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

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Abstract

Nitrous oxide (N_2O), a potent greenhouse gas and ozone depleting substance, plays a crucial role in the atmosphere. Anthropogenic emissions from agriculture contribute to a rising trend in global N_2O emissions and atmospheric concentrations. However, due to insufficient direct observations, regional N_2O emissions derived in bottom-up and top-down studies are highly uncertain. The U.S. Midwest is one of the most intensive agriculture areas worldwide and hence may contribute significantly to the observed trend. Recent top-down studies suggest that bottom-up estimates underestimate agricultural emissions in that area by up to an order of magnitude. Here we quantify nitrous oxide emissions in the Midwest in October 2017 and June-July 2019 with a top-down approach. Unique continuous aircraft-based measurements of N_2O conducted during the ACT-America campaign together with forward WRF-Chem model simulations are used to scale the EDGAR inventory thus quantifying emissions. On average we had to upscale October 2017 and June-July 2019 agricultural EDGAR 4.3.2/5.0 emissions by a factor of 6.3/3.5 and 11.4/9.9, resulting in 0.42 nmol m^{-2} s^{-1} and 1.06 nmol m^{-2} s^{-1} emissions in the Midwest, respectively. Finally, calculations of direct soil N_2O emissions from the DayCent biogeochemical model are compared to our estimates.

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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:

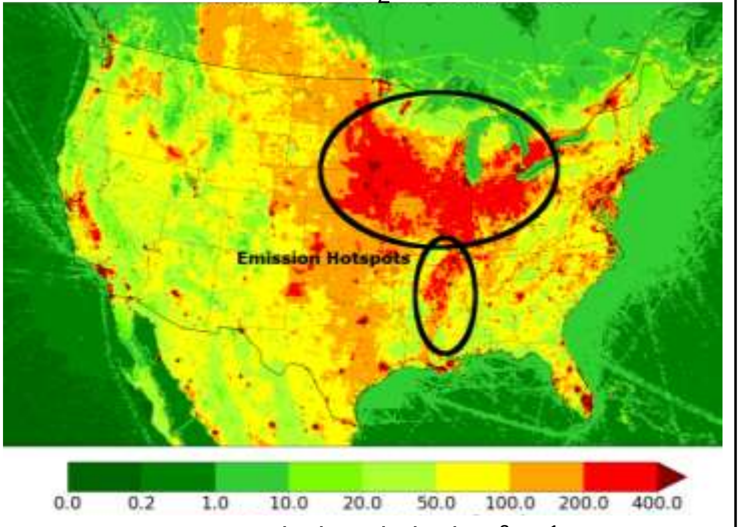
- Recent growth in emissions increased at a higher rate than expected
  (Thompson et al., 2019; Tian et al., 2020)
- Interest grows in expanding efforts to reduce emissions
  (Kanter et al., 2020)

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)

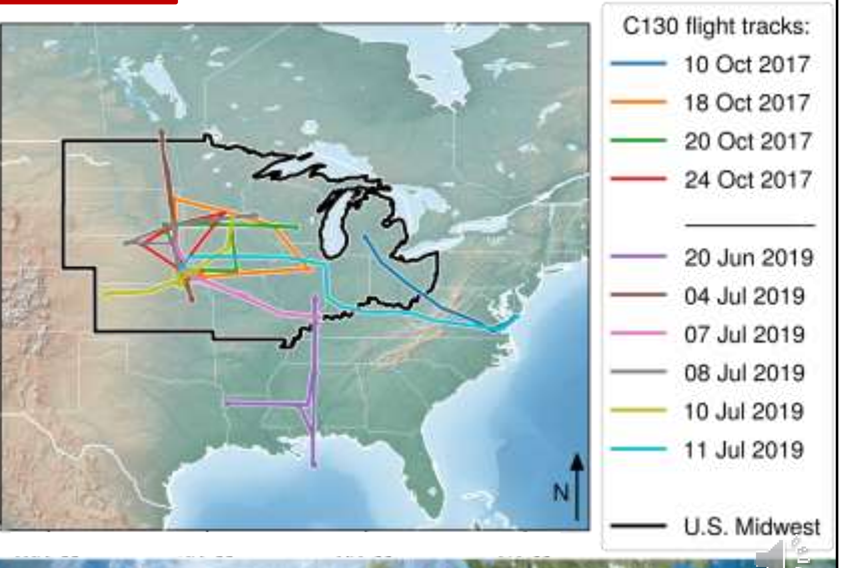
Selecting ACT-America transects over the Midwest.

