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https://research.umkc.edu/atmoschem/

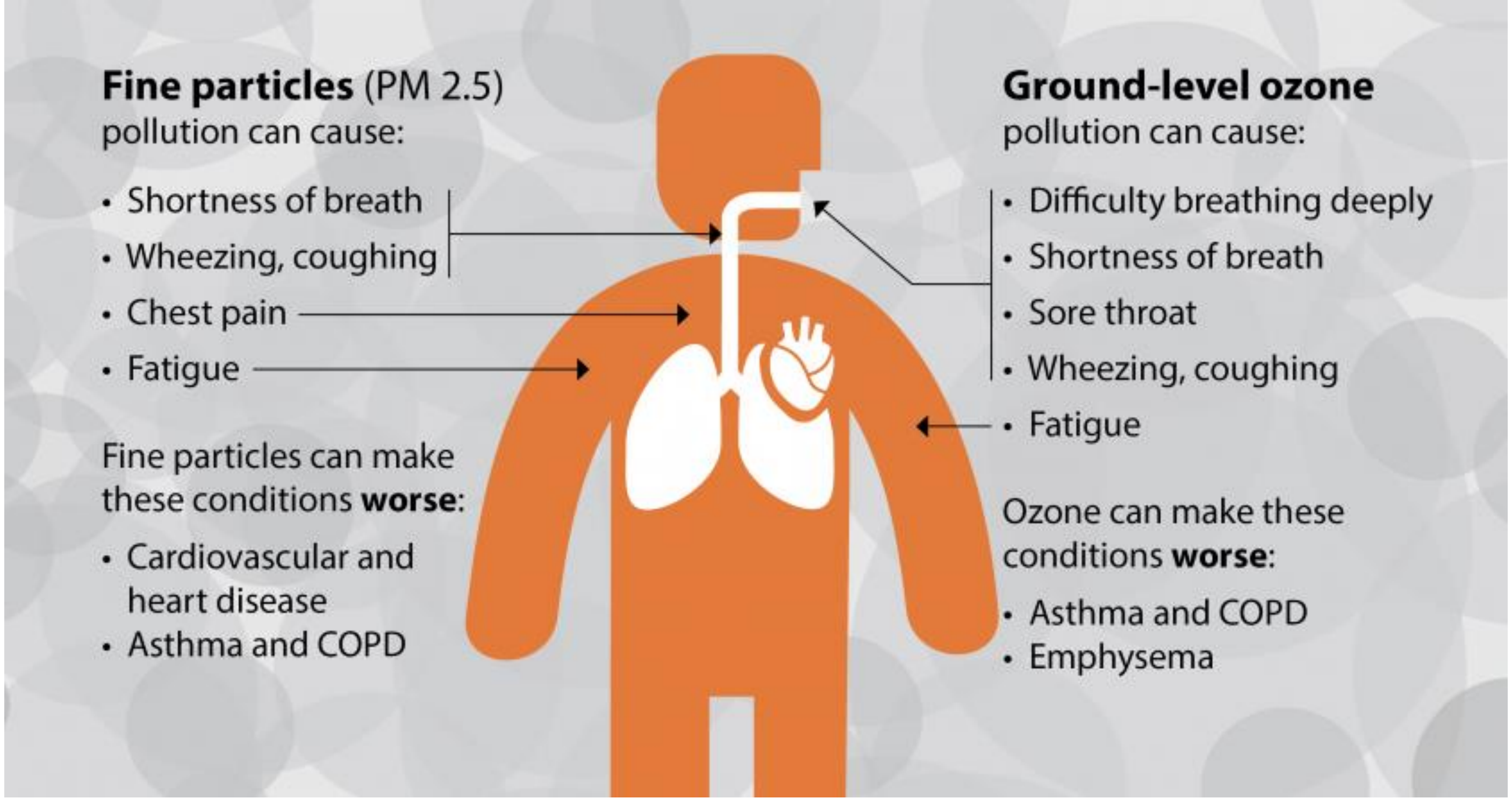
UMKC

From Farm to City:
Multi-Scale Atmospheric Chemistry Relevant to Midwestern Air Quality

Amy Christiansen, PhD
Toan Vo, Shreeram Ojha (graduate students), Dr. Luke Monroe (postdoc)

April 15, 2026

~7 million deaths linked to air pollution globally
4th-ranking mortality risk factor worldwide



https://www.pca.state.mn.us/air/why-you-should-care-air-quality-and-health
https://time.com/4167351/beijing-air-quality-pollution/
https://www.bbc.com/news/world-asia-india-58405479
EPA: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics

Clean Air Act

Introduced in 1970

- Environmental Protection Agency (EPA) formed in 1970 to implement requirements from this Act

Major revisions in 1977 and 1990

Requires EPA to establish **national ambient air quality standards (NAAQS)** based on latest science

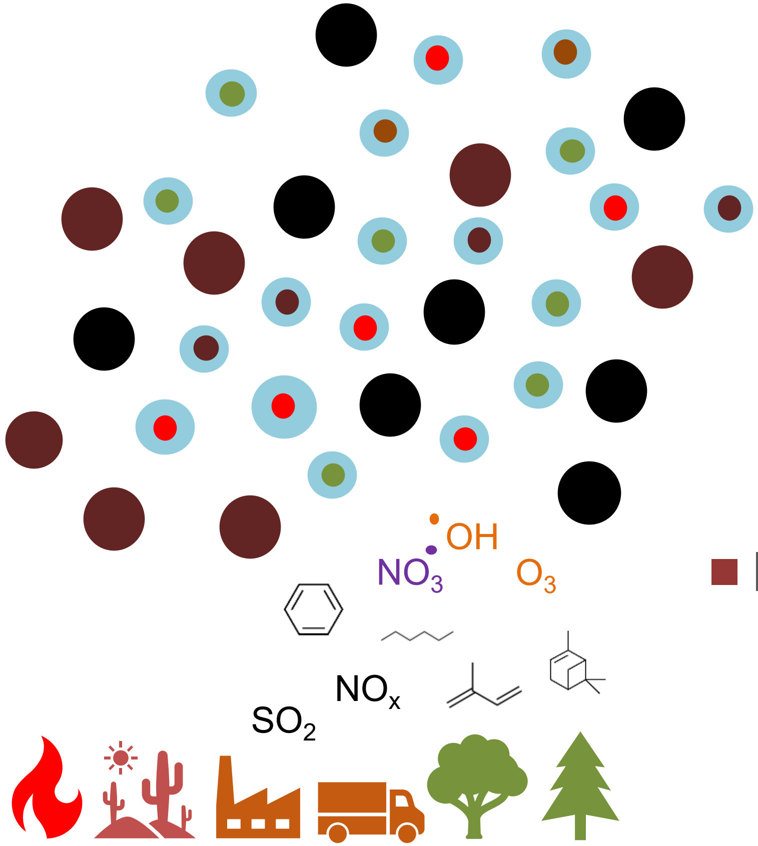
States must adopt enforceable plans to achieve and maintain air quality meeting these standards, and they must control emissions that drift across state lines

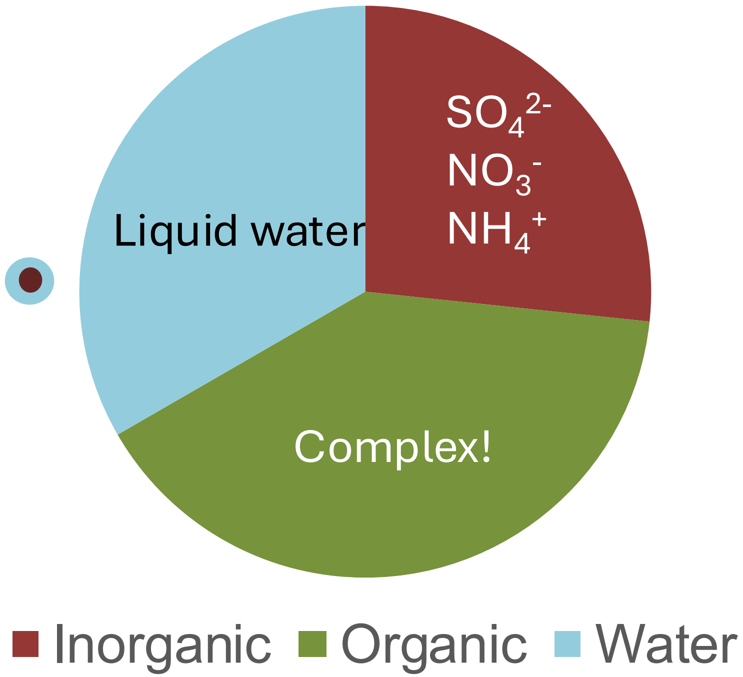
Also regulates vehicles, power plants, factories

Pollutant [links to historical tables of NAAQS reviews]		Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide (CO)		primary	8 hours	9 ppm	Not to be exceeded more than once per year
			1 hour	35 ppm	
Lead (Pb)		primary and secondary	Rolling 3 month average	0.15 $\mu g/m^3$ [1]	maximum arithmetic mean of 3 consecutive monthly means in a 3-year period
Nitrogen Dioxide (NO_2)		primary	1 hour	100 ppb	Annual 98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		primary and secondary	1 year	53 ppb [2]	Annual Mean
Ozone (O_3)		primary and secondary	8 hours	0.070 ppm [3]	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle Pollution (PM)	$PM_{2.5}$	primary	1 year	9.0 $\mu g/m^3$	annual mean, averaged over 3 years
		secondary	1 year	15.0 $\mu g/m^3$	annual mean, averaged over 3 years
		primary and secondary	24 hours	35 $\mu g/m^3$	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24 hours	150 $\mu g/m^3$	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		primary	1 hour	75 ppb [4]	Annual 99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	1 year	10 ppb	annual mean, averaged over 3 years

What is particulate matter (PM)?

- Small solid or liquid particles that are suspended in air
- Primary and secondary sources
  - Primary: Dust, sea spray, soot **(larger, PM_{10})**
  - Secondary: Oxidation of gas-phase precursor species **(smaller, $PM_{2.5}$)**
- Composed of complex chemical matrix





New Particle Formation

- Spontaneous condensation of vapors (homogeneous nucleation) unlikely due to Kelvin effect (vapor pressure increases drastically on a curved surface)
- Nucleation involves condensation onto pre-existing clusters of molecules (heterogeneous nucleation)
- Acid-base reactions dominate

$$H_2SO_{4(aq)} + 2NH_{3(g)} \rightarrow (NH_4)_2SO_{4(aq)}$$

$$HNO_{3(aq)} + NH_{3(g)} \rightarrow NH_4NO_{3(aq)} \text{ (if ammonia is in excess)}$$

- Condensation of other vapors onto existing particle
  - Organics dominate

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Requires EPA
ambient air q
based on late

Impact of Ammonia??

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Particle Pollution (PM)	$PM_{2.5}$	primary	1 year	$9.0\ \mu g/m^3$	annual mean, averaged over 3 years
		secondary	1 year	$15.0\ \mu g/m^3$	annual mean, averaged over 3 years
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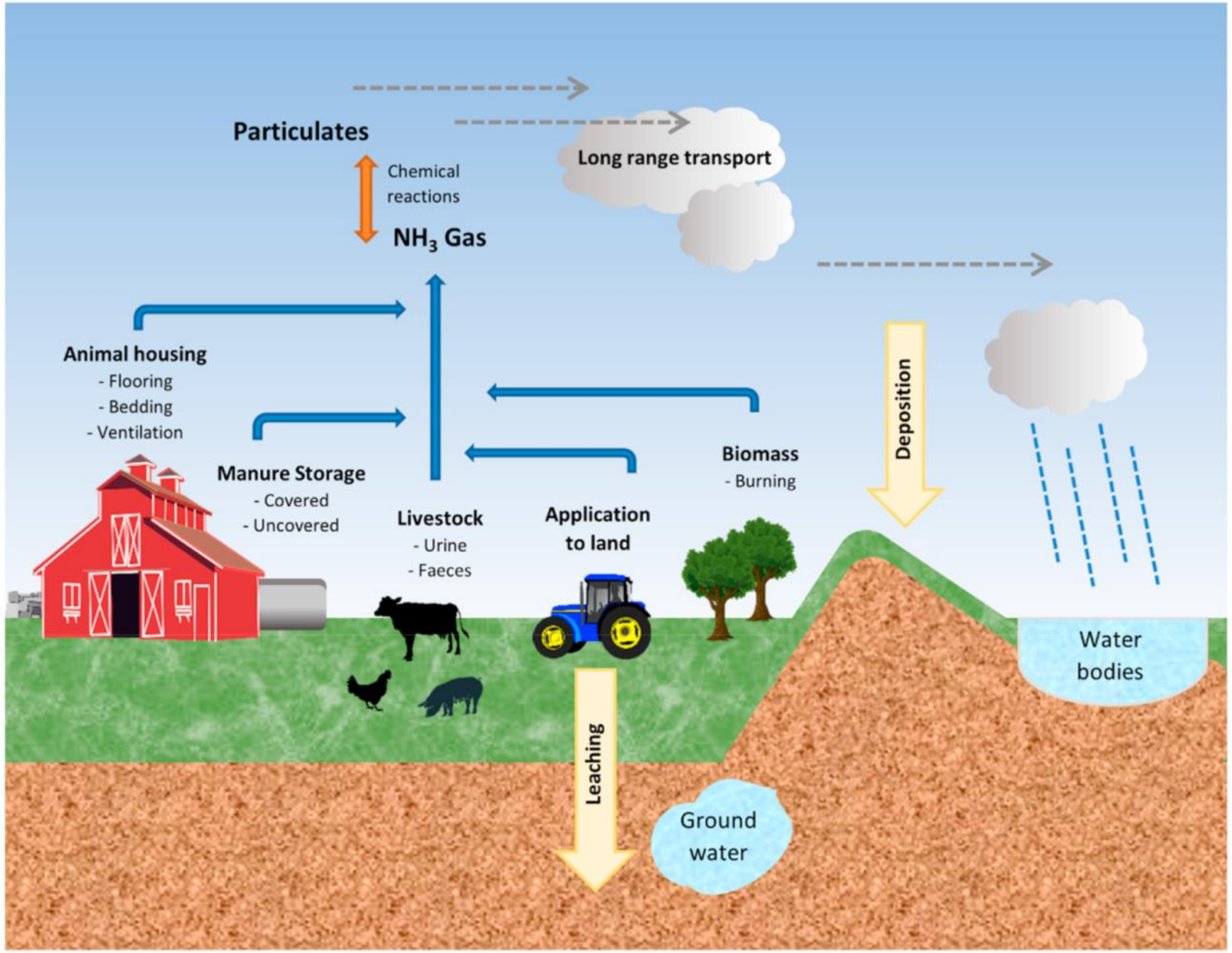
Sulfur Dioxide (SO_2)		primary	1 hour	75 ppb (4)	Annual 99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	1 year	10 ppb	annual mean, averaged over 3 years

Agricultural Emissions



- Globally, agricultural ammonia (NH_3) emissions have increased by 78% from 1980 to 2018
  - ~50% over Midwestern United States since 2001
- 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
- NH_3 serves as a key precursor gas in the formation of fine particulate matter ($PM_{2.5}$)
- Agricultural NH_3 emissions are not regulated in the US through the Clean Air Act, and the impact of agricultural NH_3 on downwind air quality is not well quantified
- **Goal: Determine the impact of increasing agricultural NH_3 on the formation of $PM_{2.5}$ throughout the MWUS from 2007 to 2019**

Outline

How have agricultural emissions impacted Midwestern air quality?

1) **Agricultural NH_3 increases $PM_{2.5}$ burden in the Midwest disproportionately compared to the contiguous US (CONUS)**

How have the chemical driving factors behind particulate nitrate formation changed over time? Can this be used to find the optimal method for controlling $PM_{2.5}$ burden?

