Quantifying the Impact of Agricultural Ammonia Increases on Particulate Matter Burden over the Midwestern United States

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BACKGROUND

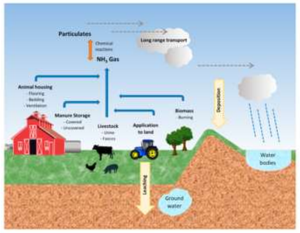

Figure 1: *Sources and routes of transport of agricultural NH_3.*[1]

- Globally, agricultural ammonia (NH_3) emissions have increased by 78% from 1980 to 2018, which can be attributed to a drastic increase in cropland and livestock emissions.[2]
- NH_3 serves as a key precursor gas in the formation of fine particulate matter ($PM_{2.5}$), and its role in $PM_{2.5}$ formation is estimated to cause 18,000 additional deaths per year in the United States.[3]
- With corn and soybeans covering a total of 75% of the region's arable land, the Midwestern United States (MWUS) is one of the world's most agriculturally intense regions and accounts for ~40% of the country's agricultural NH_3 emissions as of 2019.[4]
- Despite increasing emissions, agricultural NH_3 emissions are not federally regulated in the US, and the impact of agricultural NH_3 on downwind air quality is not well quantified.

GOAL

Here, we will determine the impact of increasing agricultural NH_3 on nitrogen deposition and the formation and chemical composition of $PM_{2.5}$ throughout the MWUS from 2007 to 2019. To do this, we utilize federal ground monitoring databases and sensitivity simulations via the 3D chemical transport model GEOS-Chem.

METHODS

We use a combination of ground monitoring data and GEOS-Chem:

- **Ammonia Monitoring Network (AMoN):** Gaseous NH_3 concentrations.[5]
- **National Trends Network (NTN) and Clean Air Status and Trends Network (CASTNET):** NH_4^+ and total N wet deposition.[6,7]
- **Interagency Monitoring of PROtected Visual Environments (IMPROVE):** $PM_{2.5}$ mass concentrations and chemical speciation.[8]
- **GEOS-Chem:** Sensitivity simulations to quantify how changes in agricultural NH_3 impact $PM_{2.5}$ mass and chemical speciation.

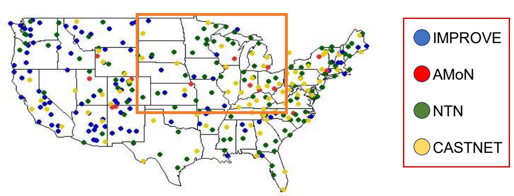

Figure 2: Locations of all ground monitoring sites with a box outlining the MWUS (2007 – 2019)

FUTURE WORK

- Investigate the impact of agricultural emissions on urban areas in the Midwest and downwind
- Investigate the impact of increasing temperatures and the urban heat island on agriculturally-influenced aerosol

RESULTS

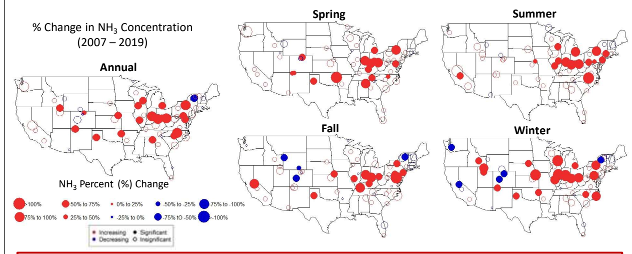

Figure 3: Annual and seasonal decadal changes (2007-2019) in gaseous NH_3 concentrations across the US. Across the MWUS, annual and seasonal NH_3 have increased by 57% on average. The largest increases occur in winter (76% on average).

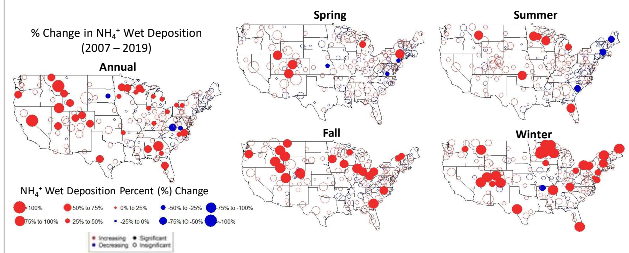

Figure 4: Annual and seasonal decadal changes (2007-2019) in NH_4^+ wet deposition across the US. Across the MWUS, annual NH_4^+ wet deposition has increased by 22% on average. The largest increases occur in winter (43% on average), and the average seasonal increase is 31%.