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

+

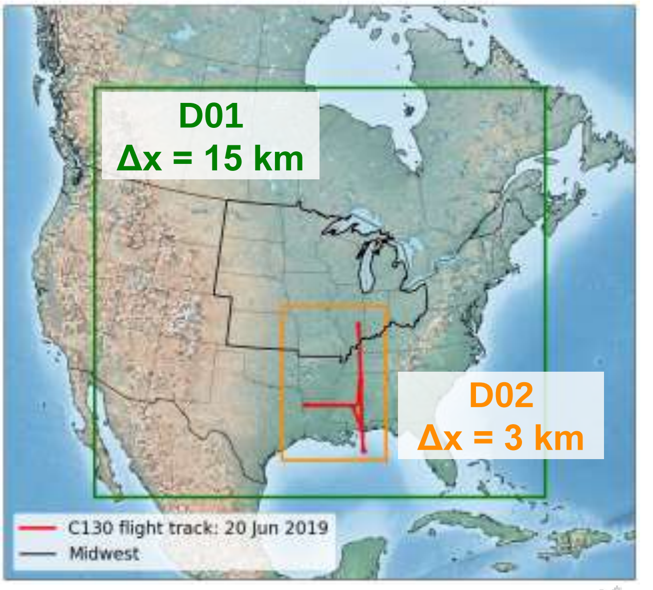
Forward simulation with **WRF-Chem**
+
emission **inventory**

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.

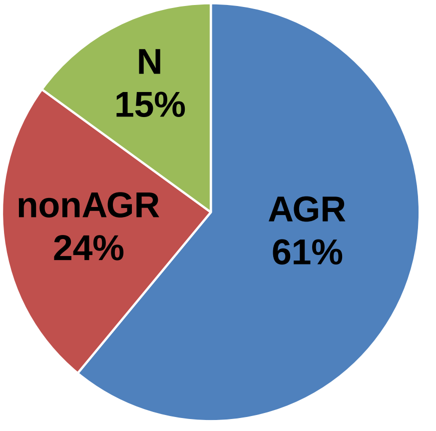
Employed bottom-up inventory: Emissions Database for Global Atmospheric Research

- 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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Airborne in situ N_2O measurements over the U.S. Midwest

+

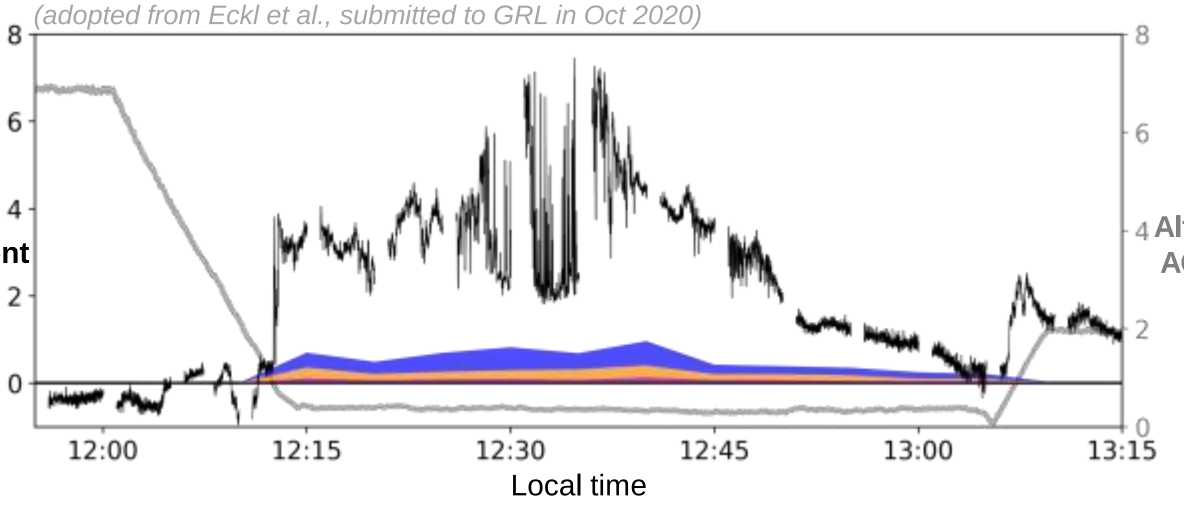
Forward simulation with **WRF-Chem** + emission **inventory**

→ **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

10 Oct 2017



Agricultural Non-agricultural anthropogenic Natural

Adjusting the inventory by scaling agricultural emissions.

