Conceptual Models of $PM_{2.5}$ in Great Lakes Region

Lining Zhang

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Prepared for Lake Michigan Air Directors Consortium (LADCO)

Outline

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  - *Chemical Speciation*
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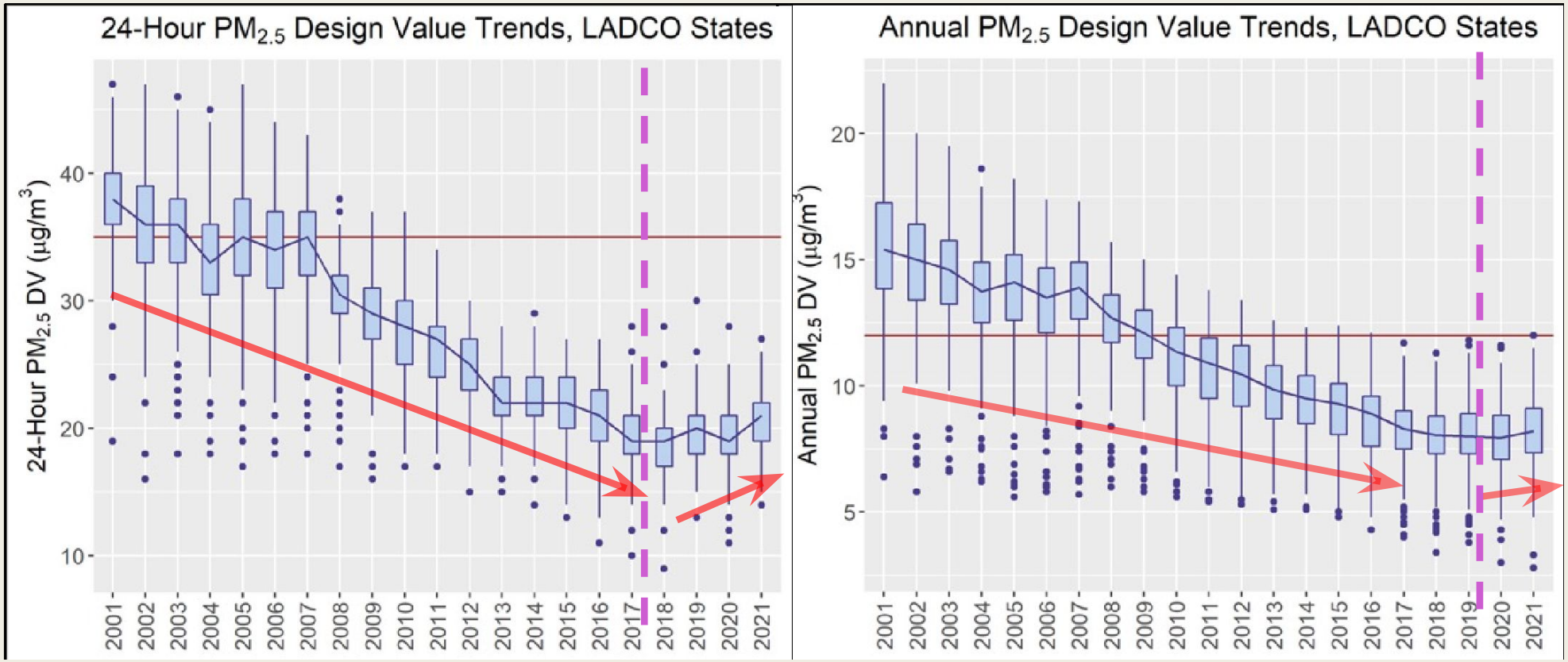
BACKGROUND

