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Agricultural ammonia emissions in China: reconciling bottom-up and top-down estimates

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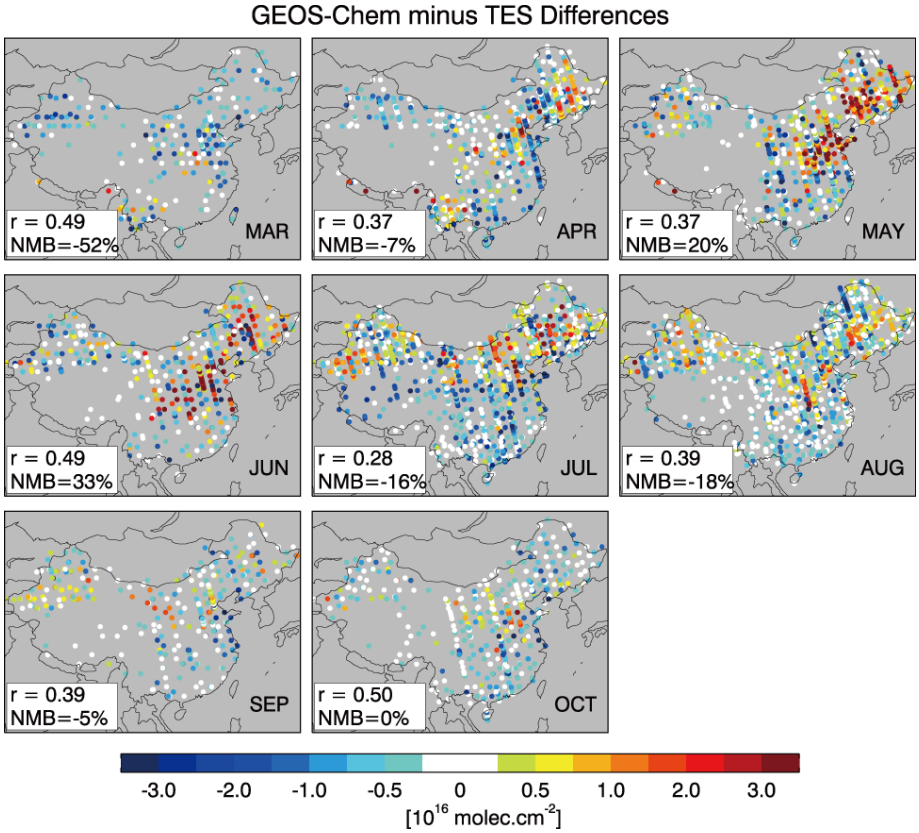

Figure S1. Differences between GEOS-Chem simulated and TES observed NH_3 column concentrations from March to October over China. GEOS-Chem results for the year 2008 are simulated using our improved bottom-up NH_3 emission inventory. Model results are also sampled along the TES measurement locations, and applied with the TES averaging kernel matrices. Correlation coefficients (r) and normalized mean biases (NMB) are shown inset.

