Response to Anonymous Referee #2

Overall response: We would like to thank reviewer 2 for these invaluable comments and detailed checking of the equations. These help improve the manuscript. Here we outline the point-by-point responses below in blue, and the relevant figures are attached.

A dynamical process-based model AMmonia–CLIMate v1.0

(AMCLIM v1.0) for quantifying global agricultural ammonia

emissions – Part 1: Land module for simulating emissions from synthetic fertilizer use by Jiang et al.

Comment: This paper describes the ammonia emissions from synthetic fertilizer. First of all I want to compliment you with this article. It is nicely written and the results and methods are clear. However I also have some concerns.

Reply: We thank the reviewer for these kind words.

Comment: 1. There is a nice description of the validation/calibration of the model on the GRAMINAE database. These are all observations on fertilized grassland. After that the application of the model is on a global scale with 16 crops. But none of these crops represent grassland. Is it reasonable to assume that grassland is a good representative for all 16 crops?

Reply: AMCLIM is developed based on the understanding at process level. The management practices at the GRAMINAE site were not complicated, which provides a suitable test context for the numerical representations of the physical and chemical processes. On the one hand, the model results show close agreement with the GRAMINAE measurements (Fig. 5), and the multi-site comparison demonstrates that the AMCLIM model have reasonable estimates for various crops under different climatic and soil conditions (Fig. 12). On the other hand, we found that the critical factor affects NH_3 emissions is the timing of fertilization and amount of fertilizer applied under current model settings (See replied and new figures Fig. R1-3, Fig. R1-4 in response to #Reviewer 1). Therefore, we think the processes included in AMCLIM are robust and representative for simulations for synthetic fertilizer use.

Comment: 2. And from the other perspective. The GRAMINAE database shows that fertilizer is used on grassland (which is common practice in for example Europe and US). None of this fertilizer is mentioned in the global estimate of ammonia? What is the

role of grassland in the global emission? Can you elaborate on this uncertainty (of not taking this load)?

Reply: In AMCLIM, only NH_3 emissions from grazed grassland were simulated, which will be described by the second part of the model in a forthcoming paper (for the livestock sector). Fertilized grasslands (with synthetic fertilizers) were not included/simulated because there is no data specified for this type of crop in the dataset we used. This is a significant gap, which we highlight in the revised manuscript as needing further work. We understand that globally the majority of synthetic fertilizer was used for croplands rather than grasslands (although in Europe and some other locations grasslands can receive significant amount of fertilizers). The total applied N from synthetic fertilizer was 102.3 Tg N yr^{-1} in AMCLIM, which is comparable to the 99.6 Tg N yr^{-1} of consumed fertilizer suggested by the International Fertilizer Association. More details are given by the reply to the reviewer's next comment.

Comment: 3. I have the impression that the global figures of the ammonia emissions (for example figure 6, but actually all maps) have a coverage of grassland and cropland. So I am wondering which land use database is used and whether the assumption is valid that all grassland is fertilized. Perhaps I am wrong, but I would expect that maps have more white area. Can you please elaborate on this as well?

Reply: The areas of croplands used in AMCLIM were from the Farming the Planet 2 (FTP2) dataset (Monfreda et al., 2008). The data for fertilization rates and crop calendars were from Global Gridded Crop Model Intercomparison Phase 3 (GGCMI3). However, fertilized grasslands were not included in the GGCMI3 datasets. We have now modified the manuscript to clarify this point.

Specific comments

Comment: Line 84: AMCLIM-Fertilizer is nowhere else mentioned. I was sometimes confused whether it should be AMCLIM or AMCLIM-Land or it should be AMCLIM-Fertilizer. Please check the document to verify that the right name is used. I think I would prefer to use AMCLIM-Fertilizer in most cases (as suggestion).

Reply: We thank the reviewer for pointing out the unclear naming in the manuscript. There are three modules in AMCLIM, namely 1) AMCLIM–Housing, 2) AMCLIM–MMS and 3) AMCLIM–Land. AMCLIM–Land is described in this study and was used to simulate NH_3 emissions from synthetic fertilizer use. We have now removed "AMCLIM–Fertilizer" and used "Fertilizer simulations" to avoid confusion.

Comment: Line 85: “AMCLIM Livestock”. Not clear to me. Not mentioned in Figure 1 and not mentioned in line 92. But the contents of this must be very clear, because this determines whether a topic is described here or in the other article.

Reply: We removed “AMCLIM Livestock” and use “Livestock simulation” to avoid confusion.

Comment: Figure 1: “chemical” fertilizers is used, but mostly in the text “synthetic” is used.

Reply: We updated Fig. 1 and Fig. 2 to have all “chemical fertilizer” changed to “synthetic fertilizer”.

