香港中文大學
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Impacts of Ammonia-Aerosol-Climate Feedbacks on Food Security and Air Quality

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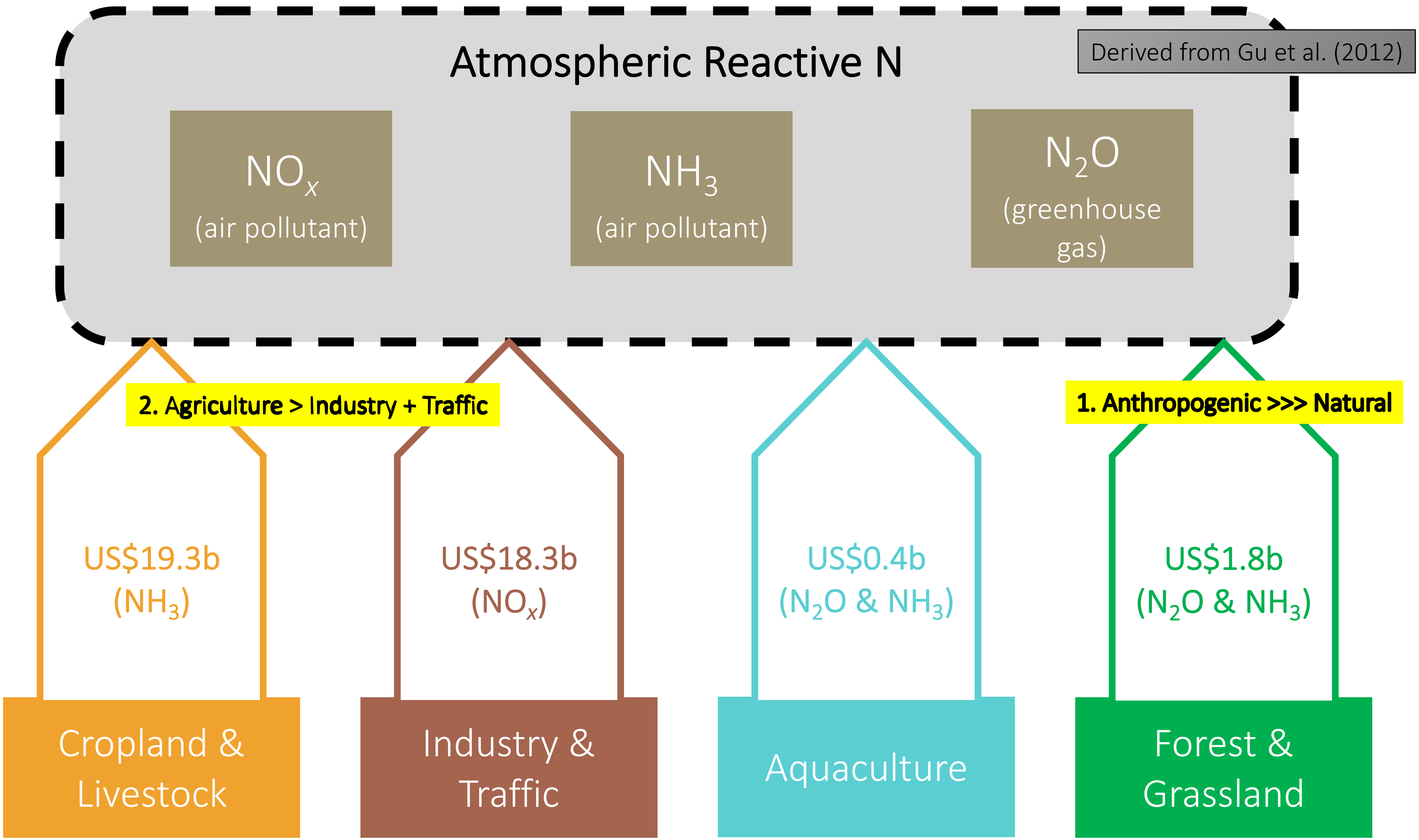
Agricultural NH_3 is equally harmful as reactive N from factories and vehicles



Health Damage Costs of Reactive N across China in 2008

Derived from Gu et al. (2012)

Atmospheric Reactive N

NO_x (air pollutant)

NH_3 (air pollutant)

N_2O (greenhouse gas)

2. Agriculture > Industry + Traffic

1. Anthropogenic >>> Natural

US$19.3b ($NH_3$)

US$18.3b ($NO_x$)

US$0.4b ($N_2O$ & NH_3)

US$1.8b ($N_2O$ & NH_3)

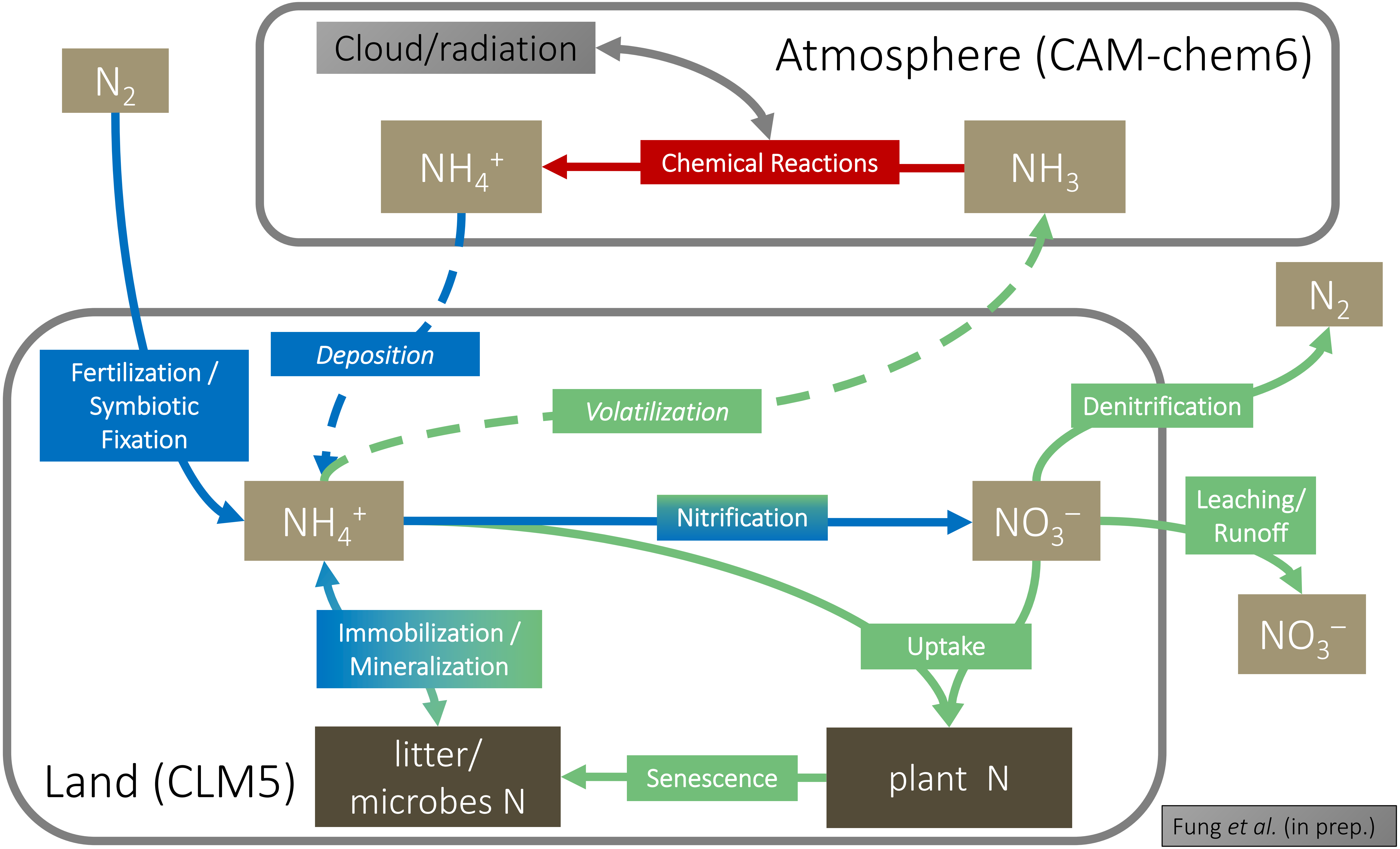
Cropland & Livestock

Industry & Traffic

Aquaculture

Forest & Grassland

The current N cycle in CESM2 and the missing bidirectional exchange of NH_3 & NH_4^+

