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.

N_2O 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:

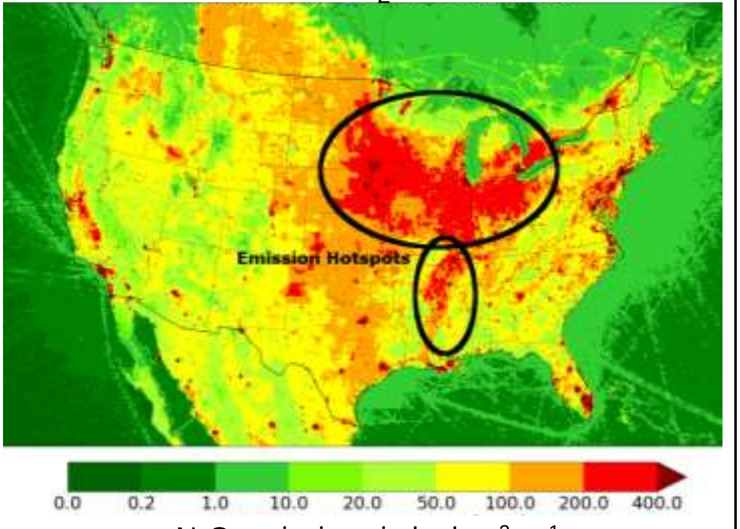
- Recent growth in emissions increased at a higher rate than expected
  (Thompson et al., 2019; Tian et al., 2020)
- Interest grows in expanding efforts to reduce emissions
  (Kanter et al., 2020)

The agriculture in the Midwest is a hotspot of N_2O 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_2O emissions**

EDGAR v4.3.2: Total N_2O emissions in 2012



N_2O emissions in kg km^{-2} yr^{-1}

Midwest N_2O 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 N_2O emissions in the Midwest?

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

Airborne in situ N_2O 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)

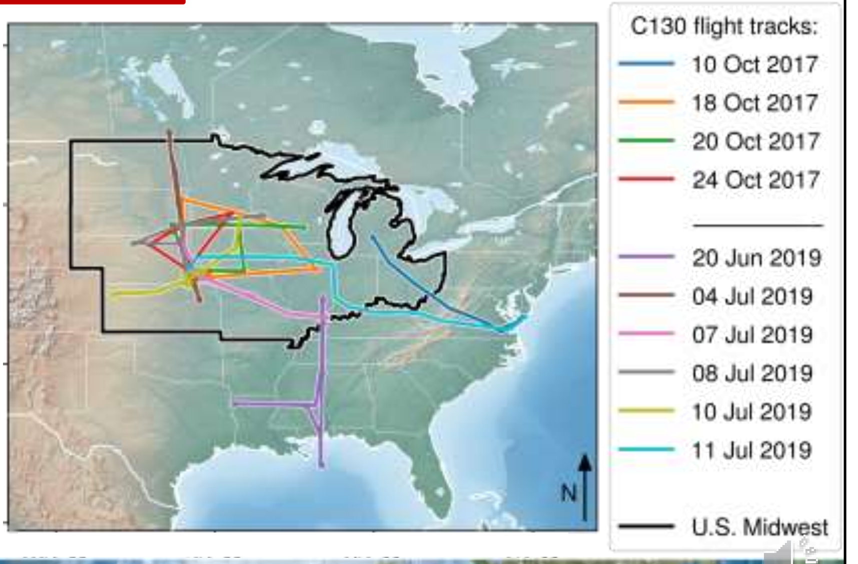
Selecting ACT-America transects over the Midwest.

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_2O plumes with WRF-Chem forward simulations.