GEOS-Chem

Emissions

Meteorology

Concentrations

Simulations	Standard	AgrOFF	NH32007	Met2007
Emissions	All emissions included	Excluded agricultural NH_3 emissions	Held agricultural NH_3 emissions constant at 2007 values	All emissions included
Meteorology	Standard meteorology	Standard meteorology	Standard meteorology	Held meteorology constant at 2007 values

Transport

Chemistry

$$\frac{\partial n_i}{\partial t} = -\nabla\cdot(n_i\mathbf{U}) + P_i - L_i$$

local trend in concentration

transport (flux divergence)

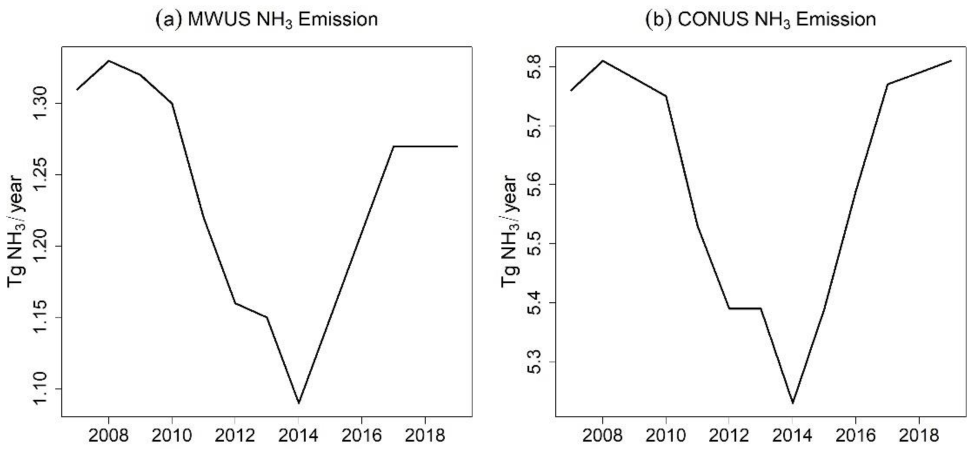
emissions, deposition, chemical and aerosol processes

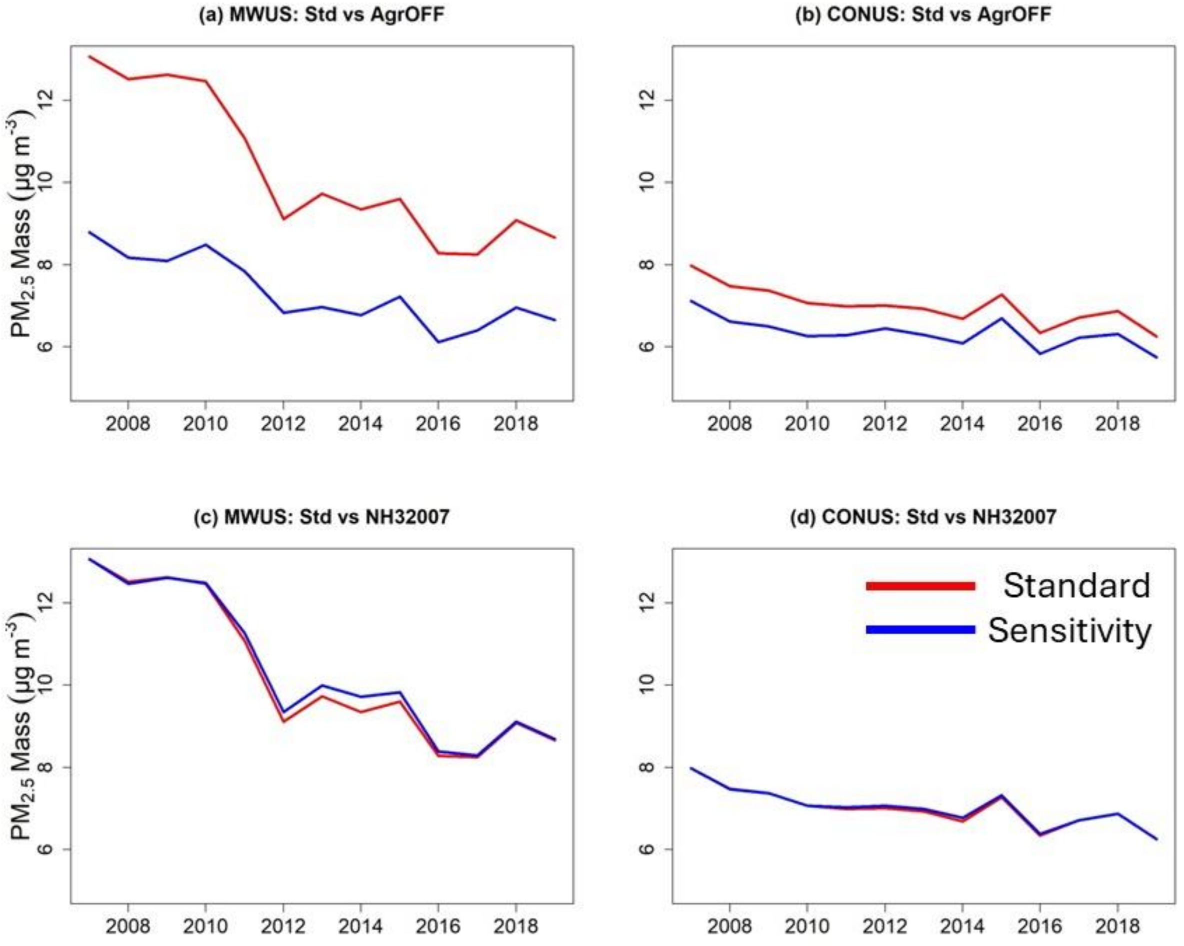
Vo and Christiansen, *ACS Earth Space Chem.*, 2024

Agricultural NH_3 Leads to Higher $PM_{2.5}$ Burden in MWUS than over CONUS

- When agricultural emissions turned off (AgrOFF)
  - CONUS $PM_{2.5}$ decreases by 9% (sensitivity decreases (Std – AgrOFF))
  - MWUS $PM_{2.5}$ decreases by 29%
  - Agricultural NH_3 contributes 10% to CONUS $PM_{2.5}$, but 40% to MWUS $PM_{2.5}$

- When NH_3 held constant at 2007 values (NH32007):
  - Sensitivity of $PM_{2.5}$ to NH_3 trend differs
  - MWUS peak to trough: 3.7% decrease
  - CONUS peak to trough: 0.5% decrease
  - Reducing NH_3 to 2014 levels results in a savings of 0.4 μg m^{-3} in the MWUS, but only 0.1 μg m^{-3} over the CONUS





Vo and Christiansen, *ACS Earth Space Chem.*, 2024

Read more!
Vo and Christiansen, *ACS Earth Space Chem.*, 2024

Summary

- Agricultural NH_3 hinders air quality improvement efforts in the MWUS
- $PM_{2.5}$ is disproportionately higher in the MWUS compared to the CONUS, and observations and models suggest that agricultural NH_3 is behind this discrepancy
  - Largest impacts occur in winter
- GEOS-Chem simulations suggest that $PM_{2.5}$ burden could be lowered by 0.4 $\mu g\ m^{-3}$ (3.5%) in the MWUS through reductions in NH_3 emissions to 2014 levels (20% decrease in emissions)
- Continued increases in agricultural NH_3 are a public health concern, and NH_3 should be regulated as a criteria pollutant

Outline

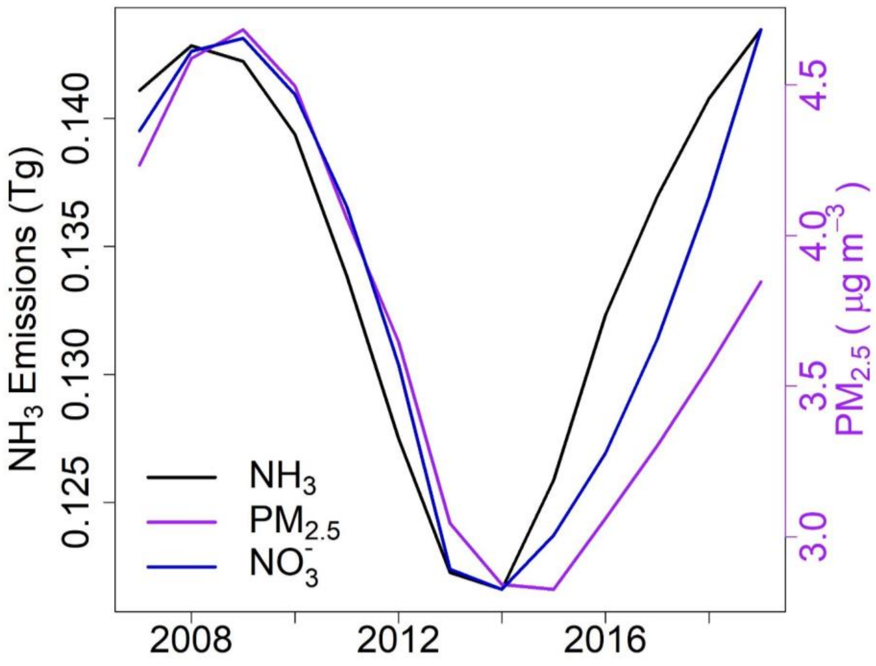
How have agricultural emissions impacted Midwestern air quality?

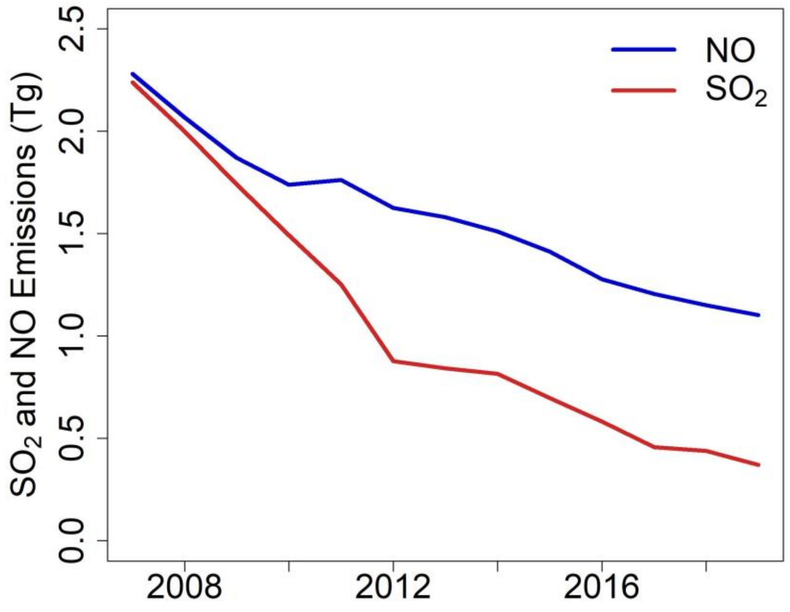
1) Agricultural NH_3 increases $PM_{2.5}$ burden in the Midwest disproportionately compared to the CONUS

How have the chemical driving factors behind particulate nitrate (PN) formation changed over time? Can this be used to find the optimal method for controlling $PM_{2.5}$ burden?

1) **Wintertime particulate nitrate formation has become more sensitive to nitrogen oxides over time.**
2) **Thus, controlling nitrogen oxide emissions will best control $PM_{2.5}$ burden.**

Wintertime NH_3 Emissions Increases Coincide with Increases in $PM_{2.5}$ and Nitrate

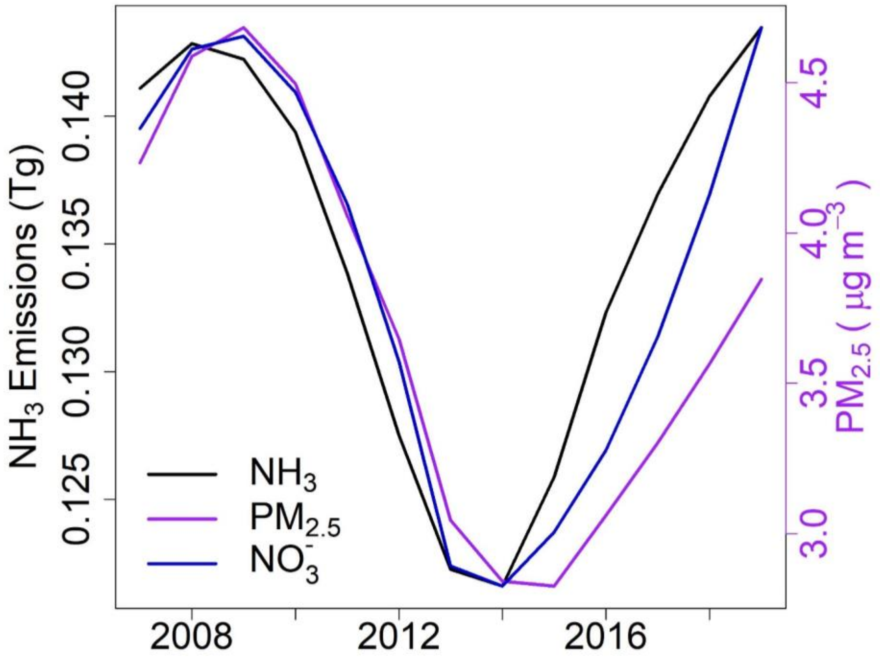


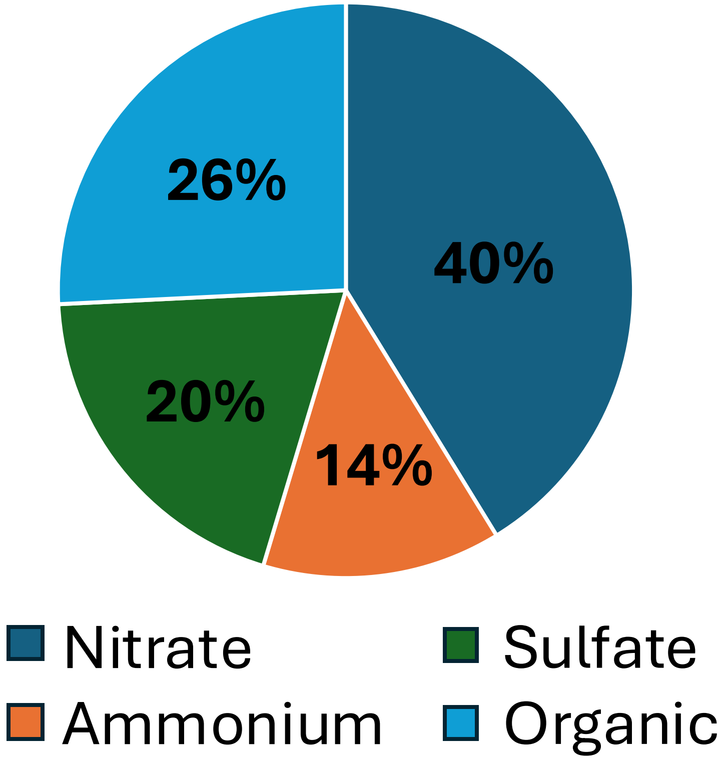


- Prior to 2014, $PM_{2.5}$ and NO_3^- from IMPROVE network show decrease in concentrations
- After 2014, $PM_{2.5}$ and NO_3^- trends begin to reverse
  - Trend only exists in winter, when semi-volatile NO_3^- is most thermodynamically stable in the particle
- Reversal of NO_3^- and $PM_{2.5}$ trend may be caused by increase in NH_3 emissions
  - Not from NO or SO_2!