Comment: Figure 2, line 122: Why is ammonification not included? This is input TAN.

Reply: The ammonification of nitrate (or DNRA) was not simulated in AMCLIM, while the decomposition of organic nitrogen (or mineralization) was included in the model but only for the livestock simulations. We have now clarified this in the revised manuscript.

Comment: Line 158: I think here m denotes mass. But in line 152 it is meter….. Please change to make it clear.

Reply: The unit of V_{H2O} is millilitre per unit area.

Comment: Line 165: eq 3: Explain in the text the names in the right hand side of the equation (so s, aq and g are not explained).

Reply: The abbreviations s, aq and g represent solid phase, aqueous phase and gaseous phase of a substance, respectively. We improved the text as the follows:

“The most important aggregated N species simulated in AMCLIM is total ammoniacal nitrogen (TAN = NH_3+ NH_4^+), which can either be partitioned into gaseous NH_3 ($M_{\mathrm{NH_3,g}}$) aqueous TAN ($M_{\mathrm{TAN,aq}}$) or adsorbed NH_4^+ ($M_{\mathrm{NH_4^+,s}}$), as shown in Eq. (3):

$$M_{\mathrm{TAN}} = M_{\mathrm{NH_3,g}} + M_{\mathrm{TAN,aq}} + M_{\mathrm{NH_4^+,s}} . \qquad (3)”$$

Comment: Line 168: Where is H+ coming from? Can you elaborate on this?

Reply: The H^+ was given by Eq. 9 and Eq. 10. The emission potential Γ is defined as $[NH_4^+]/[H^+]$. We moved sentence to from line 168 to follow Eq. 9 and Eq. 10 to improve clearness.

Comment: Line 168: Reference format of Sutton
Reply: We corrected the citation format.

Comment: Line 187 – 190: Here square brackets are used. But why? Is [NH3(g)] not the same as M_nh3,g as mentioned in eq. 3? Please make clear what your intention is here.

Reply: Square brackets are used to represent the concentrations. For example, $[NH_3(g)]$ is the gaseous concentration of NH_3, and $[NH_4^+(aq)]$ is the aqueous concentration of NH_4^+. By comparison, M denotes the mass of the species, i.e., $M_{NH_3,g}$ is the mass of gaseous NH_3.

Comment: Line 190: Why NH3(g) instead of TAN(g)?

Reply: The total ammoniacal nitrogen is represented by TAN, which is the aggregate of ammonia (NH_3) and ammonium (NH_4^+). Therefore, the gas phase should only include ammonia gas $NH_3(g)$.

Comment: Line 210: No explanation of constants or parameters is given in the text.

Reply: These constants are derived from the Henry's Law constant and dissociation constant, which have been fully explained in Sutton et al. (1994).

Comment: Line 303: "applied to cropland" What about grassland?

Reply: As mentioned, fertilized grasslands (by synthetic fertilizer) were not simulated and included in the global upscaling of AMCLIM model due to lack of global estimates of the distribution of fertilizer to grasslands.

Comment: Line 575: explain MAM. SON and DJF. I see they are explained in the caption of figure 9, but this text is before the figure.

Reply: We improved the text as the follows.

"The seasonal emissions in both years are similar, with over 50 % of NH_3 occurring in the Northern Hemisphere (NH) summer months and about 25 % in March-April-May (MAM). September-October-November (SON) and December-January-February (DJF) both contribute slightly over 10 % of the annual emissions. In the NH, more than 70 %

of annual emissions are from June-July-August (JJA), while emissions in SON and DJF are significant in the Southern Hemisphere (SH)."

Comment: Figure 9: end of caption is text missing

Reply: We corrected the caption as the follows.

"Percentage of annual emissions in the season of (b) MAM, (d) JJA, (f) SON and (h) DJF."

Comment: Figure 9: Caption says something about percentage, but figure shows fractions. I would suggest to use everywhere the Pv (%).

Reply: We changed the caption to "Figure 9. Seasonal NH3 emissions (Gg N $grid^{-1}$) from ammonium and urea fertilizer application and the relative fraction of annual emissions that are from the corresponding season (f_{season}) in 2010 simulated by AMCLIM–Land." We would like to use a different symbol to represent the contributions from each season.

Comment: Figure 9. Add per grid cell to the unit.

Reply: We changed the caption to "Figure 9. Seasonal NH3 emissions (Gg N $grid^{-1}$) from ammonium and urea fertilizer application and the relative fraction of annual emissions that are from the corresponding season (f_{season}) in 2010 simulated by AMCLIM–Land."

Comment: Figure 9: The y axes of NH3 per grid is confusing. Looks like it was for the right column. Can you put this on the left hand side of the figure or make it more clear that it belongs to the left column? This remark is for the maps figures.