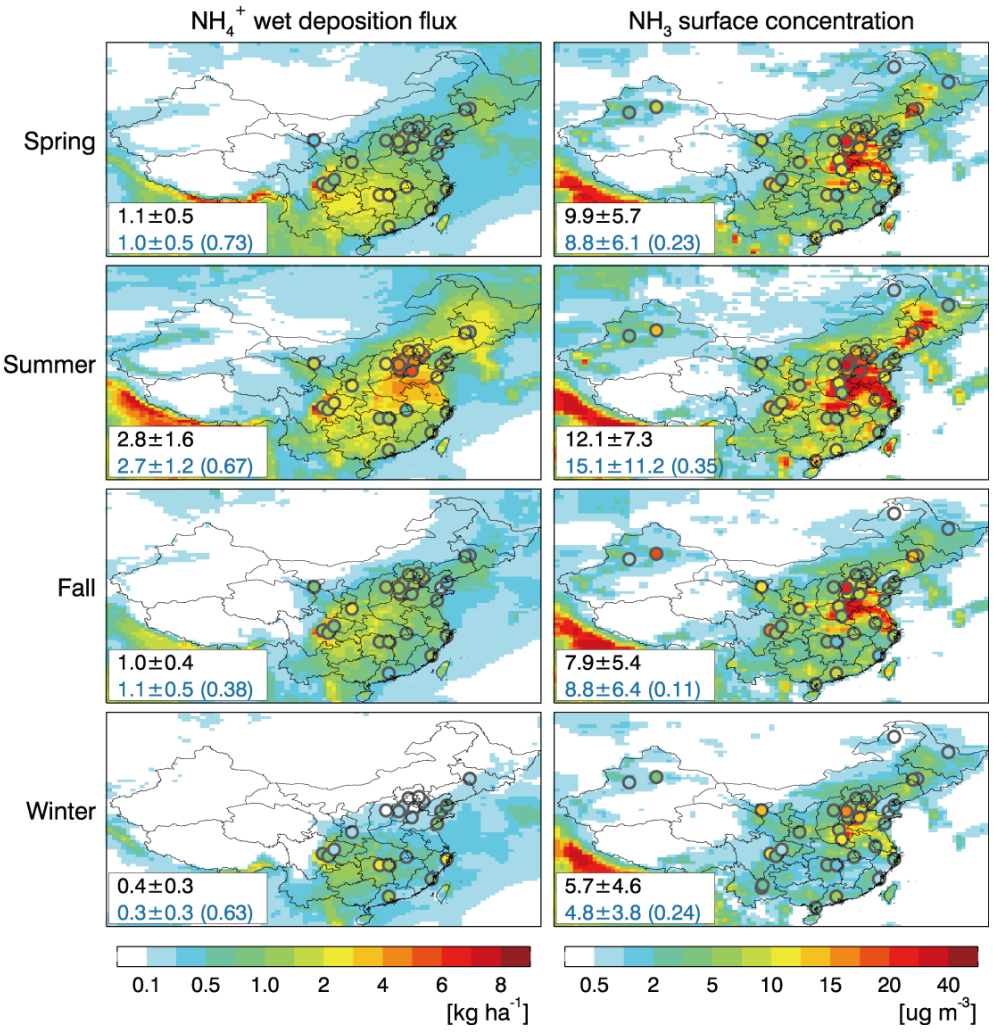

Figure S2. Spatial distributions of measured vs. simulated seasonal mean NH_4^+ wet deposition fluxes (left) and NH_3 concentrations (right) over China. Model results are 5–year (2008–2012) averages from a simulation with anthropogenic emissions (including our bottom-up NH_3 emissions) fixed to the year 2008 conditions. Values inset are seasonal averages and standard deviations for measurements (black) and model results (blue) with their correlation coefficients shown in parentheses.

Table S1. Dates of fertilizer application for main crops in China[1]

	Crops	First	Second	Third	Fourth	Fifth	Deviation[2]
Number of day after the planting date	Early rice	10	20	30	45	80	32
	Late rice	10	20	30	45	80	32
	Spring wheat	0	20	45	\	\	29
	Winter wheat	0	30	168	\	\	27
	Spring maize	0	15	25	40		36
	Summer maize	0	15	25	40		36
	Cotton	0	14	54	100	110	24
	Sweet potato	0	10	60	80	\	17
	Potato	12	29	37	\	\	23
	Rapeseed	0	30	144	151	\	30
	Soybean	0	16	71	\	\	32
	Peanut	0	20	\	\	\	22
Calendar day of year	Tobacco	90	99	109	132	\	9
	Apple	305	64	115	152	274	9
	Banana	244	35	181	\	\	9
	Grape	274	91	158	188	\	9
	Citrus	319	74	110	140	213	9
	Pear	60	105	135	316	\	9

[1]Timing of fertilizer application (up to five times) based on Liao (1993) and Zhang and Zhang (2012).

[2]Mean deviation (number of days) from the fertilizer application dates for each crop over China used in this study (σ in Eq. (4) in the main text).

Table S2. Fertilizer application rates for main crops in China[1]

Crops	First	Second	Third	Fourth	Fifth	Total
Early rice	0.8	0.8	55.2	55.2	27.6	139.6
Late rice	0.8	0.8	41.3	70.5	16.5	129.9
Spring wheat	48.9	36.4	36.4	\	\	121.7
Winter wheat	48.9	36.4	36.4	\	\	121.7
Spring maize	71	13	22	22	\	128
Summer maize	71	13	22	22	\	128
Cotton	61	9.3	16.2	16.2	29	131.7
Sweet potato	62.5	5.2	6.9	6.9	\	81.5
Potato	65.5	77	65.5	\	\	208
Rapeseed	105	64	20	25	\	214
Soybean	16.2	13.4	16.2	\	\	45.8
Peanut	70	21	\	\	\	91
Tobacco	1.3	18	30	42	\	91.3
Apple	150	30	60	30	30	300
Banana	144	108	108	\	\	360
Grape	124	37.2	62	24.8	\	248
Citrus	162	162	107	18	25	474
Pear	108	81	53	28	\	270

[1]Fertilzier application rates in unit of kg N ha^{-1} are based on Liao (1993) and Zhang and Zhang (2012). Timing of fertilizer application (up to five times) is shown in Table S1.

