation, but without statistical analysis. The annual variations were overall consistent except the year of 1999 (Fig. 13 in previous version). The discrepancy may partly attribute to the fact that less valid data samples was analyzed for chemical composition of precipitation in 1999. Although the concentration of $NH_4^+$ in precipitation sharply declined from 2005, this may be probably because the deadline of closing down the small-scale thermal power units was at the end of year 2005 according to the Tenth Five-Year Plan, resulting in the improvement of fuel efficiency, sulfur content and therefore the reduced fuel consumption and $SO_2$, $NO_X$ emission.

Even so, we totally agreed that these could only show that there were interactions between $NH_3$ emissions and $NH_4^+$ in precipitation indirectly. Although we may not able to conclude that there is a meaningful relationship between the measured $NH_4^+$ and the $NH_3$ emissions, the overall variations show the consistency, to some extent. Considering the referee's suggestions, we removed the Fig. 11-12 in the previous version and discussed the annual variations by merging the section 3.6.1 and 3.6.2. Details can be found in the new Section 3.6.1 of the revised version.

*There is however a substantial difference in winter and summer $NH_3$ emissions estimated by this inventory. Is it possible to segregate the winter/summer $NH_4^+$ precipitation concentration? Do you see a similar winter /summer difference in the measurements? This would give us confidence that the inventory is capturing the seasonal variability.*

**Response:** Thanks for the suggestion of investigating seasonal variability in alternative way. We re-conducted a very deep research about the database of $NH_4^+$ in precipitation. Finally the seasonal variability of $NH_4^+$ in precipitation was conducted in the year of 2006 (see the Fig. 1 below). As shown in Fig.1, monthly variations of $NH_4^+$ in precipitation exhibited obviously seasonal peak to valley characteristics with maximum in August and minimum in January. It has an overall consistency with winter/summer difference of the agricultural $NH_3$ emission, despite there were some discrepancies in March and April. However, the composition of the precipitation depends on local emissions, pollutants transport, and drop size, which in turn influence the rainout (in-cloud scavenging) and the washout (below-cloud scavenging) (Migliavacca et al., 2005). Hence, we could not directly judge the reasonability by comparing with $NH_4^+$ in precipitation. Nevertheless, this alternative way validated the winter/summer differences in $NH_3$ emissions. (See Lines 26-28 on Page 19 and Lines 1-2 on Page 20 in the revised version)

