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

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Eckl, M., A. Roiger, J. Kostinek, A. Fiehn, H. Huntrieser, C. Knote, Z. Barkley, S. Ogle, B. Baier, C. Sweeney, K. Davis; Quantifying nitrous oxide emissions in the U.S. Midwest - A top-down study using high resolution airborne in situ observations; submitted to Geophysical Research Letters on October 14, 2020.
N₂O plays a crucial role in the atmosphere.

| Dominant ozone-depleting substance | Third most important long-lived anthropogenic greenhouse gas |
|-----------------------------------|---------------------------------------------------------------|
| (Ravishankara et al., 2009)        | (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**

![Chart 3: EDGAR v4.3.2: Total N$_2$O emissions in 2012](image)
Midwest N\textsubscript{2}O emissions are highly uncertain.

| Current knowledge: |
|--------------------|
| • **Limited amount** of *top-down* studies |
| • **High regional uncertainties** in common inventories like EDGAR |

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**How high are N\textsubscript{2}O emissions in the Midwest?**

**How well are these emissions represented in state-of-the-art bottom-up inventories?**

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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)*
Airborne in situ N\textsubscript{2}O measurements from ACT-America campaigns.

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

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 \( N_2O \) emissions with a top-down approach.

(Approach comparable to Barkley et al., 2017)

**Airborne in situ \( N_2O \) measurements** over the U.S. Midwest

+ Forward simulation with **WRF-Chem**
  + emission **inventory**
Simulating N$_2$O plumes with WRF-Chem forward simulations.

WRF-Chem version 4.0.2 forward simulations

Emit N$_2$O from bottom-up inventory
(Atmospheric lifetime of N$_2$O: 118 years
(Prather and Hsu, 2010) → 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*)

![Chart 9](https://doi.org/10.1002/essoar.10505820.1) | Non-exclusive | First posted online: Mon, 18 Jan 2021 11:27:49 | This content has not been peer reviewed.
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

- **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

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

10 Oct 2017

$N_2O$ enhancement in ppb

Altitude AGL in km

Local time

Agricultural  Non-agricultural anthropogenic  Natural

Chart 11
Adjusting the inventory by scaling agricultural emissions.

| Dominant source: | Complexity of N$_2$O 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

\[ \text{N}_2\text{O enhancement in ppb} \]

*Scaling factor: 8.3*

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

**Scaled agricultural (±1σ)**

- **Agricultural**
- **Non-agricultural anthropogenic**
- **Natural**

Chart 13

ESSOAr | https://doi.org/10.1002/essoar.10505820.1 | Non-exclusive | First posted online: Mon, 18 Jan 2021 11:27:49 | This content has not been peer reviewed.
EDGAR strongly underestimates agricultural Midwest emissions.

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

|          | Fall 2017 | Summer 2019 |
|----------|-----------|-------------|
| EDGAR v4.3.2 (±1σ) | 6.3       | 11.4        |
| EDGAR v5.0 (±1σ)   | 3.5       | 9.9         |

Chart 14
Midwest N$_2$O emissions are strongly underestimated by EDGAR.

|        | Fall 2017 | Summer 2019 |
|--------|-----------|-------------|
| Midwest N$_2$O flux in nmol m$^{-2}$ s$^{-1}$ |           |             |
| 0.0    |           |             |
| 0.5    |           |             |
| 1.0    |           |             |

This study (uncertainties on the order of 50%)

EDGAR v4.3.2

EDGAR v5.0

Chart 15
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**
DayCent is closer to our top-down estimate than EDGAR.

|            | Fall 2017 | Summer 2019 |
|------------|-----------|-------------|
| DayCent (only agricultural emissions; 2011-2015) |           |             |
| Midwest N₂O flux in nmol m² s⁻¹ |           |             |
| 0.0        | 0.0       | 1.2         |
| 0.5        |           |             |
| 1.0        |           |             |

This study (uncertainties on the order of 50%) | EDGAR v4.3.2 | EDGAR v5.0 |

Chart 18
Summary and Outlook

Average Midwest N$_2$O emissions:
- Oct 2017: 0.42 ± 0.28 nmol m$^{-2}$ s$^{-1}$
- Jun/Jul 2019: 1.06 ± 0.57 nmol m$^{-2}$ s$^{-1}$

EDGAR fluxes underestimate U.S. Midwest N$_2$O emissions by factors up to 20

Historical DayCent Midwest N$_2$O fluxes are closer to our top-down estimate than EDGAR but still too low

How much contributed the severe flooding event in 2019 to Midwest N$_2$O emissions in June/July?

Study with DayCent simulations driven by these special conditions are planned
Summary and Outlook

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**Live overview/Q&A session:**

Friday, 11 Dec

04:48 – 04:53 PST

How much contributed the severe flooding event in 2019 to Midwest N₂O emissions in June/July?

Study with DayCent simulations driven by these special conditions are planned.
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