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Improving the Terrestrial N Cycle Modeling for A Better Estimation of Agricultural NH_3 Emission Under Sustainable Farming Alternatives

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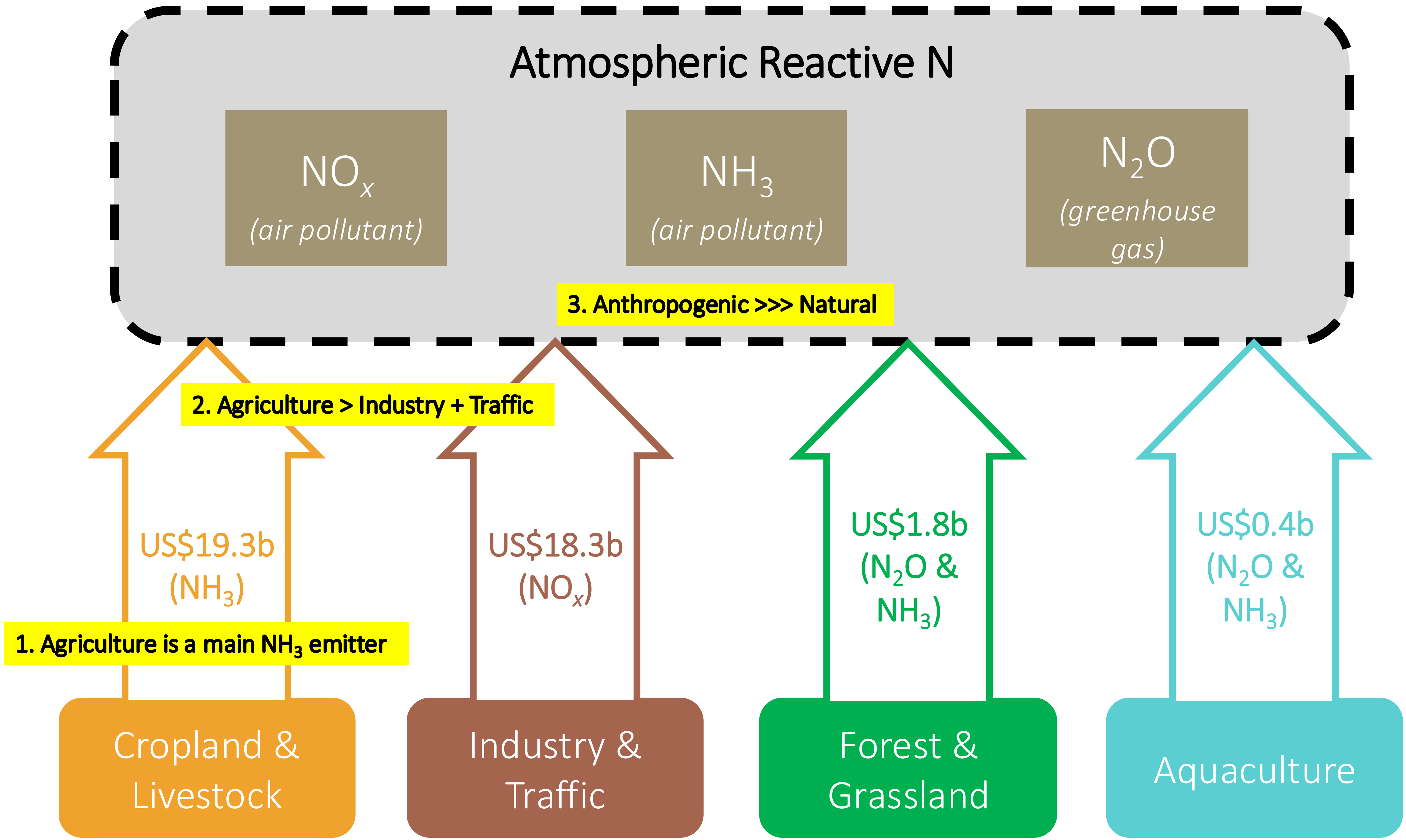
地球系統科學課程
EARTH SYSTEM SCIENCE PROGRAMME

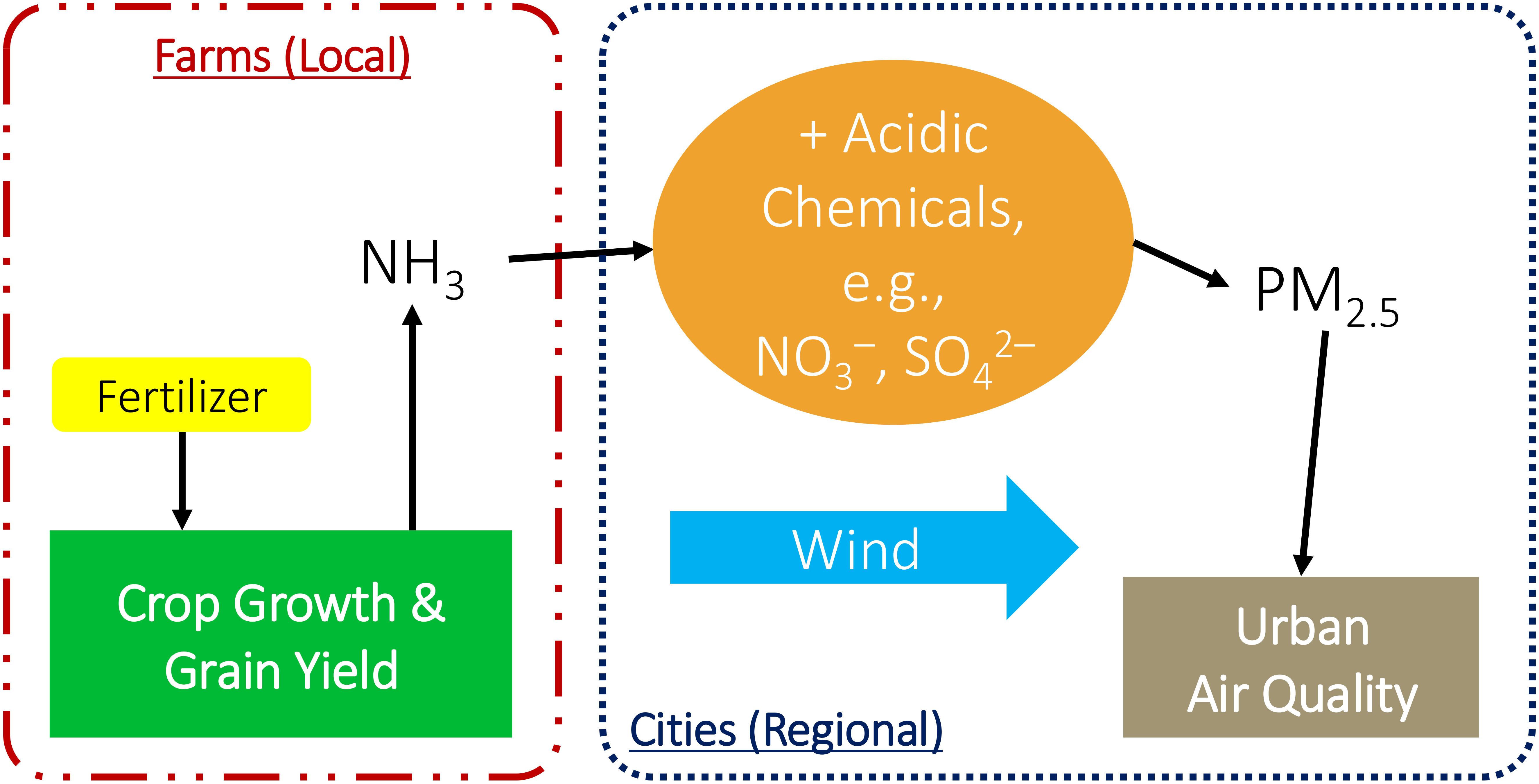
A large portion of atmospheric reactive N is emitted by terrestrial activities

Derived from Gu et al. (2012)