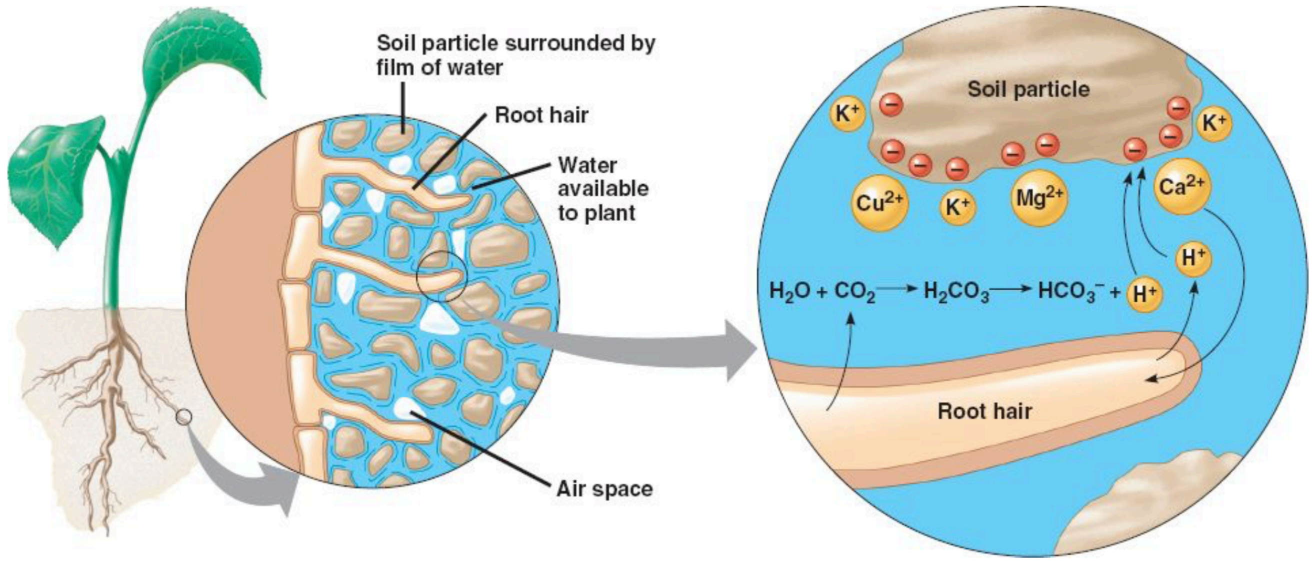


Fung *et al.* (in prep.)

We implement into CLM the "multi-step" NH_3 volatilization scheme from DNDC (Li *et al.*, 2012)

$$\left(\frac{d[NH_{3\,(g)}]}{dt}\right)_{\text{from soil}} \approx [NH^+_{4\,(soil)}](1 - f_{adsorption}) f_{dissocation} f_{vaporization} \left(\frac{1}{\Delta t}\right)$$

Campbell et al. (2008)



Aqueous NH_4^+ adsorbing on negative soil surface:

$$f_{adsorption} = 0.99(7.27 f^3_{clay} - 11.22 f^2_{clay} + 5.72 f_{clay} + 0.03)$$

clay fraction

Dissociation of free-flowing NH_4^+:

$$NH_4^+{}_{(non\text{-}ads)} \rightleftharpoons NH_{3\,(aq)} + H^+_{(aq)}$$

rate constant of dissociation

soil temperature (°C)

$$f_{dissocation} = \frac{K_w}{[H^+]K_a}$$

$$K_a = (1.4 + (0.01)T_{soil}) \times 10^{-5}\ (mol.\,L^{-1})$$

$$K_w = 10^{0.09+(0.04)T_{soil}} \times 10^{-15}\ (mol.^2\ L^{-2})$$

$$[H^+] = 10^{-pH}\ (mol.\,L^{-1})$$

$$pH = 6.8$$

rate constant of hydrolysis

more about this assumption later

Fraction of $NH_{3\,(aq)}$ to vaporize:

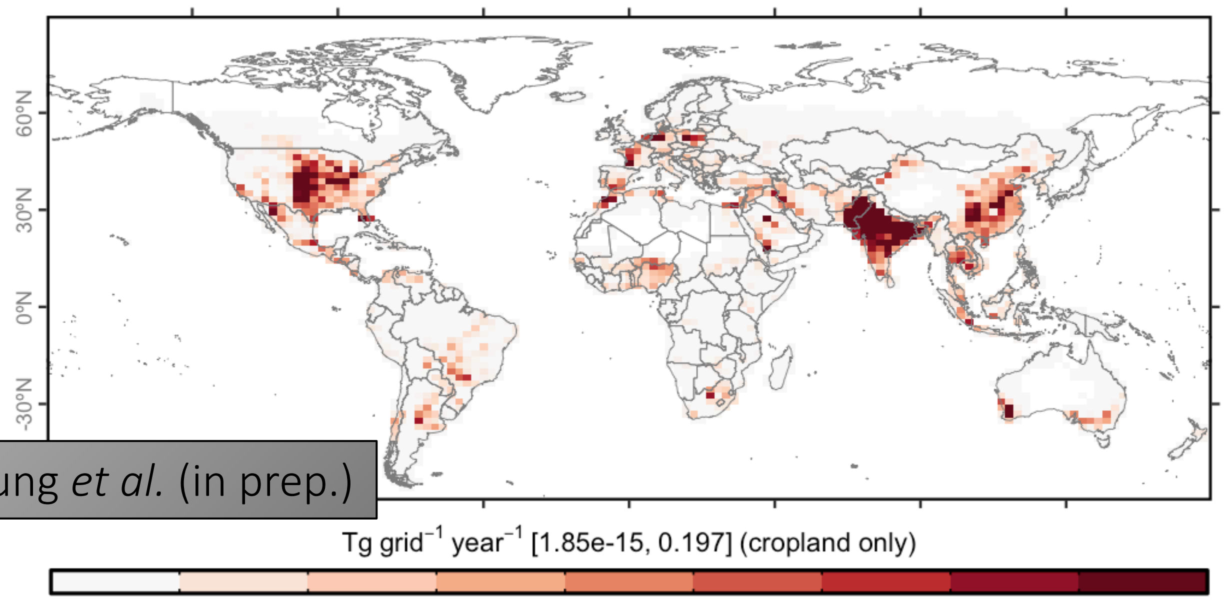
soil layer depth (m)

$$f_{vaporization} = \left(\frac{1.5s}{1+s}\right)\left(\frac{T_{soil}}{50 + T_{soil}}\right)\left(\frac{l_{max} - l}{l_{max}}\right)$$

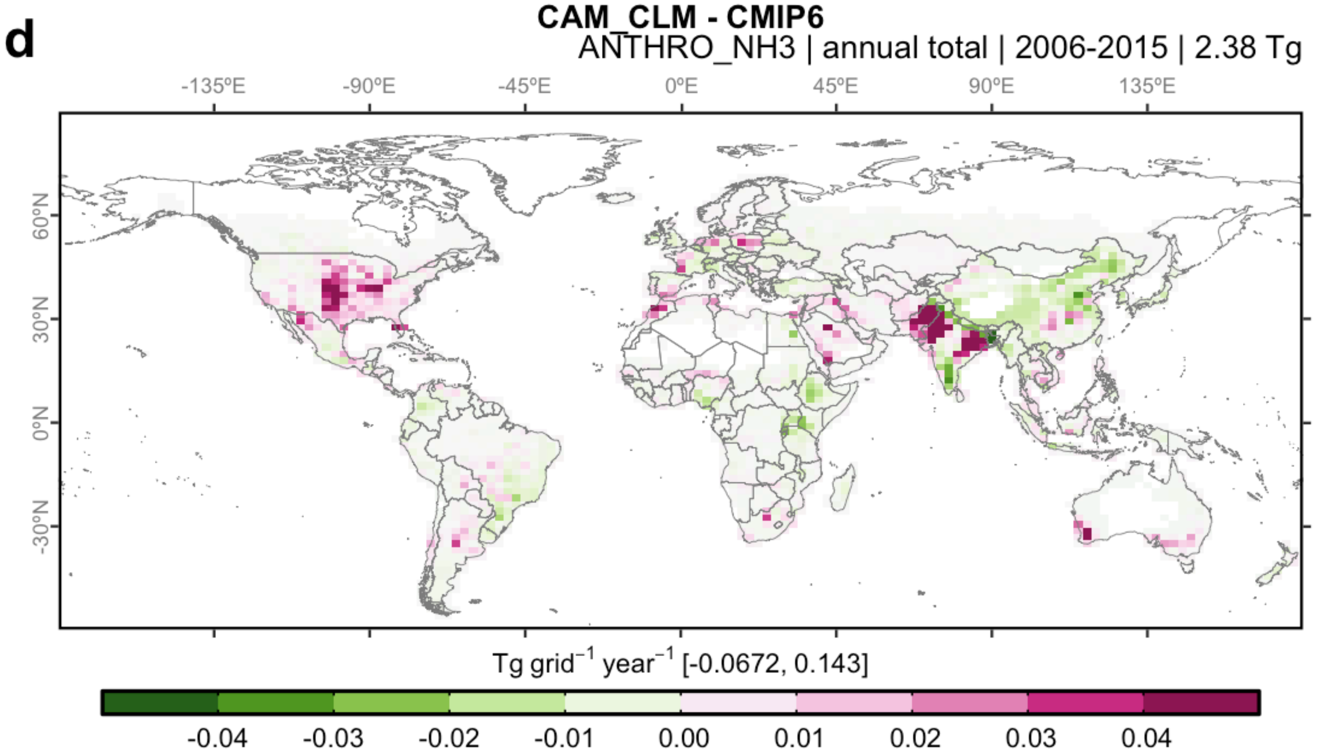
wind speed (m s^{-1})

