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Europe – China joint call on Sustainable Urbanisation in the Context of Economic Transformation and Climate Change:
Sustainable and Liveable Cities and Urban Areas

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UNCNET

Urban nitrogen cycles: new economy thinking to master the challenges of climate change

D3/1: Estimates of ammonia emissions from urban agriculture

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Organisation name of co-chairs for this deliverable: **PKU, IIASA**

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Dissemination Level		
PU	Public	☒
PP	Restricted to other programme participants (including funding agencies)	☐
RE	Restricted to a group specified by the consortium (including funding agencies)	☐
CO	Confidential, only for members of the consortium (including funding agencies)	☐

1. Executive Summary

The amount of ammonia (NH_3) emitted to the atmosphere from urban agricultural activities was estimated. Urban agriculture is mainly associated with fertilizer use and livestock raising in the core and extended areas of a city. UNCNET has developed a spatially and temporally resolved agricultural NH_3 emission inventory in China for the time period of 2005-2016. The fertilizer application amounts are estimated for 21 types of crops and fruits based on a crop harvest area and yield dataset at 5 min × 5 min resolution for the base year 2000, and are then scaled to match the province-level statistics from the National Bureau of Statistics of China (NBSC) for the individual years of 2005-2016. NH_3 emission factors for fertilizer use are derived using a function of soil properties, fertilizer type, application mode, and meteorological conditions. NH_3 emissions from livestock manure are also estimated using spatially resolved livestock population data with emission factors accounting for the influences of surface temperature and wind speed. The 2005-2016 Chinese agricultural NH_3 emission inventory has a spatial resolution of 0.25 degree and monthly temporal resolution. The agricultural NH_3 emission estimates have been gridded to a fine resolution of 9 km in Beijing as inputs to the WRF-Chem air quality model, and are now applied to simulate the changes in $PM_{2.5}$ air quality over Beijing and surrounding areas under NH_3 emission reduction scenarios.

Objectives:

The task is to estimate the amount of ammonia releasing to the atmosphere from agricultural activities in the city core and extended areas over North China.

2. Activities:

Discussions with IIASA and CAS to define urban agriculture and discussions with CAS for livestock data.

3. Results:

A Chinese agricultural ammonia emission inventory for 2005-2016 has been developed.

4. Milestones achieved:

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5. Deviations and reasons:

Insignificant delay due to slow project start-up phase

6. Publications:

7. Meetings:

Kickoff meeting at Peking University and bi-monthly UNCNET teleconferences

8. List of Documents/Annexes:

Annex: Agricultural ammonia emission estimates in China for 2005-2016

REFERENCES

ANNEX

Agricultural ammonia emission estimates in China for 2005-2016

1 Introduction

Ammonia (NH_3) is the most abundant alkaline gas in the atmosphere, and can lead to negative effects on human health and ecosystems. NH_3 in the atmosphere reacts with acids (such as sulfate acid and nitric acid) to form ammonium sulfate ($(NH_4)_2SO_4$) and ammonium nitrate (NH_4NO_3) aerosols. These inorganic aerosols (sulfate-nitrate-ammonium) have been observed to account for 20-57% of $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5 μm, also called fine particles) in Chinese cities (Yang et al., 2011; Huang et al., 2014). Both ammonia (NH_3) and ammonium (NH_4^+) can be deposited through wet and dry deposition processes to Earth surface, providing additional reactive nitrogen (fixed nitrogen) to terrestrial and aquatic ecosystems.

China is one of the countries that have the largest NH_3 emissions over the world due to its intensive agricultural activities. Over 85% of NH_3 in China is emitted from agricultural activities, including nitrogen fertilizer application to farmland and through livestock raising systems (Huang et al., 2012; Zhang et al., 2018). Previous estimates of Chinese NH_3 emissions have shown a broad range of 6.9-15 Tg N per annum over 2005-2012 (Huang et al., 2012; Zhang et al., 2017; Zhang et al., 2018), largely attributed to the missing agricultural statistics (activity data and emission factors) and a lack of NH_3 measurements to constrain the emission estimates. Our recent study (Zhang et al., 2018) has combined the bottom-up statistical approach and the top-down approach using satellite NH_3 measurements to better resolve the spatial and temporal variability of agricultural NH_3 emissions in China.

