Characterization of Atmospheric Reactive Nitrogen Emissions from Global Agricultural Soils

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Preamble

• Nitrogen is necessary to sustain all life and is required to sustain agriculture and the global food supply.

• Nitrogen emissions from agricultural (both crop and animal) sources have not been categorized well.

• Satellite measurements can now provide spatial and temporal global coverage for reactive nitrogen.
Population increase and use of nitrogen fertilizer (1900 to 2010)

International Fertilizer Industry Association
**Terminology and definitions**

- **Some examples**
  1. Important biomolecules containing N: chlorophyll, hemoglobin, all proteins, DNA, …
  2. Fertilizers: ammonia (NH$_3$), ammonium salts (NH$_4^+$), nitrate salts (NO$_3^-$), urea [(NH$_4$)$_2$CO]
  3. Nitrous oxide (N$_2$O) is radiatively active, but chemically and biologically inert
Introduction: The Nitrogen Cycle

The nitrogen cycle is the biogeochemical cycle by which nitrogen is converted into multiple chemical forms as it circulates among atmosphere, biosphere, hydrosphere and lithosphere ecosystems.

- The nitrogen cycle is the biogeochemical cycle by which nitrogen is converted into multiple chemical forms as it circulates among atmosphere, biosphere, hydrosphere and lithosphere ecosystems.
- Important processes in the nitrogen cycle include fixation, mineralization, assimilation, nitrification, and denitrification.

The nitrogen cycle in soils/water/biosphere and its connection with the atmosphere.

Global $N_2O$ emission

$N_2O$
Nitrous oxide

The global budget for $N_2O$ 
~17 Tg N/yr

- In terrestrial ecosystems, $N_2O$ is mainly produced in soils via nitrification and denitrification processes.
- There has been limited discussion on the importance of agriculture as a major contributor for the increasing atmospheric $N_2O$.

Source: 2006 IPCC
**NH₃ Ammonia**

Temporal trends of NH₃ concentration (between 2002 and 2013).

AG: Agriculture  
BB: Biomass burning

The global budget for NH₃ ~53 Tg N/yr

Source: Warner et al., 2017  
Source: Houlton et al., 2019
Global NO\textsubscript{x} emissions

NO
Nitric oxide

NO\textsubscript{x}

NO\textsubscript{2}
Nitrogen dioxide

Global distributions of the surface NO\textsubscript{x} emissions (in kg m\textsuperscript{-2} s\textsuperscript{-1}) derived from an assimilation of OMI tropospheric NO\textsubscript{2} columns

The global budget for NO\textsubscript{x} \sim 53 Tg N/yr

Source: Miyazaki et al, 2012
Objectives

• Develop statistical models to predict Nr emissions and deposition from agricultural soils based on the physical-chemical properties

• Analyze the spatial distribution of global Nr emissions from agricultural soil

• Compare and contrast the results (both global and regional) with other model framework emission inventories
3. Methodology

- **Literature Reviews**
  - Identify important factors controlling Nr production in soil
  - Gather relevant data from literatures

- **R-Studio**
  - Statistical summary of collected data
  - Fit data with appropriate regression model with Nr emission as the response and other relevant factors as predictors
  - Model diagnostic

- **ILWIS 3.31 (GIS)**
  - Global dataset preparation
  - Map calculation: apply the model to predict the Nr emissions
Methodology – Statistical Model development

e.g. NH$_3$-STAT

Right skewed → Normal distribution
Statistical Models Based Observations

- **N₂O_STAT**

\[
N_2O \text{ emission} = (\exp [1.34 + 0.03 \times T_{soil} + 0.02 \times SM - 0.35 \times pH_{soil} + 0.0003 \times N \text{ input} + 0.46 \times Fertilizer \text{ type}]) \times \frac{28}{44}
\]

- **NH₃_STAT**

\[
NH_3 \text{ emission} = (\exp [-4.6 + 0.02 \times T_{soil} + 0.01 \times SM + 0.09 \times pH_{soil} + 1.2 \times \log(N \text{ input}) + 0.5 \times Fertilizer \text{ type}]) \times \frac{14}{17}
\]

- **NOₓ_STAT**

\[
NO_x \text{ emission} = (\exp [-6.2 + 0.02 \times T_{soil} + 0.02 \times SM - 0.13 \times pH_{soil} + 1.2 \times \log(N \text{ input}) - 0.07 \times Fertilizer \text{ type}]) \times \frac{14}{30}
\]

Tsoil refers to soil temperature (°C), SM soil moisture (%), N input is differentiated by synthetic (0) or organic fertilizer (1), and is expressed as kg N ha⁻¹ yr⁻¹. The units for predicted emission are kg N ha⁻¹ yr⁻¹.
Model validation for NH3_STAT against NH₃ emissions from field experiments

\[ y = 0.6264x + 3.216 \]
\[ R^2 = 0.6829 \]
\[ \text{N}_2\text{O Results – Global} \]

- Total annual global \( \text{N}_2\text{O} \) emission from agricultural soil

This study:
3.75 Tg/year

EDGAR 2012:
4.49 Tg/year
NH₃ Results – Global

- Total annual global NH₃ emission from agricultural soil

This study:
13.9 Tg/year

EDGAR 2012:
33.0 Tg/year
**NO\textsubscript{X} Results – Global**

- **This study:**
  - Total annual NO emission from agricultural soil
  - 0.2 Tg/year

- **EDGAR 2012:**
  - 1.6 Tg/year
$\text{N}_2\text{O Results – Regional (US)}$

$\text{N}_2\text{O}_\text{STAT}: 0.35 \text{ Tg N yr}^{-1}$

$\text{EDGAR}: 0.43 \text{ Tg N yr}^{-1}$

$\text{EPA/USGS}: 0.46 \text{ Tg N yr}^{-1}$
Conclusions

- Three statistical models are developed, using only observations, for characterizing atmospheric Nr emissions from agricultural soils.

- Statistical models capture the spatial distribution of global Nr emissions by utilizing an observation-based approach, rather than emission factor and activity approach or inverse modeling approach.
Conclusions

- EDGAR has additional sources in their estimate, whereas our model is exclusive to emissions from fertilizer and manure applied as fertilizer.
- Data sets lies in the methodology of collecting the model inputs
- These statistical models only considers physicochemical variables of the emissions, excluding the soil management practices that might contribute to the emissions.
- Soil biological activity that represent the processes governing the Nr emissions was not included in the model
- Deposition analysis of Nr is currently in progress.
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