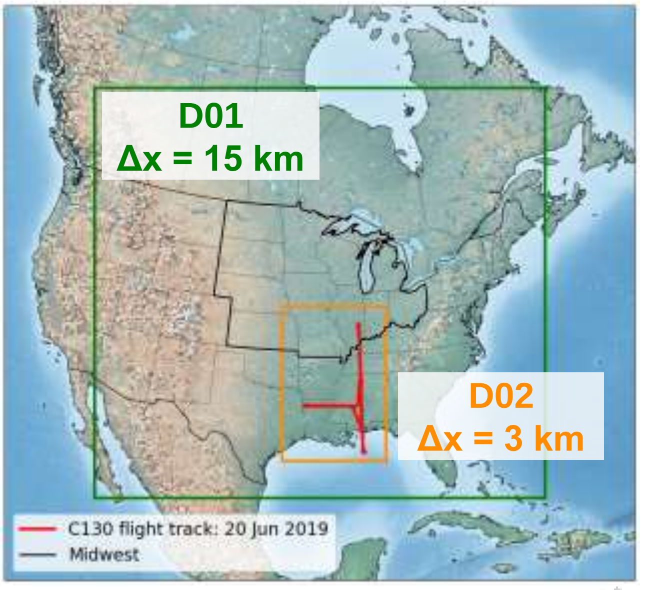
WRF-Chem version 4.0.2 **forward** simulations

↓

Emit N_2O from bottom-up inventory
(Atmospheric lifetime of N_2O: 118 years
(Prather and Hsu, 2010) → **passive tracer**)

↓

Simulated plume along PBL transect



Obtaining prior emission estimates for simulations from EDGAR.

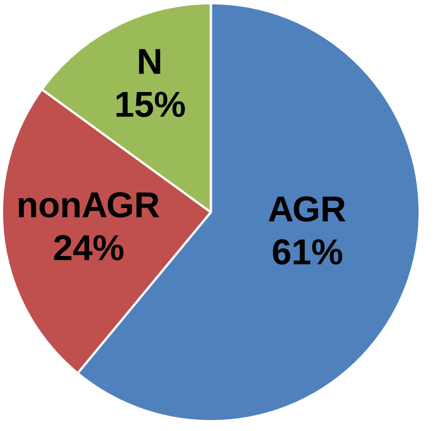
Employed bottom-up inventory: Emissions Database for Global Atmospheric Research

- 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**)

N_2O emissions in the Midwest
(EDGAR v5.0 & EDGAR v2)



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\+

Forward simulation with **WRF-Chem** + emission **inventory**

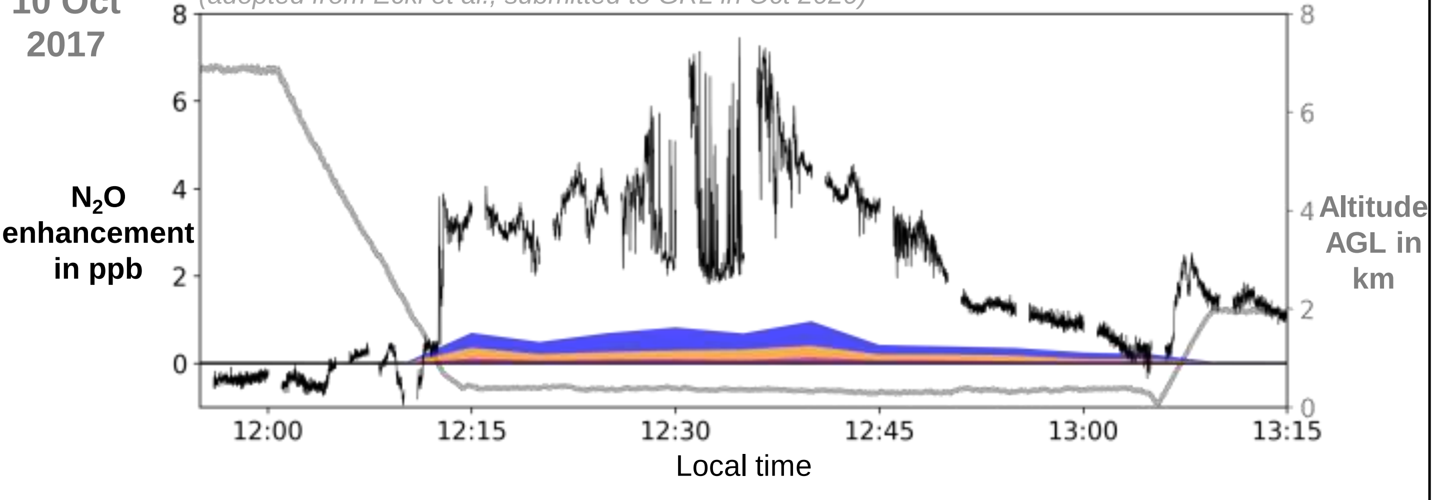
→ **Compare simulated** enhancements in the atmosphere with **measurements**