UNCNET defines urban agriculture as systems of urban plants and urban animal production. For urban agricultural N flow to the atmosphere, this mainly includes NH_3 emitting from cropland fertilizer use and livestock raising in the core and extended (rural) areas of a city. A fine spatially resolved agricultural NH_3 emission estimate is then required to better distinguish the city areas, e.g., Beijing and Shijiazhuang in UNCNET project. Here we refine our recent work on agricultural NH_3 emission inventory and further extend the estimates to the time period of 2005-2016.

2 Methodology

We improve the bottom-up approach of Zhang et al. (2018) to develop a Chinese agricultural NH_3 emission inventory covering 2005-2016. Figure 1 shows the schematic diagram of the bottom-up approach.

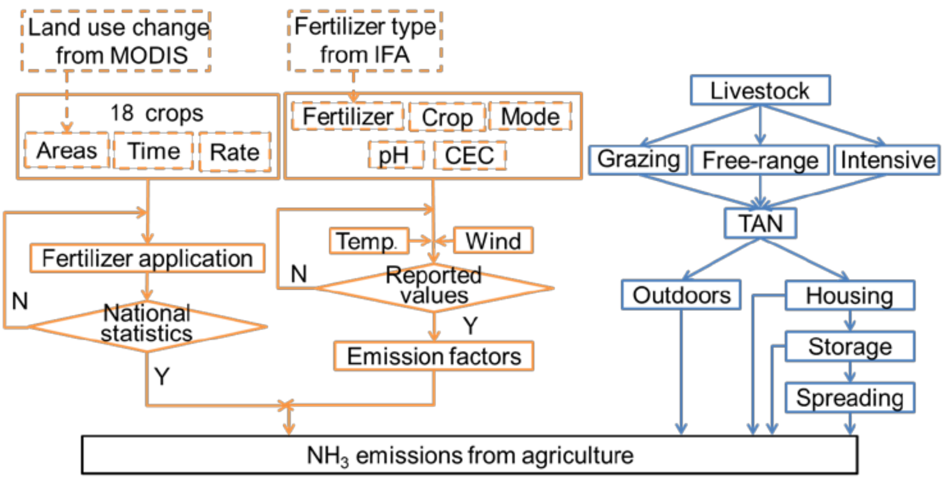

Figure 1 Schematic diagram of the bottom-up method to estimate agricultural NH_3 emissions.

Fertilizer use

NH_3 emissions from fertilizer application ($E_{\mathrm{NH_3-F}}$) are calculated as the product of synthetic fertilizer application magnitude (F) and corresponding emission factors (α_{F}):

$$E_{\mathrm{NH_3-F}} = F \times \alpha_{\mathrm{F}} \qquad (1)$$

We calculate fertilizer application amounts for 18 crops and fruits (including early/late rice, spring/winter wheat, spring/summer maize, cotton, potato, sweet potato, rapeseed, soybean, groundnut, apple, banana, citrus, pear, and grape) and 3 remaining groups (vegetables, other crops, and other fruits). We use the EarthStat dataset of global crop harvest area (EarthStat, 2015) at 5min × 5min spatial resolution for the base year of 2000. To account for the changes in crop harvest or planting areas in later years, we use the land use dataset from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instrument for 2005-2012 that provides the changes in cropland at 500 m resolution. The total calculated fertilizer use amounts are further scaled to match the province-level statistics from the National Bureau of Statistics of China (NBSC) for the individual years of 2005-2016.