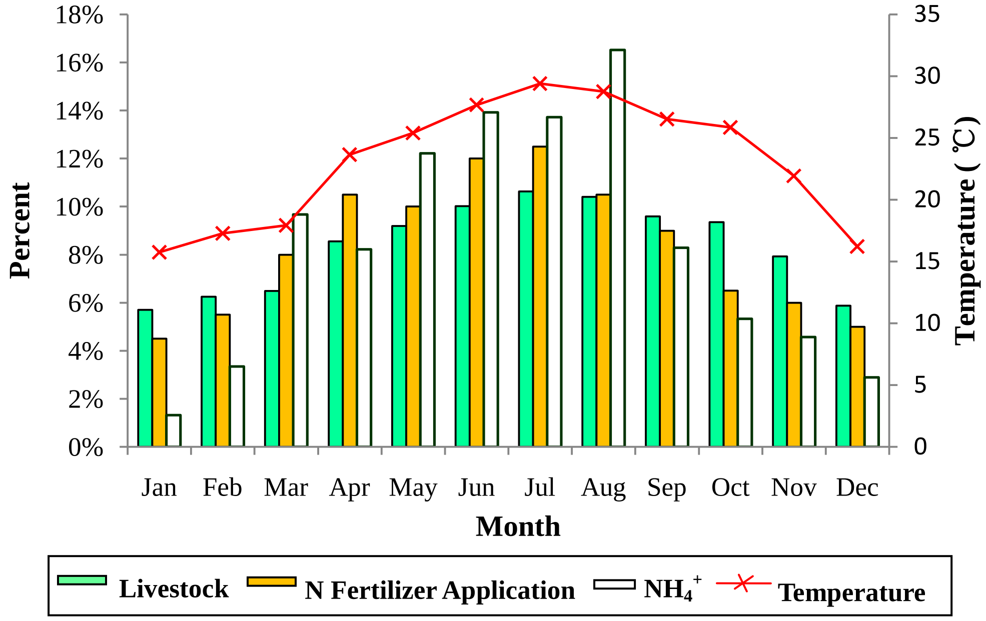


**Fig. 1.** Monthly variations in emissions from livestock and N fertilizer applications, and $NH_4^+$.

**Reference:**


Migliavacca, D., Teixeiraa, E.,Wiegand, F., Machado, A., and Sanchez, J.: Atmospheric precipitation and chemical composition of an urban site, Guaiba hydrographic basin, Brazil. Atmos. Environ., 39, 1829-1844, 2005.


*There is some evidence that the spatial patterns in the $NH_4^+$ in precipitation are influenced by local $NH_3$ emissions as quantified by this work. However, this relationship is week (R-squared of 0.203). This is to be expected, though. The $NH_4^+$ in precipitation would be expected to be influenced by a broader area than just local emissions. Also why are the data log-transformed?*

**Response:** We are grateful for the positive comments from the referee upon this point. We completely agreed that the $NH_4^+$ in precipitation would be expected to be influenced by a broader area than just local emissions like the referee said. Meanwhile it was also affected by other complex factors like meteorological condition, precursors, and atmospheric chemical processes. The main purpose of data log-transformed is to improve the normality of regression residuals.

*To build confidence in the results, the authors should compare their emission inventory to surface measurements of $NH_3$ in the gas phase, such as those recently published by Hu et al. (2008); Meng et al. (2010); Shen et al. (2011).*

**Response:** We appreciated the valued suggestion from the referee and had read the recommended articles carefully. Hu et al. (2008) conducted real-time measurements of ammonia and water-soluble ions in $PM_{2.5}$ at Xinken, as part of the Pearl River Delta (PRD) intensive field campaign. Due to the period of sampling was from 4 October to 4 November 2004, the comparison of seasonal variations could not be conducted. But the diurnal variation of $NH_3$ can be utilized to guide the high time-resolution and model-ready emission inventory which was important for air quality modeling. Meng et al. (2010) characterized the long-term observation of ammonia and analyzed the seasonal variations in ambient concentration of $NH_3$, and the results found that the concentration of $NH_3$ peaked in warm seasons at all sites and was bottomed in cold seasons. The results from the stations of Meixian and Dianbai located in Guangdong province, adjacent to the PRD region, had a peak $NH_3$ concentration in summer, while the observed $NH_3$ levels in spring were much closer to the corresponding maximum levels in Autumn. These findings supported the seasonal variations in $NH_3$ emissions in our study. Shen et al. (2011) conducted the long-term measurements of atmospheric ammonia and particulate ammonium in the North China Plain (NCP). Although the discrepancy of climate exists between the PRD region and NCP, the consistent result was found that $NH_3$ concentrations were highest in summer and lowest in winter.

On the other hand, we actually found that the surface measurements of $NH_3$ in the gas phase showed different seasonal variations between southern China like Guangdong province and northern China. In northern China, the averaged $NH_3$ concentrations across the sites in summer were 3.9, 1.5 and 1.3 times higher than those in winter, spring and autumn, respectively (Shen et al., 2011), and conversely, the observed $NH_3$ levels in spring or autumn were much closer to the corresponding maximum levels in summer in southern China (Meng et al., 2010). The phenomenon may attribute to the difference in temperature and agricultural activities at the different sampling sites (Shen et al., 2011; Robarge et al., 2002) and it suggested that the local measured $NH_3$ should be conducted in the PRD region. We have made revisions based upon these studies, and please see the Lines 16-18 on Page 25 in the revised version.