→ **Adjust inventory** so that differences between simulation and measurements are minimal

Large discrepancy between observed and simulated plume

10 Oct 2017

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



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

Adjusting the inventory by scaling agricultural emissions.

Dominant source:
Agricultural emissions

Complexity of N_2O 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

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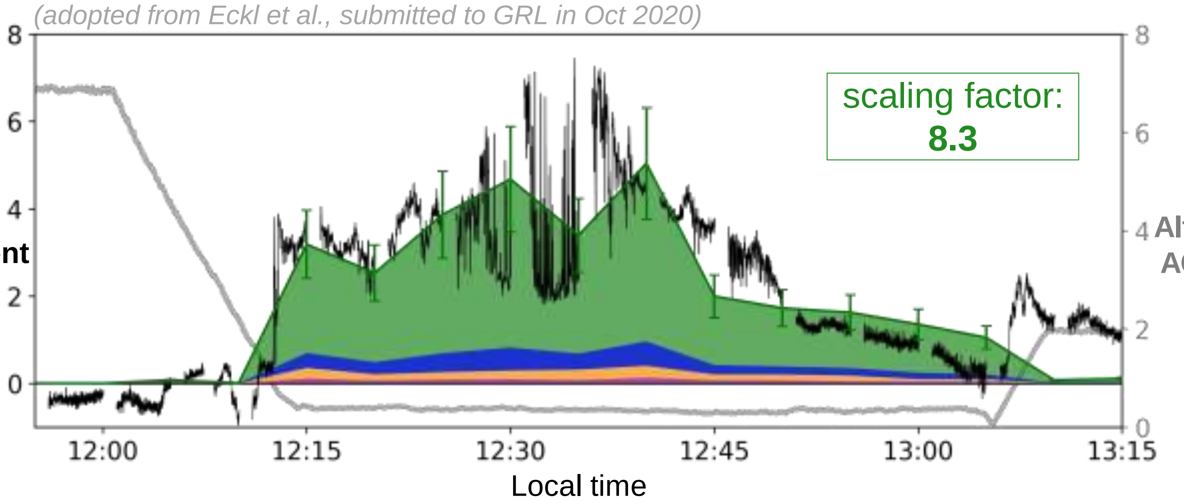


Scaled agricultural (±1σ)

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

EDGAR strongly underestimates agricultural Midwest emissions.