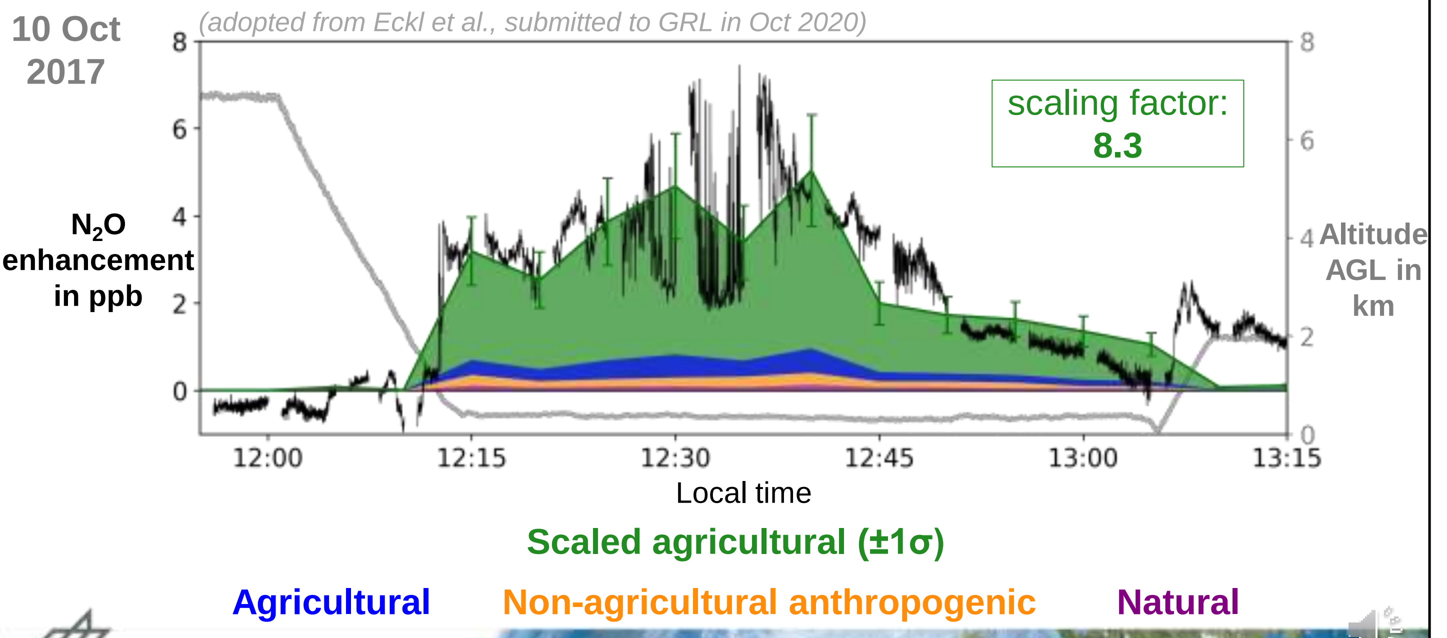
Dominant source:
Agricultural emissions

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

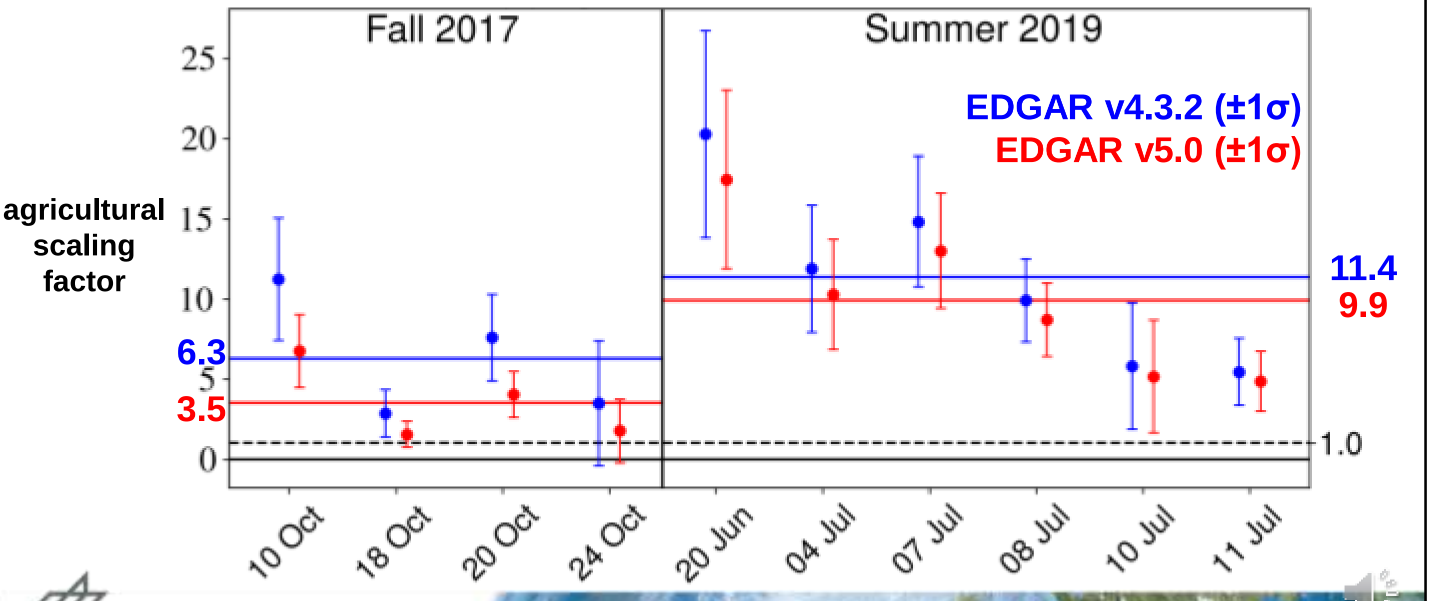
Adjust inventory by **scaling agricultural** emissions

Scaling agricultural emissions minimizes the discrepancy.