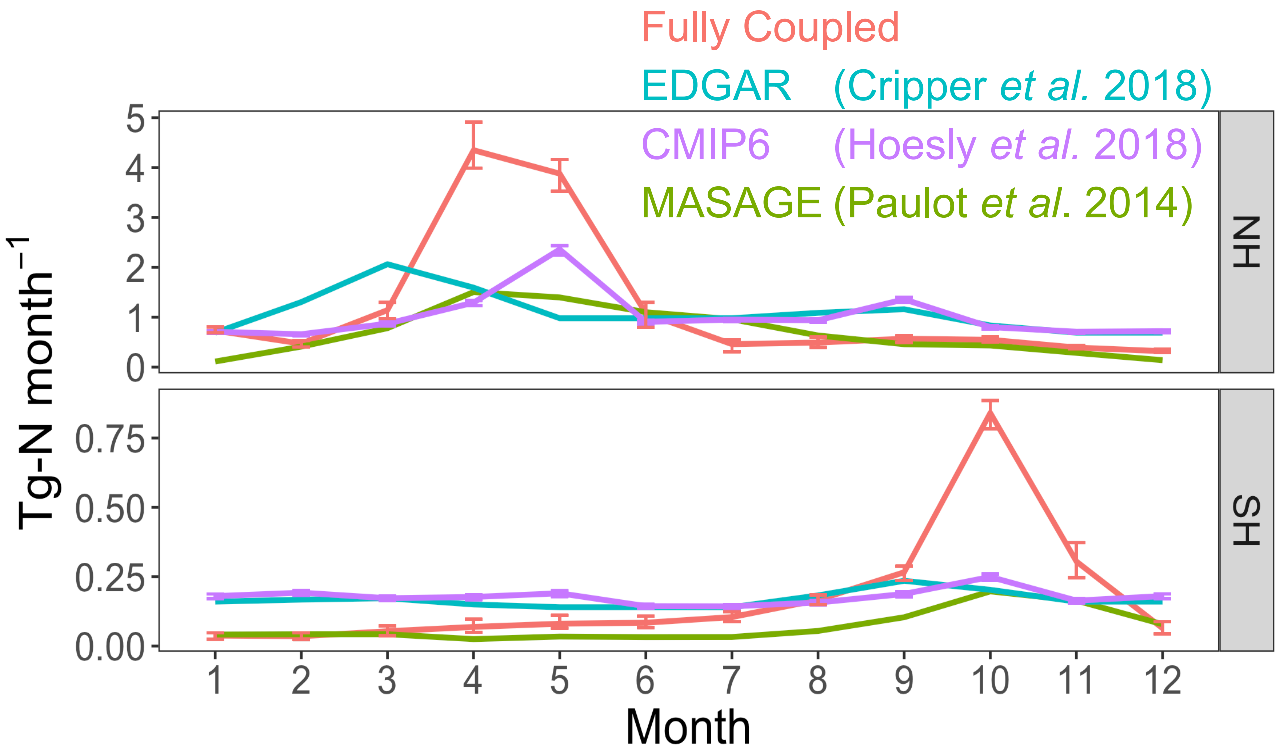
Our cropland NH_3 emission agrees reasonably well with inventories around hotspots

Fully Coupled: NH_3 Emission due to Fertilizers
(Global Total = 16.6 Tg-N $year^{-1}$)

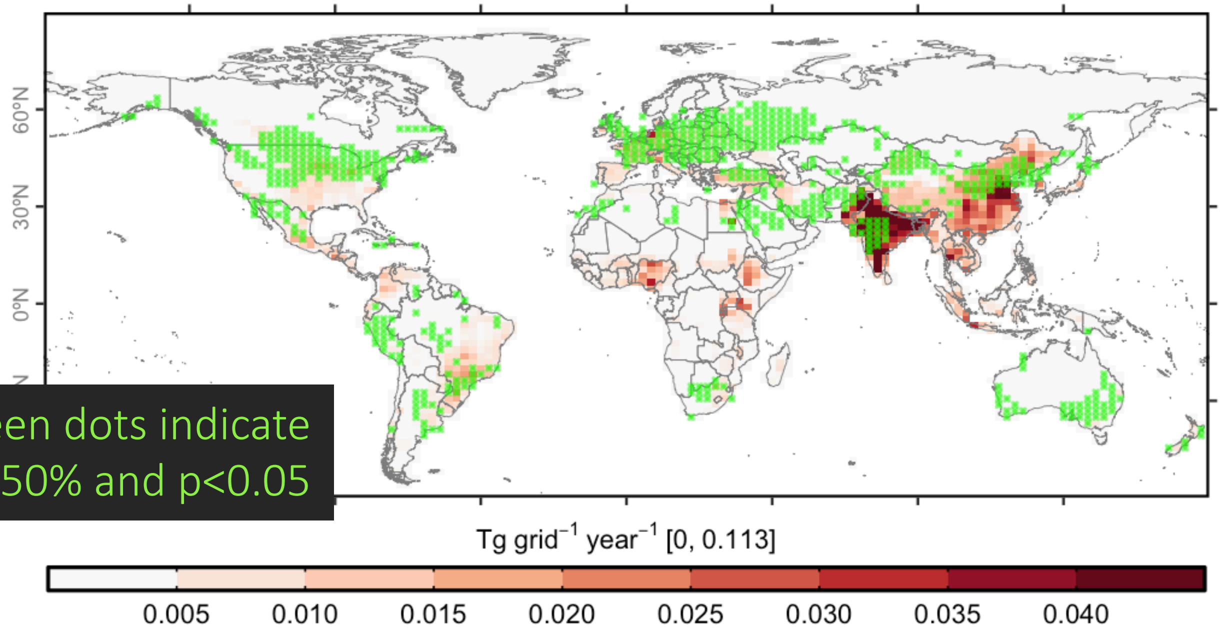


Fung *et al.* (in prep.)