We did some discussions based upon three studies about the surface e measurements of $NH_3$ in the gas phase, and have revised the manuscript by referring to the results (See the added Section 2.5 and Section 3.3 in the revised version).

**Reference:**

Hu, M., Wu, Z., Slanina, J., Lin P., Liu, S., and Zeng, L. M.: Acidic gases, ammonia and water-soluble ions in pm2.5 at a coastal site in the pearl river delta, China, Atmos. Environ., 42, 6310-6320, 2008.

Meng, Z. Y., Xu, X. B., Wang, T., Zhang, X. Y., Yu, X. L, Wang, S. F., Lin, W. L., Chen, Y. Z., Jiang, Y. A., and An, X. Q.: Ambient sulfur dioxide, nitrogen dioxide, and ammonia at ten background and rural sites in china during 2007-2008, Atmos. Environ., 44, 2625-2631, 2010.

Robarge, W. P., Walker, J. T., McCulloch, R. B., and Murray, G.: Atmospheric concentrations of ammonia and ammonium at an agricultural site in the southeast United States, Atmos. Environ., 36, 1661-1674, 2002.

Shen, J. L., Liu, X. J., Zhang, Y., Fangmeier, A., Goulding, K., and Zhang, F. S.: Atmospheric ammonia and particulate ammonium from agricultural sources in the north China plain, Atmos. Environ., 45, 5033-5041, 2011.

**Referee comments**

*1.4 Characterization of uncertainty*

*I applaud the authors for characterizing the uncertainty. This is an important goal. However, the results from this characterization should be propagated through all of the results. An example is shown in Figure 2, but then single value, deterministic results are presented in all of the rest of the figures.*

**Response:** We appreciated it very much for the reviewer's positive comments on uncertainty analysis. Actually, the results in emission estimates were propagated through the overall emission model in which sector-based emission models were encapsulated by using the Monte Carlo simulation. Even for some parameters or the estimates for few sectors, deterministic results or single values were used due to lack of uncertainty information, but they can still be propagated to the overall emission model under the Monte Carlo simulation framework. The corresponding author has been working on the quantification of uncertainty in emission models, and has rich experience in handling uncertainty analysis in emission estimates (Frey and Zheng, 2002a, 2002b; Zheng and Frey, 2004; Zheng and Frey, 2005; Zheng et al., 2010).

**Reference:**

Frey H.C., Zheng J.Y.: Probabilistic Analysis of Driving Cycle-Based Highway Vehicle Emission Factors, Environ. Sci. Technol, 36, 5184 -5191, 2002a.

Frey H.C., Zheng J.Y.: Quantification of Variability and Uncertainty in Air Pollutant Emission Inventories: Method and Example Case Study for Utility NOx Emissions, J. Air Waste Manage. Assoc, 52, 1083-1095, 2002b.

Zheng J. Y., Frey H. C.: Quantification of Variability and Uncertainty Using Mixture Distributions: Evaluation of Sample Size, Mixing Weight and Separation between Components, Risk Analysis, 24, 553-571, 2004.

Zheng J. Y., Frey H. C.: Quantitative Analysis of Variability and Uncertainty with Measurement Error: Methodology and Case Study, Risk Analysis, 25, 663-675, 2005.

Zheng J. Y., Zheng Z. Y., Yu Y. F., Zhong L. J.: Temporal, Spatial Characteristics and Uncertainty of Biogenic VOC Emissions in the Pearl River Delta Region, China, Atmos. Environ, 44, 1960-1969, 2010.

*From your uncertainty characterization (Section 3.5) – what are the most important uncertainties? Where efforts should be focused for the biggest benefit? Some of the largest uncertainties are in sectors that contribute relatively little. The research needs are presented at the end, but it seems that these are based on data availability, rather* *than importance to reducing uncertainty.*

**Response:** Thanks for comments! In the revised study, we conducted the sensitivity analysis of the uncertainty results in model input and output parameters (NARSTO, 2005), and identified key uncertainty sources in the current PRD $NH_3$ inventory (See Table 8 in the revised version). We discussed the results about important uncertainty sources, and provided suggestions for future improvement in $NH_3$ emission inventories. Please see the added Section 3.4.2 in the revised revision.