Vo and Christiansen, *ACS Earth Space Chem.*, 2024

Controlling Wintertime PN is Critical to Reducing $PM_{2.5}$ Burden over the MWUS

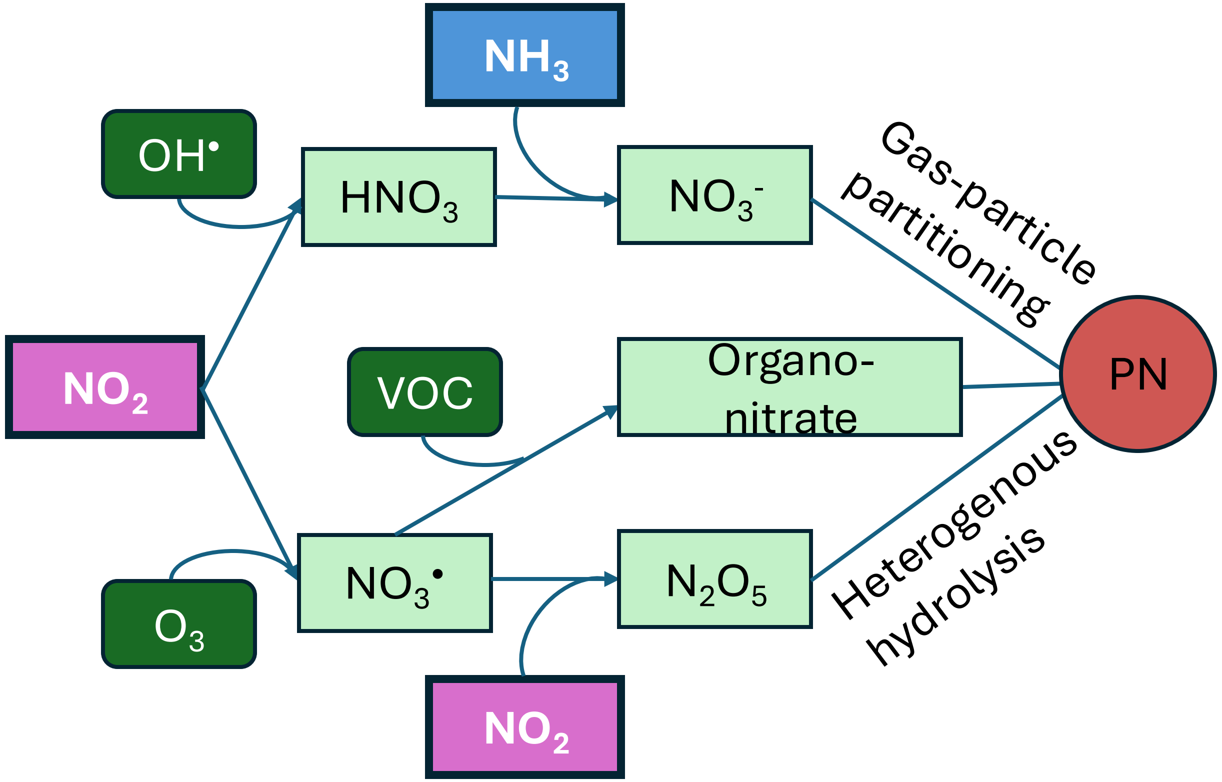




PN drives many pollution events and controls water uptake processes

Impacting human health, weather and climate

PN Formation Sensitivity



PN formation is sensitive to whichever gas is the limiting reagent (**NO_x, NH_3, or VOC**)

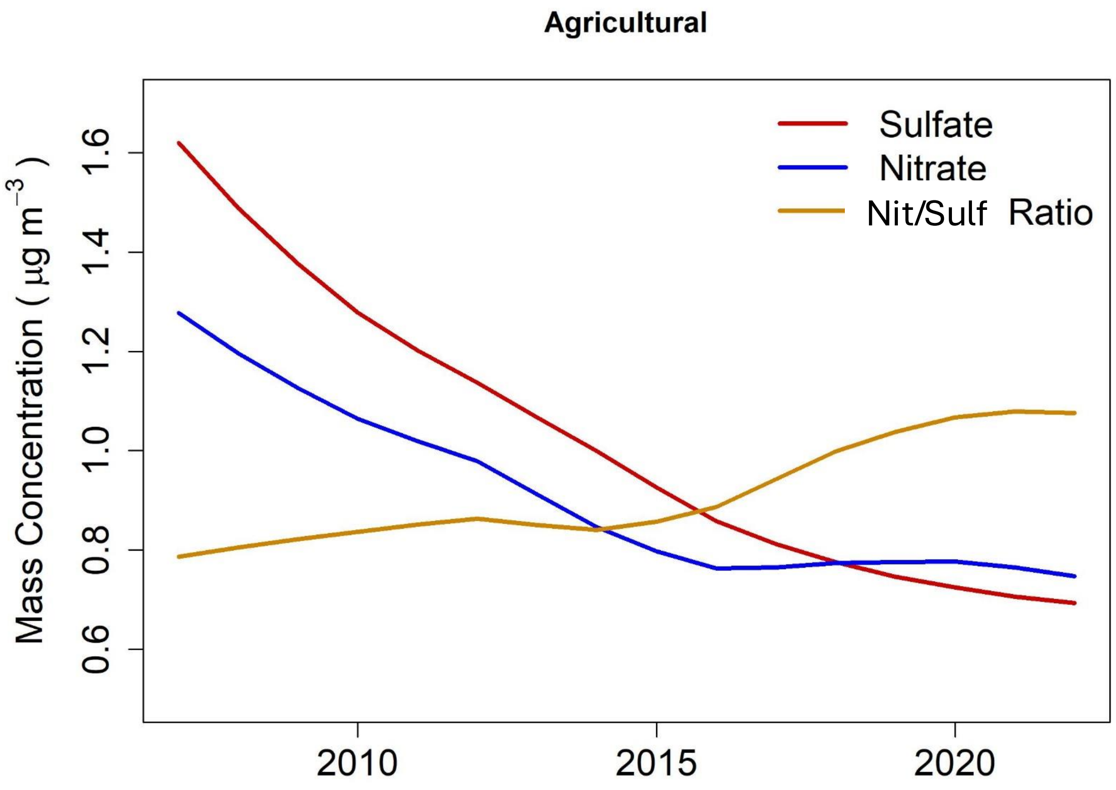
Previous methods in diagnosing PN sensitivity are highly uncertain and computationally intensive

Satellite observations can overcome the limitations

Goal

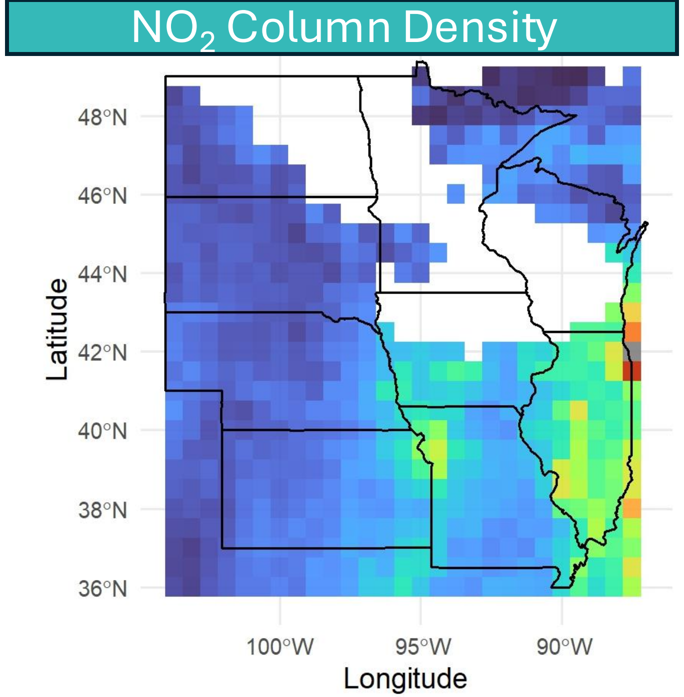
Quantify the changing sensitivity of wintertime PN to NH_3, NO_x, and VOCs over the MWUS from 2007 to 2023 using satellite observations, ground monitoring data, and model simulations.

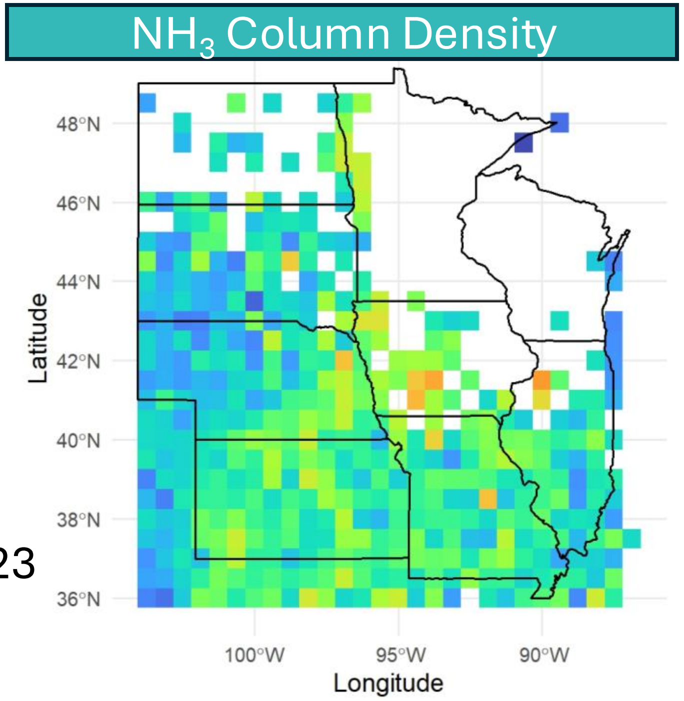
Understanding the sensitivity of PN formation in winter over the MWUS provides insights to the most effective $PM_{2.5}$ mitigation strategy.



Diagnosing Wintertime PN Sensitivity

- Satellite retrievals for NO_2 and NH_3 column densities (2007-2023)
  - Ozone Monitoring Instrument (OMI) and Infrared Atmospheric Sounding Interferometer (IASI)
- Averaged to a 0.5° x 0.625° resolution to match GEOS-Chem simulations
- Calculated satellite tropospheric column NH_3/NO_2 ratios





Dang et al., *Geophys. Res. Lett.*, 2023
Dang et al., *Env. Sci. Technol.*, 2024
Vo and Christiansen, ACPD, 2026

Diagnosing Wintertime PN Sensitivity

GEOS-Chem sensitivity simulations

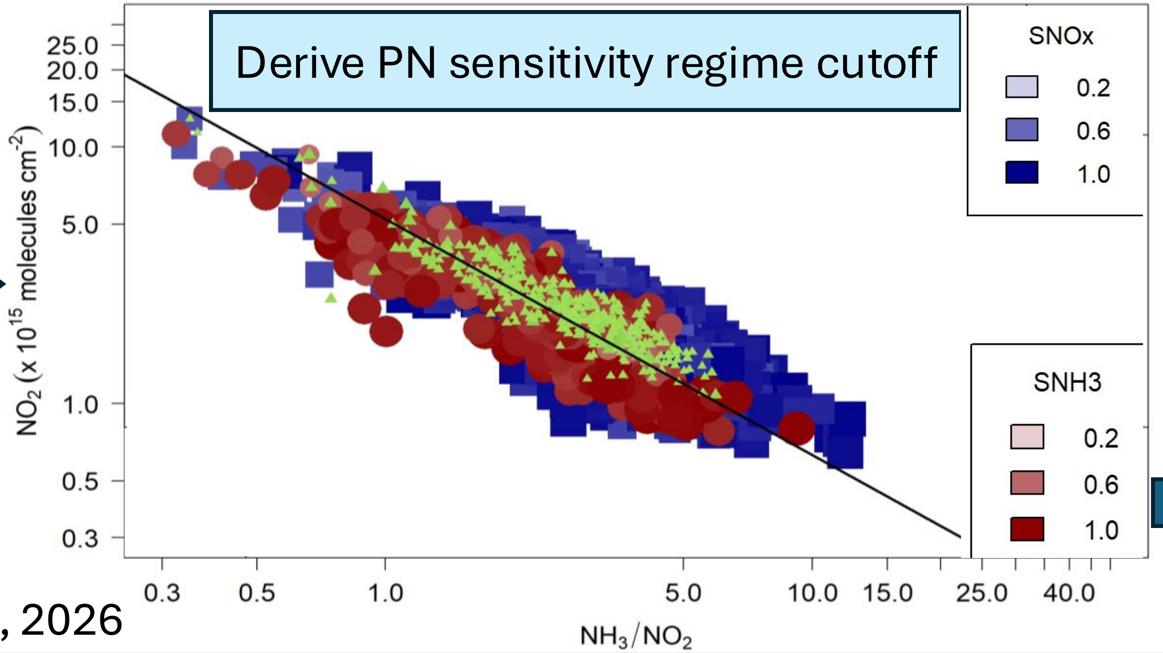
Simulation	NOx	NH_3	VOCs
Base	Normal	Normal	Normal
NOx Sensitivity	-20%	Normal	Normal
NH_3 Sensitivity	Normal	-20%	Normal
VOC Sensitivity	Normal	Normal	-20%

$$S_i = \frac{\Delta \log(PN)}{\Delta \log(E_i)}$$

Reduced-major-axis regression

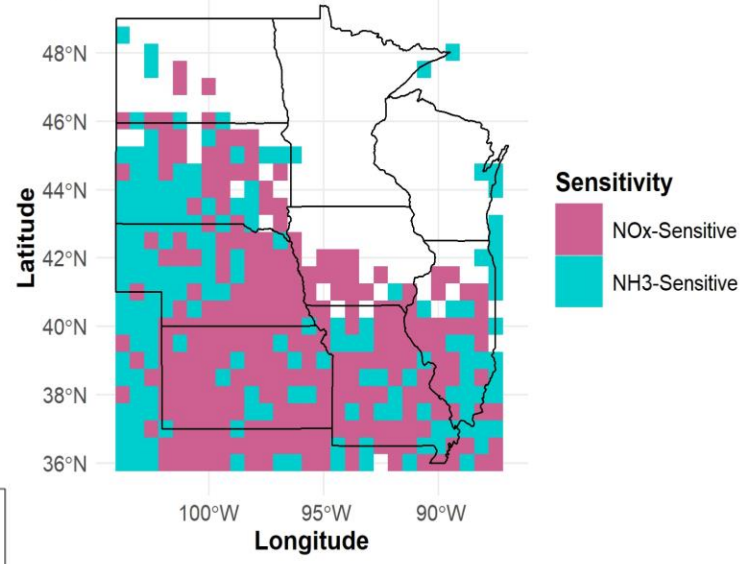
Sensitivity calculation

Derive PN sensitivity regime cutoff

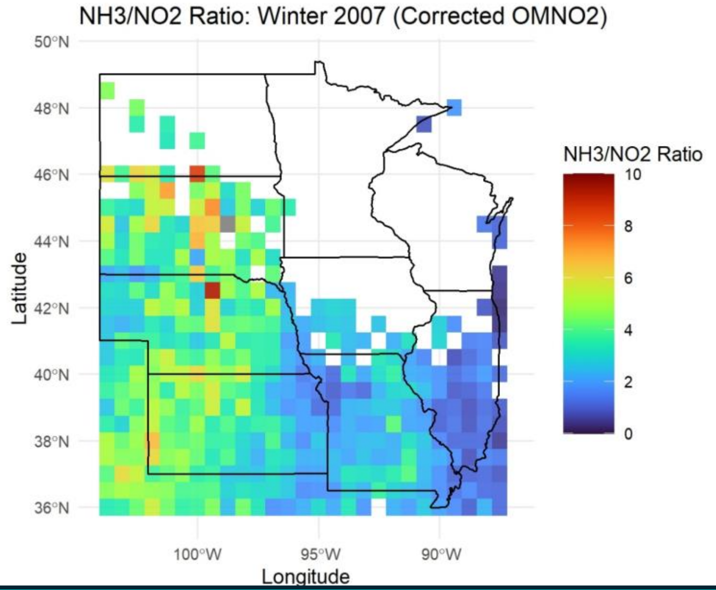


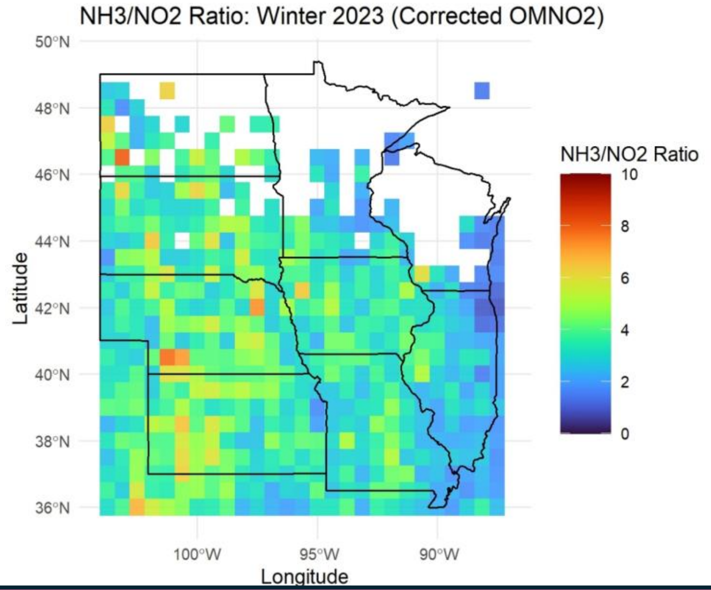
Apply satellite NH_3/NO_2 ratio

PN Sensitivity Regime



Vo and Christiansen, ACPD, 2026





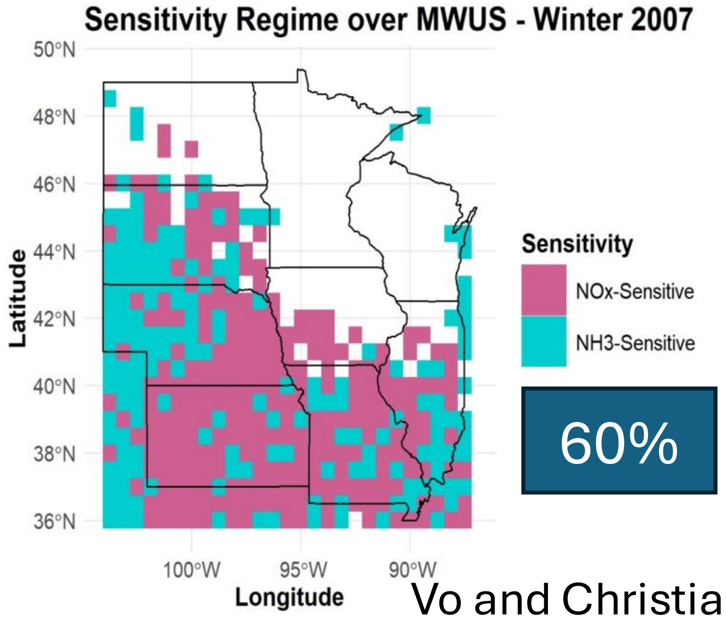
PN sensitivity over the MWUS has shifted to a predominantly NO_X-sensitive regime.