Reply: We addressed this point by clarifying the unit in the figure caption. The position of colour map label is more of a default setting in the data visualization.

Comment: Line 599: End of caption misses text.

Reply: We corrected the caption to "Figure 10. Global monthly NH3 emissions (Gg N $month^{-1}$) from ammonium and urea fertilizer applications for 16 major crops in 2010 simulated by AMCLIM–Land."

Comment: Line 623: In figure a small f is used in F_region.

Reply: We corrected the caption to "Figure 11. Monthly NH_3 emissions from ammonium and urea fertilizer application in different regions of the world and the

relative fraction of the global monthly emissions that are from the corresponding regions (f_{region}). Annual total NH3 emissions of the region are given at the top right corner of each plot, with the percentage of emissions from this region. The figure is for 2010."

Comment: Line 628: AMLIM -> AMCLIM

Reply: We corrected the typo.

Comment: Line 810: Assumptions -> assumptions

Reply: We corrected the typo.

Comment: Figure A4: same remarks as for Figure 9.

Reply: We corrected the caption as for Fig. 9.

Comment: Caption figure A7: Mention unit in Gg N per grid cell.

Reply: We corrected the caption.

Supplementary information

Comment: Eq SM 2 and 3: in the main text (line 184: "In addition, diffusive and drainage fluxes
considered as losses in the soil layer above become sources of nitrogen for the layer underneath."). I don't see this in these equations.

Reply: These fluxes are considered to be included by I_{TAN} in the original manuscript. We updated the equations to make it explicit.

Comment: Line 35: Unit of K_d?

Reply: The unit of K_d is $m^3\ m^{-3}$.

Comment: Line 36: "fractional soil clay content": Is this determined per grid cell. So here it is the upper soil layer? From what is this a fraction?

Reply: The fraction of clay, sand and silt (soil texture) of each grid is from the Regridded Harmonized World Soil Database (HWSD) v1.2 (Wieder et al., 2014).

Comment: Line 44: K_Knitrif,opt -> K_nitrif,opt

Reply: We corrected the symbol.

Comment: Line 45: Is the unit of K_nitrif,opt in percentage??

Reply: The unit is percentage per time.

Comment: Line 49: small t was reserved for time, but now it is temperature. Make the T (T_opt, T_max)

Reply: We updated the symbols.

Comment: SM8: change k_nitrif,T -> K_nitrif,T

Reply: We updated the symbol.

Comment: In line 50, K is used for Kelvin (correct) Perhaps it is an idea to change all K variable into small k variables (also in main text) to avoid confusing.

Reply: We propose to include a table of all model parameters and variables in the revised manuscript.

Comment: Line 82: Unit of J_C,N?

Reply: It is a dimensionless parameter.

Comment: Lines 87-88: What is the unit of 4 and 40?

Reply: The units are g C m^{-2} and g N m^{-2}, respectively, as specified in line 85. We updated the units to make it clear.

Comment: Equation SM17: use the alfa_root and J_C,N in this formula.

Reply: We updated Eq. SM17.

Comment: Line 92 -99: "There are four ….. [end of table]" I would move this under equation SM14. Now it is coming too late.

Reply: We moved this under Eq. SM14.

Comment: Line 102: unit of W_uptake?

Reply: The unit is m s^{-1}. We added the unit.

Comment: Line 110: remove one of the closing brackets

Reply: We removed one closing bracket.

Comment: Line 114: What is 20.1 and 14.9?

Reply: These are the atomic diffusion volumes of air and NH_3, respectively.

Comment: Line 114: unit of pressure?

Reply: The unit is Pa. We added in the manuscript.

Comment: I stopped here. Please check whether the units of all parameters are given and whether they are explained in the text.

Reply: We would like to thank the reviewer again for these useful comments.

Reference

Monfreda, C., Ramankutty, N., and Foley, J. A.: Farming the planet: 2. Geographic distribution of crop areas, yields, 1105 physiological types, and net primary production in the year 2000: GLOBAL CROP AREAS AND YIELDS IN 2000, Global Biogeochem. Cycles, 22, n/a-n/a, https://doi.org/10.1029/2007GB002947, 2008.

Sutton, M. A., Asman, W. A. H., and Schørring, J. K.: Dry deposition of reduced nitrogen, Tellus B, 46, 255–273, 1994.

Wieder, W. R., Boehnert, J., and Bonan, G. B.: Evaluating soil biogeochemistry parameterizations in Earth system models with observations: Soil Biogeochemistry in ESMs, Global Biogeochem. Cycles, 28, 211–222, https://doi.org/10.1002/2013GB004665, 2014.