Health Damage Costs of Reactive N across China in 2008

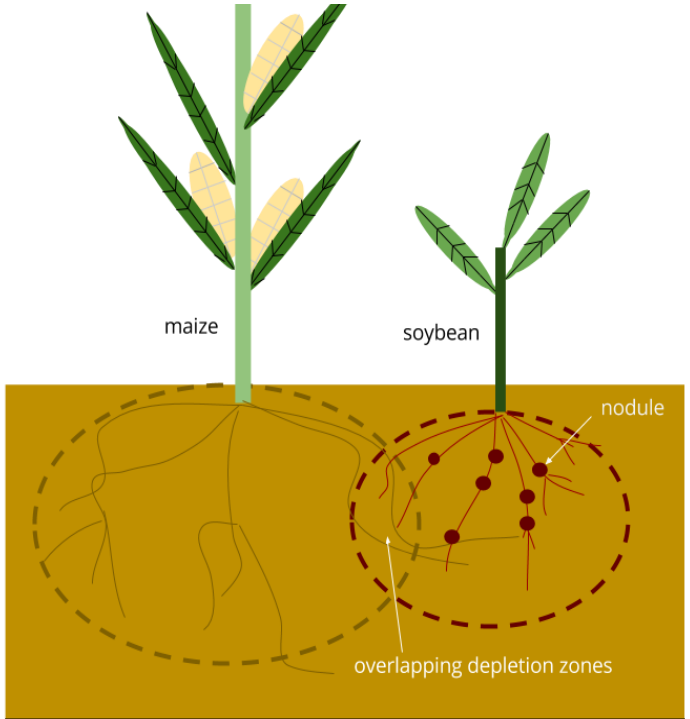


Growing food demand poses a bigger threat to the environment and public health

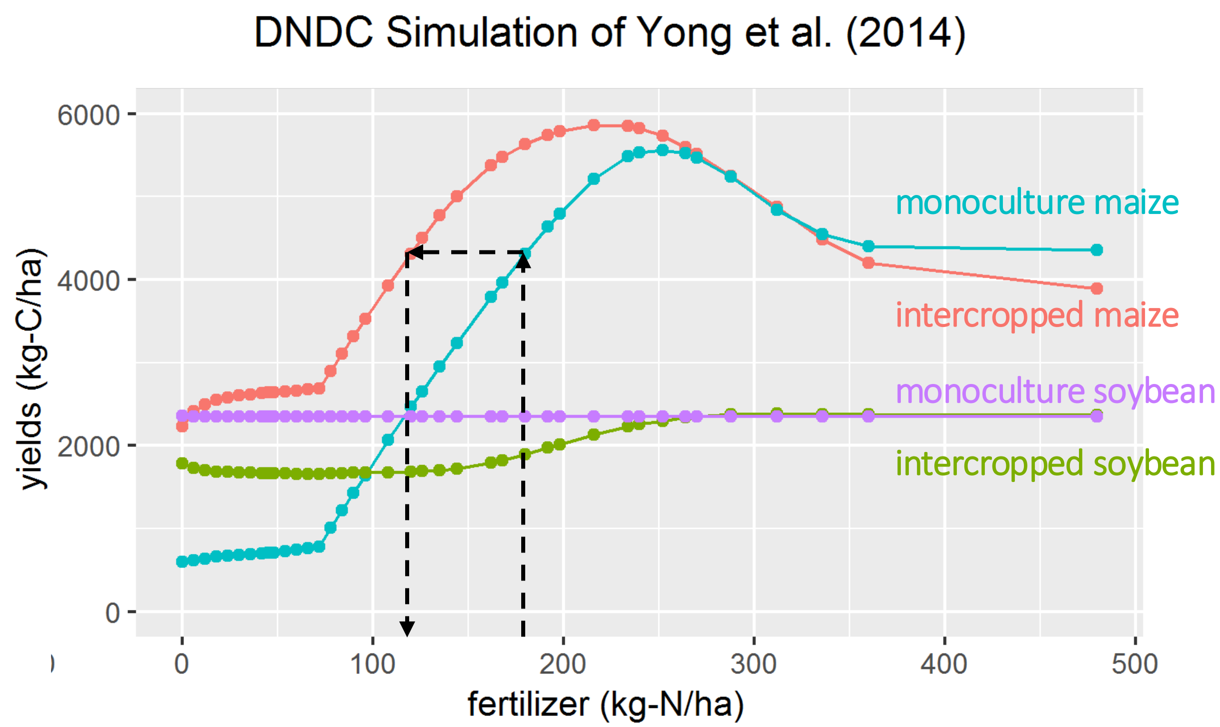


Can we secure future food supply without sacrificing the clean air?

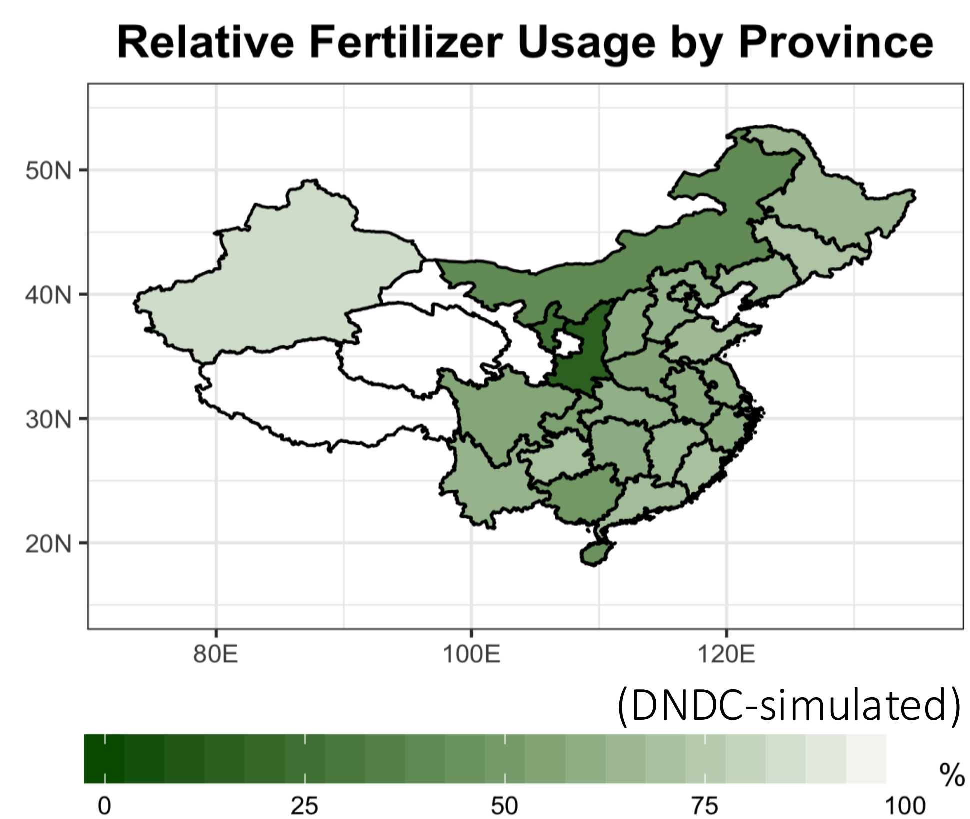
Intercropping requires less fertilizer to produce the same amount of crops



Intercropping allows crop competition and enhance biological nitrogen fixation



1. 33% less fertilizer to generate the same quantity of maize
2. On the same land, additional soybean can be harvested



Assuming all maize and soybean croplands are now adopting maize-soybean intercropping, on average, **42% less fertilizer** is needed to maintain maize yield in each cropland

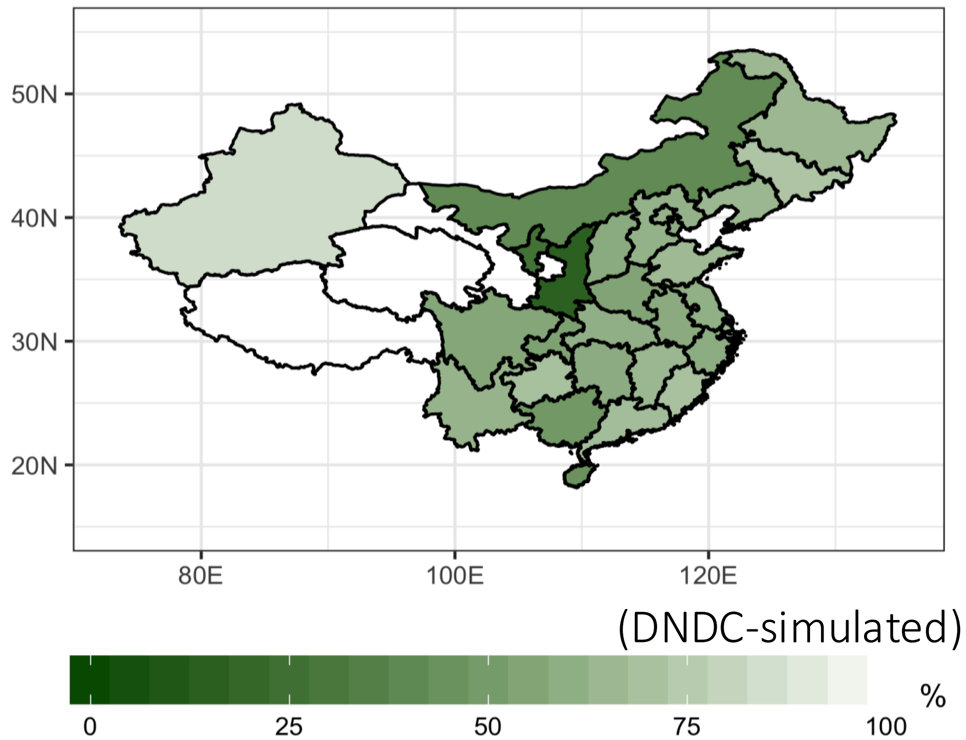
Fung et al. (in review)