Emission factors of NH_3 from fertilizer application are estimated as a function of soil properties and agricultural activity information, and further modulated by meteorological conditions (Zhang et al., 2018). The emission factor is first calculated as:

$$\alpha_0 = e^{f_{\mathrm{pH}}+f_{\mathrm{CEC}}+f_{\mathrm{type}}+f_{\mathrm{crop}}+f_{\mathrm{mode}}} \qquad (2)$$

where the factors (*f*) represent effects of soil pH, cation exchange capacity (CEC), fertilizer type (e.g., urea, ammonium bicarbonate (ABC), ammonium sulfate (AS), and others), and application mode (broadcast and injection) on NH_3 volatilization mainly based on Bouwman et al. (2002). Monthly scalars are then applied to account for the seasonality driven by meteorology:

$$\alpha_F = \alpha_0 \left(e^{0.0223\mathrm{T}_i+0.0419\mathrm{W}_i}\right) \Big/ \left(\frac{1}{12}\sum_{j=1}^{12} e^{0.0223\mathrm{T}_j+0.0419\mathrm{W}_j}\right) \qquad (3)$$

where T_i and W_i are 2m (meter) air temperature in °C and 10m wind speed in m s^{-1} for month *i*, respectively, as obtained from the GEOS-FP assimilated meteorological data at 0.25 degree × 0.3125 degree resolution.

Livestock manure

NH_3 emissions from livestock waste are estimated as the product of livestock population and emission factors. We apply a process-based mass-flow approach by considering the transformation of nitrogen in animal husbandry following Huang et al. (2012) as described in Zhang et al. (2018). We estimate the animal excreta from six kinds of livestock, including beef cattle, dairy cows, goat, sheep, pig, and poultry as raised through three main livestock raising systems: free-range, intensive, and grazing. The most common in the rural area is free-range, which is the traditional way to raise livestock. The intensive raising system is the most popular way in megacities due to its high efficiency and easiness to manage the shelter environment, and grazing is mostly applied in Northwest China.

We use the gridded livestock (e.g., pork, beef, dairy, sheep, poultry) population at 5 min resolution from the Gridded Livestock of the World (GLW, 2015), and then adjust them to match the province-level annual records of NBSC for individual years of 2005-2016. Emission factors of NH_3 from livestock manure also account for the meteorological influences, including surface air temperature and wind speed as shown by Eq. (3).

Other sources

NH_3 emissions from non-agricultural activities, including residential burning, industry, transportation, and biomass burning, are from Kang et al. (2016) for 2005-2012. We extend their emissions to 2013-2015 by scaling to match the interannual changes in anthropogenic emissions of sulfur dioxide (SO_2) in China as reported in the MIX emission inventory (Li et al., 2017).

3 Agricultural ammonia emission estimates

Figure 2 show the interannual changes in Chinese NH_3 emissions from fertilizer application, livestock manure management, and total anthropogenic sources from 2005 to 2016. Figure 3 shows their spatial distributions. Total Chinese anthropogenic NH_3 emissions from fertilizer are 5.0 Tg in 2005, then increase to 5.3 Tg in 2012, and further decrease to 4.5 Tg in 2016. Meanwhile, the fertilizer application amounts have increased from 24.2 Tg in 2005 to 26.7 Tg in 2016. Ammonium bicarbonate (ABC) has a much higher emission factor than urea and compound fertilizer (NPK). The use of compound fertilizer has increased (from 7.7 Tg in 2005 to 15.4 Tg in 2016) during the past decade, while the use of ammonium bicarbonate (ABC) has largely decreased (from 5.5 Tg in 2005 to 1.7 Tg in 2016). As ABC has a much higher emission factor than urea and compound fertilizer (NPK), the NH_3 emissions from fertilizer in eastern China has been decreasing during the past decade as also shown in the Figure 3.