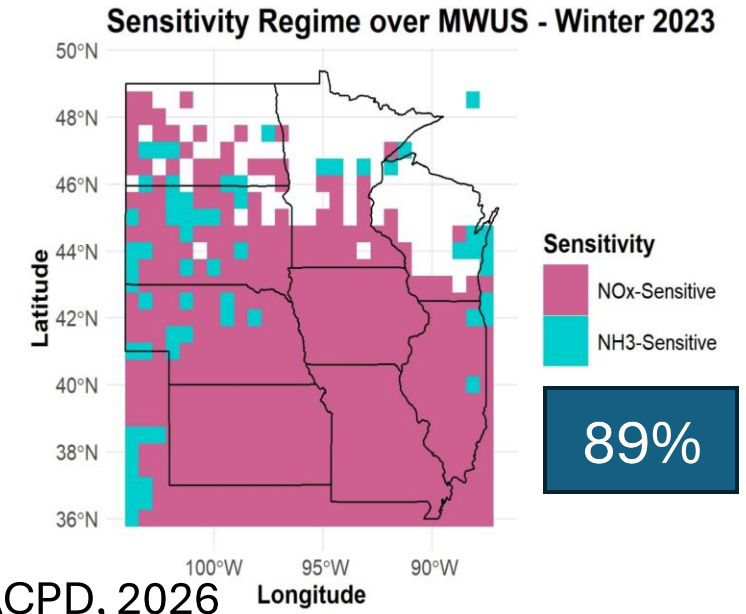
For NH_3 − sensitive regime:

$$\log\left(\frac{NH_3}{NO_2}\right) < 0.72 - 0.92 \times \log(NO_2)$$

For NO_x − sensitive regime:

$$\log\left(\frac{NH_3}{NO_2}\right) > 0.72 - 0.92 \times \log(NO_2)$$

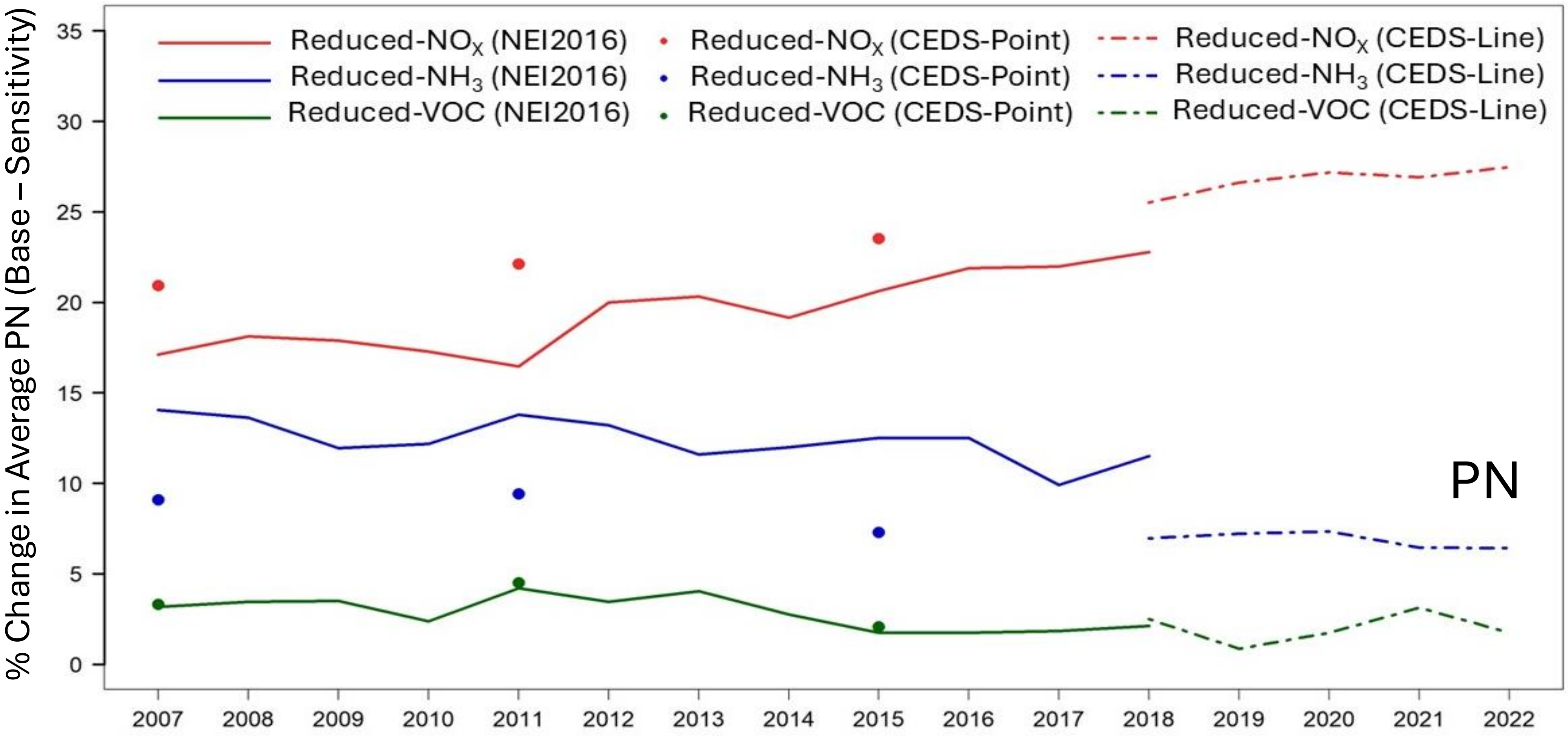




Controlling wintertime NO_x emissions will effectively reduce PN over the MWUS.

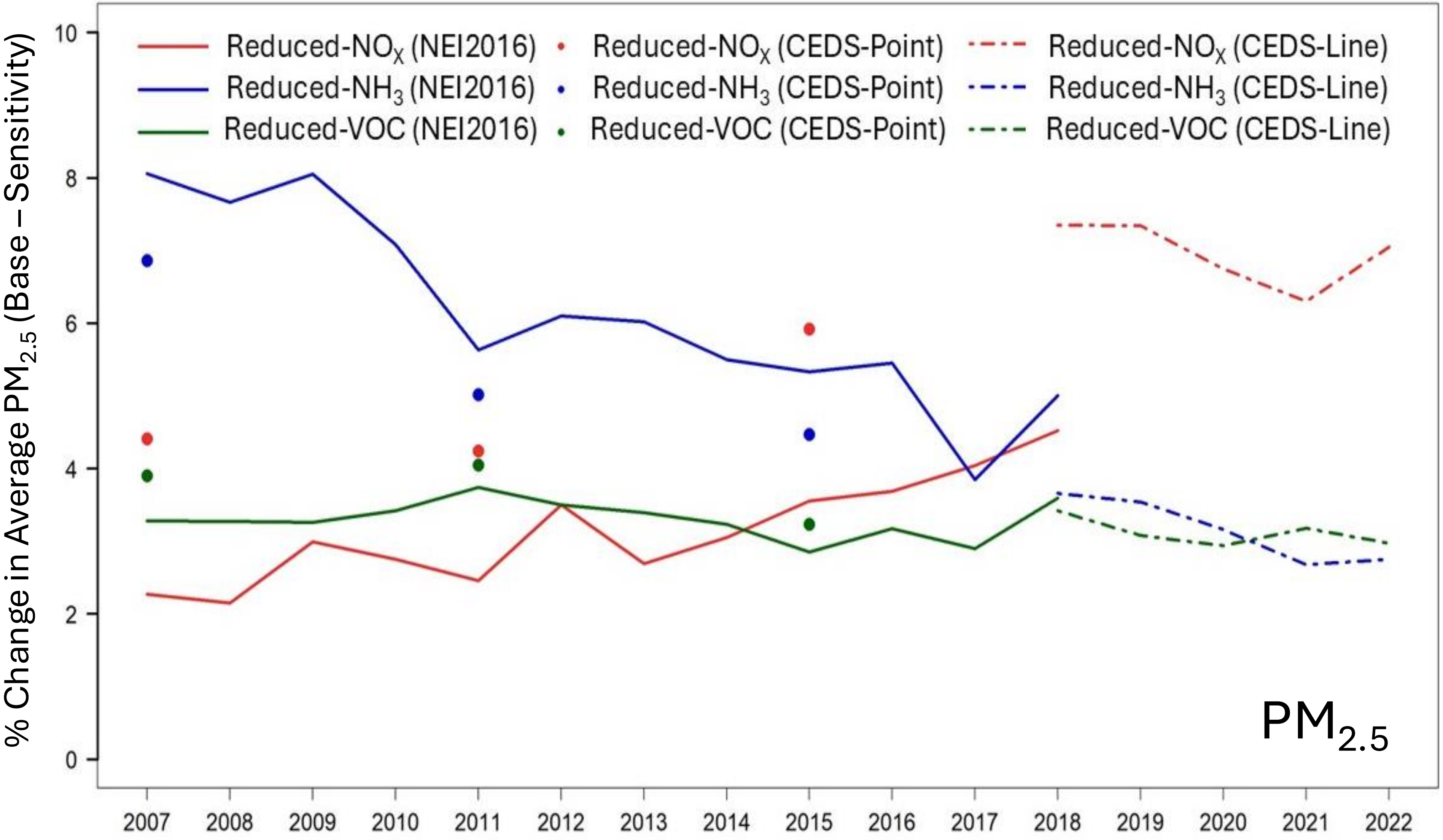
Vo and Christiansen, ACPD, 2026

PN Sensitivity over the MWUS Has Shifted to a Predominantly NO_X-sensitive Regime



Vo and Christiansen, ACPD, 2026

Controlling Wintertime NO_X Emissions Will Effectively Reduce Wintertime $PM_{2.5}$ over the MWUS

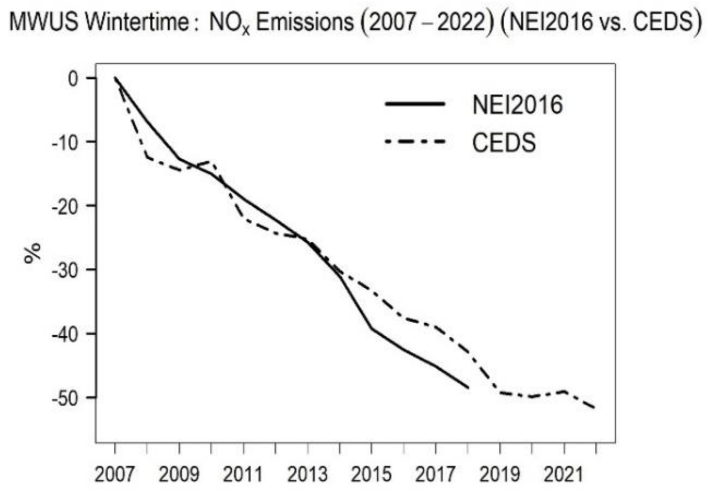


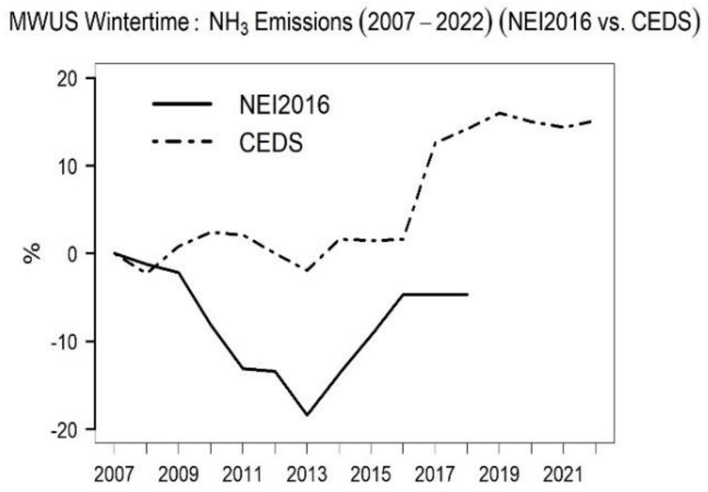
Vo and Christiansen, ACPD, 2026

Read more! Preprint on EGUSphere:
Vo and Christiansen, *Atmos. Chem. Phys. Disc.*, 2026

Summary

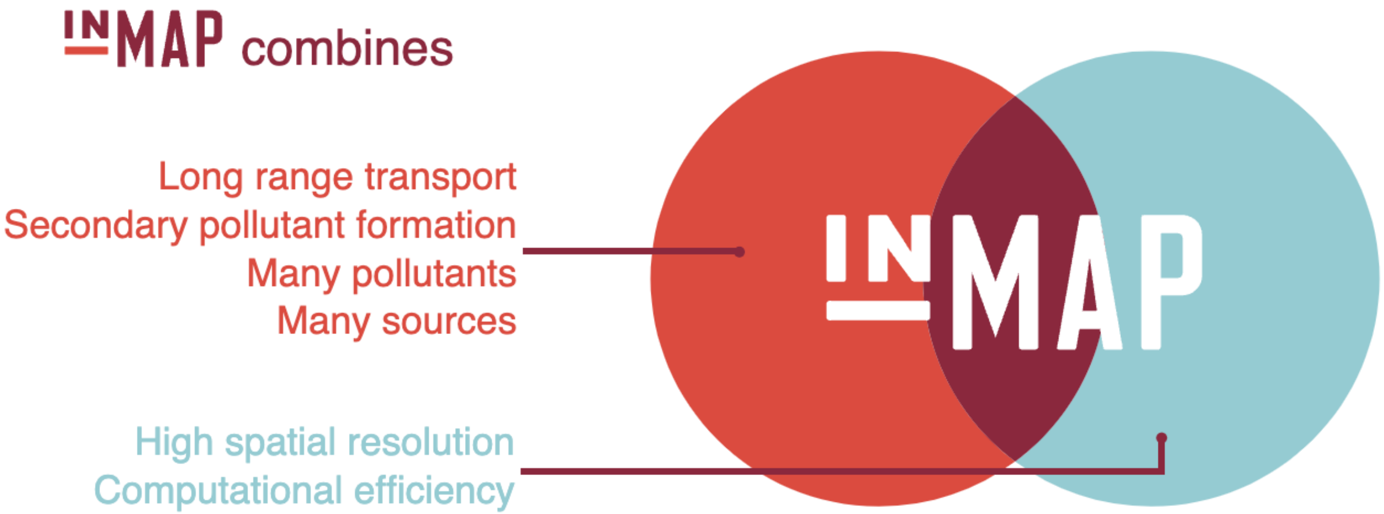
- Wintertime PN formation is becoming more sensitive to NO_x emissions over the MWUS
  - Driven by multidecadal changes in precursor gas emissions
- Chemically, it is beneficial to target NO_x emissions to reduce wintertime PN and $PM_{2.5}$ over MWUS
- Future work should investigate the sensitivity of PN and $PM_{2.5}$ to precursor gas emissions in other seasons