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

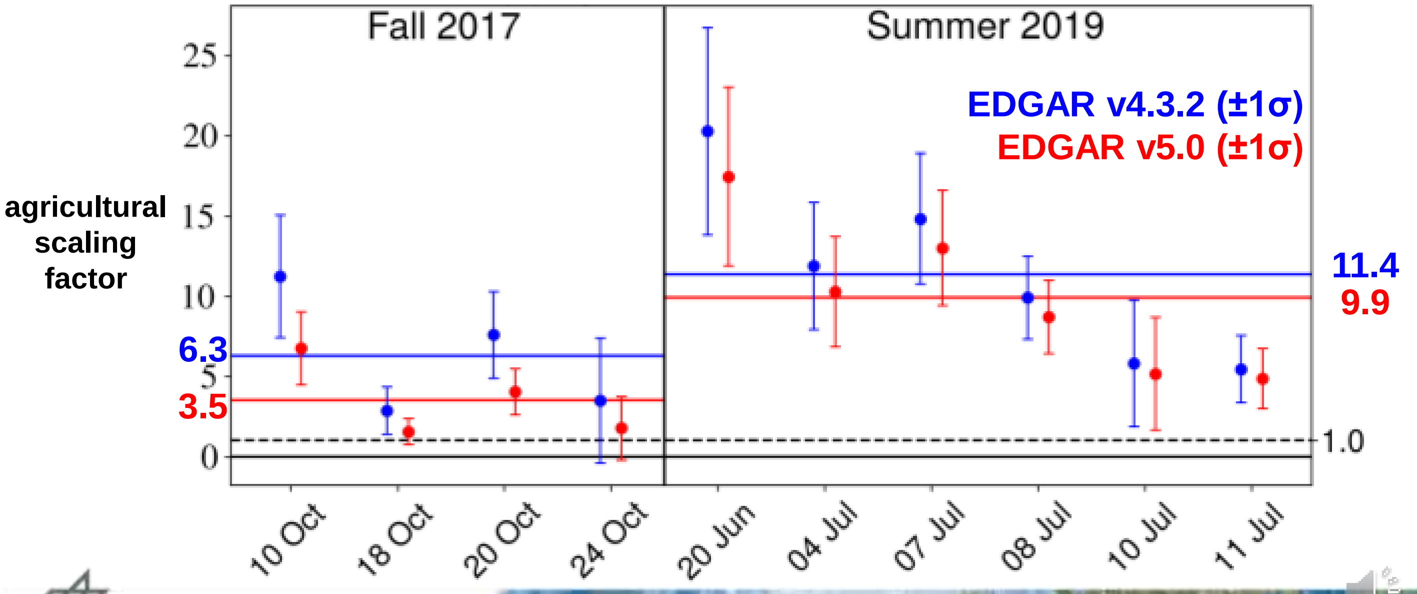
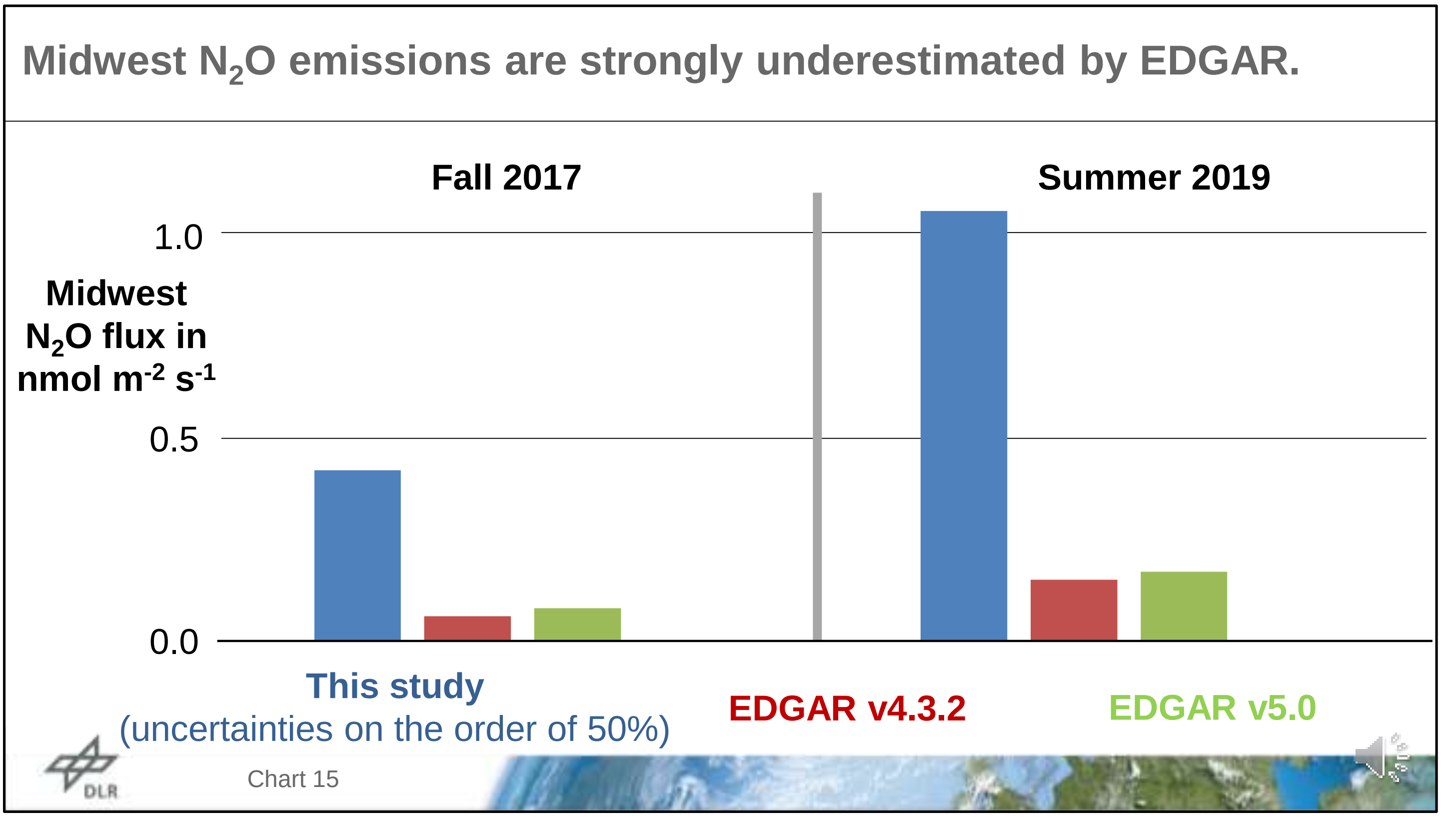