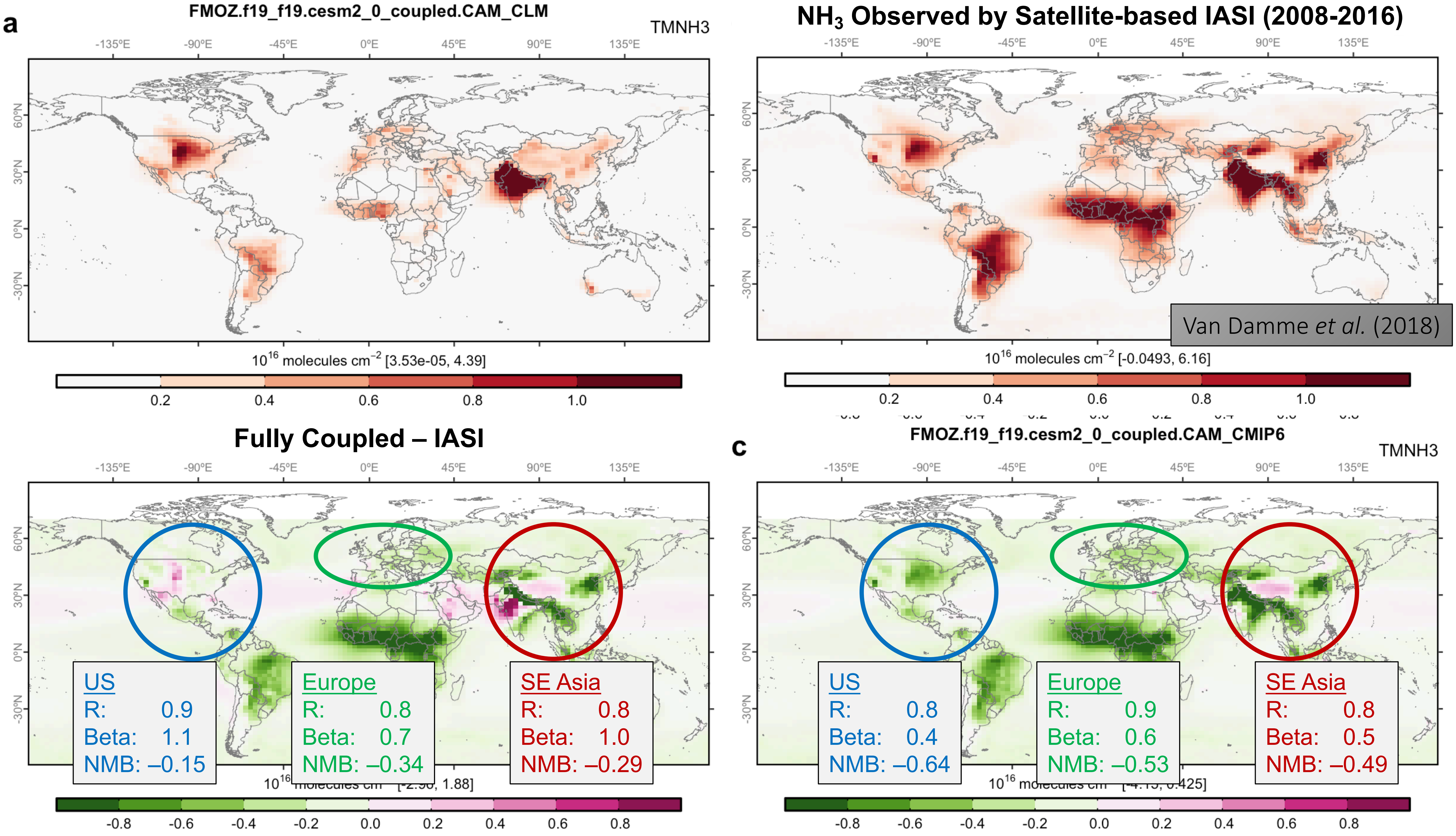
Grid-by-grid Correlation of Monthly Emission Rates (Fully Coupled vs CMIP6)



Green dots indicate $R^2>50\%$ and $p<0.05$

Colormaps are saturated at respective values.