$PM_{2.5}$ Trends and Concentrations in Great Lakes region

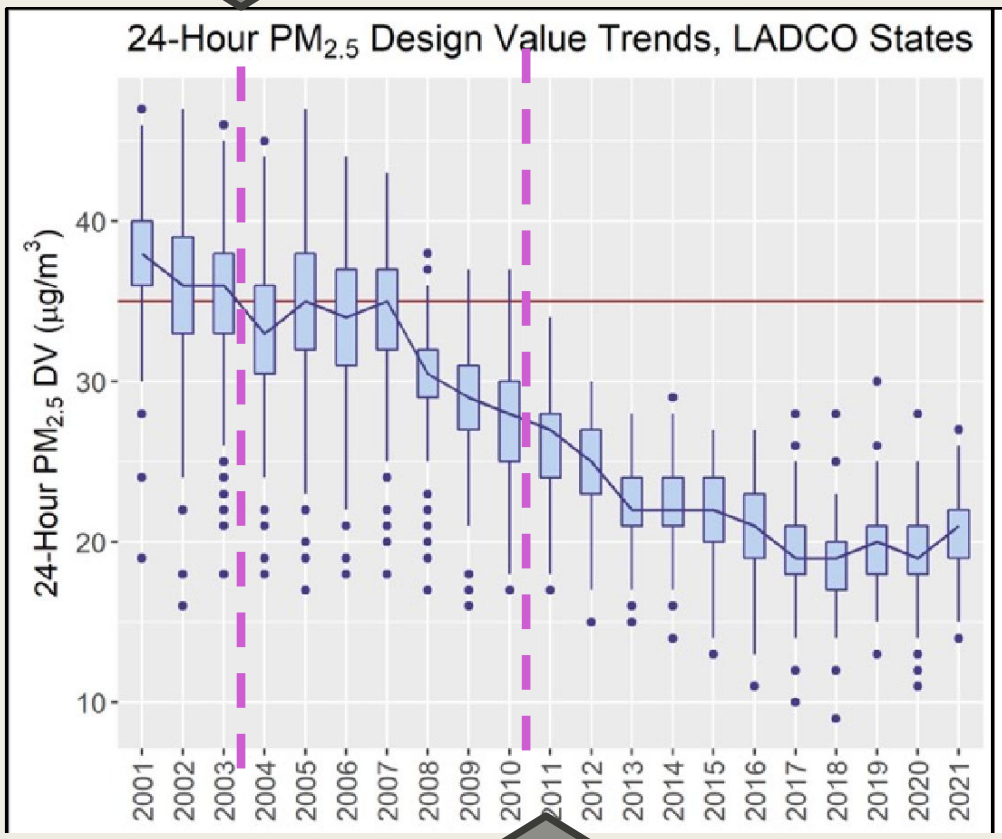


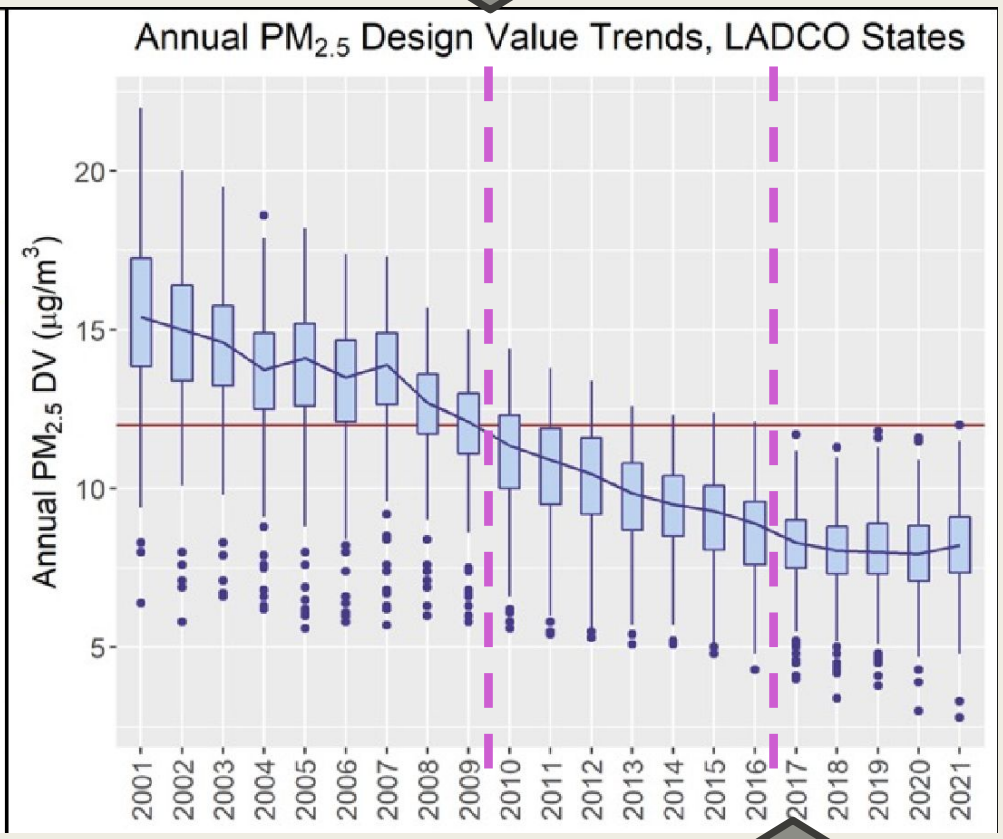
- $PM_{2.5}$ concentration decreased significantly over these 20 years.
  - much lower than 24-hour NAAQS standard and slightly lower than annual NAAQS standard.
- However, it started to increase again recently.

Figures from LADCO $PM_{2.5}$ Trends 2001-2021

Median 24-Hour design values were at or lower than NAAQS standard.

Median annual design values were at or lower than NAAQS standard.



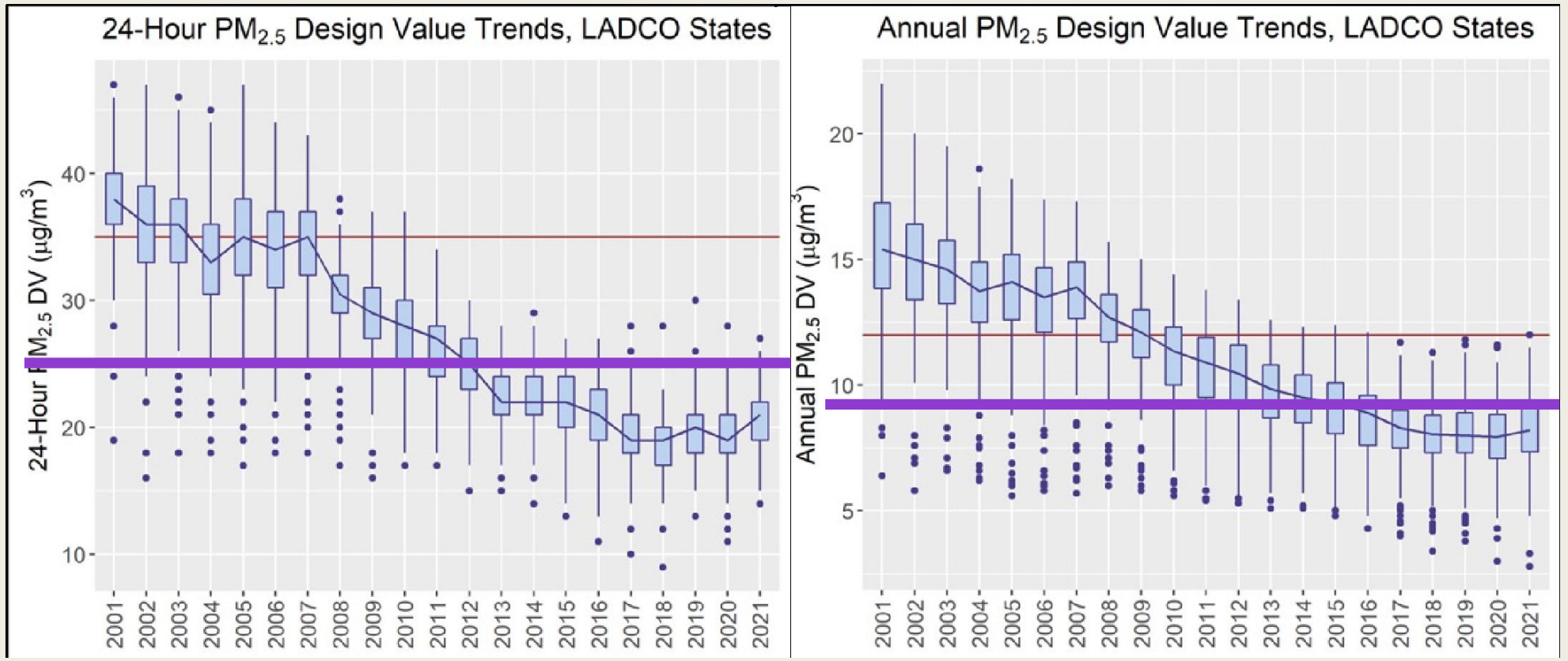


All design values were lower than NAAQS standard.