National adoption of intercropping also helps safeguard air quality

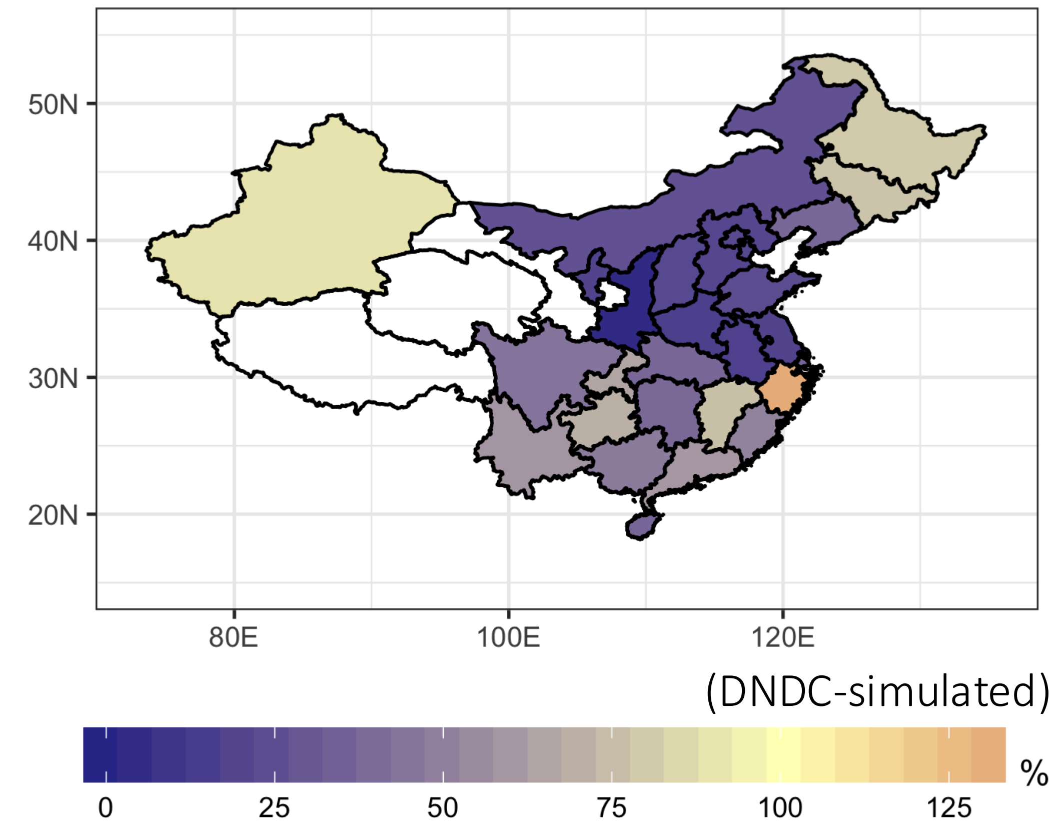
Such reduced fertilization cuts national agricultural NH_3 emission by 45%

On average, **42% less fertilizer** is needed to maintain maize yield on each cropland

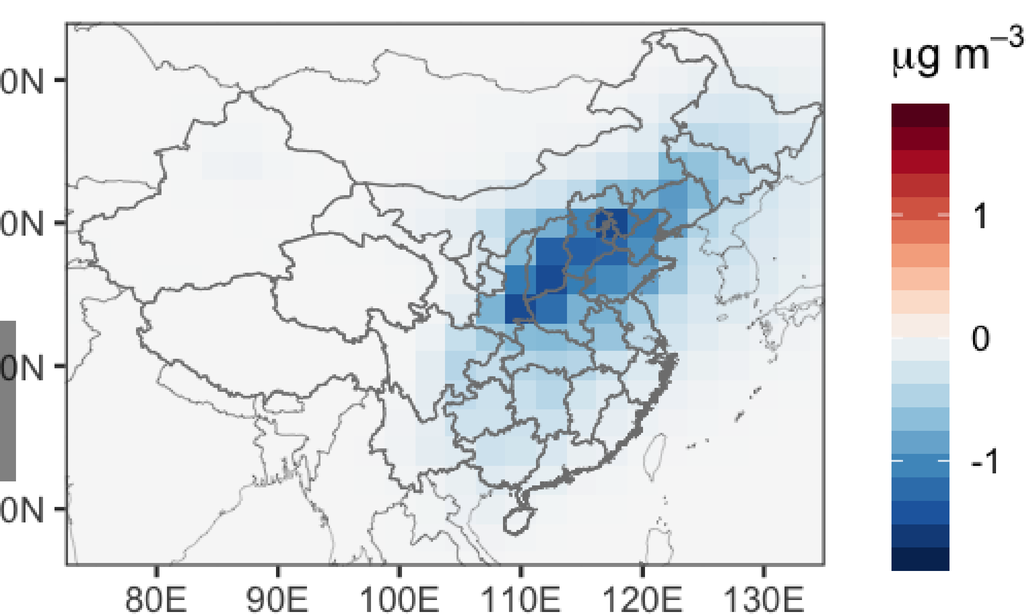
Relative Fertilizer Usage by Province



Relative NH_3 Emissions (Maize-Soybean)



Inorganic $PM_{2.5}$

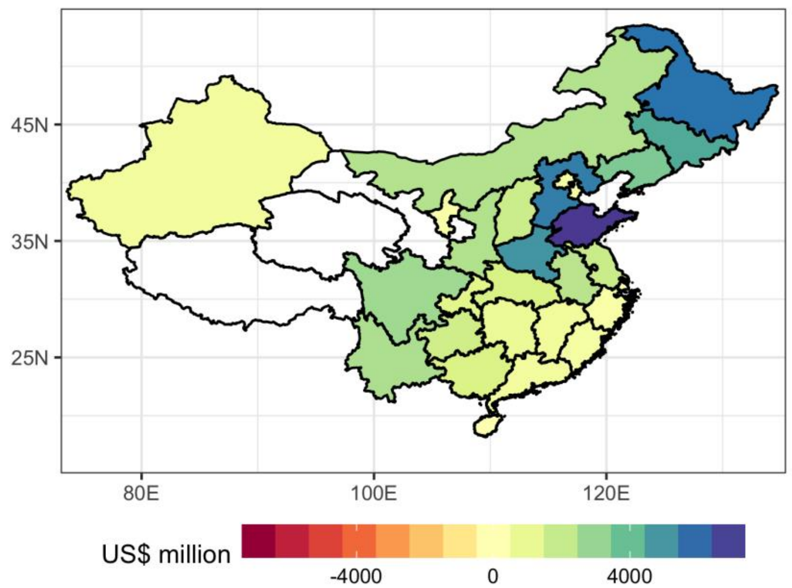


GEOS-Chem-simulated annual $[PM_{2.5}]$
Greatest change = -1.5 μg m^{-3} (-2.1%)

Fung et al. (in review)

Intercropping could be more economic than the current practice in China

More Grain = +US$58b



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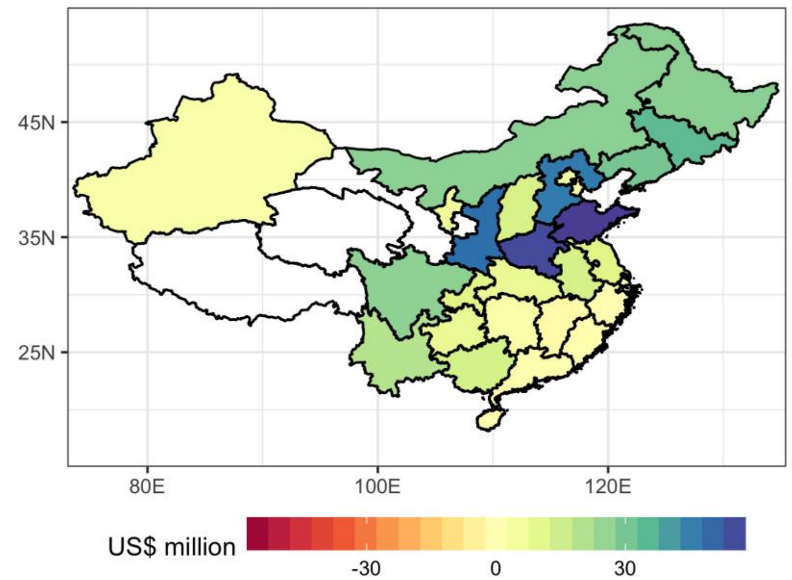
Reduced Fertilizer = +US$0.5b