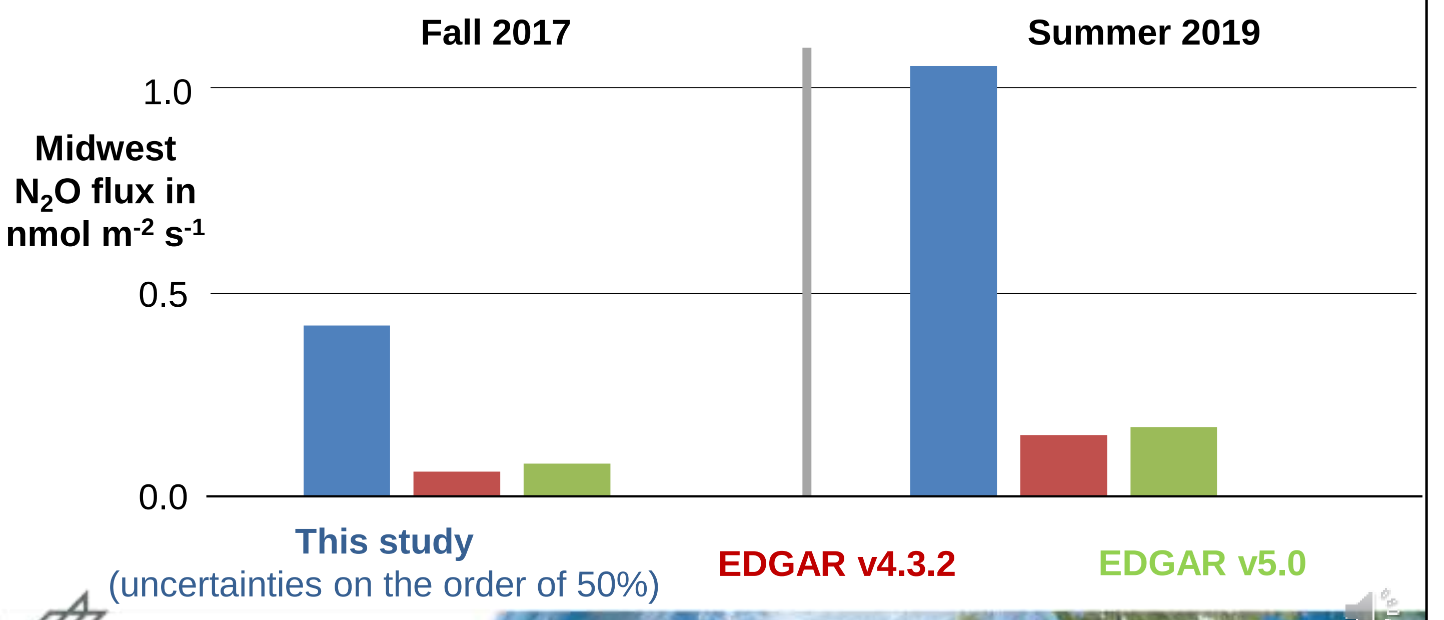


EDGAR strongly underestimates agricultural Midwest emissions.

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