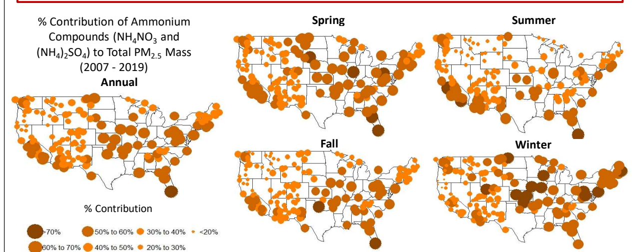

Figure 5: The percent contribution of ammonium compounds (NH_4NO_3 and $(NH_4)_2SO_4$) to total $PM_{2.5}$ mass in 2019. Across the MWUS and directly downwind, the annual percent contribution by mass of ammonium compounds to $PM_{2.5}$ exceeds 50% on average. The highest percent contribution of NH_4^+ compounds to $PM_{2.5}$ occurs during winter (>70% on average) in the MWUS.

RESULTS

Table 1: Summary of GEOS-Chem sensitivity simulation results. On average, agricultural NH_3 emissions increase $PM_{2.5}$ mass in the MWUS by 0.8 μg/m³ (13%) and increase $PM_{2.5}$ mass over the entire US by 0.6 μg/m³ (9%). This contribution has remained steady in the MWUS from 2007-2019 but has decreased across the US.

US	$PM_{2.5}$ Mass (Including Agricultural NH_3) (μg/m³)	$PM_{2.5}$ Mass (Excluding Agricultural NH_3) (μg/m³)	% Difference
2007	8.1	7.3	10.2%
2019	6.1	5.7	7.6%

MWUS	$PM_{2.5}$ Mass (Including Agricultural NH_3) (μg/m³)	$PM_{2.5}$ Mass (Excluding Agricultural NH_3) (μg/m³)	% Difference
2007	7.5	6.6	13.4%
2019	5.2	4.6	12.9%

DISCUSSION AND CONCLUSIONS

- NH_3 increased significantly from 2007 to 2019 in the MWUS (57% on average).
  - Overuse of nitrogen fertilizers is a significant contributor to the increase in agricultural NH_3. Approximately 50 kg N ha^{-1} yr^{-1} was unnecessarily applied to crops from 1980 to 2018.[2]
- NH_4^+ wet deposition increased by 22% on average from 2007 to 2019, most strongly in winter (43%).
  - The average contribution of NH_4^+ to total nitrogen wet deposition increased from 41% in 2007 to 52% in 2017.
- In 2019, the contribution of ammonium compounds (NH_4NO_3 and $(NH_4)_2SO_4$) to total $PM_{2.5}$ mass in the MWUS exceeded 50% across all seasons and surpassed 70% in spring and winter.
- Agricultural NH_3 increased $PM_{2.5}$ mass concentrations in the MWUS by ~13% on average in both 2007 and 2019 despite overall decreases in $PM_{2.5}$.
  - Increases in $PM_{2.5}$ mass attributable to NH_3 in the MWUS are 31% greater than those over the entire US in 2007, and this difference rose to 70% in 2019.
- This analysis suggests that increases in agricultural NH_3 emissions have widespread impacts on nitrogen deposition, particle chemistry, and particle mass concentrations.
  - This work joins the growing body of literature recommending the reduction of NH_3 emissions to benefit public health.

REFERENCES

1. Wyer et al., *Journal of Environmental Management*, 2022.
2. Liu et al., *Proc. Natl. Acad. Sci. U.S.A.*, 2022.
3. Domingo et al., *Proc. Natl. Acad. Sci. U.S.A.*, 2021.
4. U.S. Climate Resilience Toolkit, 2019.
5. National Atmospheric Deposition Program. Ammonia Monitoring Network. Accessed: 17 May 2023. https://nadp.slh.wisc.edu/networks/ammonia-monitoring-network/.
6. National Atmospheric Deposition Program. National Trends Network. Accessed: 22 May 2023. https://nadp.slh.wisc.edu/networks/ammonia-monitoring-network/.
7. United States Environmental Protection Agency. Clean Air Status and Trends Network. Accessed: 23 May 2023. https://gaftp.epa.gov/castnet/CASTNET_Outgoing/data/.
8. Colorado State University. Interagency Monitoring of Protected Visual Environments. Accessed: 11 July 2023. https://vista.cira.colostate.edu/Improve/improve-data/.

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