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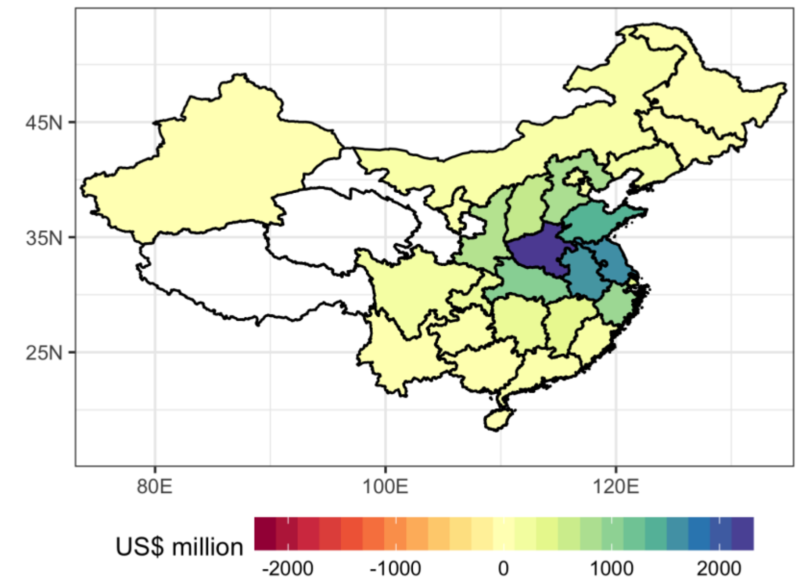
Avoided Health Costs = +US$13b



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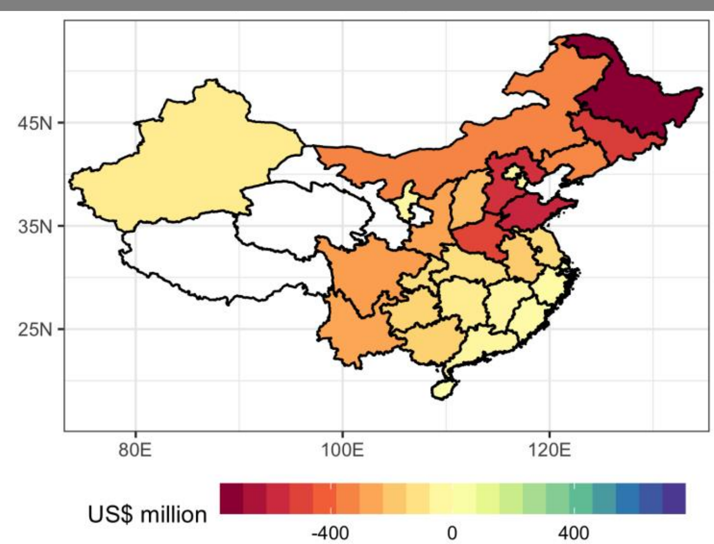
Additional Machinery & Labor = –US$6.0b



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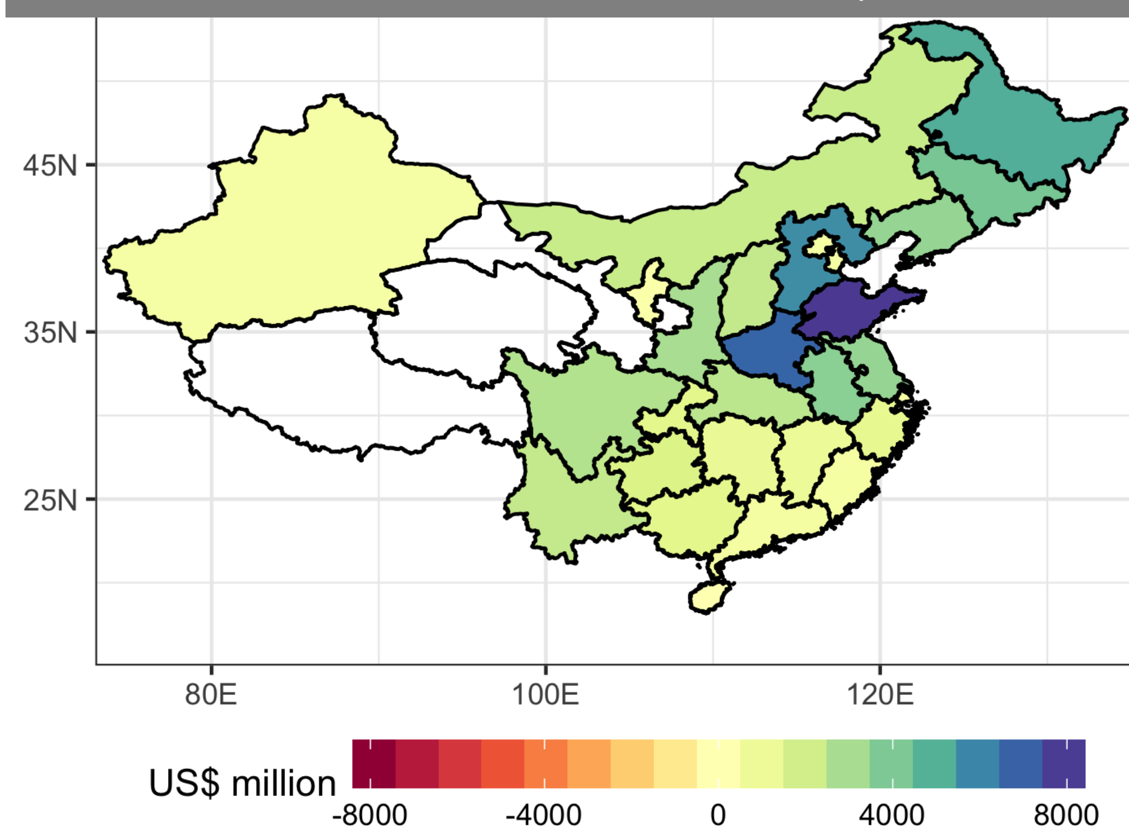
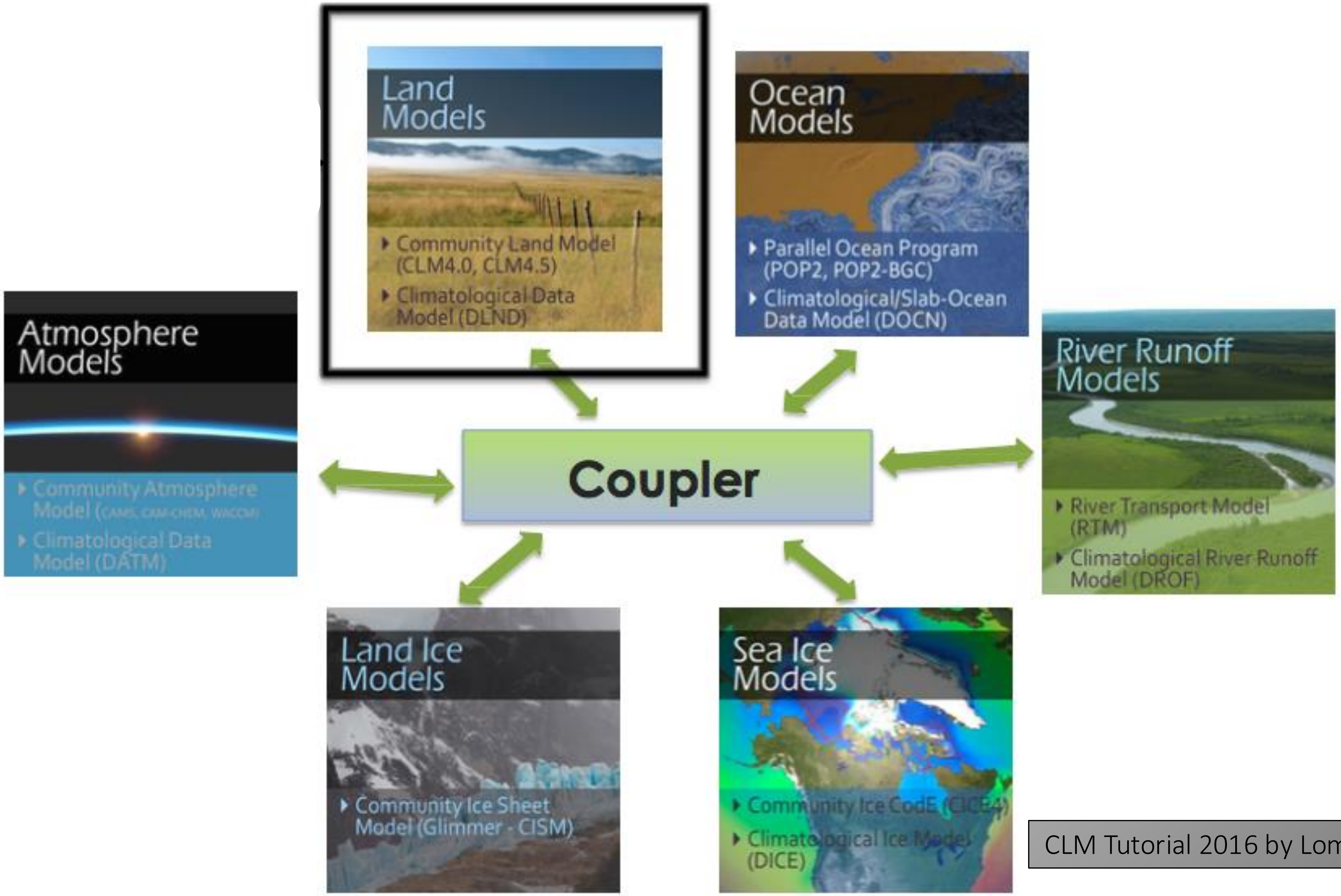
Net profit = +US$67b
(+93% relative to the current practice)