Chart 14



Midwest N2O emissions are strongly underestimated by EDGAR.
Fall 2017
Summer 2019
1.0
0.5
0.0
Midwest N2O flux in nmol m-2 s-1
This study
(uncertainties on the order of 50%)
EDGAR v4.3.2
EDGAR v5.0
DLR
Chart 15

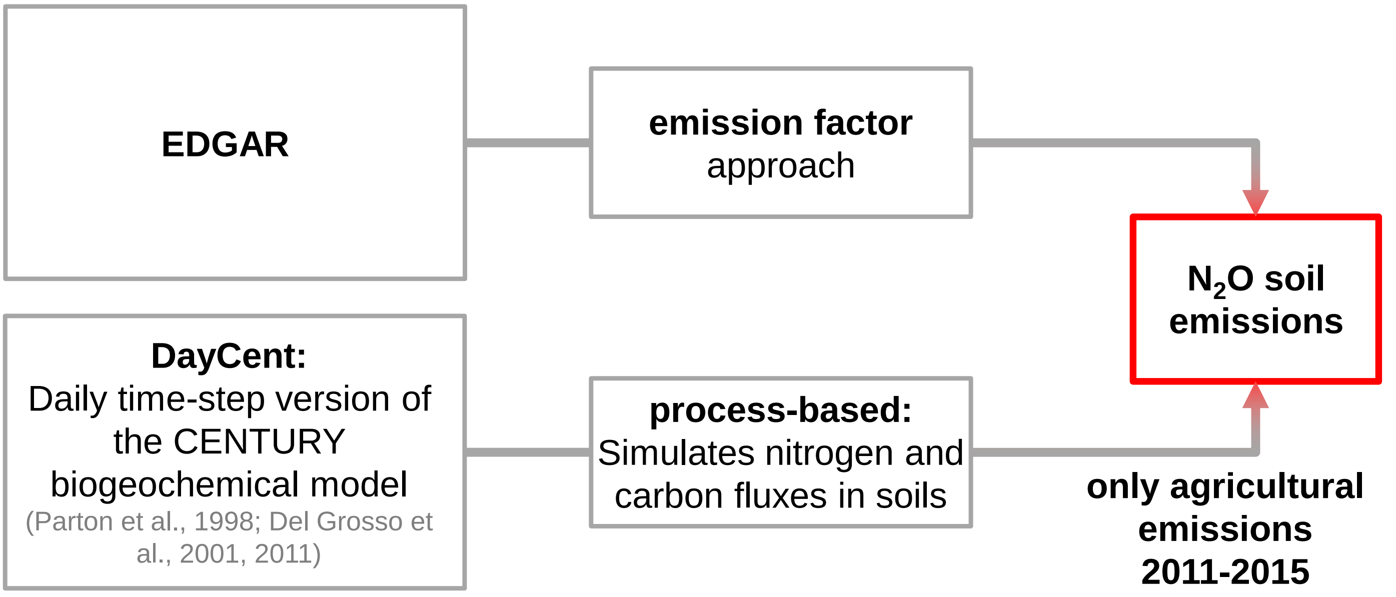
How much contributed the severe flooding event in 2019?