**Reference:**

NARSTO, Improving Emission Inventories for Effective Air Quality Management Across North America[R], Assessment Prepared by: The NARSTO Emission Inventory Assessment Team, 2005.

**Referee comments**

***2 Editorial Issues***

*Please address these editorial issues. I recommend an editor read the document for other errors I have missed.*

*(1) L24, P33735 "few works are reported regarding how ammonia emissions" consider "few studies have reported how ammonia emissions..."*

**Response:** Accepted! The sentence is revised as "…, few studies have reported how ammonia emissions may impact on the $PM_{2.5}$ formation and acid deposition in this region using a modeling approach." (See Line 3 on Page 4 in the revised version)

*(2) L15, P33737 "examination of literatures" consider "previous studies"*

**Response:** Accepted. The sentence is revised as "These include previous studies, agricultural statistics, and government/institute reports." (See Line 23 on Page 5 in the revised version)

*(3) L19, P33737 what is "scalper"?*

**Response:** In Chinese official statistical yearbook (Agricultural Statistical Yearbook of Guangdong), there are four special types of cattle including yellow cattle, buffalo, dairy and beef cattle. In order to clarify this issue, we changed the sub-category of scalper and cattle into yellow cattle and beef cattle, respectively. Also, the same replacements are made in Table 1 and Table 3 and the text of the current version. (See Line 27 on Page 5 in the revised version)

*(4) L13, P33750 what is "dairy life"?*

**Response:** We are sorry for the mistake. The word "dairy life" has been removed.

*(5) Table 1 convert from 6 columns to 2 columns to make this more clear.*

**Response:** Accepted! Thanks for referee's suggestion. In the revised version, we attempted to redrawn Table 1 converting from 6 columns to 2 columns for ammonia emission source categories. Unfortunately, due to the larger number in sub-categories, the length of Table 1 is too long when it converts from 6 columns to 2 columns. But we change 6 columns to 4 columns as far as possible, and meanwhile, each category and sub-category was guaranteed in one column avoiding confusions. (See Table 1 in the revised version)

*(6) Figure 8 There is a semicolon in the middle of "Agricultural" on the left axis.*

**Response:** Thanks! It has been corrected (See Figure 9 in the revised version). Double checking has been conducted to avoid the same mistakes in the revised version.

*(7) References I was not able to find documentation on AuvToolPro. Please provide a reference or describe more completely.*

**Response:** Accepted! The AuvToolPro is an extension version of AuvTool developed by Dr.Zheng and Frey (2002). The AuvToolpro was developed by Dr. Zheng, the corresponding author of this manuscript. It is able to conduct quantitative variability and uncertainty analysis in model inputs and outputs for any user-defined models with the use of bootstrap simulation and Monte Carlo simulation, and to identify key sources leading to uncertainty in model outputs using sensitivity analysis approaches (Lau et al, 2010; Zheng et al., 2011).

**Reference:**

Lau, A. K. H., Zheng, J.Y., Lin, B., et al.: Study on Analysis of Variability and Uncertainty for Hong Kong Air Pollutant Emission Inventories, Environmental Protection Department, HKSAR for Provision of Service, 2010.

Zheng, J. Y. and Frey, H. C.: AuvTool User's Guide, Prepared for Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC, 2002.

Zheng J. Y., Wang S. S., Yu Y. F.: Development and demonstration of emission inventory uncertainty technology [R], Sub subject of the Chinese National 863 Key High-Tech Scientific Programs in the "Eleventh five-year Plan": Synthesized Prevention Techniques for Air Pollution Complex and Integrated Demonstration in Key City-Cluster Region, South China University of Technology, 2011 (in Chinese).