All design values were at or lower than NAAQS standard.

Figures from LADCO $PM_{2.5}$ Trends 2001-2021

U.S. EPA has proposed to lower the level of the annual $PM_{2.5}$ NAAQS standard to between 9.0 to 10.0 µg/m^3 and is taking comments on lowering the 24-hour NAAQS standard to as low as 25 µg/m^3 (U.S. EPA, 2023).

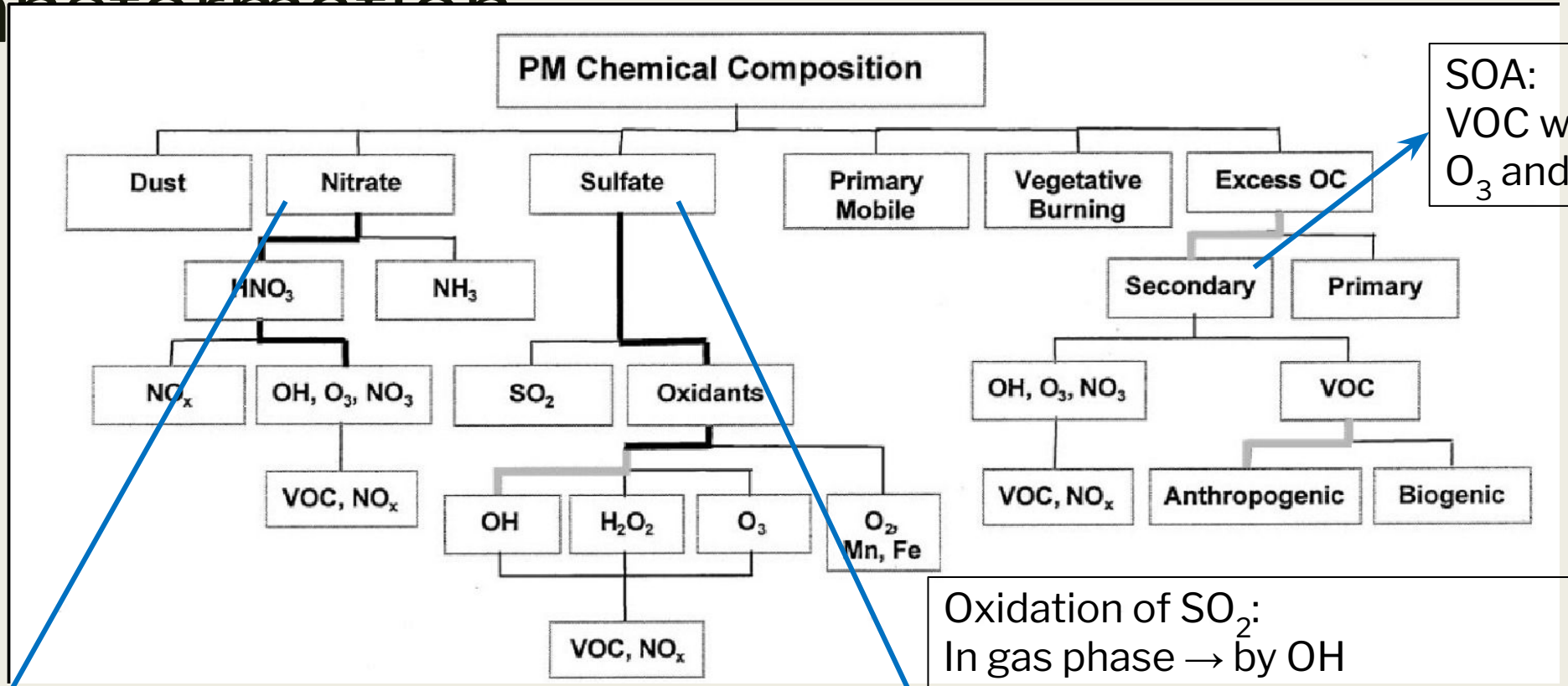


New EPA standard

Figures from LADCO $PM_{2.5}$ Trends 2001-2021

Drivers of $PM_{2.5}$ Formation and Transportation

Chemical Composition and Transformation



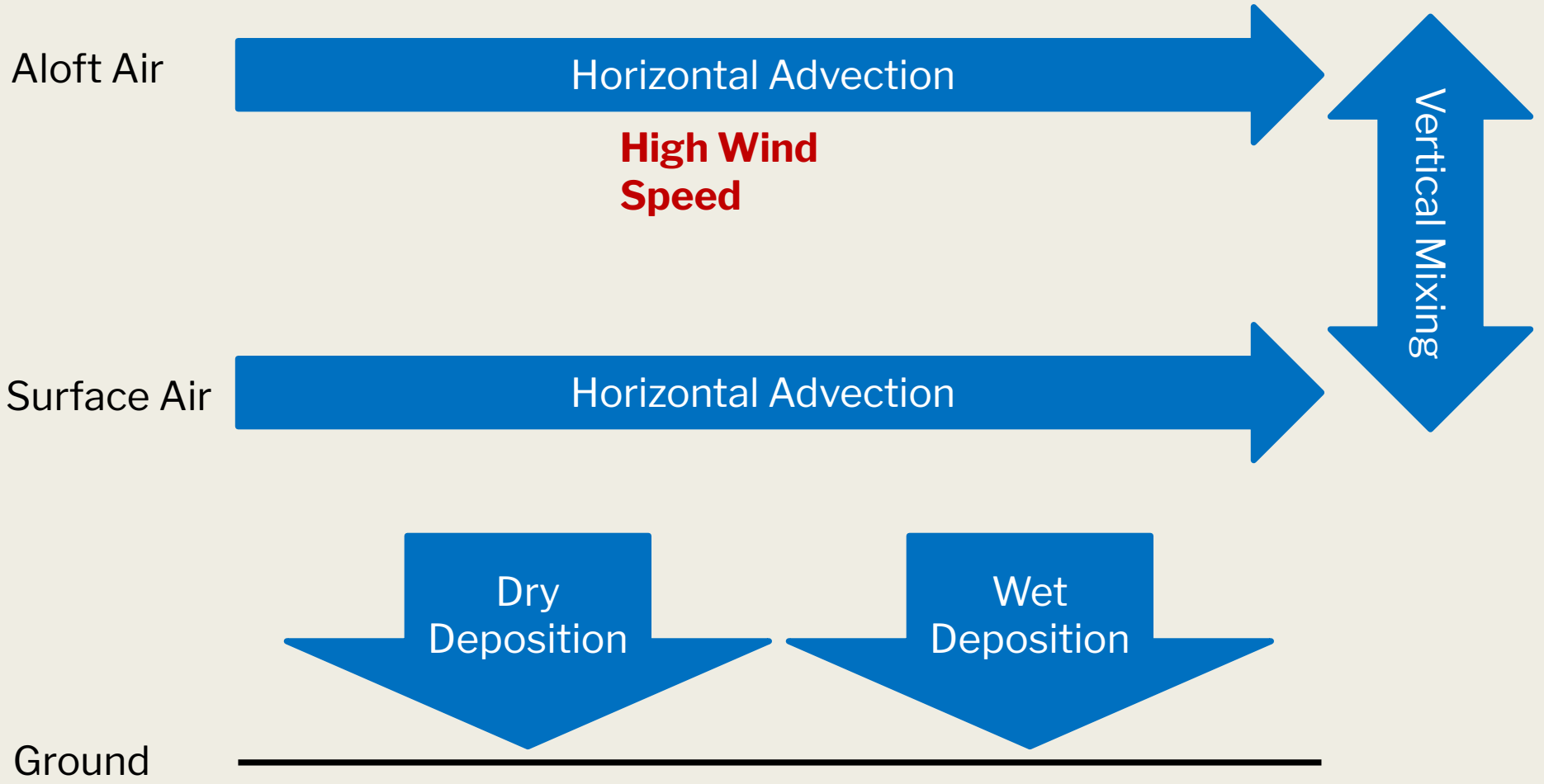
SOA:
VOC with OH, O_3 and NO_3

Daytime: $OH + NO_2 \rightarrow HNO_3 \rightarrow$ nitrate by partition
Night: $NO_2 + O_3 \rightarrow NO_3 \rightarrow N_2O_5 \rightarrow$ nitrate

Oxidation of SO_2:
In gas phase → by OH
Inside fog drops →
(1) by O_3
(2) by O_2 with Fe^{3+} or Mn^{2+} as catalysts
(3) by H_2O_2

Figure from Pun and Seigneur, 1999.