Item	US$ Per Unit
Maize	0.25/kg
Soybean	0.41/kg
Urea	0.27/kg
Statistical Life	160k
Labor	186.50/ha
Machinery	40.00/ha

Fung et al. (in review)

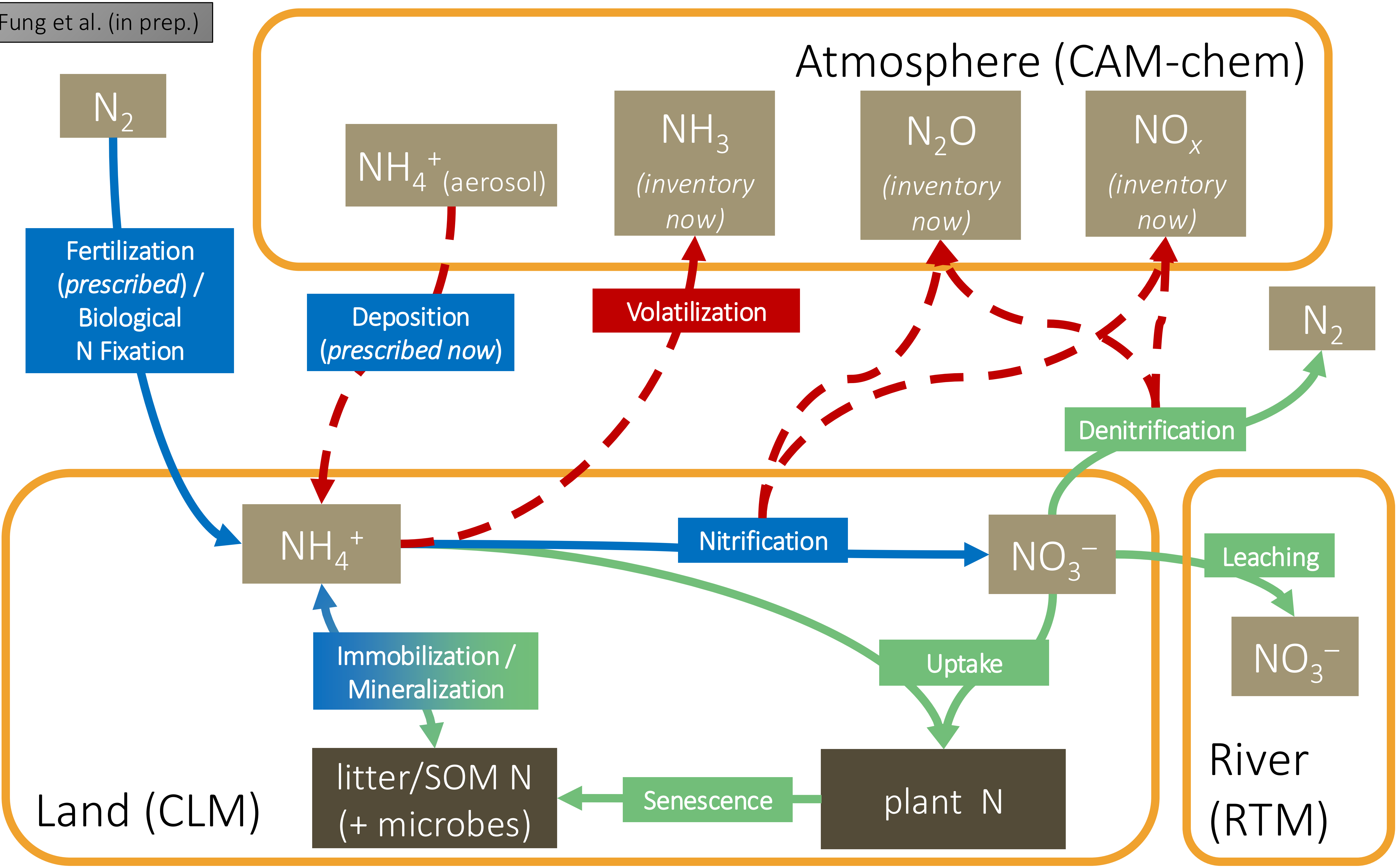
We will use CESM to evaluate the potential benefits of intercropping under future climate and socioeconomic scenarios



CLM Tutorial 2016 by Lombardozzi

N-cycle in CESM and the missing pathways

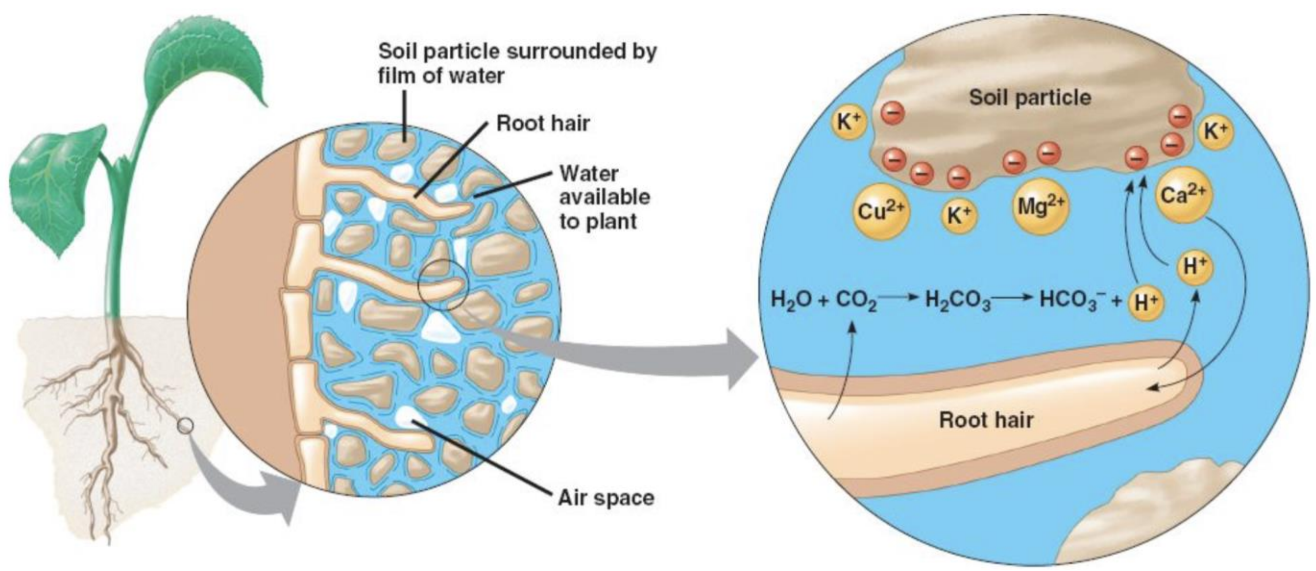
Fung et al. (in prep.)



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

$$\frac{d[\mathrm{NH}_{3\,(g)}]}{dt} \approx [\mathrm{NH}^{+}_{4\,(\mathrm{soil})}](1 - f_{\mathrm{ads}})f_{\mathrm{dis}}f_{\mathrm{vol}}\left(\frac{1}{\Delta t}\right)$$

Campbell et al. (2008)



Fraction of soil NH_4^+ adsorbed is determined by an empirical equation for adsorption:

$$f_{\mathrm{ads}} = 0.99(7.2733 f^{3}_{\mathrm{clay}} - 11.22 f^{2}_{\mathrm{clay}} + 5.7198 f_{\mathrm{clay}} + 0.0263)$$

clay fraction

Fraction of dissociated non-adsorbed NH_4^+:

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

rate constants of dissociation

$$f_{\mathrm{dis}} = \frac{K_{\mathrm{w}}}{[\mathrm{H}^{+}]K_{\mathrm{a}}}$$

soil temperature (°C)

$$K_{\mathrm{a}} = (1.416 + (0.01357)T_{\mathrm{soil}}) \times 10^{-5}\ (\mathrm{mol\ L^{-1}})$$

$$K_{\mathrm{w}} = 10^{0.08946 + (0.03605)T_{\mathrm{soil}}} \times 10^{-15}\ (\mathrm{mol^{2}\ L^{-2}})$$

$$[\mathrm{H}^{+}] = 10^{-\mathrm{pH}}\ (\mathrm{mol})$$

$$\mathrm{pH} = 6.8$$

rate constants of hydrolysis

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

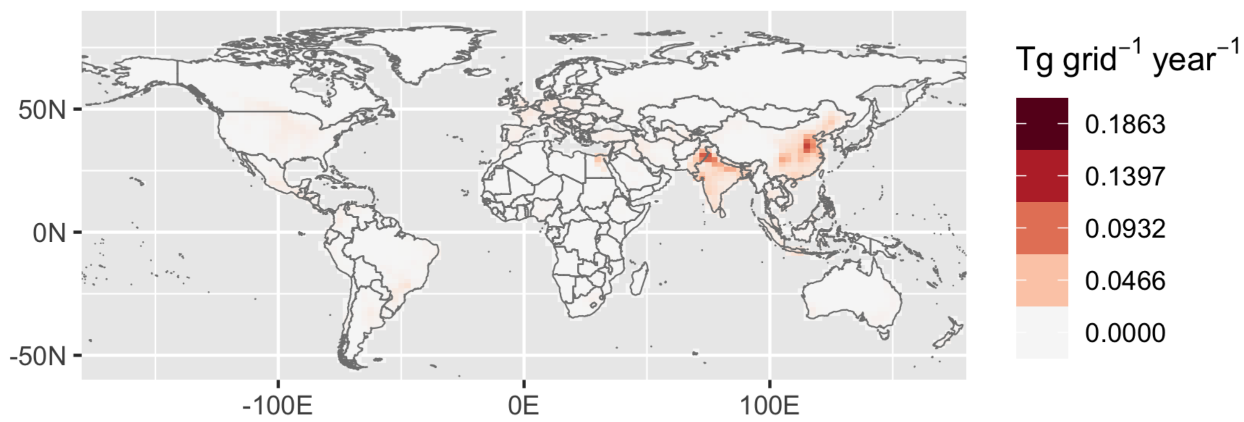
soil layer depth (m)