NH_3 emissions from livestock reached 8.2 Tg in China in 2005 and decreased to 7.0 Tg in 2016. The trend could be largely explained by the switch of free-range raising to large intensive raising systems since 2007 (Fig. 2b). In 2007, the Chinese government started to encourage farmers to transform free-range livestock to large intensive raising systems. In addition, the number of pigs and cattle dropped significantly in 2007 due to diseases among pigs and increased cost to raise cattle. This leads to a large decrease in NH_3 emission from livestock in 2007.

The total anthropogenic emissions of NH_3 in China decreased from 14.4 Tg NH_3 yr^{-1} in 2005 to 13.1 Tg NH_3 yr^{-1} in 2007, and remained relatively stable in the range of 12.9 Tg - 13.9 Tg NH_3 yr^{-1} over 2008-2016. We find that the observed recent increases in atmospheric NH_3 levels over North China (Warner et al., 2017) are not driven by the changes in NH_3 emissions, but to a large extent by the changes in SO_2 emissions over this region.

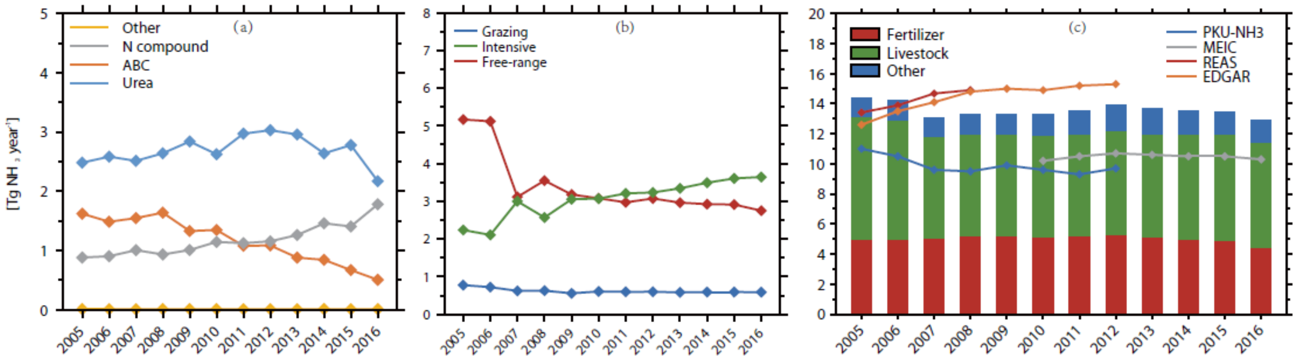

Figure 2. NH_3 emissions from (a) nitrogen fertilizer: urea, ABC, nitrogen compound, and other nitrogen fertilizers, (b) livestock: free-range, intensive, and grazing system, (c) NH_3 emissions from fertilizer, livestock, and other anthropogenic sources over 2005-2016 in China. The lines in (c) are emission inventories from other studies: PKU-NH3, MEIC, REAS and EDGAR.