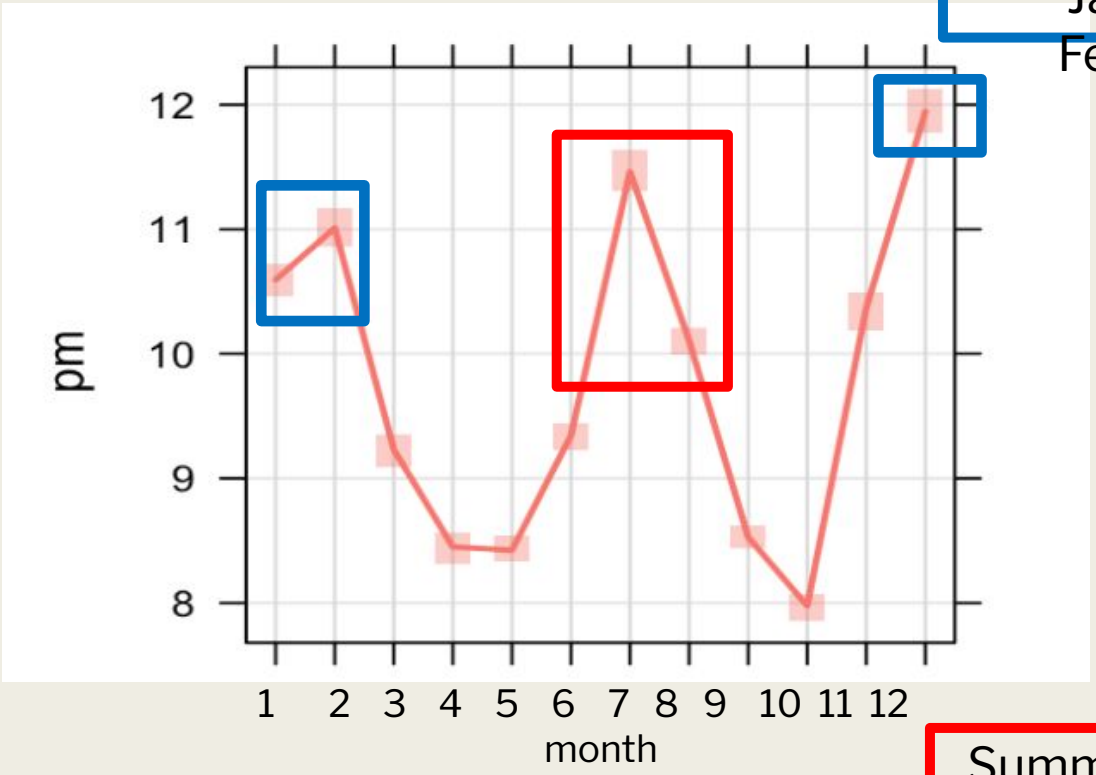
Physical Transport



DATA AND METHOD

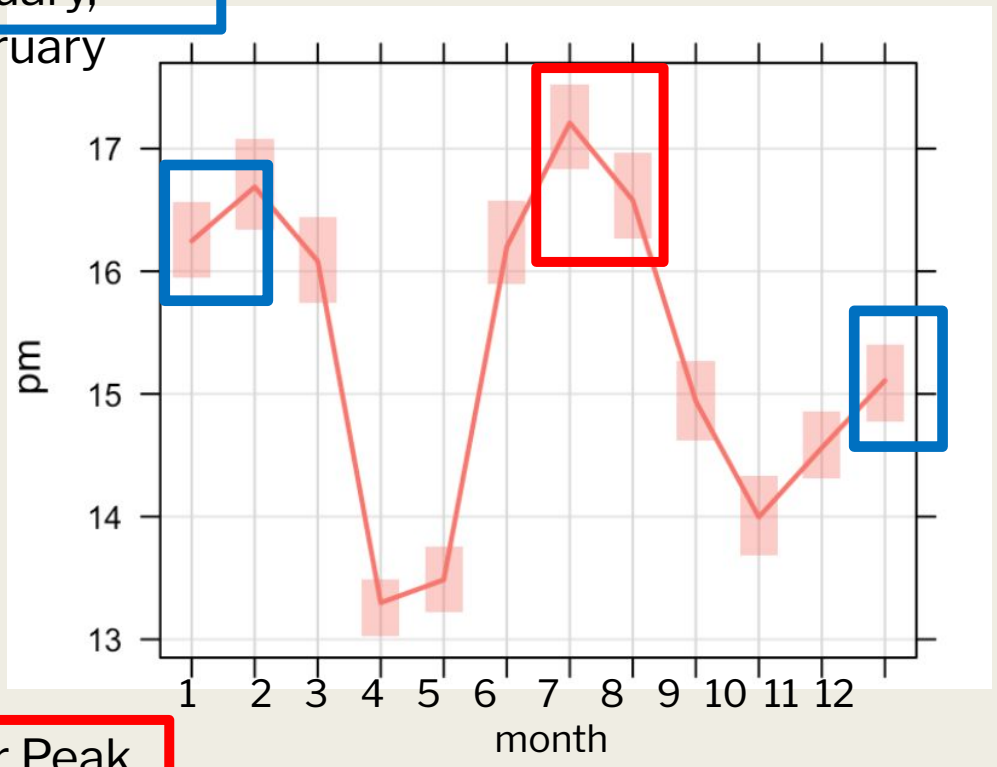
Data Source: Air Quality System (AQS) by EPA
Time Period: 2018-2022 and 2000-2004
Locations: Chicago, Cincinnati, Cleveland, Detroit, Indianapolis, Milwaukee and Minneapolis