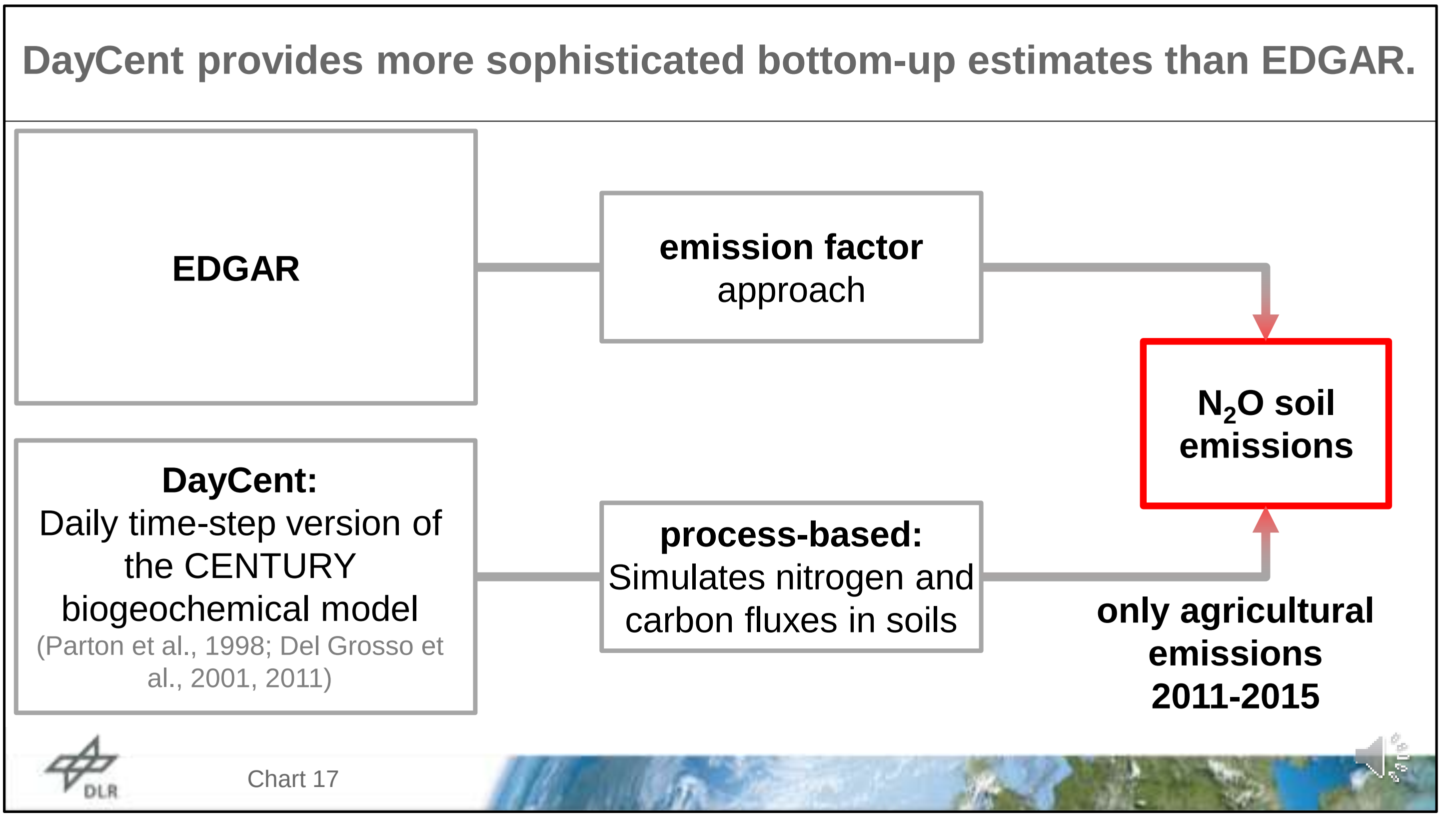
Midwest N_2O emissions are strongly underestimated by EDGAR.