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Table S3. Emission factor index for synthetic fertilizer application[1]

Factor	Value
Crop type	
Upland crops	-0.045
Flooded crops	0
Fertilizer type	
Ammonium sulfate	0.429
Urea	0.666
Ammonium nitrate	-0.35
Other straight N	-0.507
Compound NPK	0.014
Ammonium bicarbonate[2]	0.928
Application mode	
Broadcast	-1.305
Injection	-1.895
Soil pH[3]	$0.067\times pH^2-0.69\times pH+0.68$
Soil CEC	
CEC ≤16	0.088
16＜CEC≤24	0.012
24＜CEC≤32	0.163
CEC＞32	0

[1]Values used for calculating NH_3 emission factors from fertilizer application (Eq. (5) in the main text) based on Bouwman et al. (2002) with modifications noted in the table.

[2]The value for ammonium bicarbonate is corrected according to observations from Zhu et al. (1989).

[3]For soil pH, a second-order function is applied to fit the segmental values given in Bouwman et al. (2002).

Table S4. A summary of reported emission factors (EF) for NH_3 from fertilizer application in China

Study	Region	Method[1]	Fertilizer type[2]	pH	CEC[3]	Crops	Application mode[4]	EF[5]
Su et al., 2006	Beijing	WTS	U	8	＜16	Bare soil	b/f	25.4
Su et al., 2006	Beijing	WTS	U	8	＜16	Bare soil	b/f	23
Su et al., 2006	Beijing	WTS	U	8	＜16	Bare soil	b/f	25.8
Su et al., 2006	Beijing	WTS	CAN	8	＜16	Bare soil	b/f	2.9
Su et al., 2006	Beijing	WTS	ASN	8	＜16	Bare soil	b/f	19.8
Su et al., 2006	Beijing	WTS	U	8	＜16	Bare soil	b/f	17.5
Su et al., 2007	Beijing	WTS	U	8	＜16	Summer Maize	b	33.1
Su et al., 2007	Beijing	WTS	U	8	＜16	Summer Maize	b	23.7
Wang et al., 2012	Jiangxi	EIV	U	5.24	16-24	Late Rice	i	18.9
Wang et al., 2012	Jiangxi	EIV	U	5.24	16-24	Late Rice	b	9.2
Wu et al., 2015	Yunnan	VM	U	6.34	＜16	Snow Peas	b	26.02
Wu et al., 2015	Yunnan	VM	U	6.34	＜16	Snow Peas	b	29.8
Wu et al., 2015	Yunnan	VM	U	6.34	＜16	Snow Peas	b	29.1
Wu et al., 2015	Yunnan	VM	U	6.34	＜16	Zucchini	b	15.42
Wu et al., 2015	Yunnan	VM	U	6.34	＜16	Zucchini	b	14.56
Wu et al., 2015	Yunnan	VM	U	6.34	＜16	Zucchini	b	14.08
Wu et al., 2015	Yunnan	VM	U	6.34	＜16	Sweet Maize	b	11
Wu et al., 2015	Yunnan	VM	U	6.34	＜16	Sweet Maize	b	12.35
Wu et al., 2015	Yunnan	VM	U	6.34	＜16	Sweet Maize	b	11.62
Cai et al., 2002	Henan	MT	U	8.6	＜16	Maize	b/f	18
Cai et al., 2002	Henan	MT	U	8.6	＜16	Maize	b	44
Cai et al., 2002	Henan	MT	U	8.6	＜16	Maize	b	48
Yang et al., 2010	Henan	VM	U	8.2	＜16	Winter Wheat	i	15.96
Zhu et al., 1989	Henan	MT	U	8.8	＜16	Rice	i	30.1
Zhu et al., 1989	Henan	MT	ABC	8.8	＜16	Rice	i	39.1
Zhao et al., 1988	Tianjin	^{15}N	AS	8	16-24	Bare Soil	b	18.32
Zhao et al., 1988	Tianjin	^{15}N	AS	8	16-24	Bare Soil	b	22.07
Zhao et al., 1988	Tianjin	^{15}N	AS	8	16-24	Bare Soil	b	15
Zhao et al., 1988	Tianjin	^{15}N	AS	8	16-24	Bare Soil	b	32
Zhao et al., 1988	Tianjin	^{15}N	ABC	8	16-24	Bare Soil	b	50.92
Zhao, et al. 1988	Tianjin	^{15}N	AS	8	16-24	Bare Soil	b	17.69
Dong et al., 2014	Liaoning	VM	U	6.13	16-24	Bare Soil	b	26.94
Wu et al., 2009	Hunan	CC	U	4.9	＜16	Early Rice	i	2.2