Atmospheric NH_3 is less biased comparing to observations than default CESM2



Fully Coupled – IASI

US
R: 0.9
Beta: 1.1
NMB: –0.15

Europe
R: 0.8
Beta: 0.7
NMB: –0.34

SE Asia
R: 0.8
Beta: 1.0
NMB: –0.29

FMOZ.f19_f19.cesm2_0_coupled.CAM_CMIP6

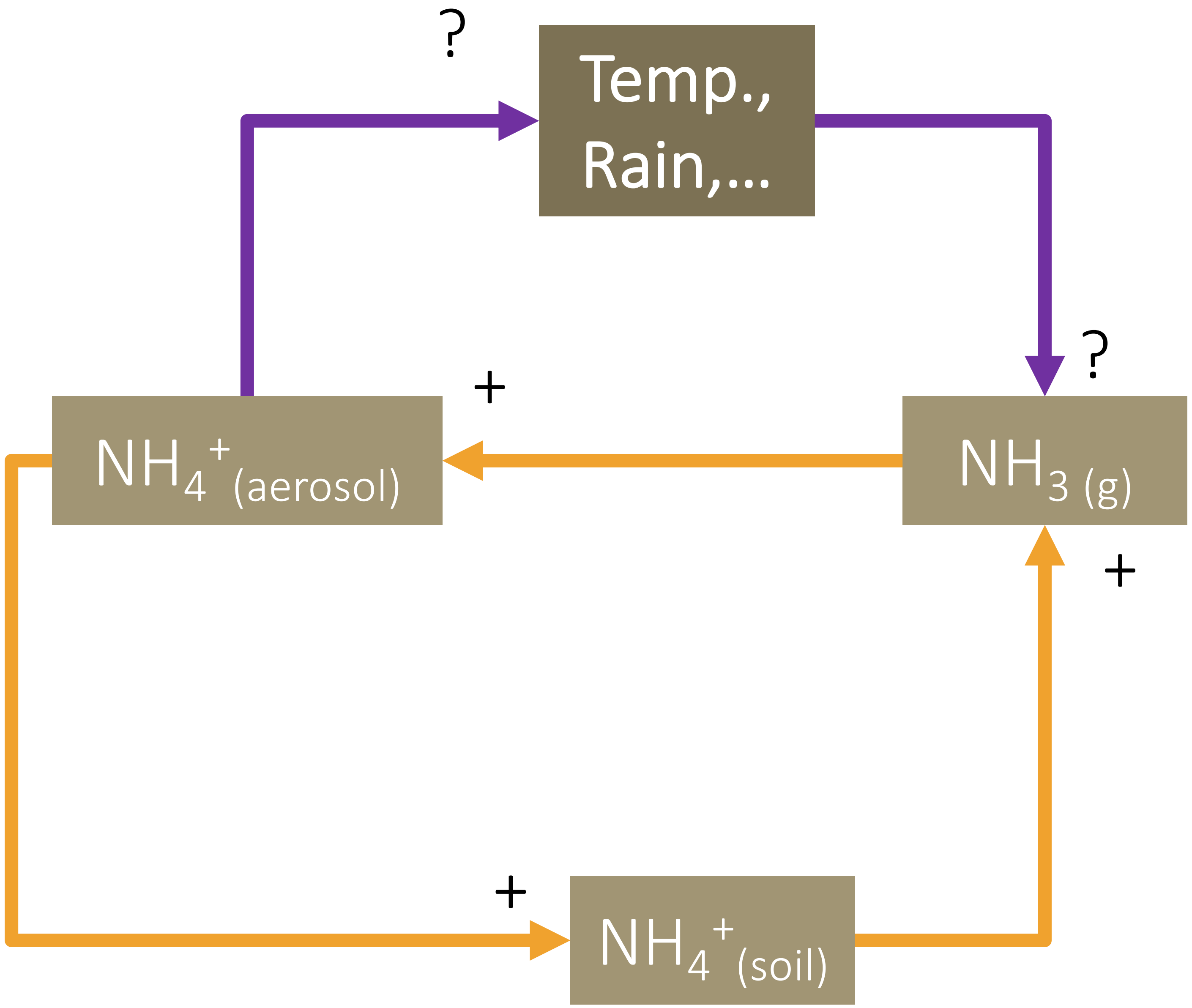
US
R: 0.8
Beta: 0.4
NMB: –0.64

Europe
R: 0.9
Beta: 0.6
NMB: –0.53

SE Asia
R: 0.8
Beta: 0.5
NMB: –0.49

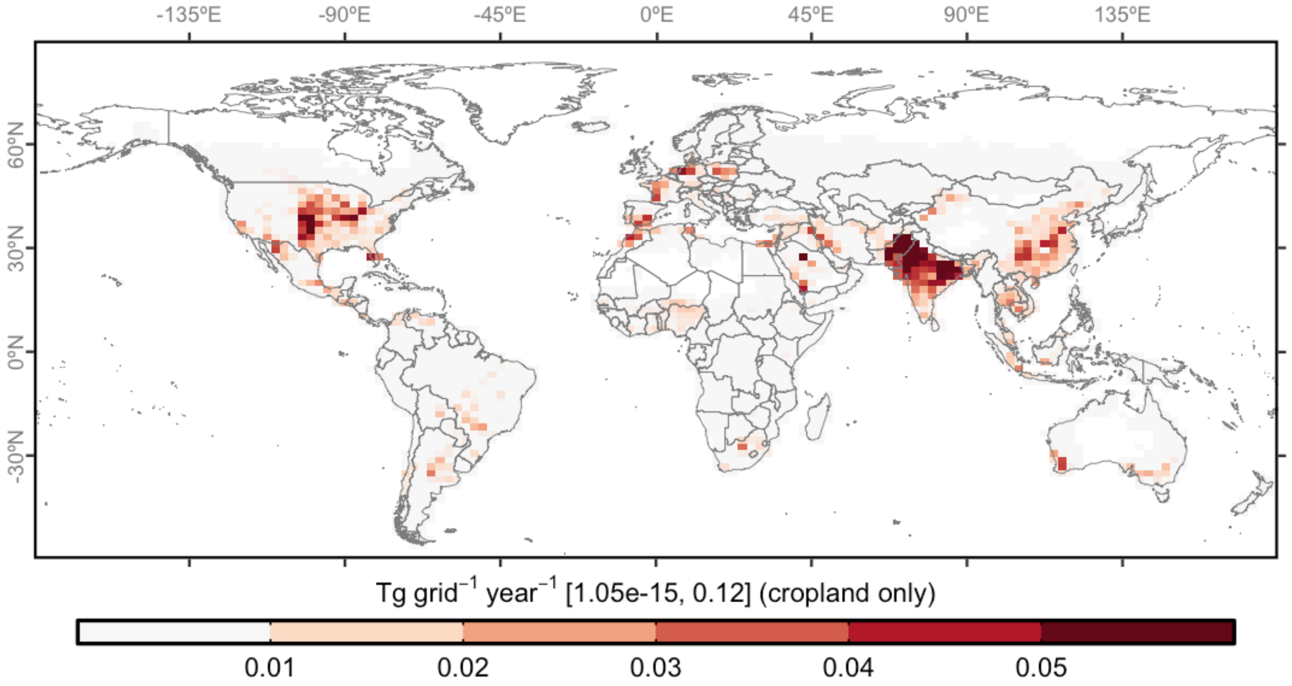
Colormaps are saturated at respective values.

Experiment 1:
Feedbacks between NH_3, aerosol, and climate



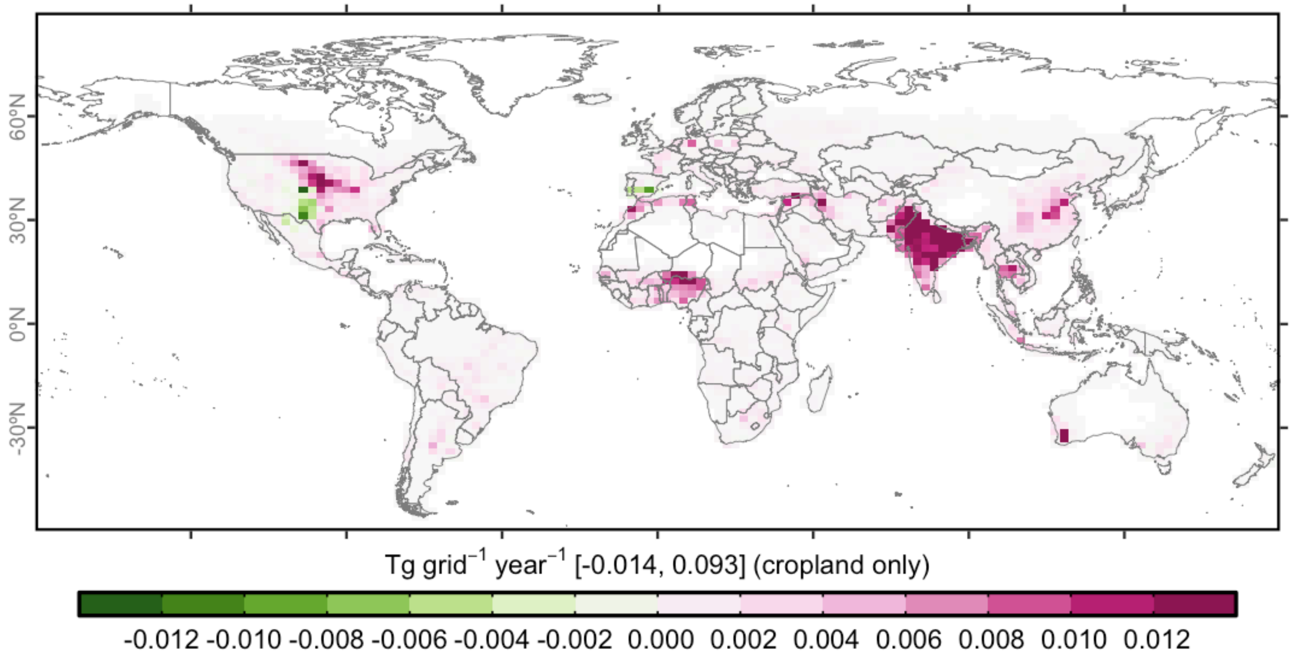
Fung *et al.* (in prep.)

Cropland NH_3 emission raised by N deposition, but suppressed by aerosol-climate interactions



CAM_CLM_XCOU_XDEP

F_NH3_VOL_TO_ATMOS | annual total | 2006-2020 | 13.9 Tg

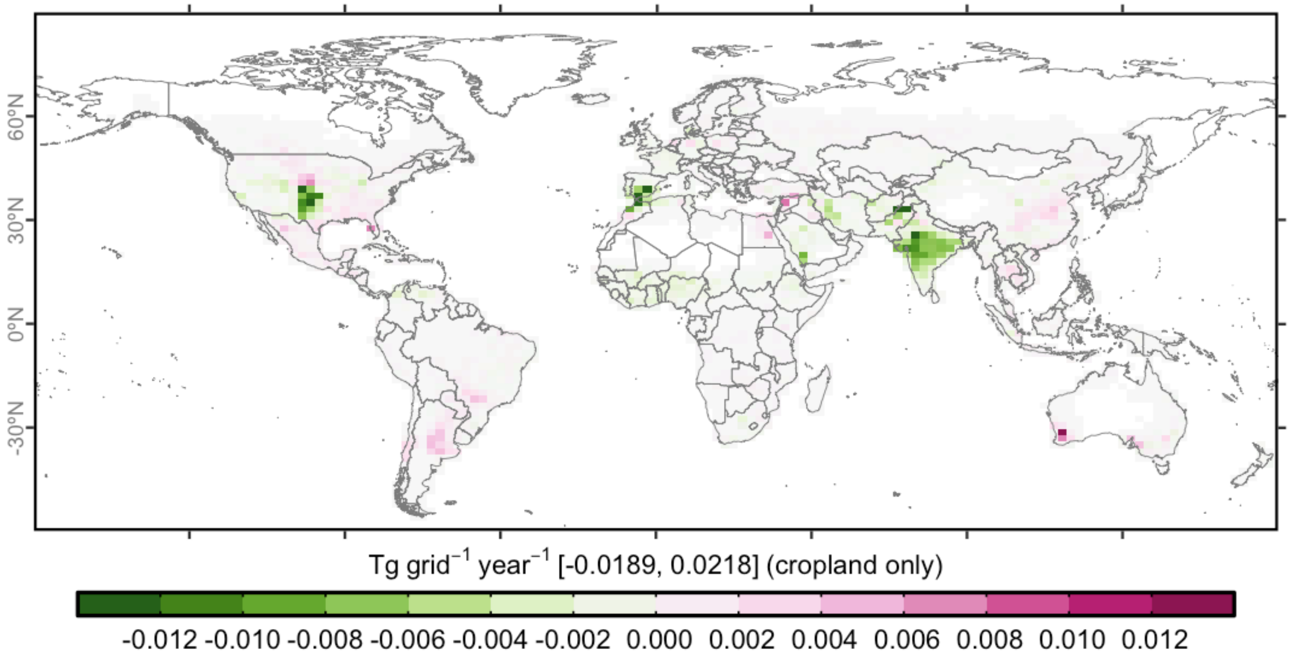


With Deposition Only

(+3.1 Tg-N year^{-1})