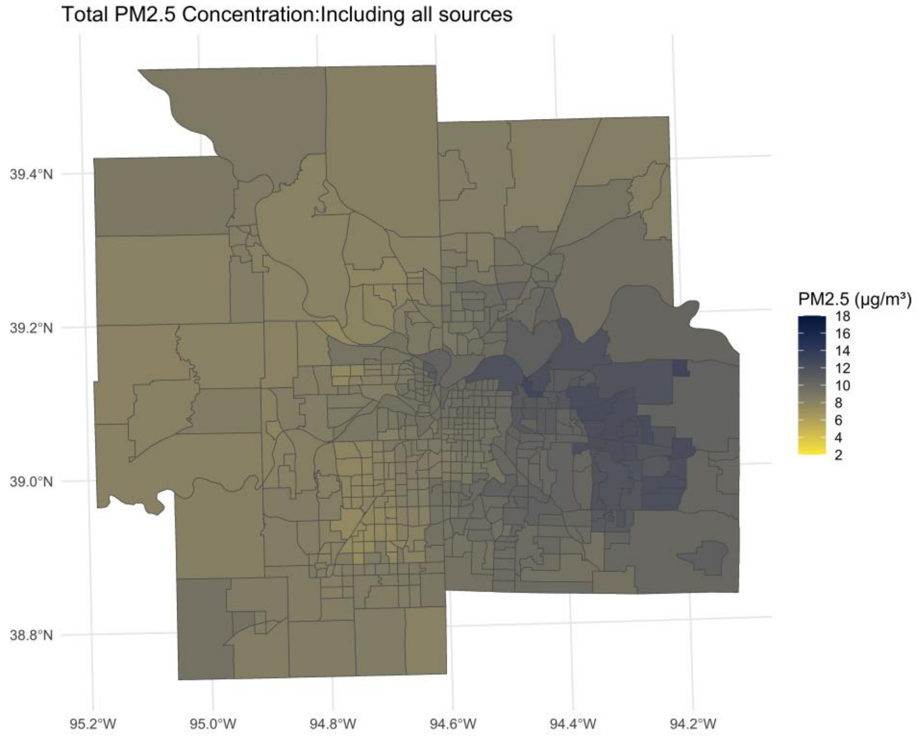




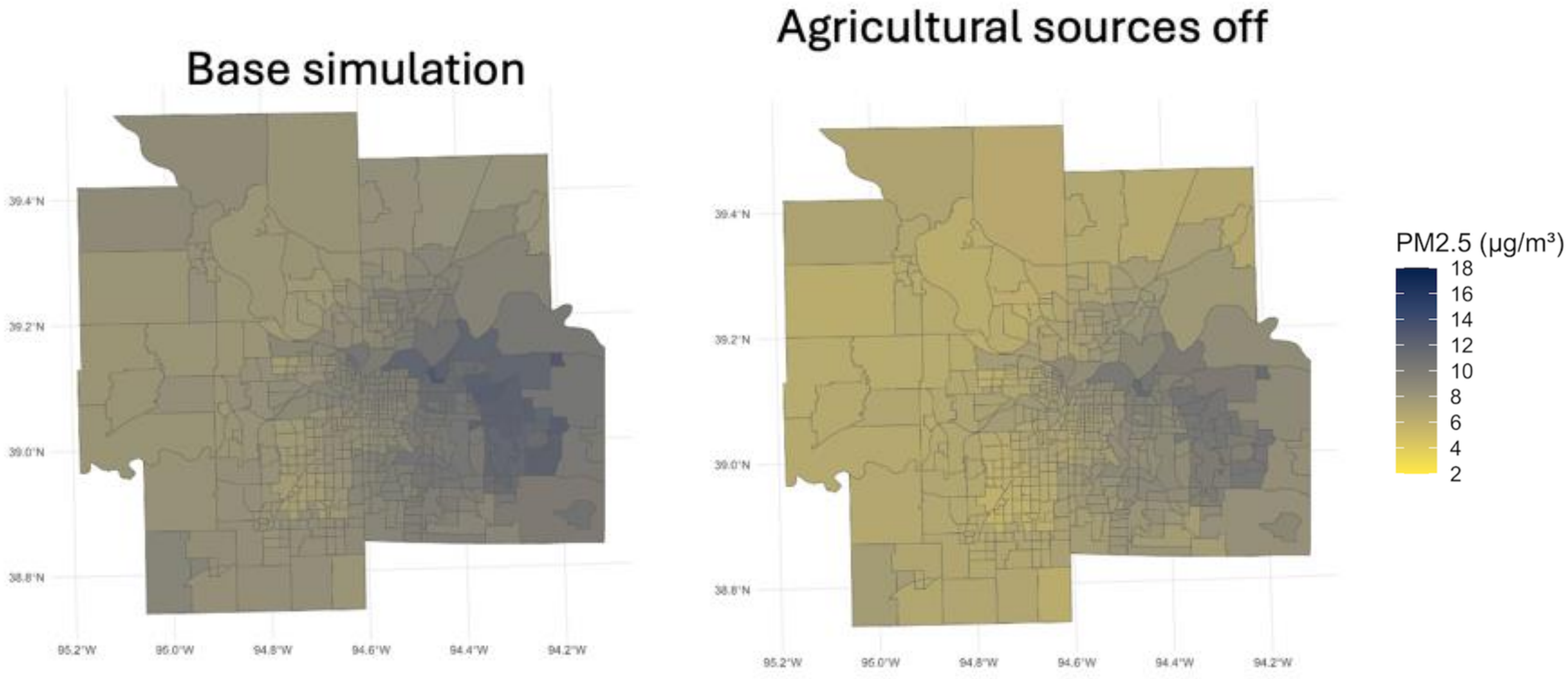
One last thing… Kansas City-specific AQ

- InMAP
  - InMAP is a simplified air quality model
- Determines grid size dynamically:
  - High population → fine grid (2 × 2 km²): urban areas
  - Low population → coarse grid (12 × 12 km²): rural areas
- InMAP estimates annual average total $PM_{2.5}$ concentration





Eliminating agricultural emissions results in a $PM_{2.5}$ reduction of 1.6 µg m^{-3} (18%) in Kansas City



Acknowledgements

- Christiansen group members
  - **Toan Vo**
  - **Shreeram Ojha**
  - **Dr. Luke Monroe** (now at NW Missouri State)
  - Kabin Chemjong
  - Lizbeth Gracida-Basurto
- UMKC Funding for Faculty Excellence
- US DOT

- Visit our website: https://research.umkc.edu/atmoschem/

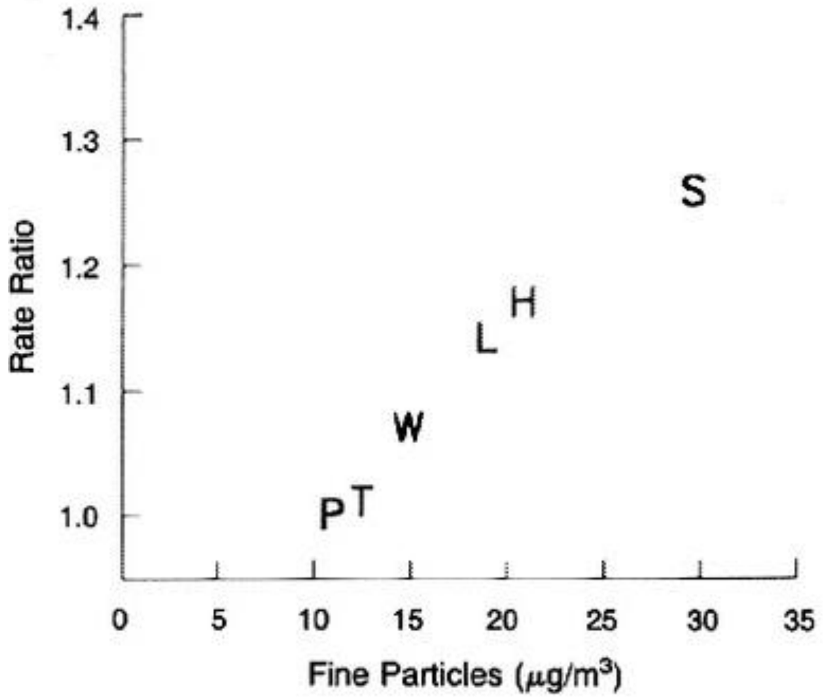
- Contact me: achristiansen@umkc.edu

Harvard Six Cities Study 1993

Long-term study of six cities with varying pollution levels

Tracked rate of mortality over 14-16 years

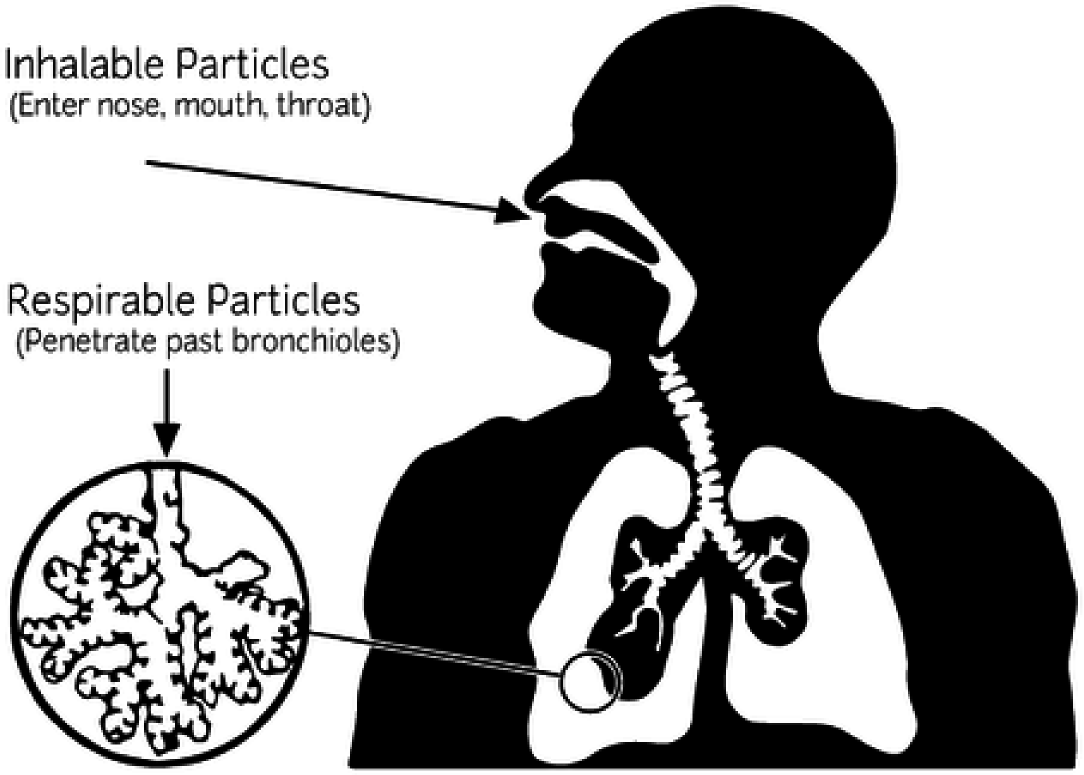
Watertown, MA
Harriman, TN
St. **L**ouis, MO
Steubenville, OH
Portage, WI
Topeka, KS



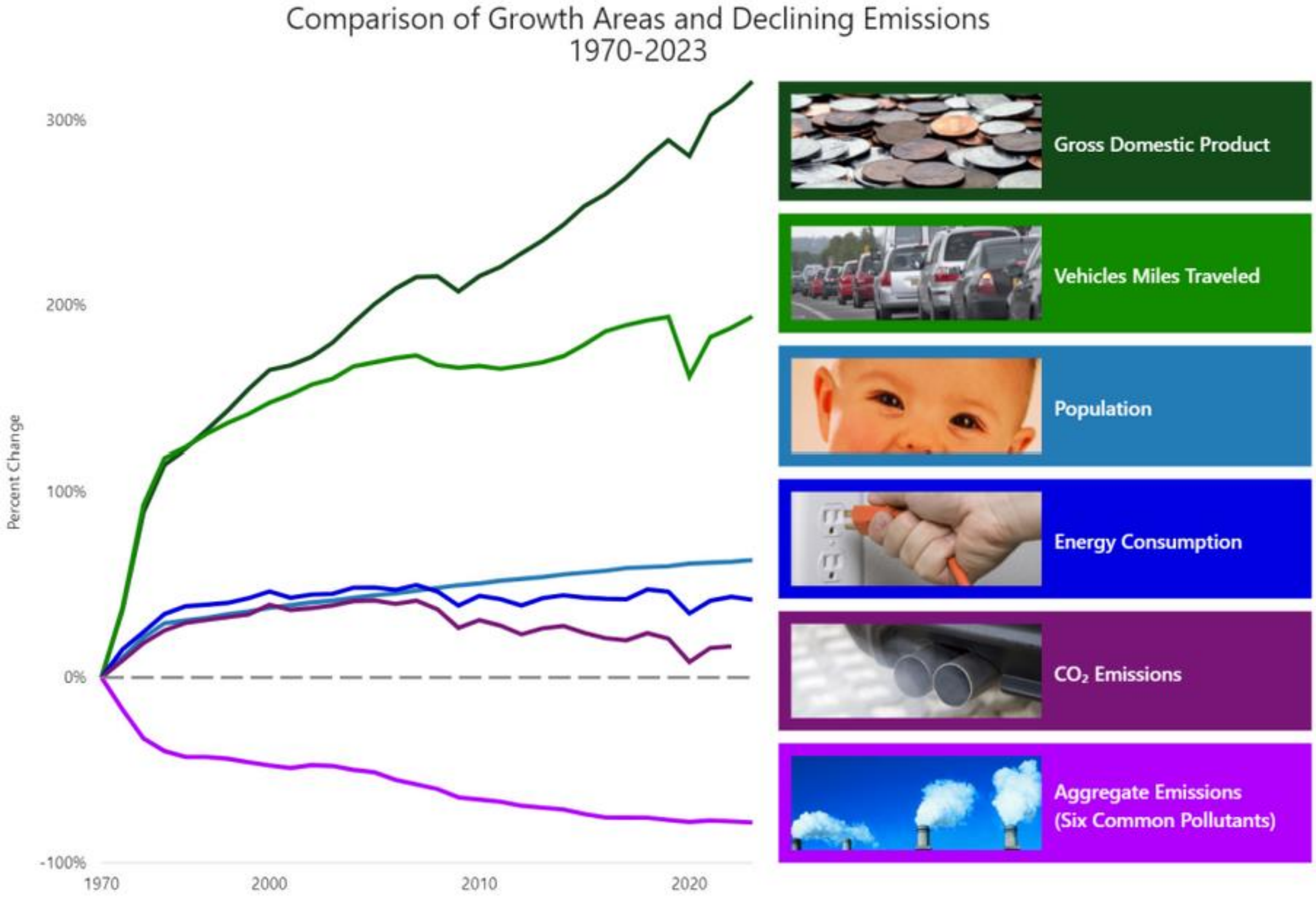
Clear association between particle mass and mortality!

Why $PM_{2.5}$?

- $PM_{2.5}$ can get past protective layer of lungs (cilia) and enter bloodstream
  - Oxidative stress, inflammatory response → disease

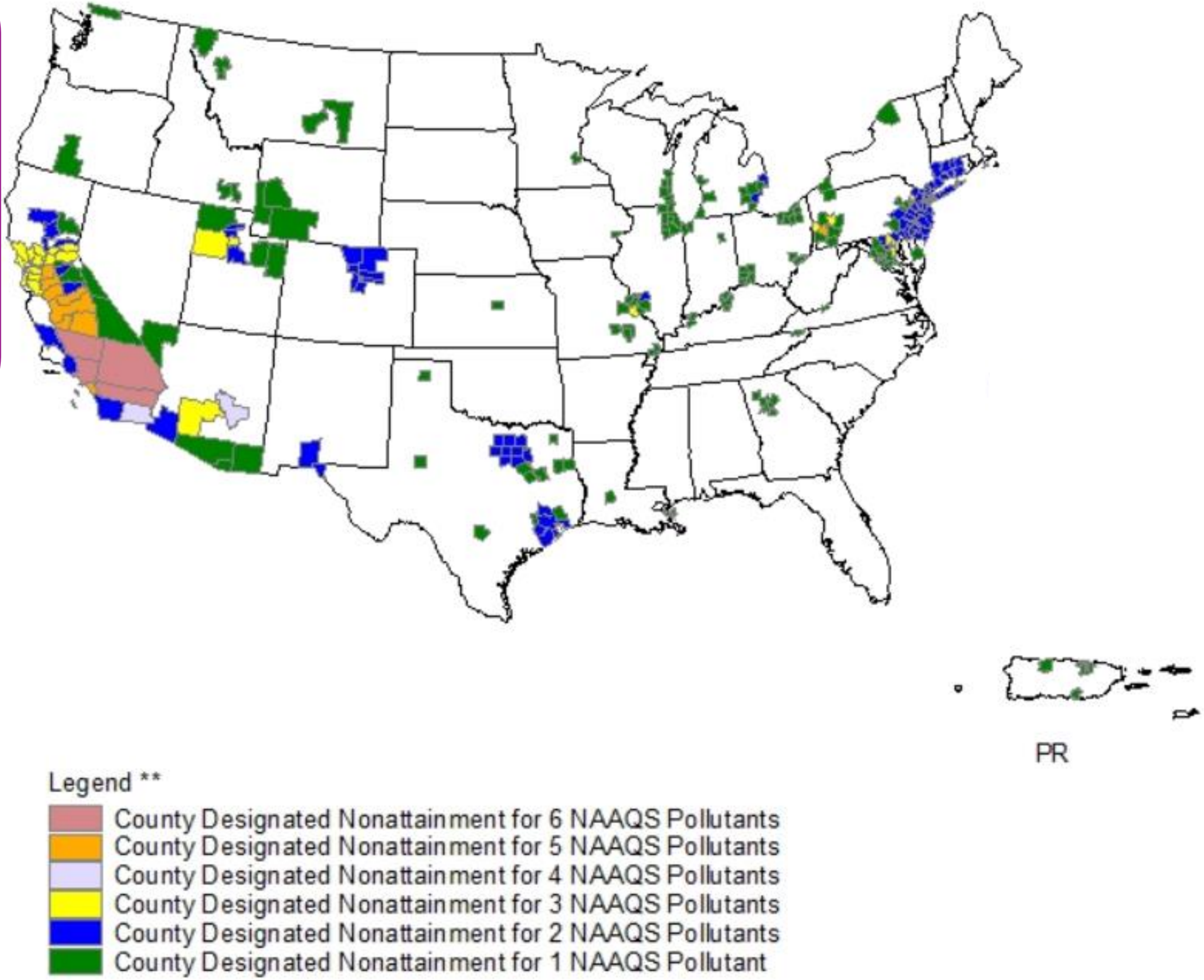


particles in the nose, throat, and lungs
an edited version of Figure 4-1 EPA/600/R-95/115