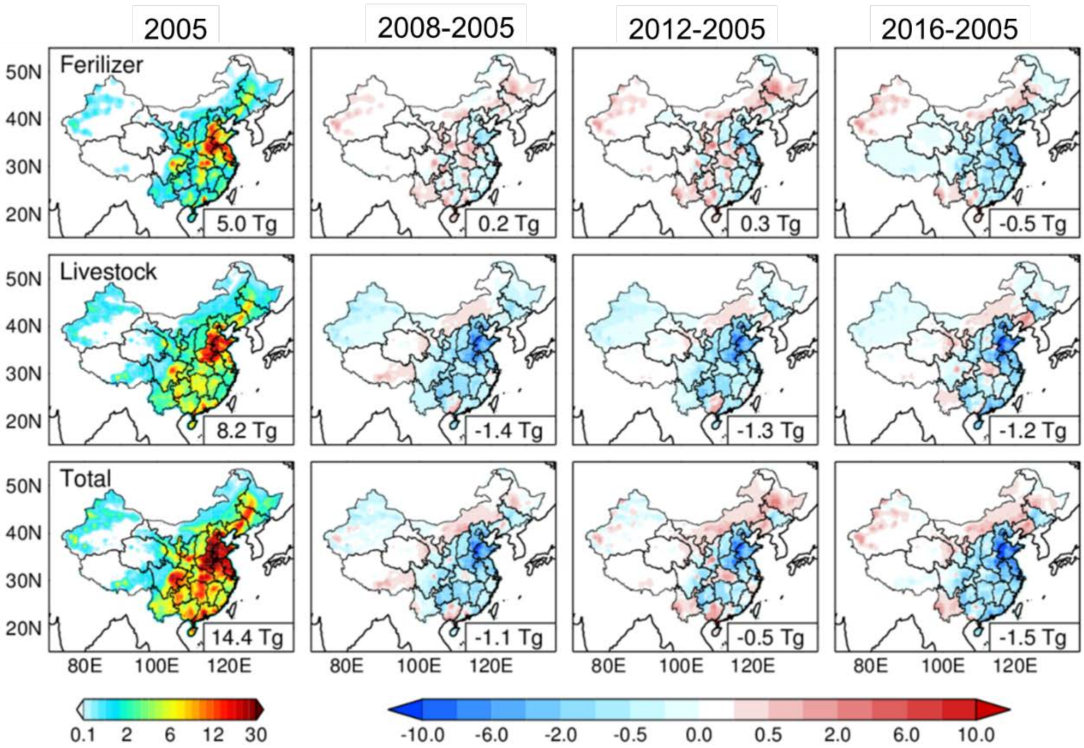

Figure 3. Spatial distribution of NH_3 emissions from fertilizer application, livestock manure, and total anthropogenic sources in 2005 at 0.25 degree resolution, and their changes in the years 2008, 2012, and 2016. The total emission values in China are shown inset.

We have also set up the WRF-Chem air quality model to simulate the $PM_{2.5}$ air pollution over North China, and to investigate the influences of NH_3 emission reductions. The NH_3 emission estimates as described above have been gridded to a spatial resolution of 9 km as inputs to the WRF-Chem model. Figure 4 shows the spatial distributions of NO_x, SO_2, and NH_3 emissions in North China for the year 2015. Our NH_3 emissions over North China (110°-120° E, 35°-43° N) are estimated to be 0.12 Tg/month in January and 0.29 Tg/month in July. Our initial results show that the effectiveness of NH_3 emission reductions is significantly higher in July than in January; a 20 % NH_3 emission reduction in July would lead to 5-10 % reduced $PM_{2.5}$ concentrations over BTH.

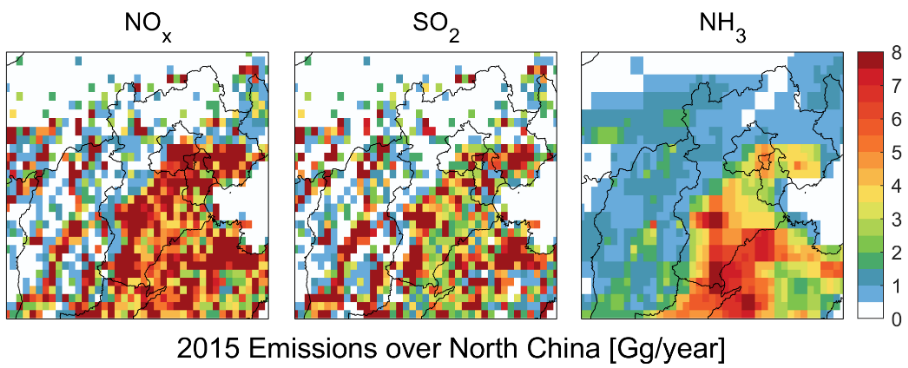

Figure 4. Annual emissions of NO_x, SO_2, and NH_3 over North China in 2015 as emission inputs to the WRF-Chem air quality model. The Chinese SO_2 and NO_x emissions are from the MIX inventory (Li et al., 2017).

-- manuscript in preparation

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