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

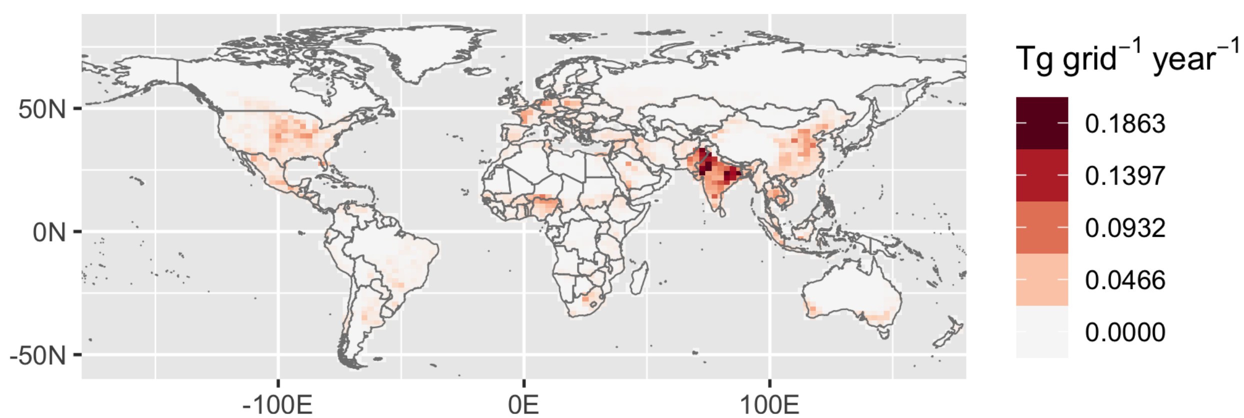
wind speed (m s^{-1})

Comparing with MASAGE (Paulot et al, 2014)

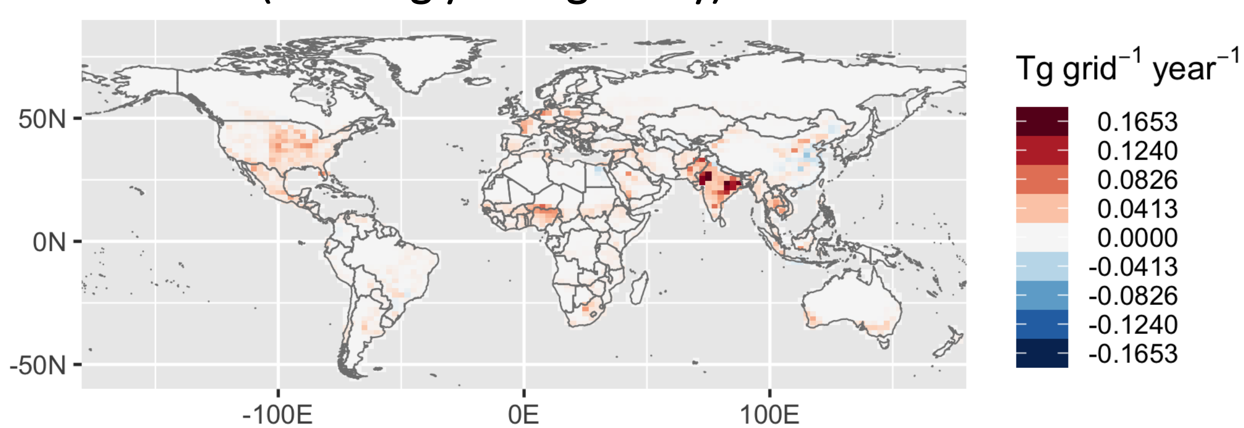
MASAGE NH_3 Emission (fertilizer-induced only)
(9.08 Tg year^{-1} globally)



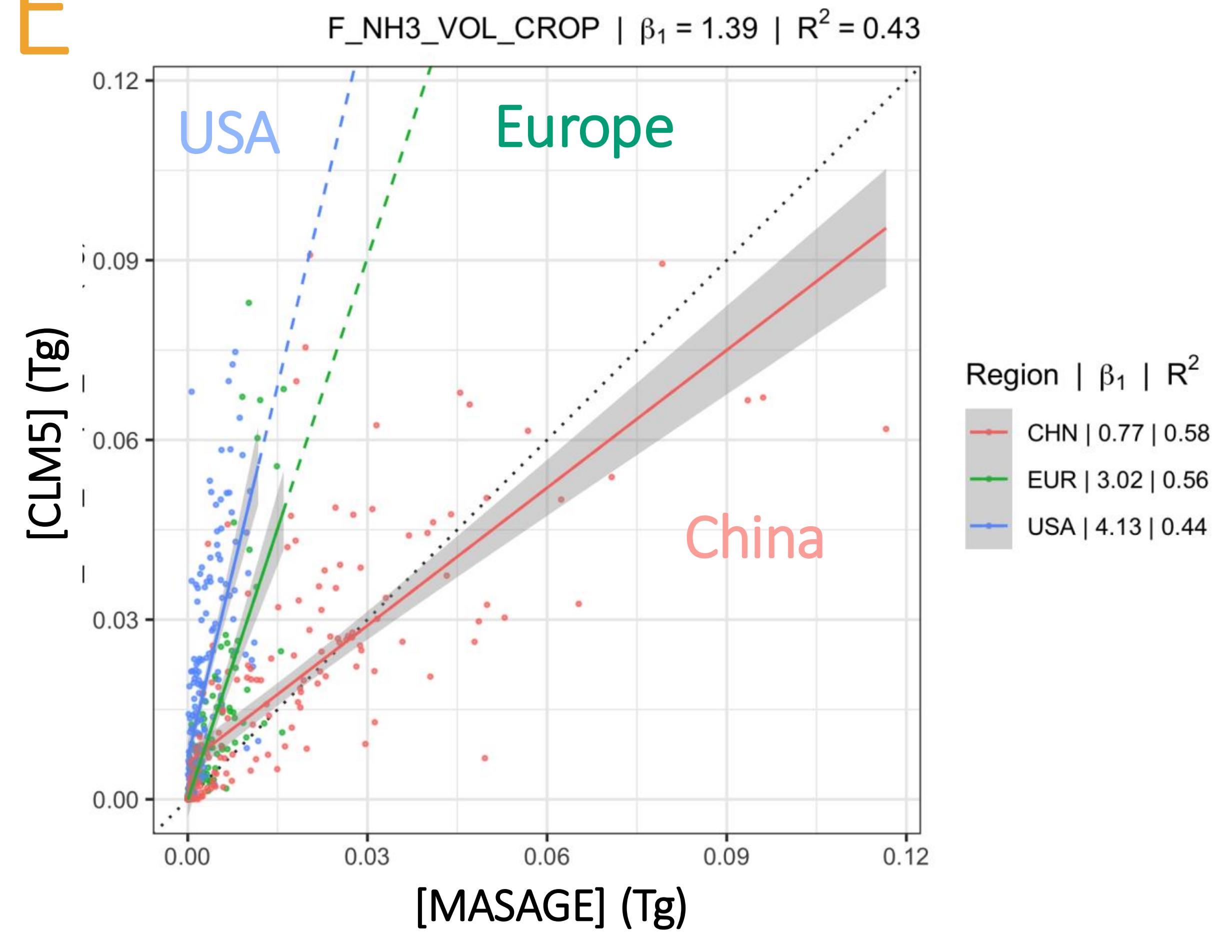
CLM5 NH_3 Emission (fertilizer-induced only)
(24.6 Tg year^{-1} globally)