2018-2022



Winter Peak
December,
January,
February

2000-2004

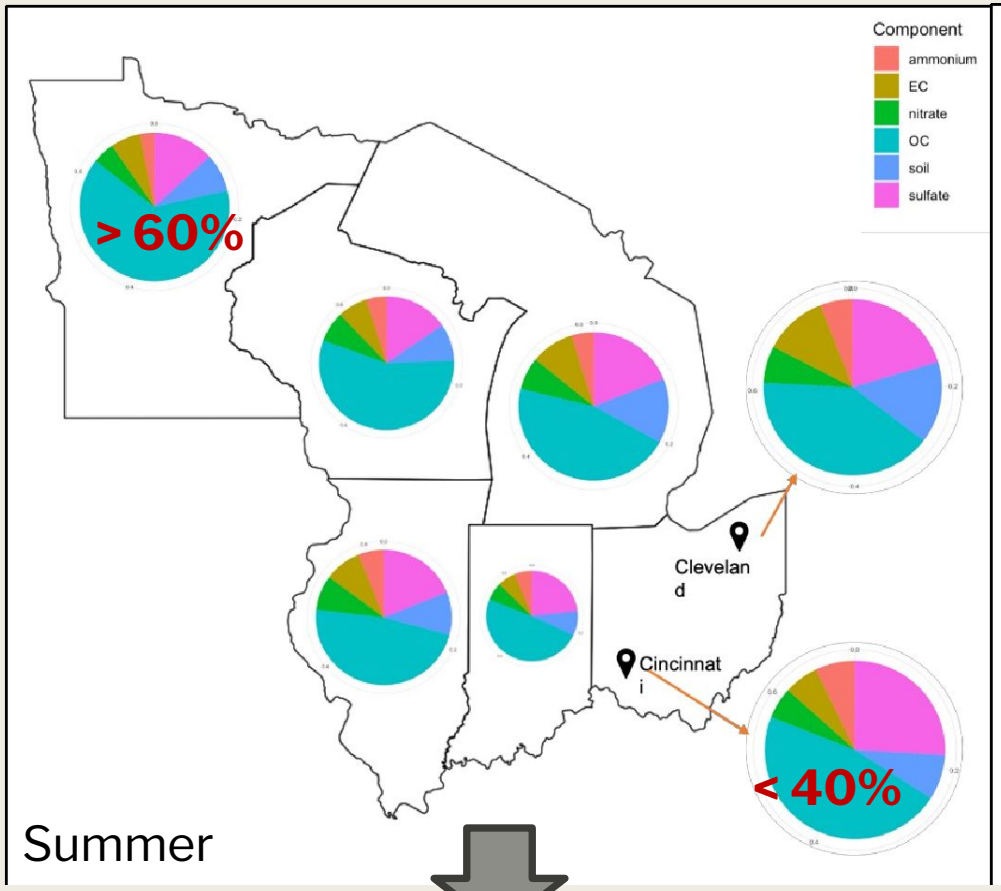


Summer Peak
July, August

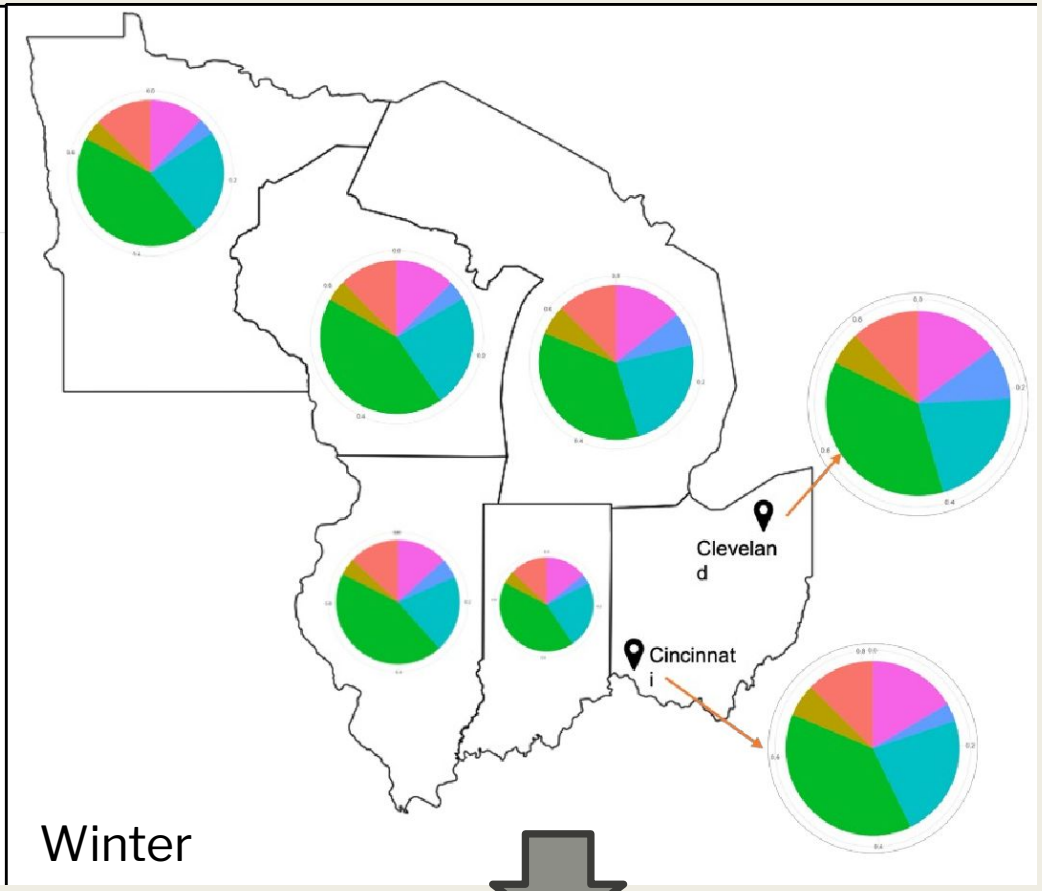