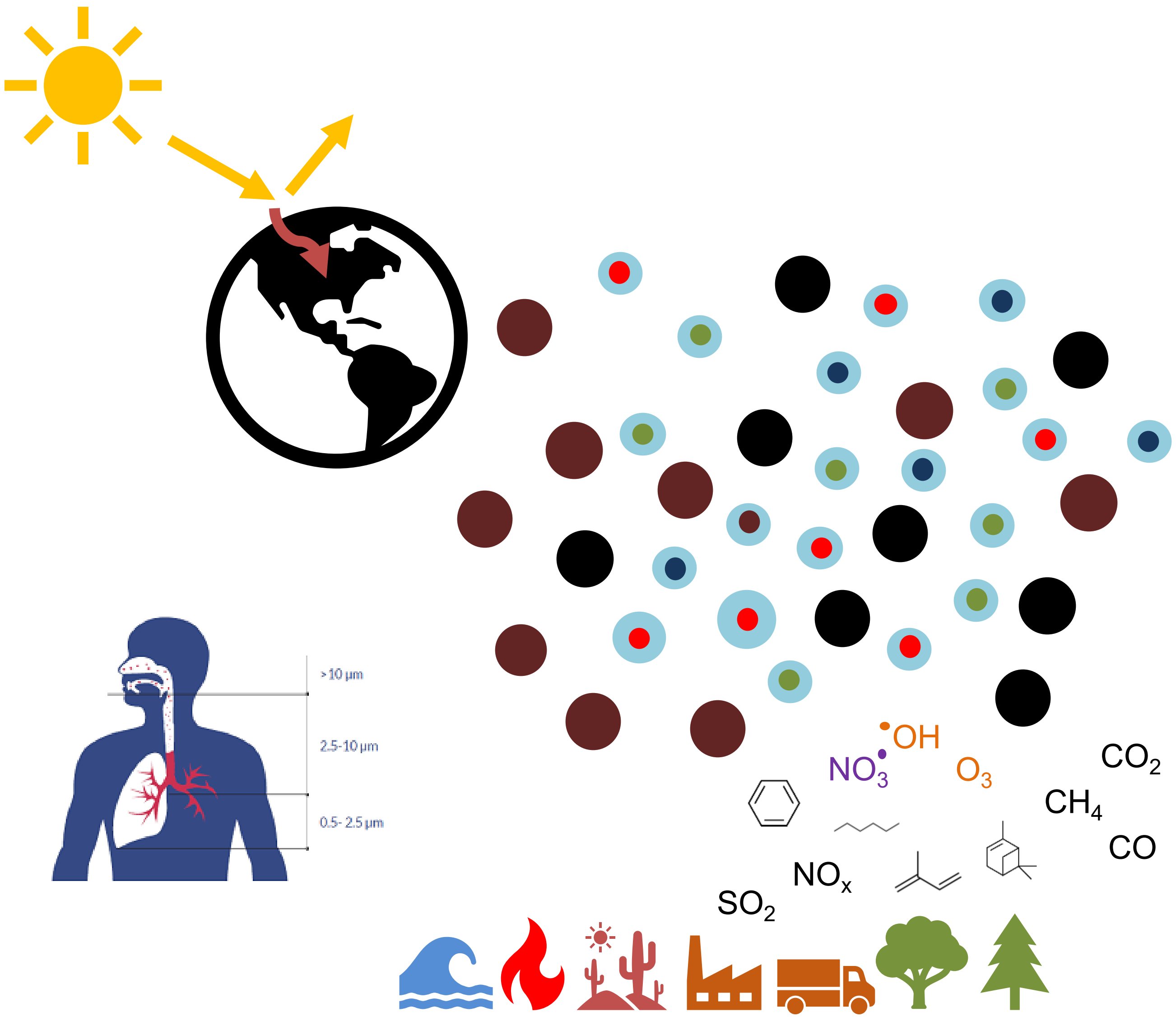

Comparison of Growth Areas and Declining Emissions
1970-2023
Percent Change
300%
200%
100%
0%
-100%
1970
2000
2010
2020
Gross Domestic Product
Vehicles Miles Traveled
Population
Energy Consumption
CO_2 Emissions
Aggregate Emissions
(Six Common Pollutants)

Air pollution problems persist today

Approximately 120 million people nationwide live in counties with pollution levels above regulations



Fundamental Questions in Atmospheric Chemistry

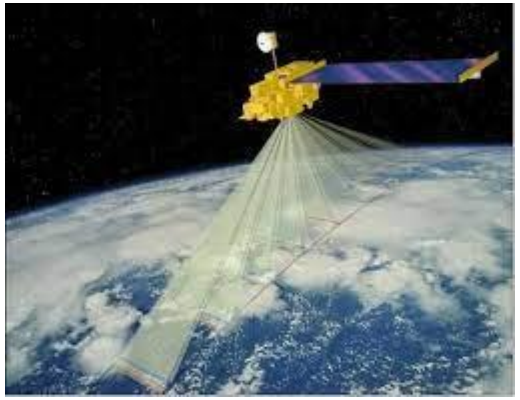
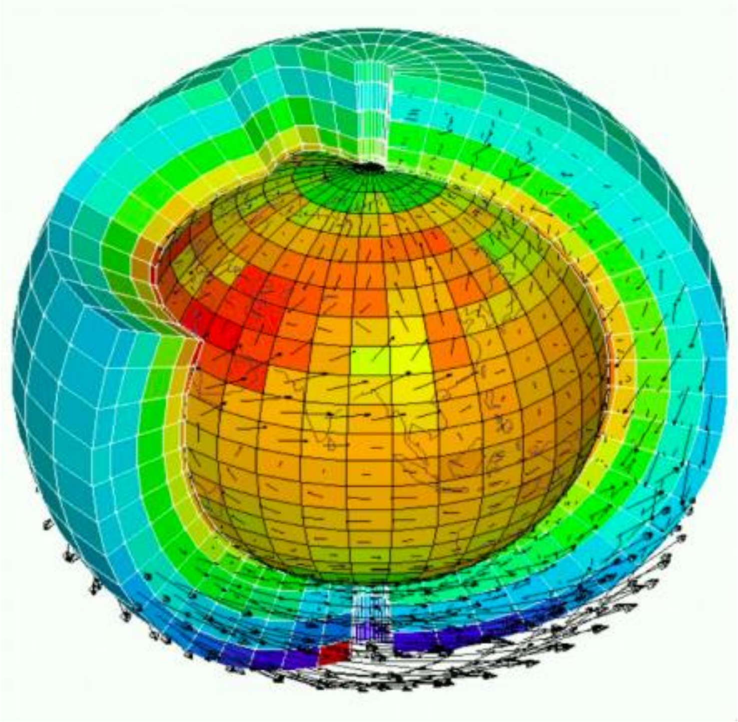


- What are the spatial distribution and temporal trends of pollutants?
- What drives these trends?
- How can we apply our scientific knowledge of trends and drivers to broader concepts? How do pollutants impact Earth's radiation budget and human health?

https://www.who.int/airpollution/household/pollutants/combustion/en/

Christiansen Lab General Methods



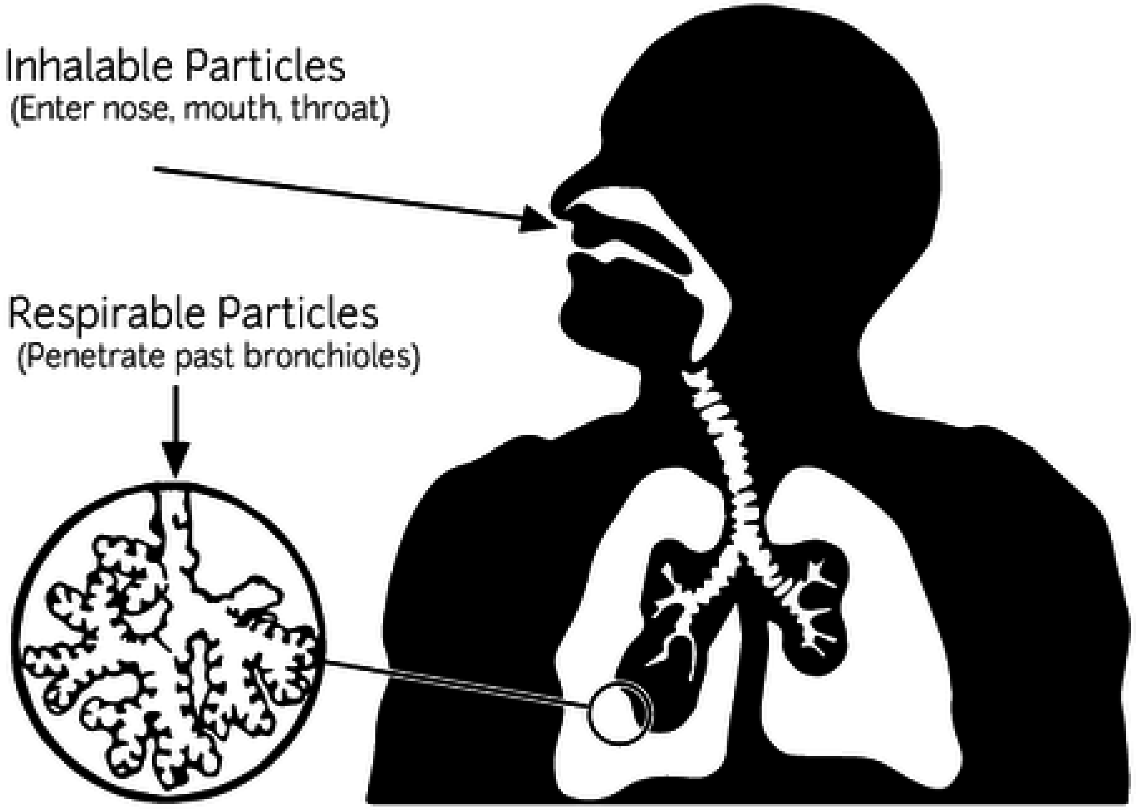



Environmental monitoring datasets (ground measurements, vertical profiles, satellites)
Atmospheric models

1) Combine datasets in unique ways
2) Combine measurements with models to help understand interactions
3) Use measurements to improve models

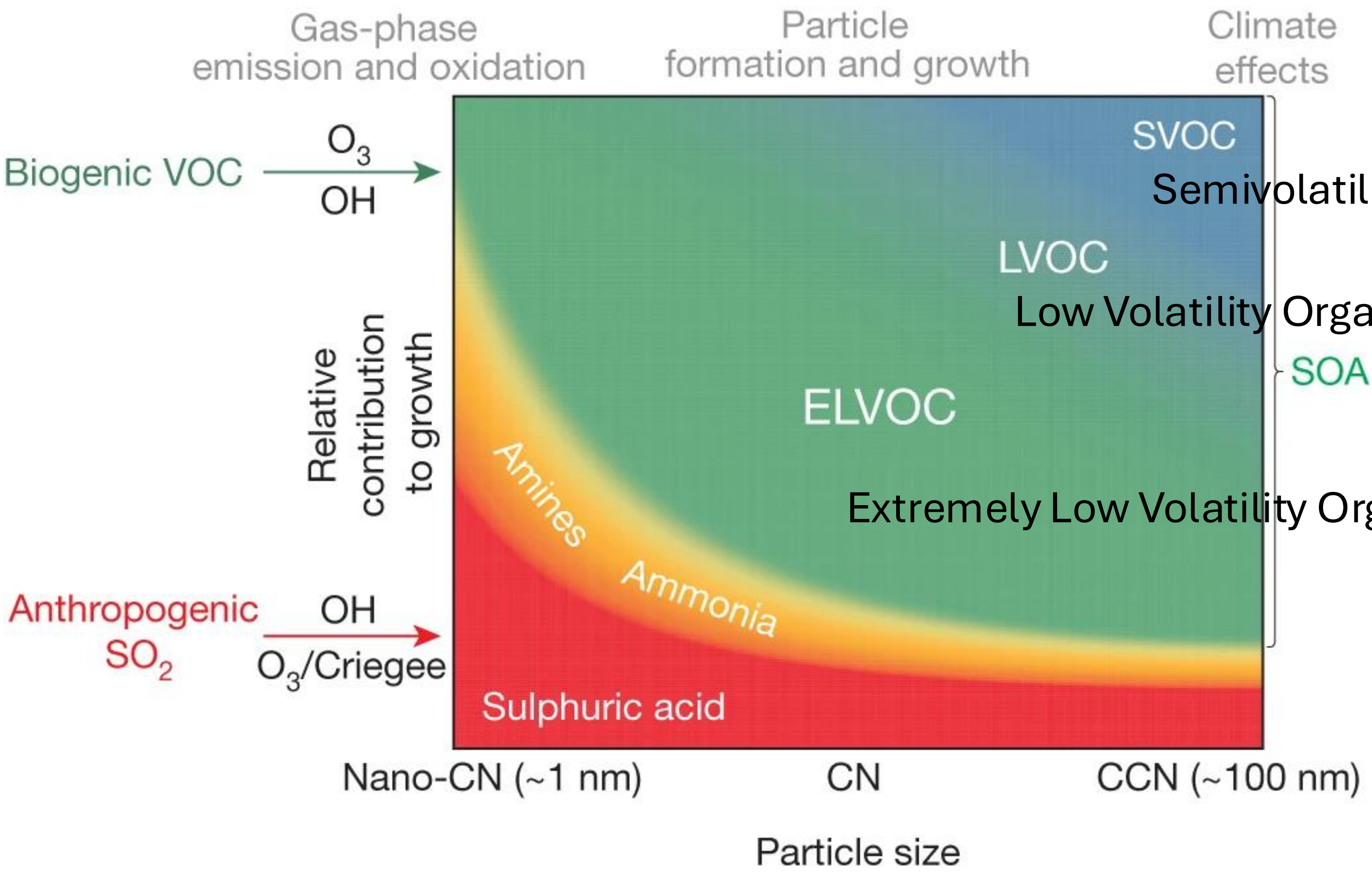
Why are air pollutants harmful?

- Some particles can get past protective layer of lungs (cilia) and enter bloodstream
  - Oxidative stress, inflammatory response → disease



particles in the nose, throat, and lungs
an edited version of Figure 4-1 EPA/600/R-95/115