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
emission factor approach
N₂O soil emissions
DayCent:
Daily time-step version of the CENTURY biogeochemical model
(Parton et al., 1998; Del Grosso et al., 2001, 2011)
process-based:
Simulates nitrogen and carbon fluxes in soils
only agricultural emissions 2011-2015
DLR
Chart 17

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

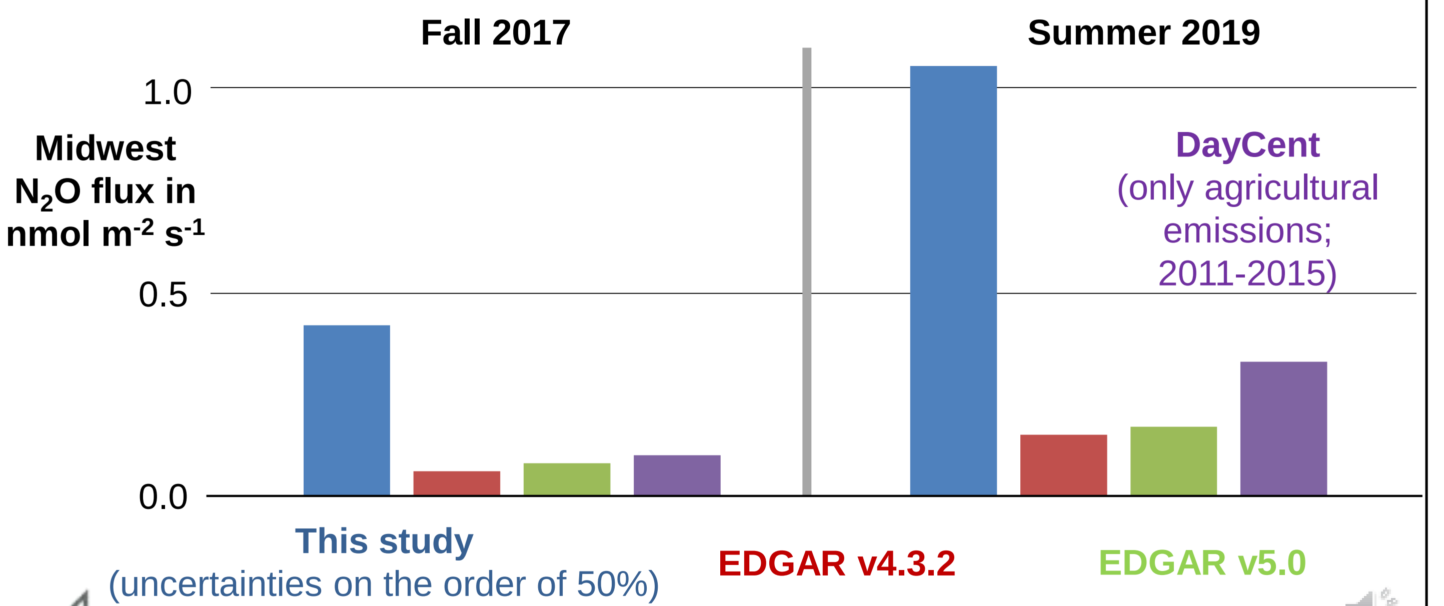


Chart 18

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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