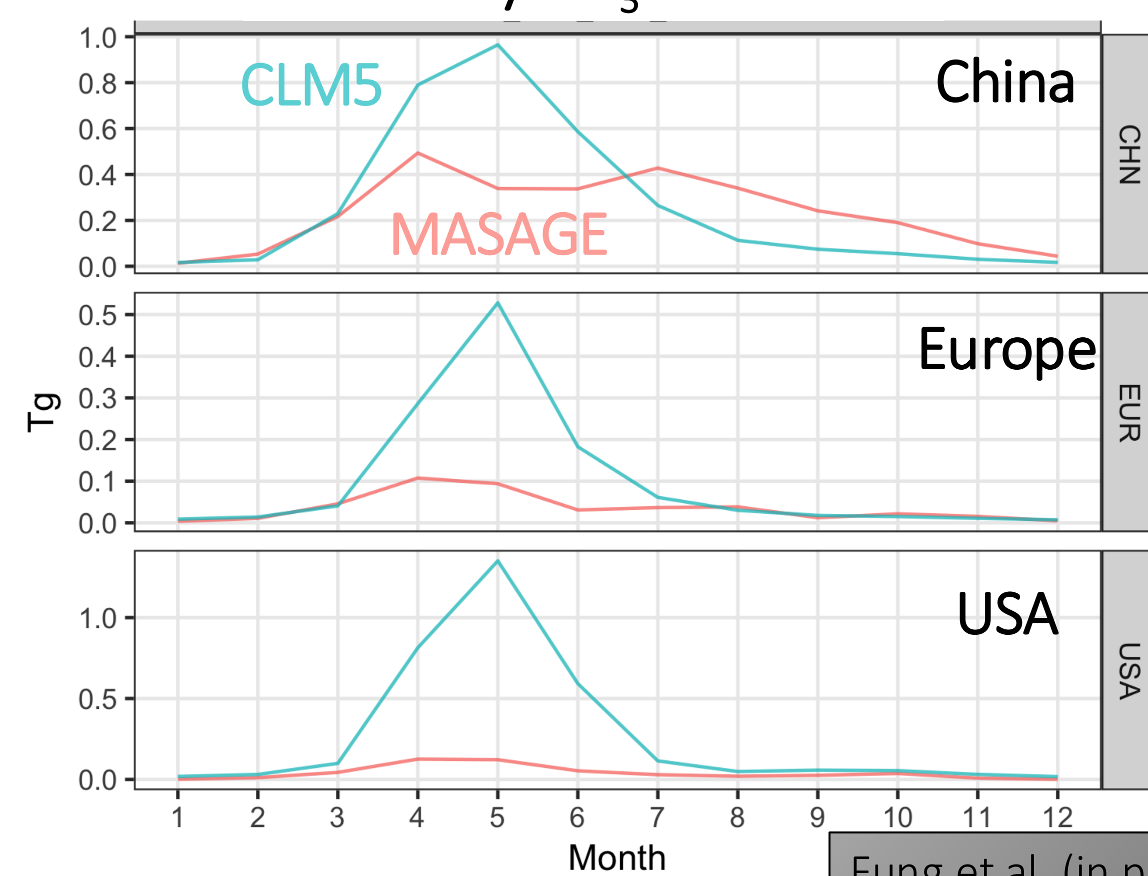
[CLM5] – [MASAGE]
(+15.5 Tg year^{-1} globally)



[CLM5] vs [MASAGE]



Monthly NH_3 Emission

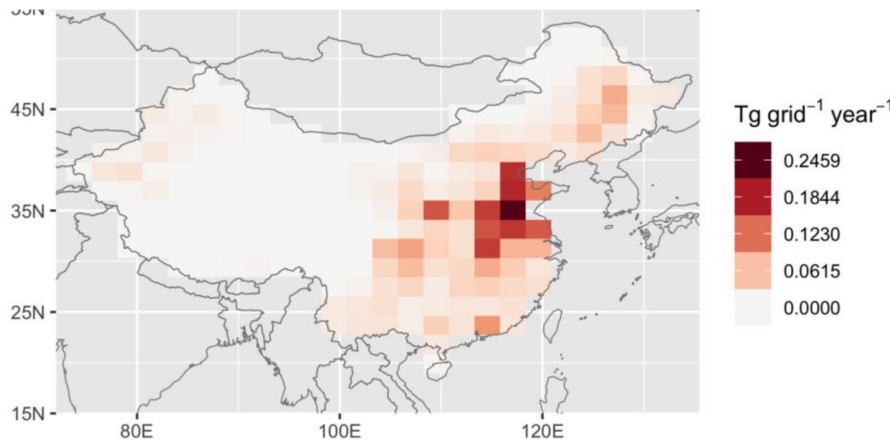


Fung et al. (in prep.)

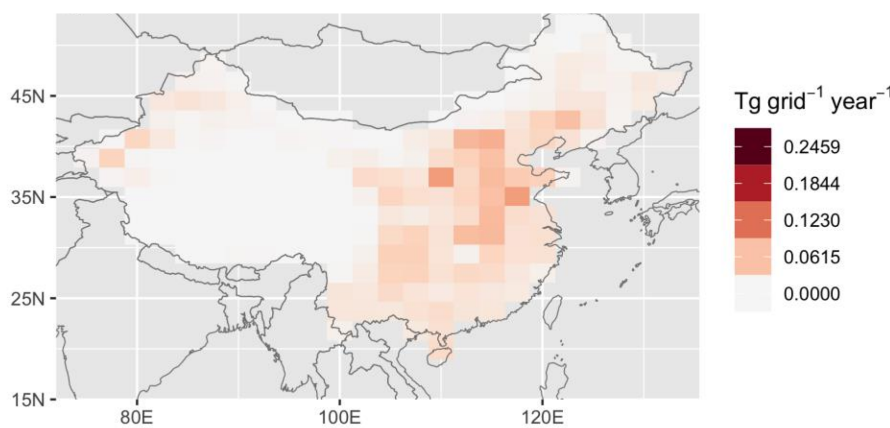
Comparing with a Chinese NH_3 emission inventory (Zhang et al, 2018)

Fung et al. (in prep.)

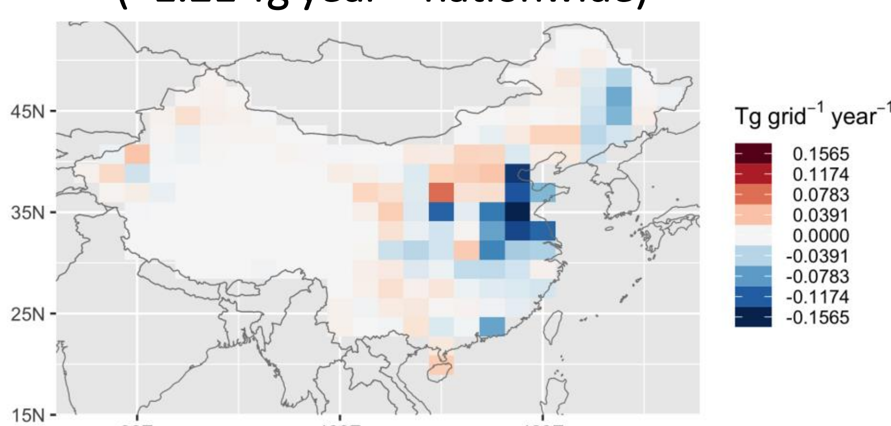
Zhang2018 NH_3 Emission (fertilizer-induced only)
(4.45 Tg year^{-1} nationwide)



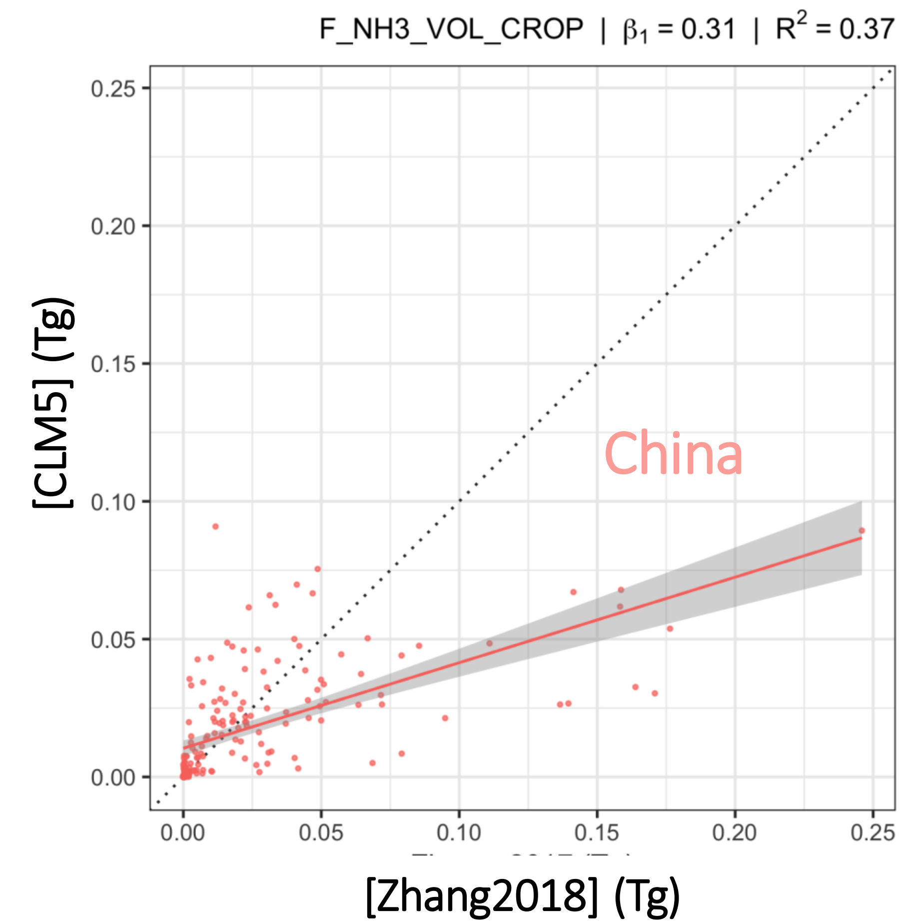
CLM5 NH_3 Emission (fertilizer-induced only)
(3.24 Tg year^{-1} nationwide)