CONCEPTUAL MODEL

Chemical Speciation

2018-2022



Summer

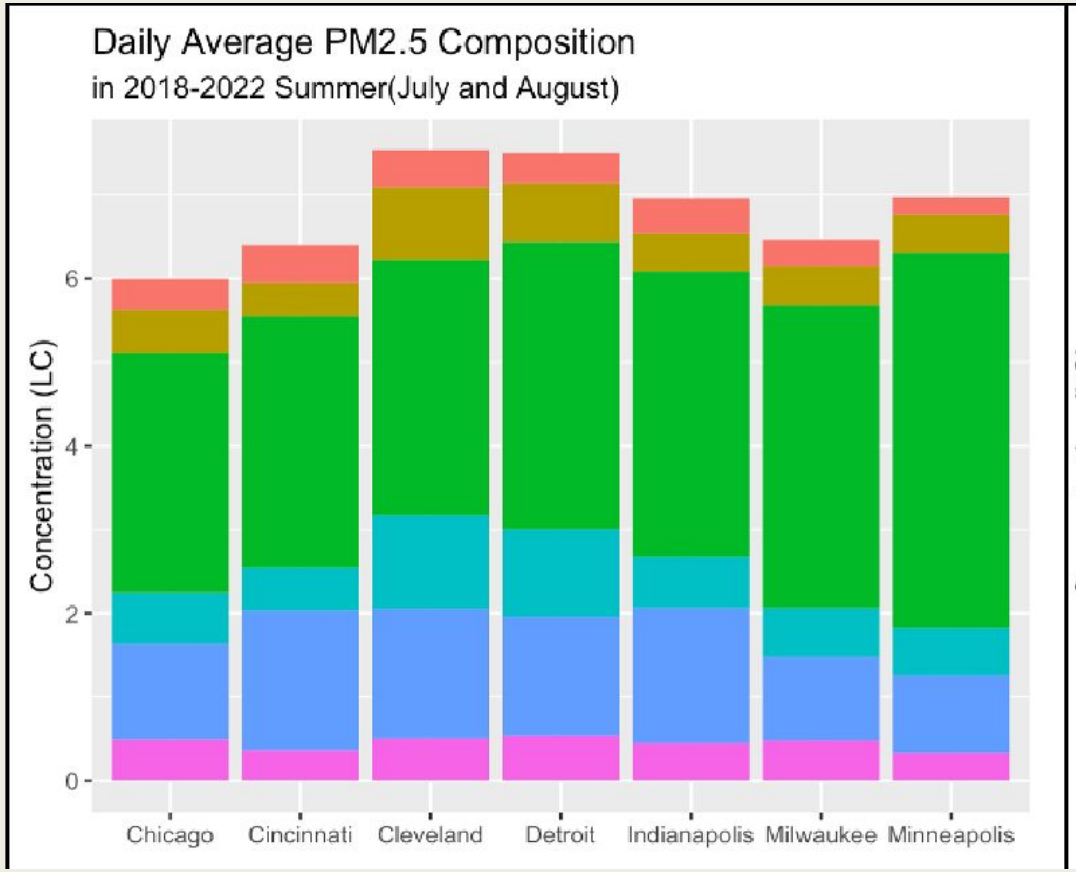


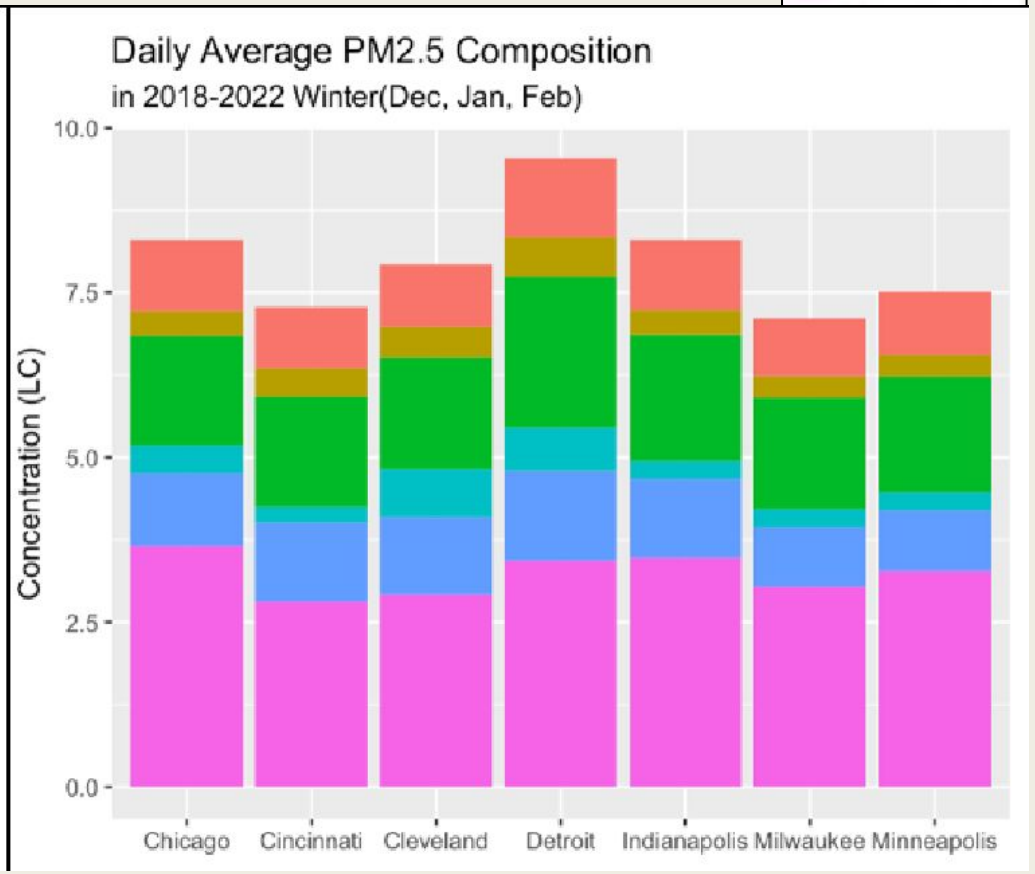
Winter

OC >>sulfate > soil >nitrate ≈ EC > ammonium

