Quantifying nitrous oxide emissions in the U.S. Midwest – A top-down study

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N$_2$O plays a crucial role in the atmosphere.

**Dominant ozone-depleting substance**
(Ravishankara et al., 2009)

**Third most important long-lived anthropogenic greenhouse gas**
(Myhre et al./IPCC AR5, 2013)

**Atmospheric abundance:**

- Rising since industrialization (~20%)
  (McFarling Meure 2004 & 2006)

- Globally in January 2020: ~330 ppb
  (Combined Nitrous Oxide data from the NOAA/ESRL Global Monitoring Division)

**Emissions:**

- Recent growth in emissions increased at a higher rate than expected
  (Thompson et al., 2019; Tian et al., 2020)

- Interest grows in expanding efforts to reduce emissions
  (Kanter et al., 2020)
The agriculture in the Midwest is a hotspot of N$_2$O emissions.

- **Agriculture**/Application of **nitrogen fertilizer** is the main anthropogenic source.

- **U.S. Cornbelt** within the **Midwest** is a wide area, dominated by agricultural activity

→ **The Midwest is a regional hotspot of agricultural N$_2$O emissions**

EDGAR v4.3.2: Total N$_2$O emissions in 2012

N$_2$O emissions in kg km$^{-2}$ yr$^{-1}$
Midwest $\text{N}_2\text{O}$ emissions are highly uncertain.

**Current knowledge:**

- **Limited amount** of top-down studies

- **High regional uncertainties** in common inventories like EDGAR

  e.g.: Fu et al., 2017: *agricultural EDGAR v4.2 emissions in the Cornbelt must be multiplied by a factor up to 19.0 – 28.1 (tall tower measurements + WRF-Chem)*

**How high are $\text{N}_2\text{O}$ emissions in the Midwest?**

**How well are these emissions represented in state-of-the-art bottom-up inventories?**
Airborne in situ N\textsubscript{2}O measurements from ACT-America campaigns.

<table>
<thead>
<tr>
<th>ACT-America fall 2017 &amp; summer 2019</th>
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Measurements onboard NASA's C-130:

- Quantum Cascade Laser Spectrometer (QCLS; DLR) (Kostinek et al., 2019) → **continuous in-situ measurements**

- Flask measurements (PFP; NOAA; Colm Sweeney & Bianca Baier) (Sweeney et al., 2015, 2018; Baier et al., 2020)
Selecting ACT-America transects over the Midwest.

**ACT-America fall 2017 & summer 2019**

Transects within the PBL over the Midwest required

Selected:

- **Four** flights of October 2017
- **Six** flights of June/July 2019
Quantifying Midwest \( \text{N}_2\text{O} \) emissions with a top-down approach.

(Approach comparable to Barkley et al., 2017)

- **Airborne in situ \( \text{N}_2\text{O} \) measurements** over the U.S. Midwest

+ Forward simulation with **WRF-Chem**
  + Emission **inventory**
Simulating $\text{N}_2\text{O}$ plumes with WRF-Chem forward simulations.

WRF-Chem version 4.0.2 forward simulations

Emit $\text{N}_2\text{O}$ from bottom-up inventory
(Atmospheric lifetime of $\text{N}_2\text{O}$: 118 years
(Prather and Hsu, 2010) $\rightarrow$ passive tracer)

Simulated plume along PBL transect
Obtaining prior emission estimates for simulations from EDGAR.

**Employed bottom-up inventory:** Emissions Database for Global Atmospheric Research

- Anthropogenic emissions: **EDGAR v4.3.2** (2010) and **EDGAR v5.0** (2015)
- Natural: **EDGAR v2** (1990)

Merging emission sectors to:
1. Agricultural (**AGR**)
2. Non-agricultural anthropogenic (**nonAGR**)
3. Natural (**N**)

**N₂O emissions in the Midwest** (EDGAR v5.0 & EDGAR v2)

- AGR: 61%
- **nonAGR**: 24%
- **N**: 15%
Quantifying Midwest N₂O emissions with a top-down approach.

(Approach comparable to Barkley et al., 2017)

Airborne in situ N₂O measurements over the U.S. Midwest

Forward simulation with WRF-Chem + emission inventory

Compare simulated enhancements in the atmosphere with measurements

Adjust inventory so that differences between simulation and measurements are minimal
Large discrepancy between observed and simulated plume

N₂O enhancement in ppb

10 Oct 2017

Altitude AGL in km

12:00 12:15 12:30 12:45 13:00 13:15

Local time

Agricultural  Non-agricultural anthropogenic  Natural

Chart 11

(adapted from Eckl et al., submitted to GRL in Oct 2020)
Adjusting the inventory by scaling agricultural emissions.

**Dominant source:** Agricultural emissions

**Complexity of N₂O soil emissions**
→ agricultural emissions exhibit much higher uncertainties than others

(Butterbach-Bahl et al., 2013)

**Assumption:**
Discrepancy between simulation and observations is caused by agricultural emissions

Adjust inventory by **scaling agricultural** emissions
Scaling agricultural emissions minimizes the discrepancy.

10 Oct 2017

\( \text{N}_2\text{O} \) enhancement in ppb

(adopted from Eckl et al., submitted to GRL in Oct 2020)

Scaled agricultural (±1σ)

Agricultural  Non-agricultural anthropogenic  Natural

Chart 13

Scaling factor: 8.3
EDGAR strongly underestimates agricultural Midwest emissions.

(adopted from Eckl et al., submitted to GRL in Oct 2020)

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<tr>
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<td></td>
<td>6.3</td>
<td>11.4</td>
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<tr>
<td></td>
<td>3.5</td>
<td>9.9</td>
</tr>
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Chart 14
Midwest N₂O emissions are strongly underestimated by EDGAR.

This study (uncertainties on the order of 50%)
How much contributed the severe flooding event in 2019?

Spring/early summer 2019
Wettest period in 125 years in the U.S, with severe flooding in the Midwest
(NOAA, 2020)

Contribution to our June/July 2019 result?!
DayCent provides more sophisticated bottom-up estimates than EDGAR.

**EDGAR**

**DayCent:**
Daily time-step version of the CENTURY biogeochemical model
(Parton et al., 1998; Del Grosso et al., 2001, 2011)

**emission factor approach**

**process-based:**
Simulates nitrogen and carbon fluxes in soils

**N₂O soil emissions**

**only agricultural emissions 2011-2015**

Chart 17
DayCent is closer to our top-down estimate than EDGAR.

<table>
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<th>Midwest N₂O flux in nmol m⁻² s⁻¹</th>
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<th>Summer 2019</th>
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DayCent
(only agricultural emissions; 2011-2015)
Summary and Outlook

**Average Midwest \( \text{N}_2\text{O} \) emissions:**
- Oct 2017: \( 0.42 \pm 0.28 \, \text{nmol m}^{-2} \, \text{s}^{-1} \)
- Jun/Jul 2019: \( 1.06 \pm 0.57 \, \text{nmol m}^{-2} \, \text{s}^{-1} \)

**EDGAR** fluxes underestimate U.S. Midwest \( \text{N}_2\text{O} \) emissions by **factors up to 20**

Historical **DayCent** Midwest \( \text{N}_2\text{O} \) fluxes are **closer to our top-down estimate** than **EDGAR but still too low**

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How much **contributed the severe flooding event in 2019** to Midwest \( \text{N}_2\text{O} \) emissions in June/July?

Study with DayCent simulations driven by these special conditions are planned.
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Live overview/Q&A session:
Friday, 11 Dec
04:48 – 04:53 PST

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References (2/4)


References (3/4)


Summary and Outlook

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