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

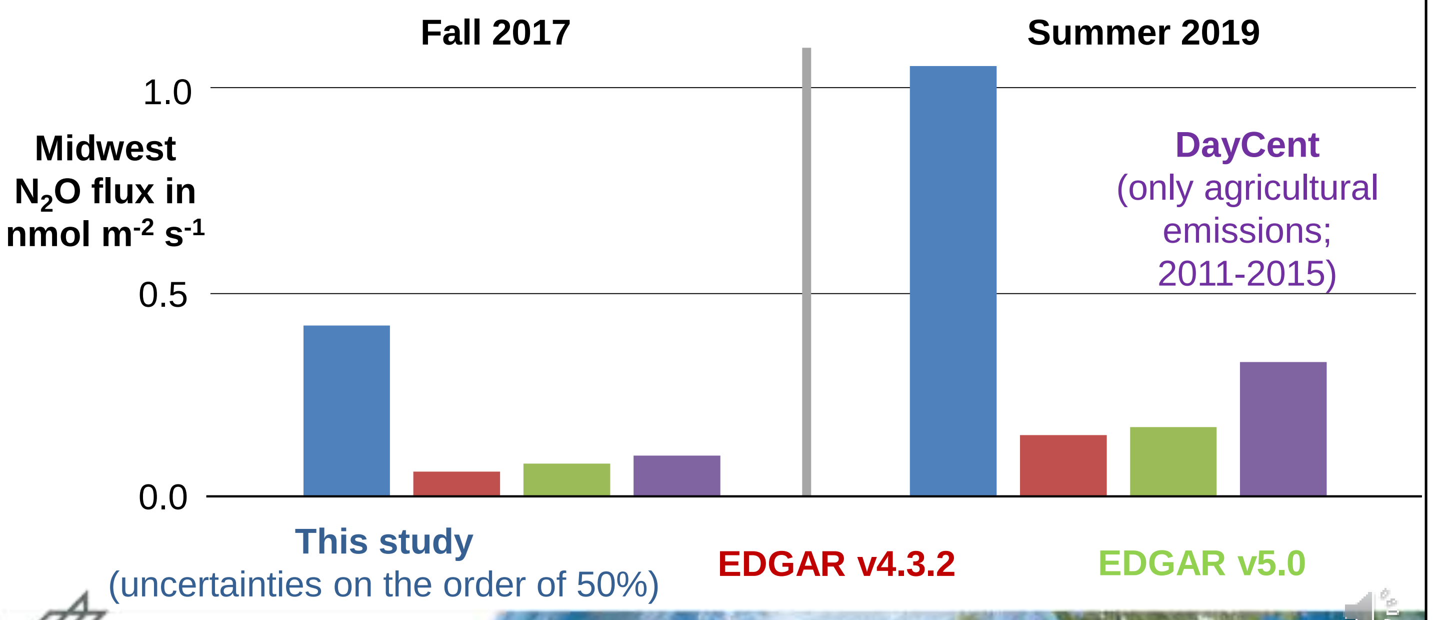
Contribution to our June/July 2019 result?!

Mississippi flooding
27 June 2019
out of C-130

DayCent provides more sophisticated bottom-up estimates than EDGAR.



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



Summary and Outlook

Average Midwest N_2O 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_2O emissions by **factors up to 20**

Historical **DayCent** Midwest N_2O 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_2O emissions in June/July**?**

↓

Study with DayCent simulations driven by these special conditions are planned

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