Organics contribute greatly to growth of new particles



Semivolatile Organic Compounds

Low Volatility Organic Compounds

Extremely Low Volatility Organic Compounds

Clustering

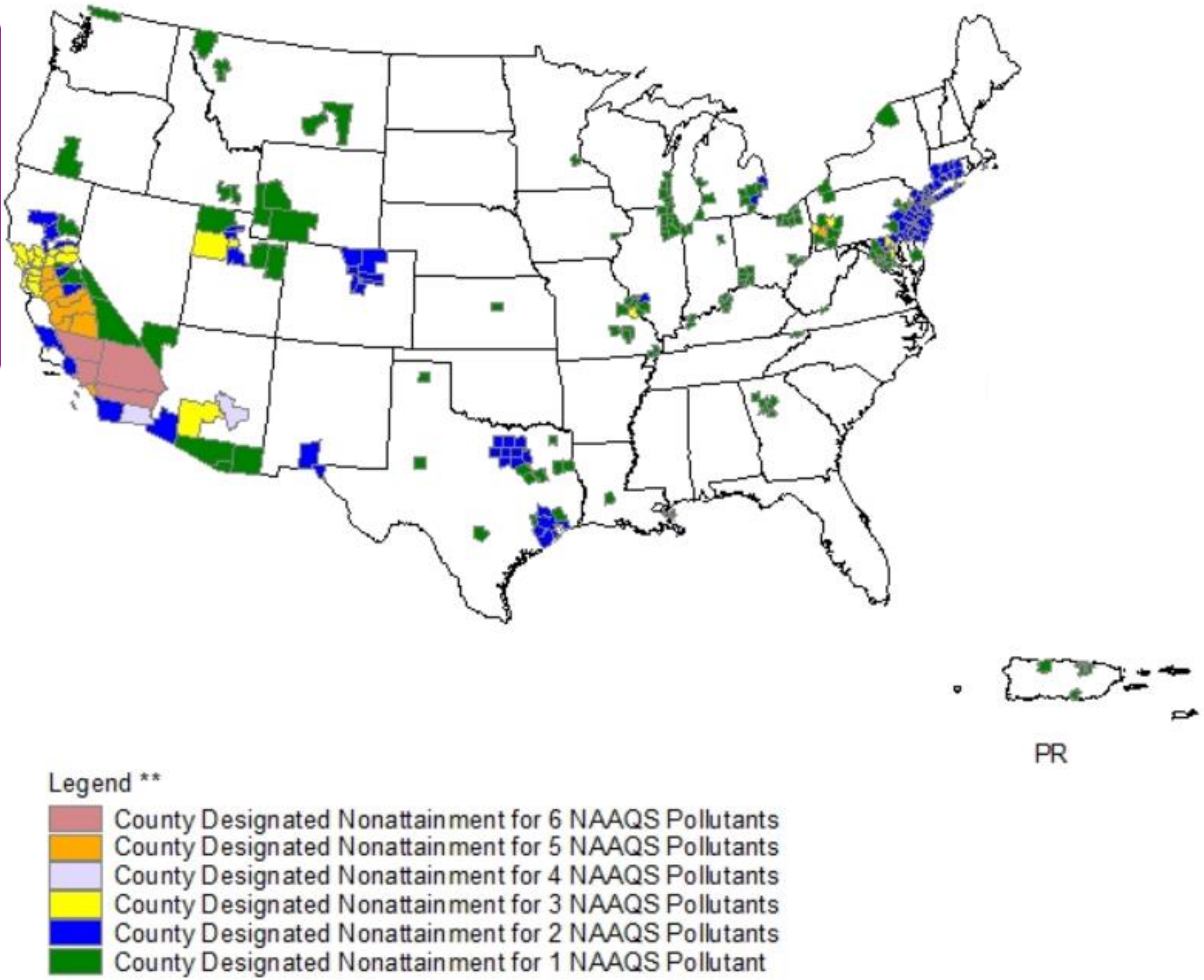
Condensation

Coagulation

Ehn et al., *Nature*, 2014

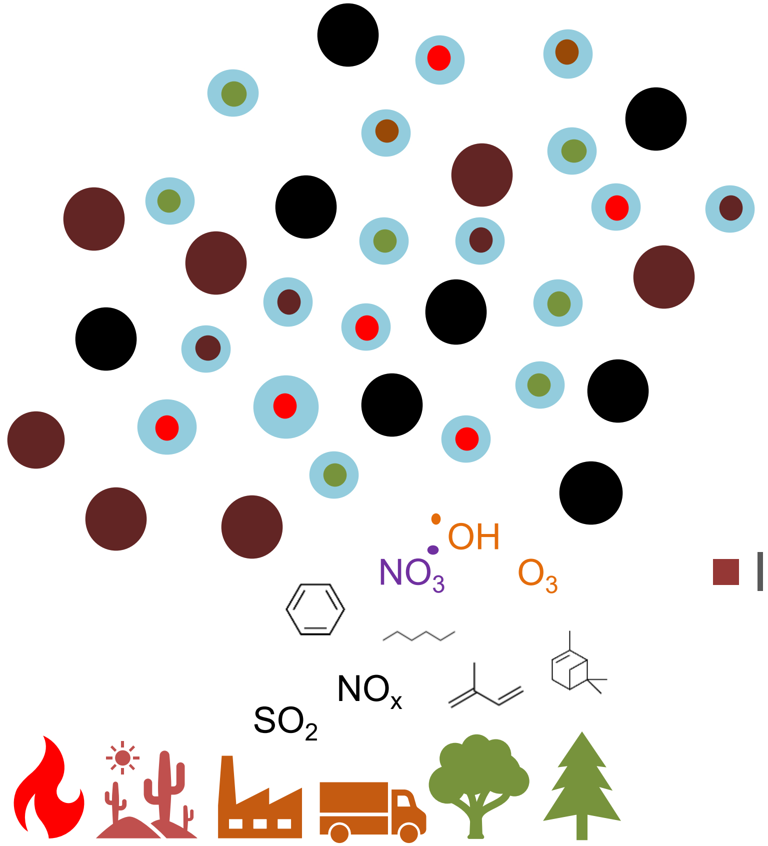
Air pollution problems persist today

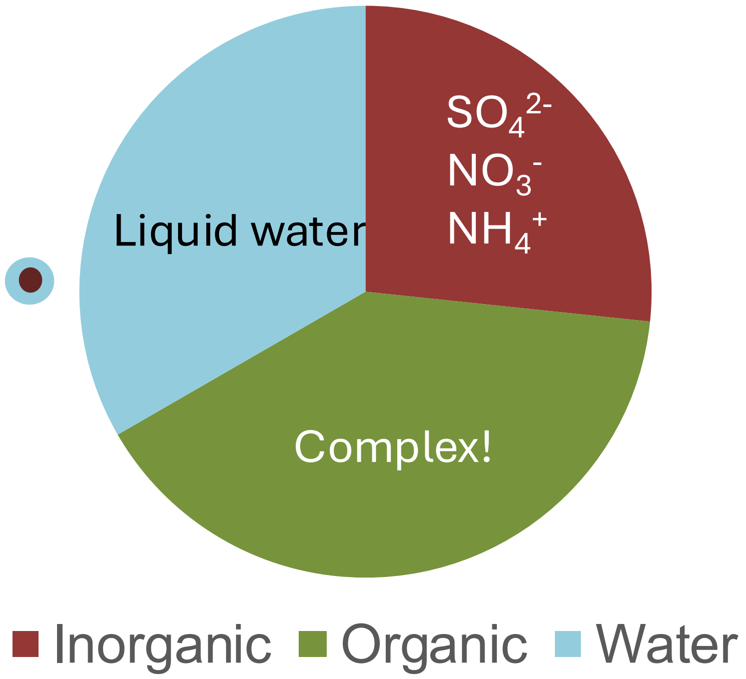
Approximately 120 million people nationwide live in counties with pollution levels above regulations



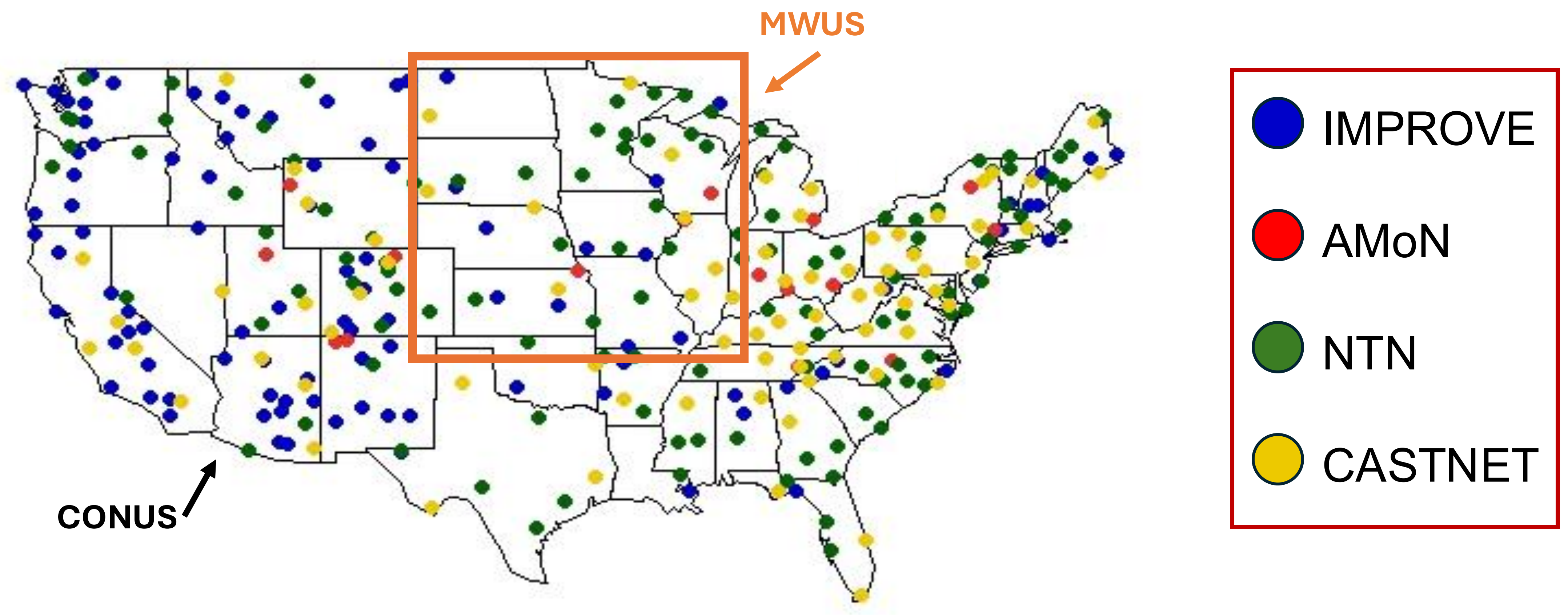
What is particulate matter (PM)?

- Small solid or liquid particles that are suspended in air
- Primary and secondary sources
  - Primary: Dust, sea spray, soot
  - Secondary: Oxidation of gas-phase precursor species
- Composed of complex chemical matrix





Observational Data (2007-2019)



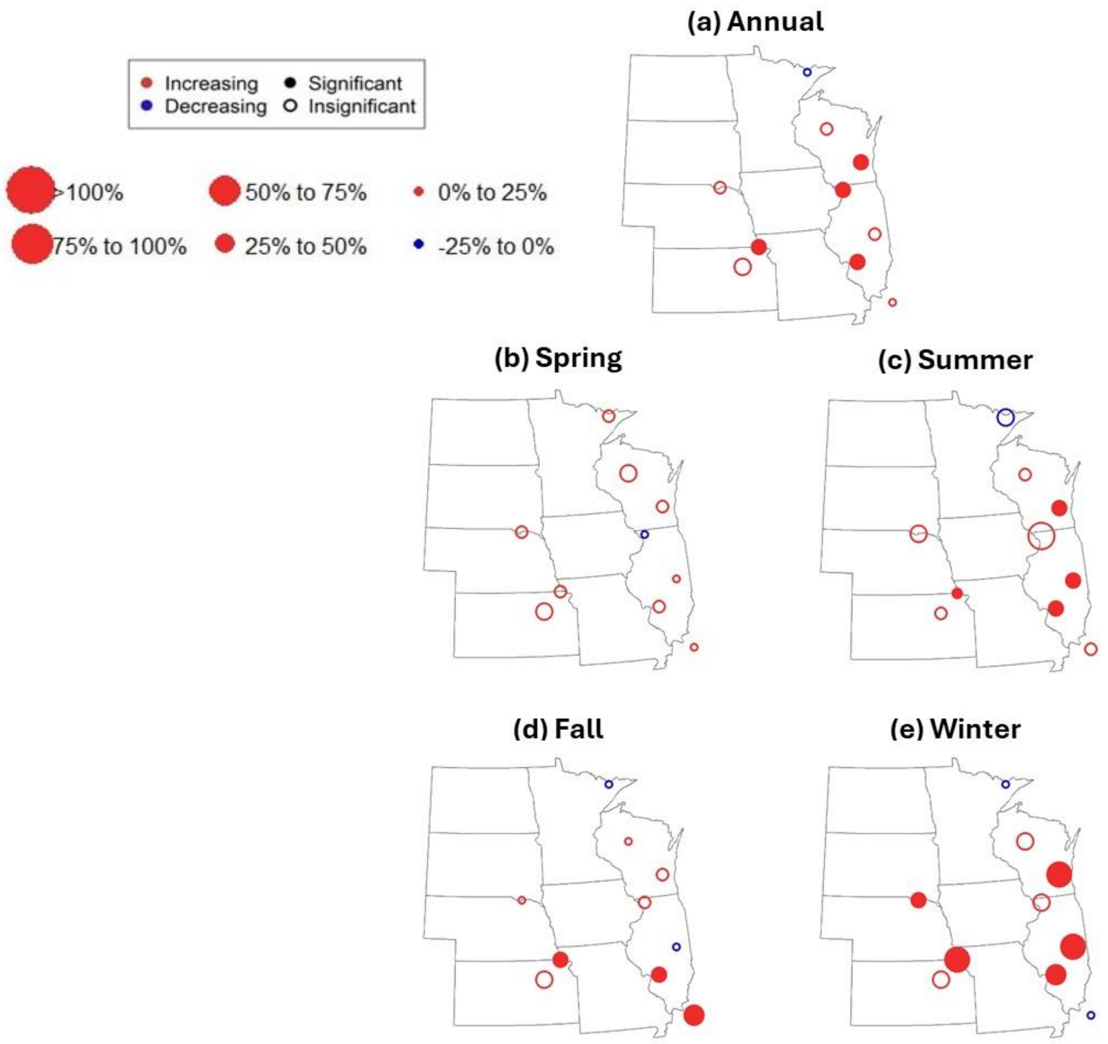
IMPROVE (Interagency Monitoring of PROtected Visual Environments): $PM_{2.5}$ concentrations and chemical speciation

AMoN (Ammonia Monitoring Network): NH_3 concentrations

NTN and CASTNET (National Trends Network and Clean Air Status and Trends Network): NH_4^+ and total N deposition

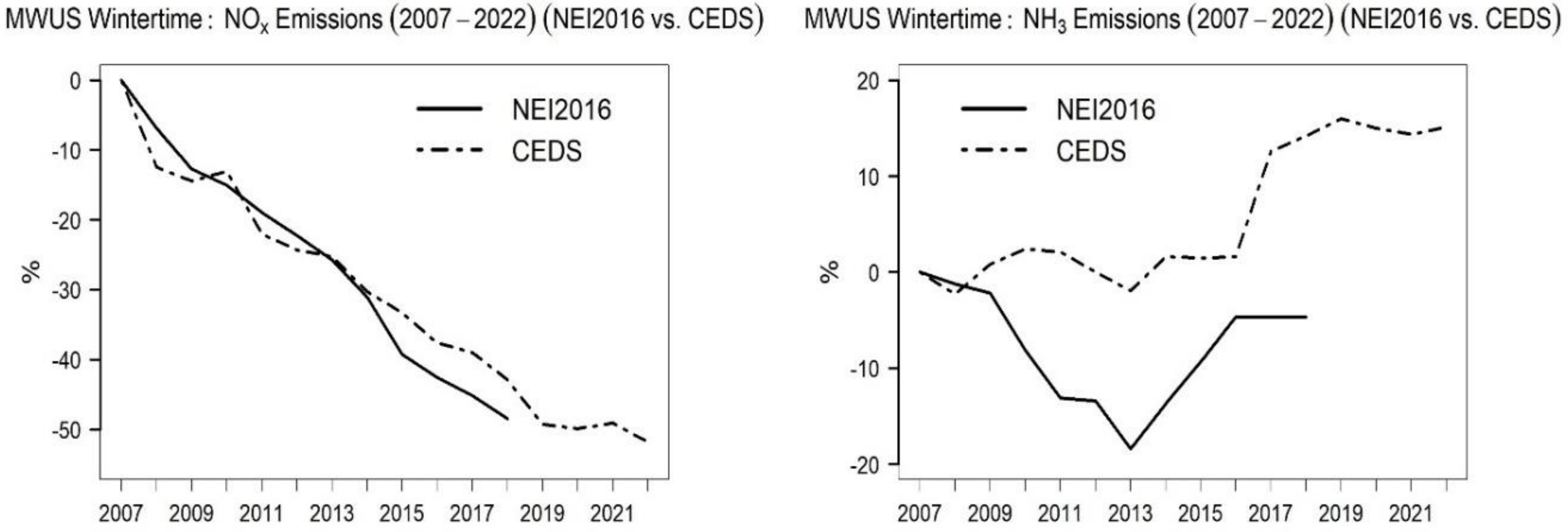
NH_3 Concentrations Increase in the MWUS Faster than the CONUS