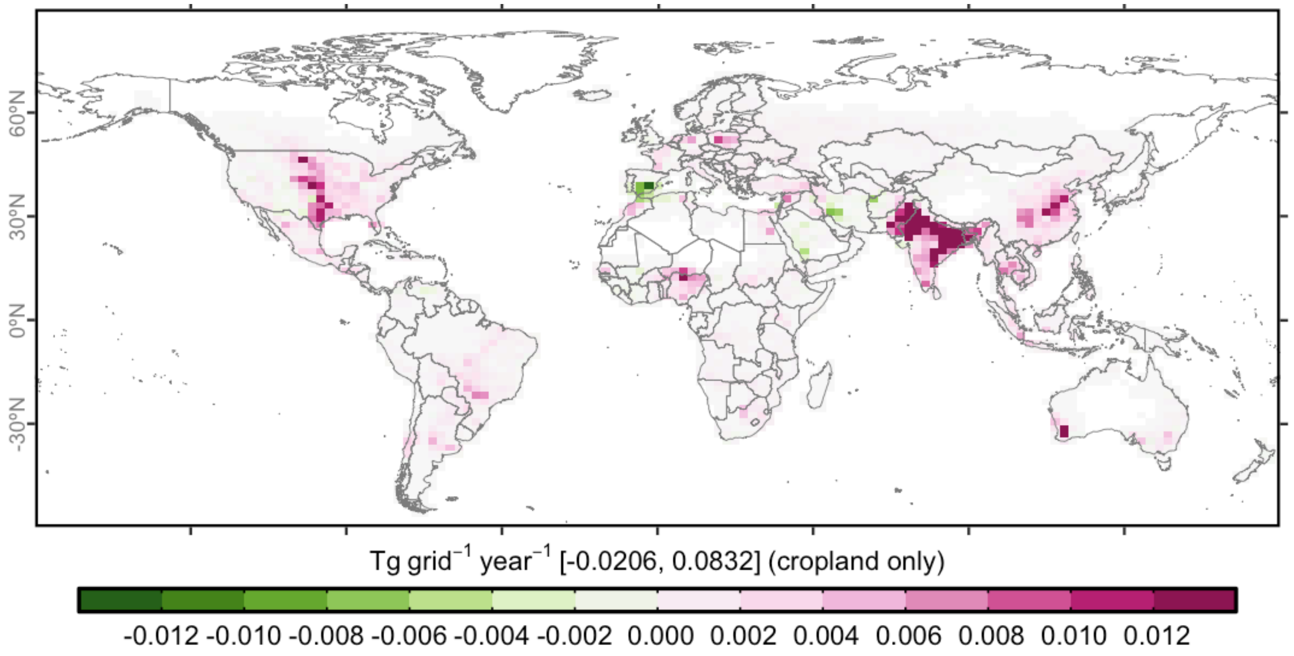
With Aerosol-climate Interactions Only

(–0.4 Tg-N year^{-1})



Fully Coupled – Baseline

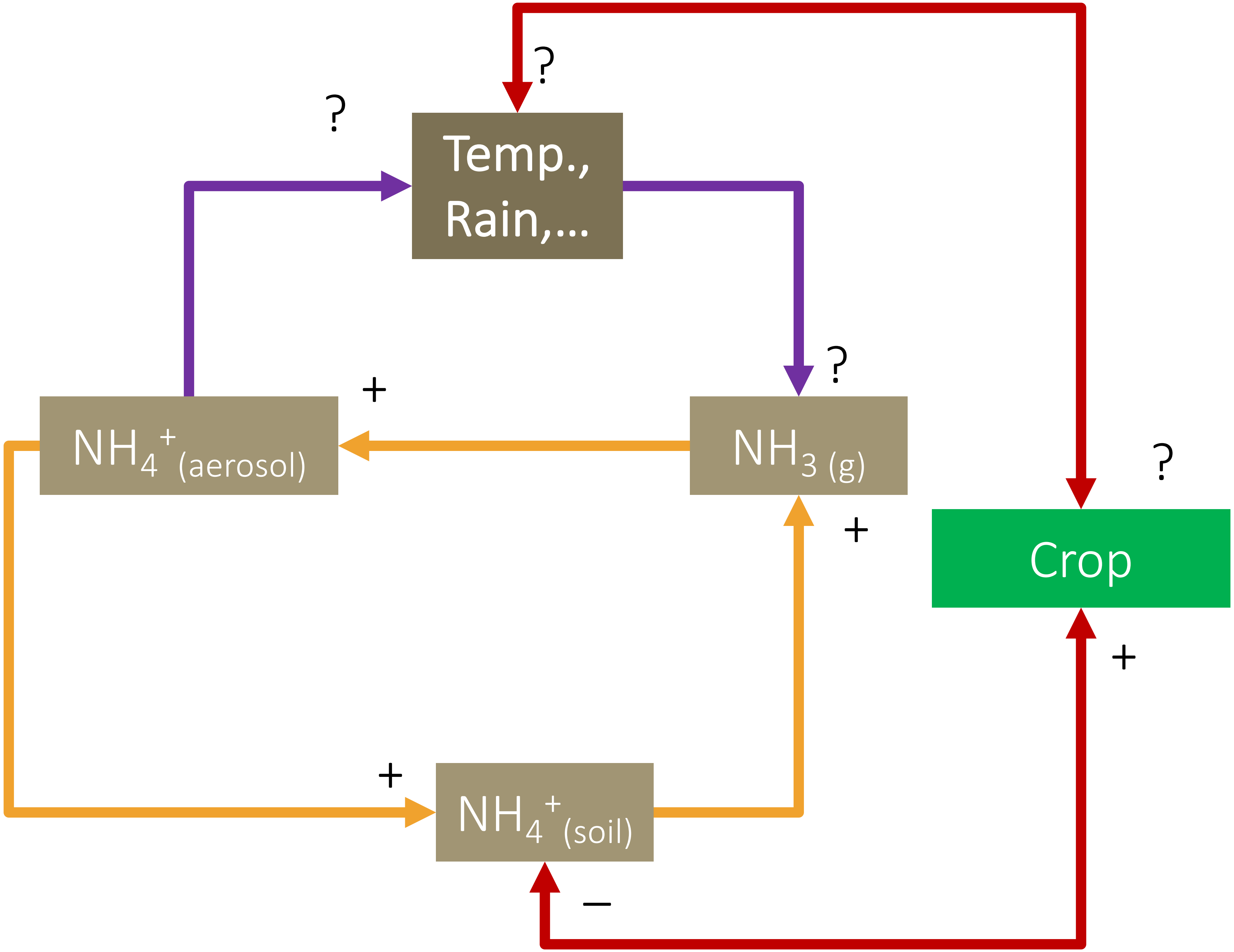
(+2.7 Tg-N year^{-1})



Colormaps are saturated at respective values.

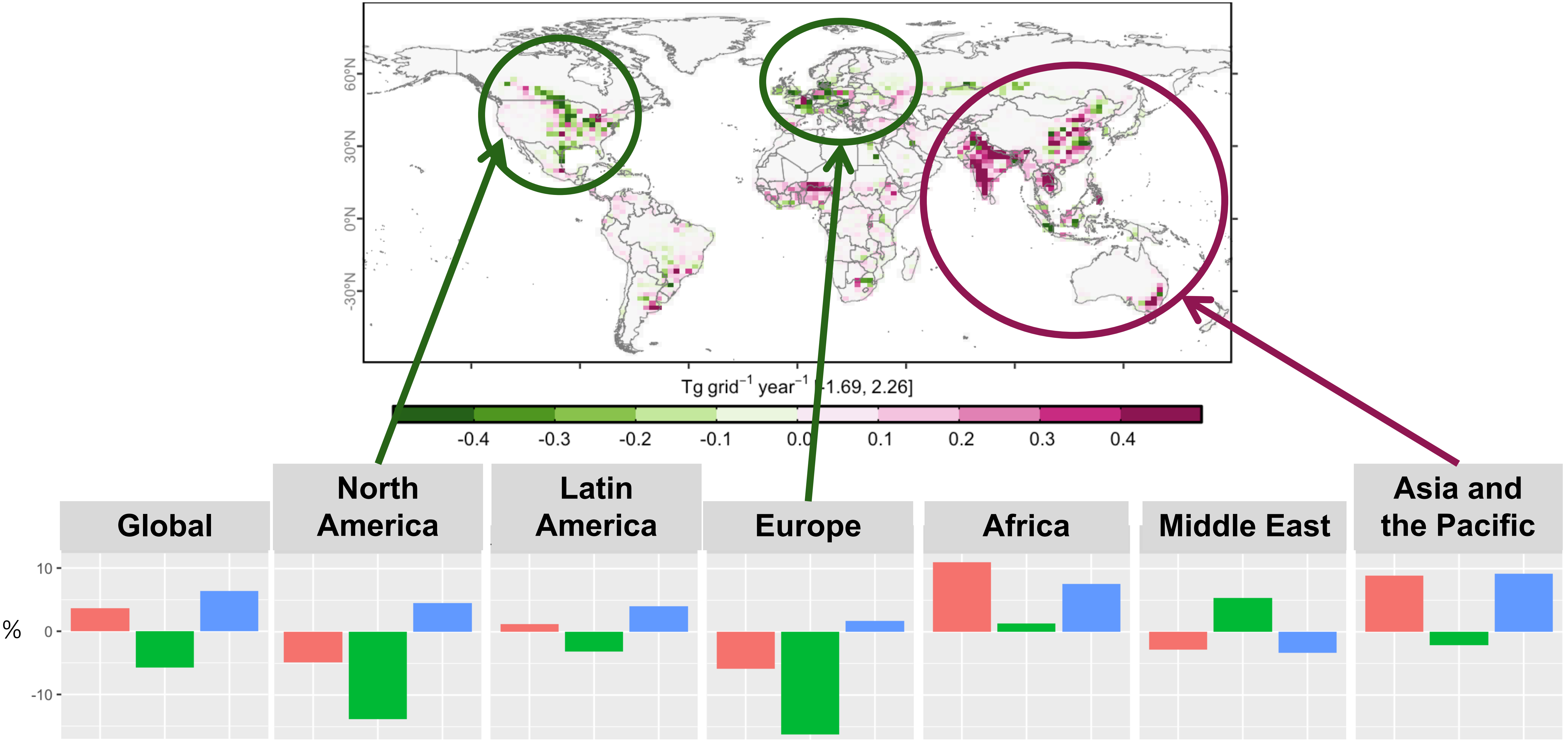
Fung *et al.* (in prep.)