Wu et al., 2009	Hunan	CC	U	4.9	＜16	Late Rice	i	5
Wu et al., 2009	Hunan	CC	U	4.9	＜16	Late Rice	b	11.3
Xi et al., 1987	Shanghai	CC	U	7.9	＜16	Cabbage	i	11.12
Li et al., 1993	Shannxi	Ha	AS	7.9	＜16	Bare Soil	b	34.6
Tian et al., 2007	Jiangsu	EIV	U	7.3	16-24	Rice	i	8.4
Tian et al., 2007	Jiangsu	EIV	U	7.3	16-24	Rice	b	27.4
Yu et al., 2013	Jiangsu	VM	U	6.99	16-24	Rice		19.4
Zhu et al., 1985	Jiangsu	EIV	AS	6.6	16-24	Early Rice	i	1.5
Zhu et al., 1985	Jiangsu	EIV	U	6.6	16-24	Early Rice	i	4.5
Zhu et al., 1985	Jiangsu	EIV	AS	8	16-24	Early Rice	i	10.2
Zhu et al., 1985	Jiangsu	EIV	U	8	16-24	Early Rice	i	11.3
Zhu et al., 1985	Jiangsu	EIV	ABC	5.7	＜16	Late Rice	i	15.4
Zhu et al., 1985	Jiangsu	EIV	U	5.7	＜16	Late Rice	i	16
Zhu et al., 1985	Jiangsu	EIV	AS	5.7	＜16	Late Rice	i	10.2
Fan et al., 2005	Jiangsu	MT	U	7.15	16-24	Wheat	b	22.7
Fan et al., 2005	Jiangsu	MT	U	7.15	16-24	Wheat	b	26.2
Cai et al., 1985	Jiangsu	MT	U	5.3	16-24	Rice	b	8.8
Cai et al., 1985	Jiangsu	MT	ABC	5.3	16-24	Rice	b	19.5
Xia et al., 2010	Hubei	CAEM	U	6.3	＜16	Rice	i	13.79

[1]For the methods, WTS denotes wind tunnel system, EIV denotes enclosed intermittent vent method, VM denotes venting method, ^{15}N denotes ^{15}N stable tracer isotope, MT denotes micrometeorological technique, CC denotes closed air-flow chamber, Ha denotes Hargroue's method, and CAEM denotes continuous air flow enclosure method.

[2]U denotes Urea, ABC denotes ammonium bicarbonate, AS denotes ammonium sulfate, AN denotes ammonium nitrate, CAN denotes calcium ammonium nitrate, and ASN denotes ammonium sulfate-nitrate.

[3]Soil cation exchange capacity (CEC) in unit of cmol(+)/kg.

[4]b denotes broadcast, i denotes cultivate after broadcasting, and b/f denotes flood after broadcasting.

[5]EF in unit of %.

References

Bouwman, A. F., Boumans, L. J. M., and Batjes, N. H.: Estimation of global NH3 volatilization loss from synthetic fertilizers and animal manure applied to arable lands and grasslands, Global Biogeochem. Cy., 16, 2, 1024, doi:10.1029/2000GB001389, 2002.

Cai, G. X., Zhu, Z. L., Zhu, Z. W., Trevitt, A. C. F., Freney, J. R., and Simpsom, J. R.: The research of nitrogen losses from ammonium bicarbonate and urea in rice paddy field Soils, 17, 225-256,doi:10. 13758 /j . cnki . tr . 1985. 05. 001, 1985 (in Chinese).

Cai, G. X., Chen, D. L., Ding, H., Pacholski, A., Fan, X. H., and Zhu, Z. L.: Nitrogen losses from fertilizers applied to maize, wheat and rice in the North China Plain, Nutr. Cycl. Agroecosys., 63, 187-195, doi:10.1023/a:1021198724250, 2002.

Dong, Y. H., Zhang, Y. G., Sun, S. L., Jin, D., and Wang, Y. G.: Soil ammonia volatilization under different urea combined fertilization treatments, Chinese Journal of Ecology, 33, 2943-2949, 2014 (in Chinese with English abstract).

Fan, X. H., Song, Y. S., Lin, D. X., Yang, L. Z., and Zhou, J. M.: Ammonia volatilization losses from urea applied to wheat on a paddy soil in Taihu Region, China, Pedosphere, 15, 59-65, 2005.