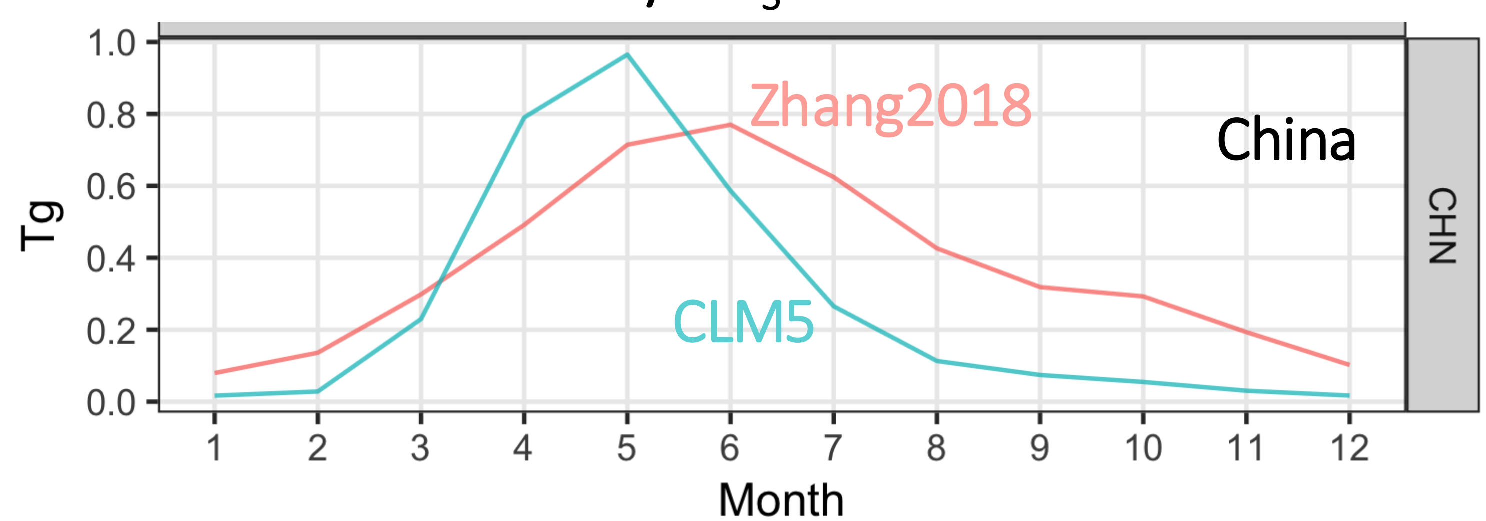
[CLM5] – [Zhang2018]
(–1.21 Tg year^{-1} nationwide)



[CLM5] vs [Zhang2018]



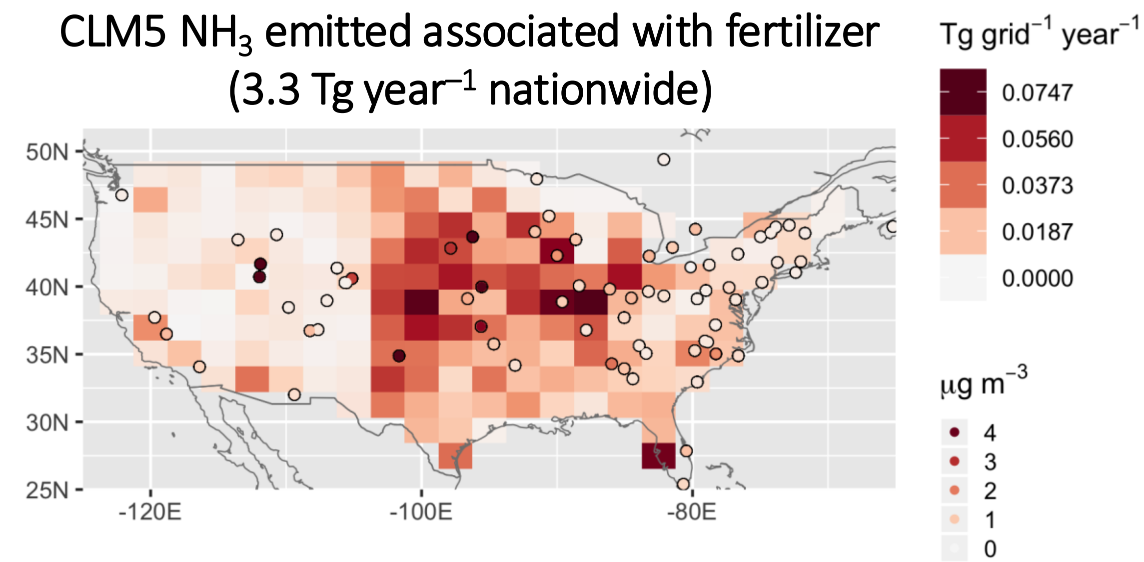
Monthly NH_3 Emission



On-going and Future Work

- Possible reasons for the model-inventory differences:
  - Absence of the canopy reduction factor
  - Inconsistent crop maps
  - Mismatch in fertilization application rates
  - Deviation in prescribed data: soil pH, deposition
- Now: fine-tuning the new NH_3 schemes against field and satellite measurements
- Maria Val Martin is trying to implement:
  - Flux exchange between CLM and CAM-chem, including emission of N_2O, NO_x & NH_3 and deposition of NH_4^+
  - Surface dataset of soil pH
- Next: investigating emission scenarios under future climate and their potential feedback mechanisms

Comparing with AMoN site measurement



Satellite measurement by Van Damme et al. (2015)

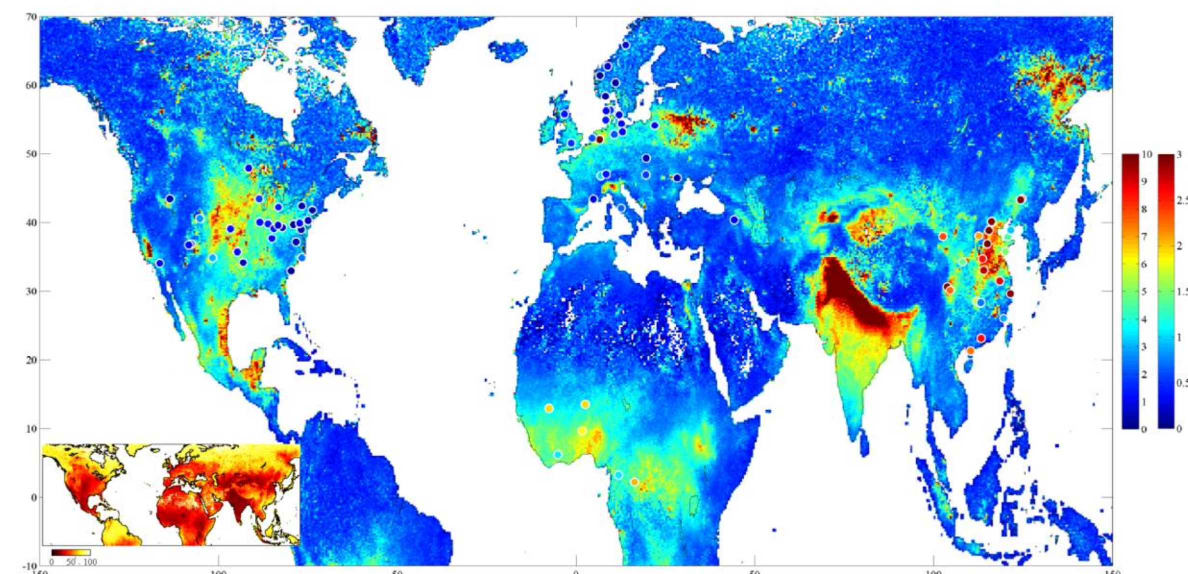


Figure 2. Yearly averaged surface concentrations ($\mu g\,m^{-3}$, left vertical color bar) from IDAF, AMoN, EMEP and NNDMN data sets plotted on top of the NH_3 IASI satellite column ($\times 10^{16}$ molec cm^{-2}, right vertical color bar) distribution for 2011 gridded at 0.25° lat × 0.5° long. Columns and relative error (%, bottom left inset) have been calculated as a weighted mean of all IASI measurements within a cell, following equations described in Van Damme et al. (2014a) (columns with an associated relative above 100 % have been filtered).

Thank you