nitrate > OC > ammonium ≈ sulfate > soil ≈ EC

2018-2022



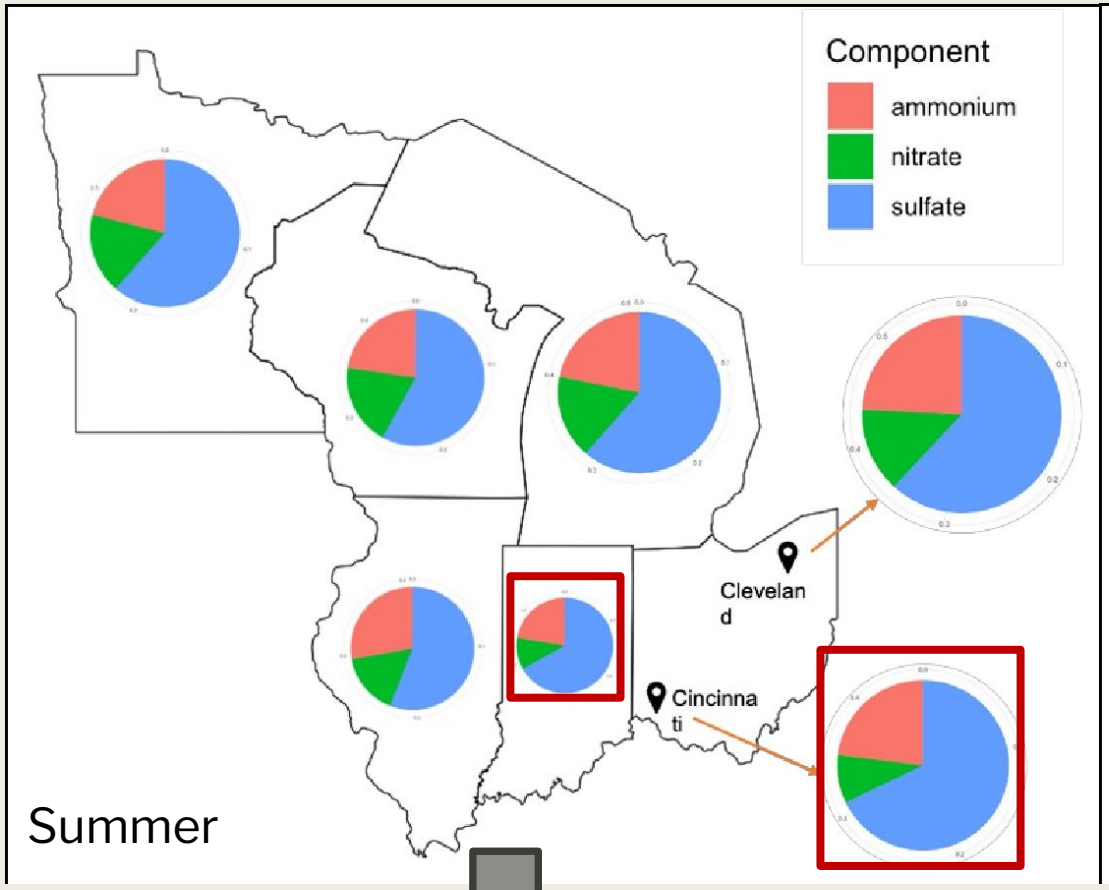


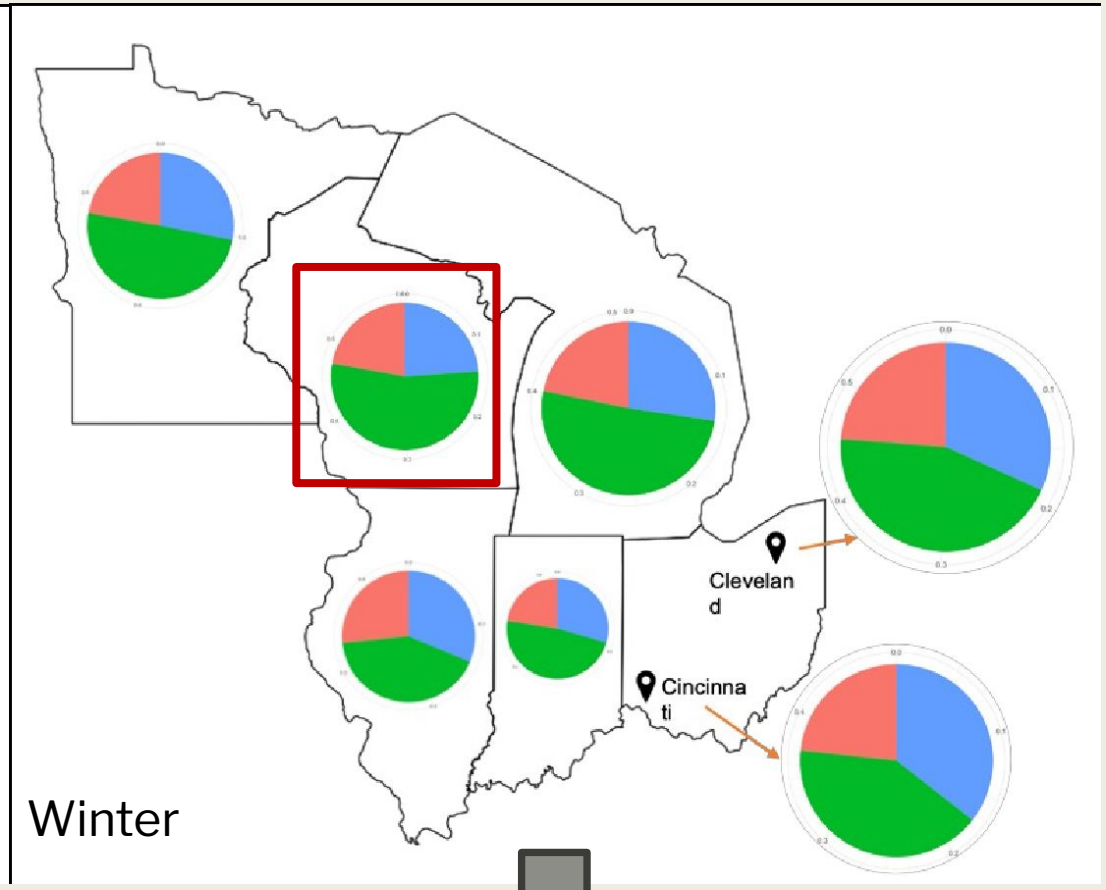