Experiment 2:
Impacts of the feedbacks on crop production



Fung *et al.* (in prep.)

Diverging effects on grain production: ups in Asia, downs in the US and Europe



Fully Coupled – Baseline: Grain Production

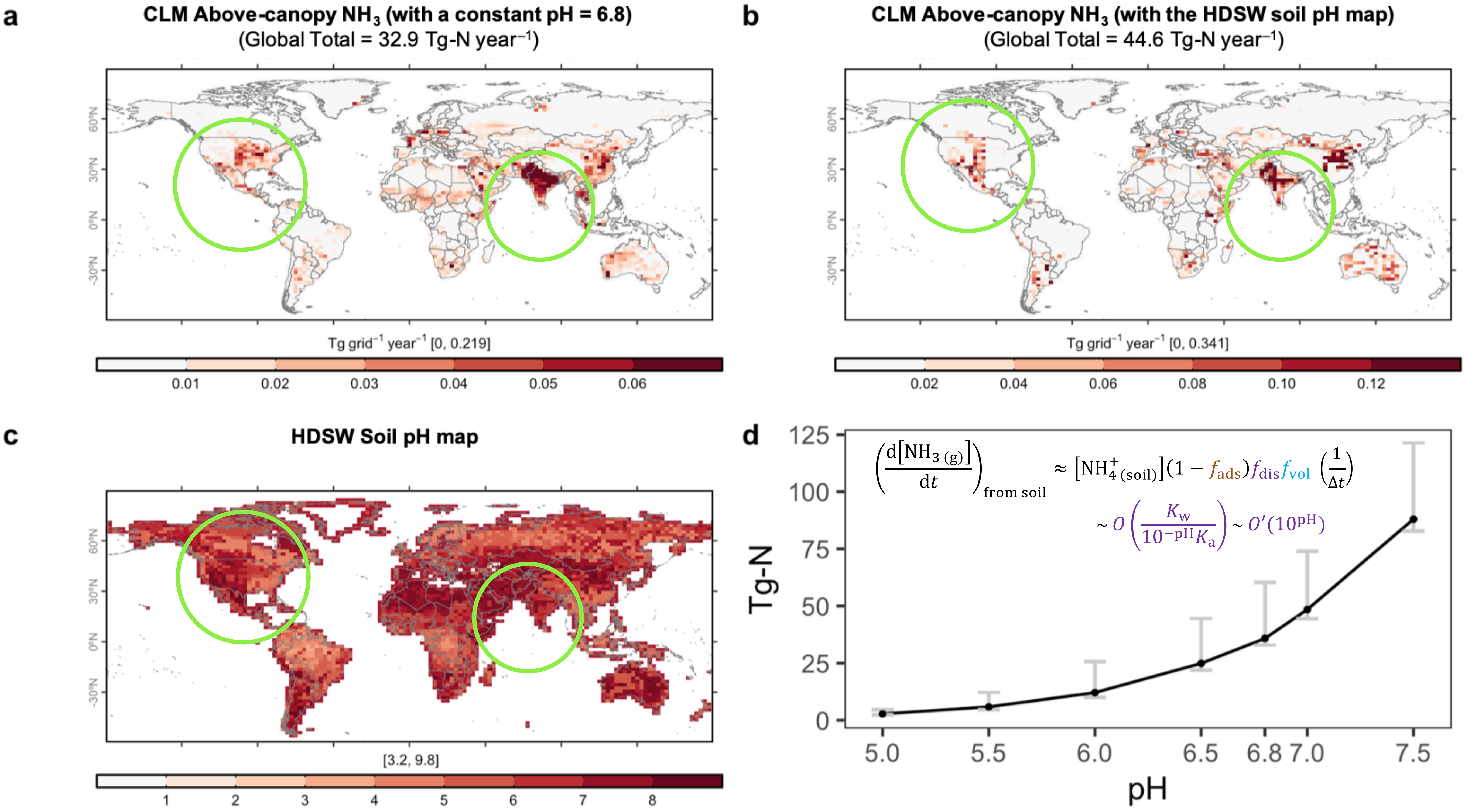
(Global Total = +47 Mt-C year^{-1} / +3.5 %)

Grain-C production relative to the baseline, annual total (%)

Fully Coupled **Aerosol-climate Interactions Only** **Deposition Only**

Fung *et al.* (in prep.)

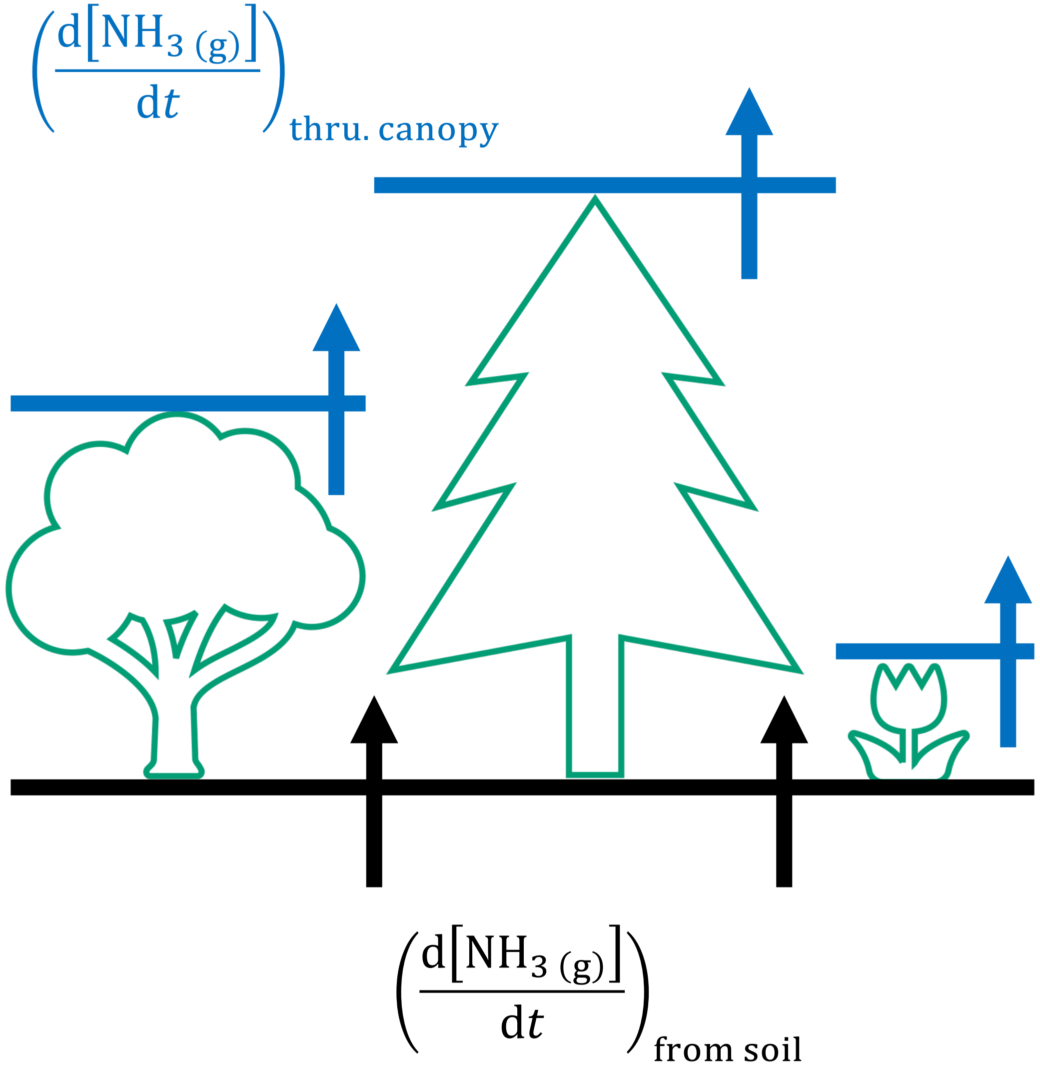
Uncertainty: NH_3 emission is highly sensitive to soil pH