NH3 Concentration Trends over the MWUS

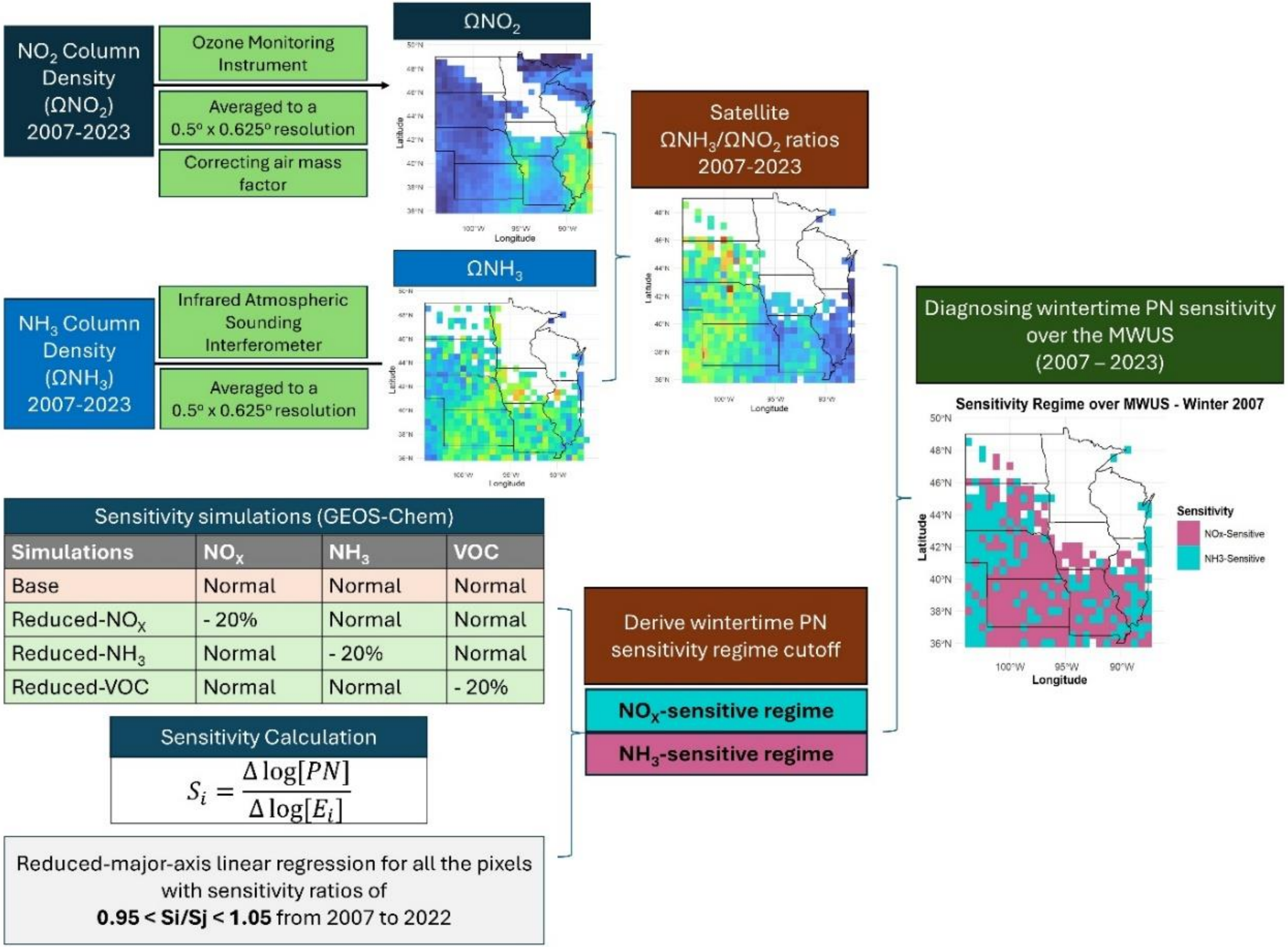


- NH_3 increases by 42% in the MWUS on average from 2007-2019 and are larger than the CONUS average (35%)
  - Winter shows largest increases (63% on average)
- Primarily agriculture: ~95% of total NH_3 emissions in MWUS are from agriculture
  - No correlation with meteorological variables
  - Perhaps due to nitrogen fertilizer overuse or unreacted NH_3

Vo and Christiansen, *ACS Earth Space Chem.*, 2024

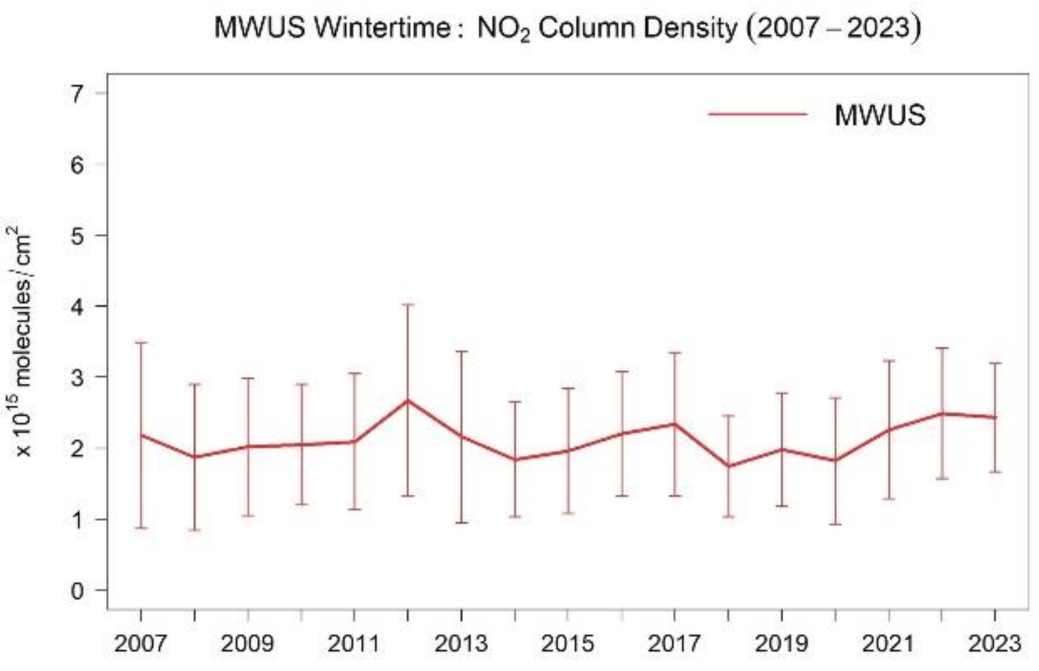


MWUS Wintertime : NO_x Emissions (2007 – 2022) (NEI2016 vs. CEDS)
NEI2016
CEDS
%
0
-10
-20
-30
-40
-50
2007
2009
2011
2013
2015
2017
2019
2021
MWUS Wintertime : NH_3 Emissions (2007 – 2022) (NEI2016 vs. CEDS)
NEI2016
CEDS
%
20
10
0
-10
-20
2007
2009
2011
2013
2015
2017
2019
2021


NO2 Column Density (ΩNO2) 2007-2023
Ozone Monitoring Instrument
Averaged to a 0.5° x 0.625° resolution
Correcting air mass factor
ΩNO2
NH3 Column Density (ΩNH3) 2007-2023
Infrared Atmospheric Sounding Interferometer
Averaged to a 0.5° x 0.625° resolution
ΩNH3
Satellite ΩNH3/ΩNO2 ratios 2007-2023
Diagnosing wintertime PN sensitivity over the MWUS (2007 – 2023)
Sensitivity Regime over MWUS - Winter 2007
Latitude
Longitude
Sensitivity
NOx-Sensitive
NH3-Sensitive
Sensitivity simulations (GEOS-Chem)
Simulations | NOx | NH3 | VOC
Base | Normal | Normal | Normal
Reduced-NOx | - 20% | Normal | Normal
Reduced-NH3 | Normal | - 20% | Normal
Reduced-VOC | Normal | Normal | - 20%
Sensitivity Calculation
$S_i = \frac{\Delta \log[PN]}{\Delta \log[E_i]}$
Reduced-major-axis linear regression for all the pixels with sensitivity ratios of 0.95 < Si/Sj < 1.05 from 2007 to 2022
Derive wintertime PN sensitivity regime cutoff
NOx-sensitive regime
NH3-sensitive regime

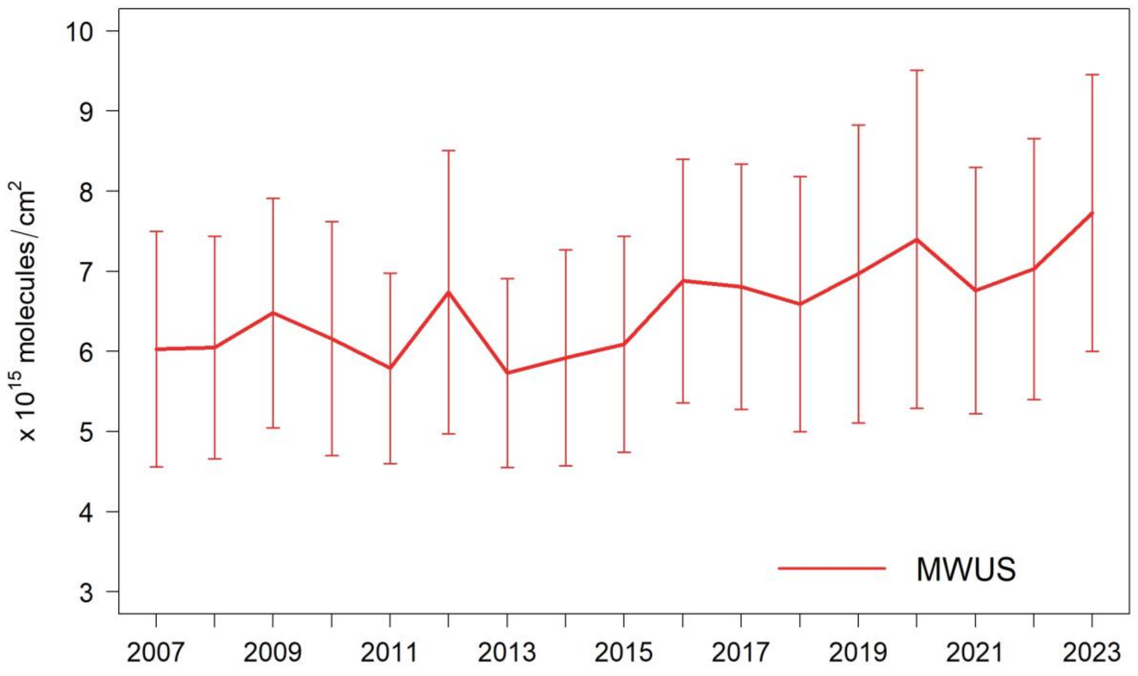
NO_2 and NH_3 Column Density Trends over MWUS (2007 – 2023)

NO_2 Column Densities (2007-2023)

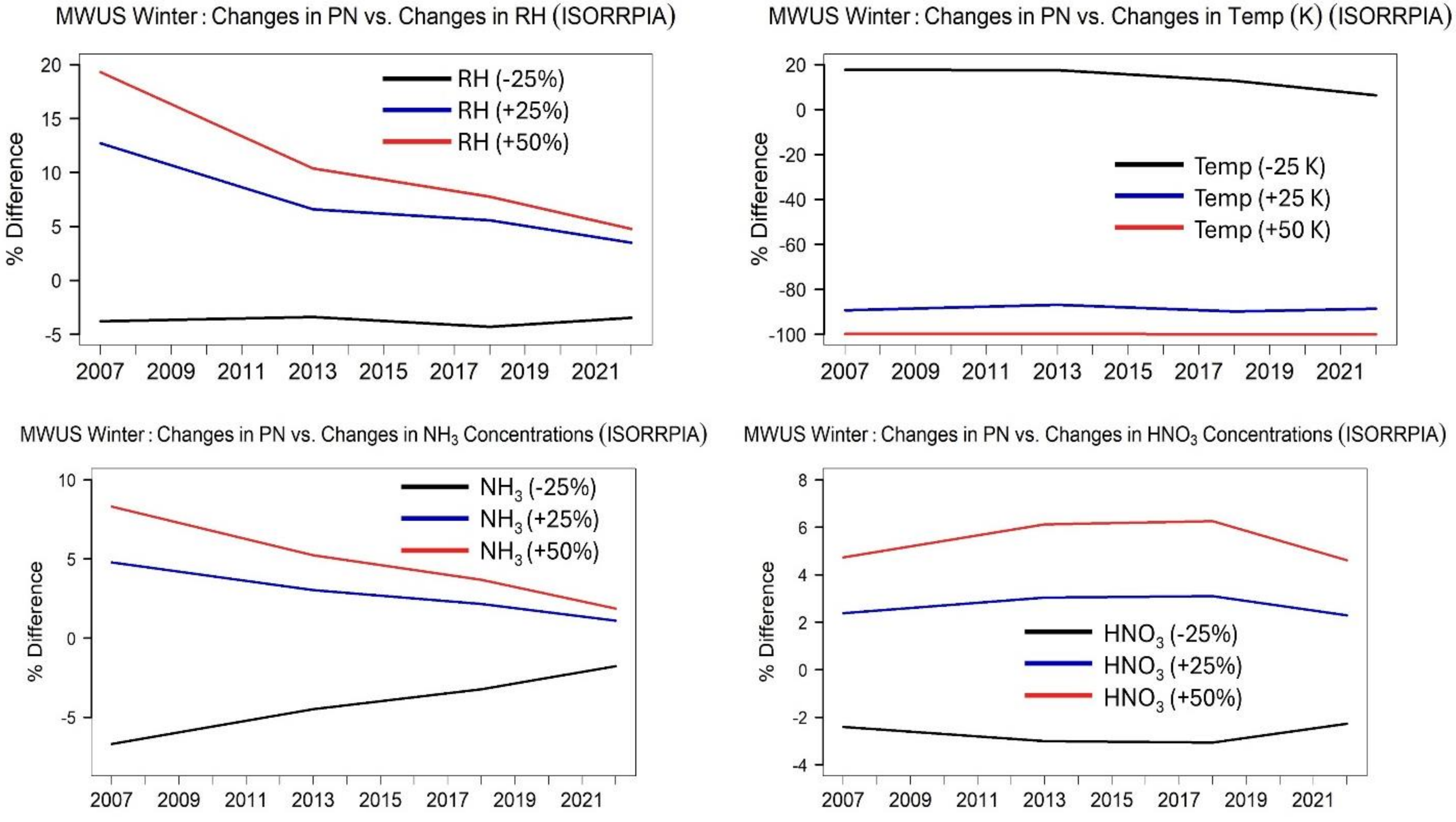


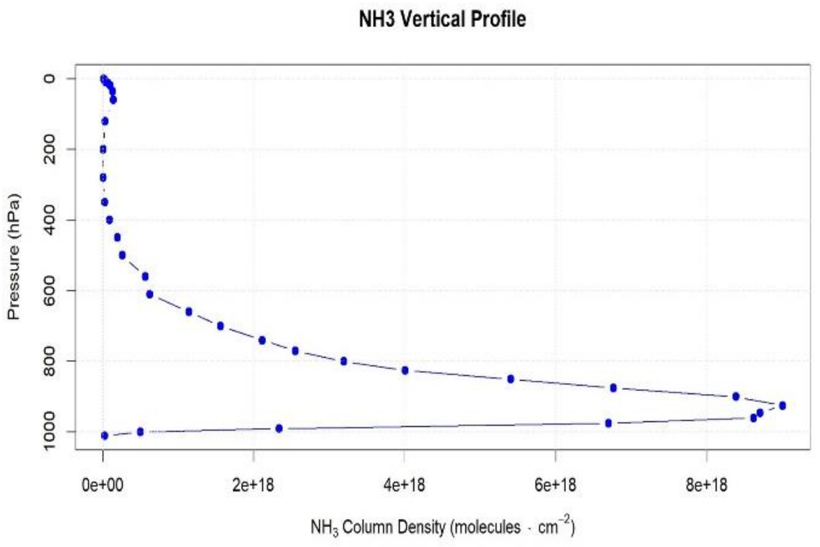
The flat trend in regional NO_2 is driven by natural sources and free tropospheric NO_2

NH_3 Column Densities (2007-2023)

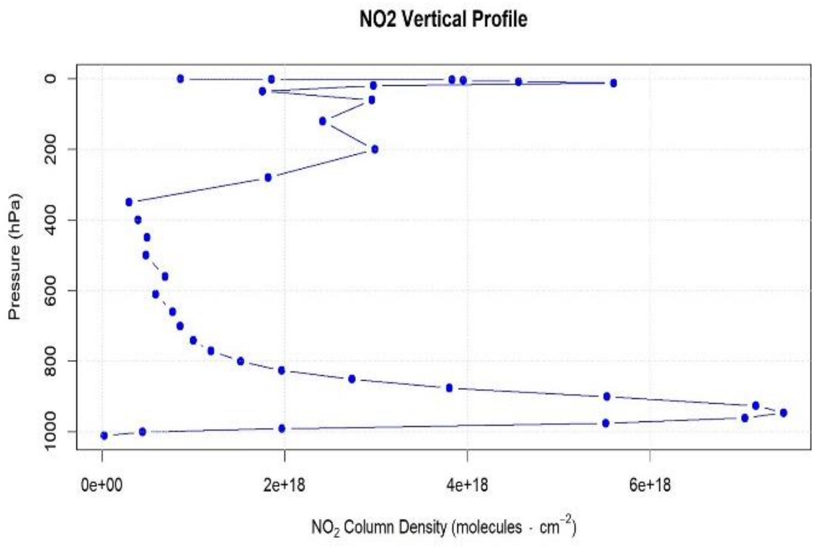


The increase in NH_3 column densities is partly attributable to increases in agricultural activities


MWUS Winter : Changes in PN vs. Changes in RH (ISORRPIA)
RH (-25%)
RH (+25%)
RH (+50%)
% Difference
MWUS Winter : Changes in PN vs. Changes in Temp (K) (ISORRPIA)
Temp (-25 K)
Temp (+25 K)
Temp (+50 K)
MWUS Winter : Changes in PN vs. Changes in NH3 Concentrations (ISORRPIA)
NH3 (-25%)
NH3 (+25%)
NH3 (+50%)
MWUS Winter : Changes in PN vs. Changes in HNO3 Concentrations (ISORRPIA)
HNO3 (-25%)
HNO3 (+25%)
HNO3 (+50%)
2007 2009 2011 2013 2015 2017 2019 2021



NH3 Vertical Profile
Pressure (hPa)
0
200
400
600
800
1000
0e+00
2e+18
4e+18
6e+18
8e+18
NH_3 Column Density (molecules · cm^{-2})



NO2 Vertical Profile
Pressure (hPa)
0
200
400
600
800
1000
0e+00
2e+18
4e+18
6e+18
NO_2 Column Density (molecules · cm^{-2})