Li, S. X., and Liu, C. Y.: Ammonia volatilization from calcareous soil I. effects of soil properties on N loss by volatilization, Agricultural Research in the Arid Areas, 11 Suppl., 125-129, 1993 (in Chinese with English abstract).

Liao, J.: Fertilizer application and analysis, Shanghai science and Technology Press, Shanghai, 1993 (in Chinese).

Su, F., Ding, X. Q., Gao, Z. L., Huang, B. X., Chen, X. P., and Zhang, F. S.: Ammonia volatilization from nitrogen fertilization of winter wheat-summer maize rotation system in the North China Plain, China Environmental Science, 27, 409-413, 2007 (in Chinese with English abstract).

Su, F., Huang, B. X., Ding, X. Q., Gao, Z. L., Chen, X. P., Zhang, F. S., Martin, K., and Volker, R.: Ammonia volatilization of different nitrogen fertilizer types, Soils, 38, 682-686, 2006 (in Chinese with English abstract).

Tian, Y. H., He, F. Y., Yin, B., and Zhu, Z. L.: Ammonia volatilization from paddy field in the Taihu Lake Region as affected by N and P combination in fertilization, Acta Pedologica Sinica, 44, 893-900, 2007 (in Chinese with English abstract).

Wang, C., Zhou, W., LI, Z. Z., Liu, X. M., Sun, G., Xia, W. J., Wang, X. B., and Liu, G. R.: Effects of different nitrogen application rates on ammonia volatilization from paddy fields under double-harvest rice system, Plant Nutrition and Fertilizer Science, 18, 349-358, 2012 (in Chinese with English abstract).

Wu, P. P., Liu, J. J., Yang, X. X., Shang, Q. Y., Zhou, Y., Xie, X. L., Sheng, Q. R., and Guo, S. W.: Effects of different fertilization systems on ammonia volatilization from double-rice cropping field in red soil region, Chinese Journal of Rice Science, 23, 85-93, 2009 (in Chinese with English abstract).

Wu, T. C., Lan, Z. Q., Hu, Z. Y., Wang, H. H., and Zhu, X. Q.: Effect of different nitrogen fertilizer amount on soil ammonia volatilization and crop yield at vegetables field in Chaihe Basin of Dianchi Lake, Modern Agricultural Sciences and Technology, 205-208, 2015 (in Chinese with English abstract).

Xi, Z. B., Shi, X. Z., Huang, W. Y., Yao, Z., Humphereys, E., Freney, J. R., and Simpson, J.

R.: Measuring urea loss from ammonia volatilization by a micrometeorological method, Acta Agricultruae Shanghai, 3, 47-56, 1987(in Chinese with English abstract).

Xia, W. J., Zhou, W., Liang, G. Q., Wang, X. B., Sun, J. W., Li, S. L., Hu, C., and Chen, Y. F.: Effect of optimized nitrogen application on ammonia volatilization from paddy field under wheat-rice rotation system, Plant Nutrition and Fertilizer Science, 16, 6-13, 2010 (in Chinese with English abstract).

Yang, S. L., Zhu, A. N., Zhang, J. B., Chen, X. M., and Zhu, Q. G.: Ammonia volatilization loss and its affecting factors under different amounts and ways of N application in field, Arid Zone Research, 27, 415-421, 2010 (in Chinese with English abstract).

Yu, Y. L., Xue, L. H., and Yang, L. Z.: Ammonia volatilization from paddy fields under different nitrogen schemes in Tai Lake Region, Journal of Agro-Environment Science, 32, 1682-1689, doi:10.11654/jaes.2013.08.028, 2013 (in Chinese with English abstract).

Zhang, W. F. and Zhang, F. S.: Report on the development of fertilizer in China, China Agriculture University Press, 2012b (in Chinese).

Zhao, Z. D., Zhang, J. S., Ren, S. R., and Zhou, Y. M.: The Nitrogen balance of crop field soil in north area of China, Acta Pedologica Sinica, 3, 67-72, 1988 (in Chinese with English abstract).

Zhu, Z. L., Cai, G. X., Xu, Y. H., and Zhang, S. L.: Ammonia volatilization and its significance to the losses of fertilizer nitrogen applied to paddy soil, Acta Pedologica Sinica, 22, 321-328, 1985 (in Chinese with English abstract).

Zhu, Z. L., Simpson, J. R., Zhang, S. L., Cai, G. X., Chen, D. L., Freney, J. R., and Jackson, A. V.: Investigations on nitrogen losses from fertilizers applied to flooded calcareous paddy soil, Acta Pedologica Sinica, 26, 337-343, 1989 (in Chinese with English abstract).