Fung *et al.* (in prep.)

Uncertainty: Canopy capture process of emitted NH_3

$$\left(\frac{\mathrm{d}[\mathrm{NH}_{3\,(g)}]}{\mathrm{d}t}\right)_{\text{thru. canopy}} = \left(\frac{\mathrm{d}[\mathrm{NH}_{3\,(g)}]}{\mathrm{d}t}\right)_{\text{from soil}} (1 - f_{\text{capturing}})$$



Derived from DNDC (Li *et al.*, 2012) and CMAQ (Pleim *et al.*, 2013), fraction of NH_3 captured by canopy is estimated as:

$$f_{\text{capturing}} = \overbrace{b(h_{\text{top}} - h_{\text{bot}})}^{\text{Effect of canopy height; } b = 14\ \text{m}^{-1}\ \text{here}} \times \mathrm{TLAI} \times \frac{1}{v_{\text{fric}}} \times \mathrm{RH}_{\text{canopy}} \times v_{\mathrm{NH}_3}$$

Snow-free one-sided leaf area index (LAI)

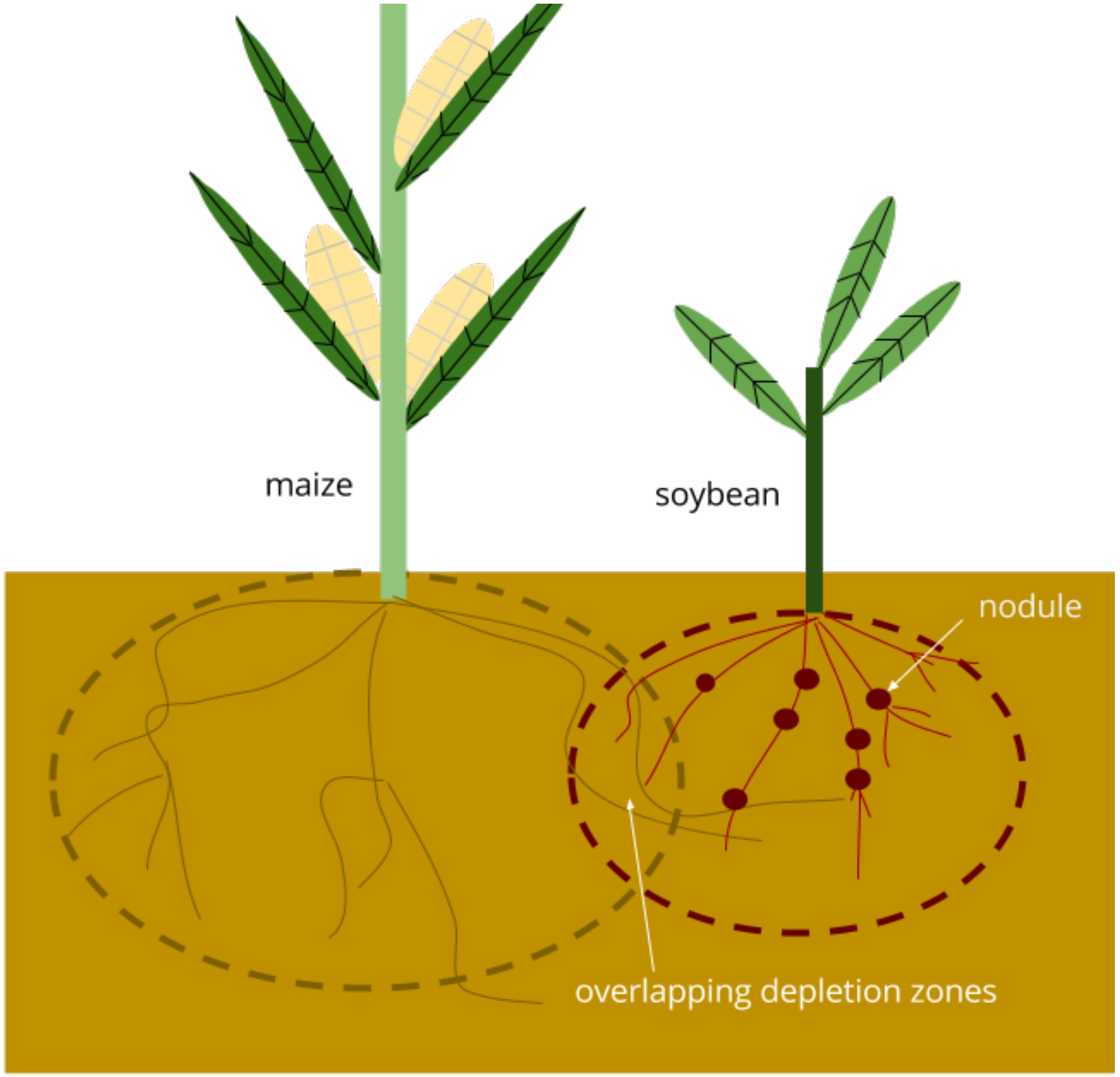
friction velocity (m s^{-1})

Relative humidity within canopy

Deposition velocity of NH_3 on leaves (0.05 m s^{-1} here)

Fung *et al.* (in prep.)

On-going: modeling sustainable farming alternatives, such as intercropping (already implemented into CLM4.5)



Fung et al. (in prep.)

1. Assuming surface area of a crop's root is proportional to its mass, a crop's competition factor (CF) is then defined as:

$$CF_{\text{crop}} = \frac{\text{total root surface area a crop}}{\text{total root surface area of both crops}}$$

$$\approx \frac{\text{mass}_{\text{root,crop}} \cdot \text{weighting}_{\text{crop}}}{\sum_{\text{system}} \text{mass}_{\text{root,crop}} \cdot \text{weighting}_{\text{crop}}}$$

2. The amount of soil N a crop can take up is co-limited by its demand and accessible soil N:

$$N_{\text{uptake,crop}}$$

$$= \min\left(N_{\text{demand,crop}}, CF_{\text{crop}} \cdot \sum_{\text{system}} N_{\text{deployed,crop}}\right)$$

Summary

Thank you!

Please visit https://kamingfung.wordpress.com for more.
Special thanks to the NCAR LMWG Travel Support,
and other supports from Colette Heald's Group

- **Coupled NH_3 emission and NH_4^+ deposition** between CLM5 and CAM-chem6
    - ➢ Cropland NH_3 emission agrees well with CMIP6 inventory
    - ➢ Modeled atmospheric NH_3 is less biased than the default simulation when comparing with IASI NH_3 observations
- Feedbacks of N deposition and aerosol-climate interaction
    - ➢ **NH_3 emission** raised by N deposition (+22%) but suppressed by aerosol-climate interactions (–3%)
    - ➢ **Grain production** is lower in North America & Europe (–5%) likely due to dryer & warmer regional climate, but higher in Asia and Africa primarily because of N enrichment by deposition (+10%)
- Next steps:
    - ➢ **Dynamic soil pH**
    - ➢ Finetuning the **canopy capture** scheme
    - ➢ Investigate whether NH_3-aerosol-climate feedbacks would hinder sustainable farming under future scenarios and climate conditions