OC contributed more in northern states (WI/MI/MN).
- highest in Minneapolis

Sulfate contributed more in southern states(IN/OH)

Uniform in winter

2000-2004

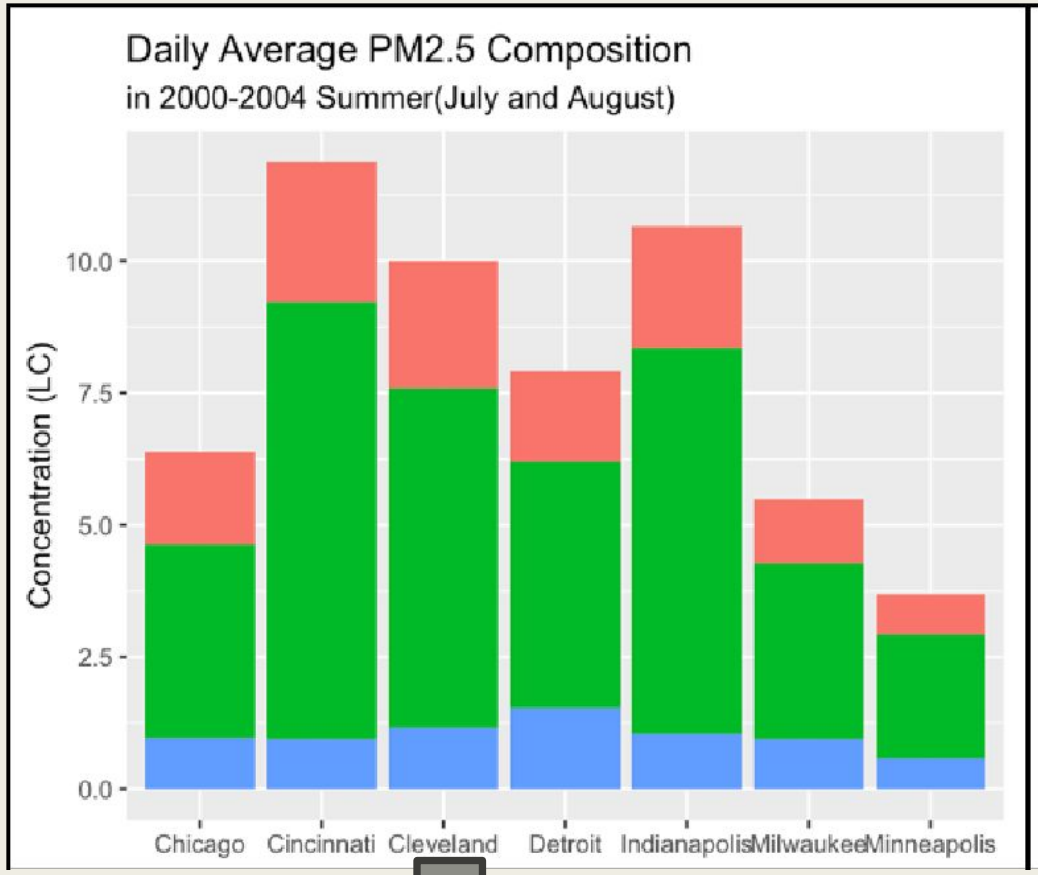


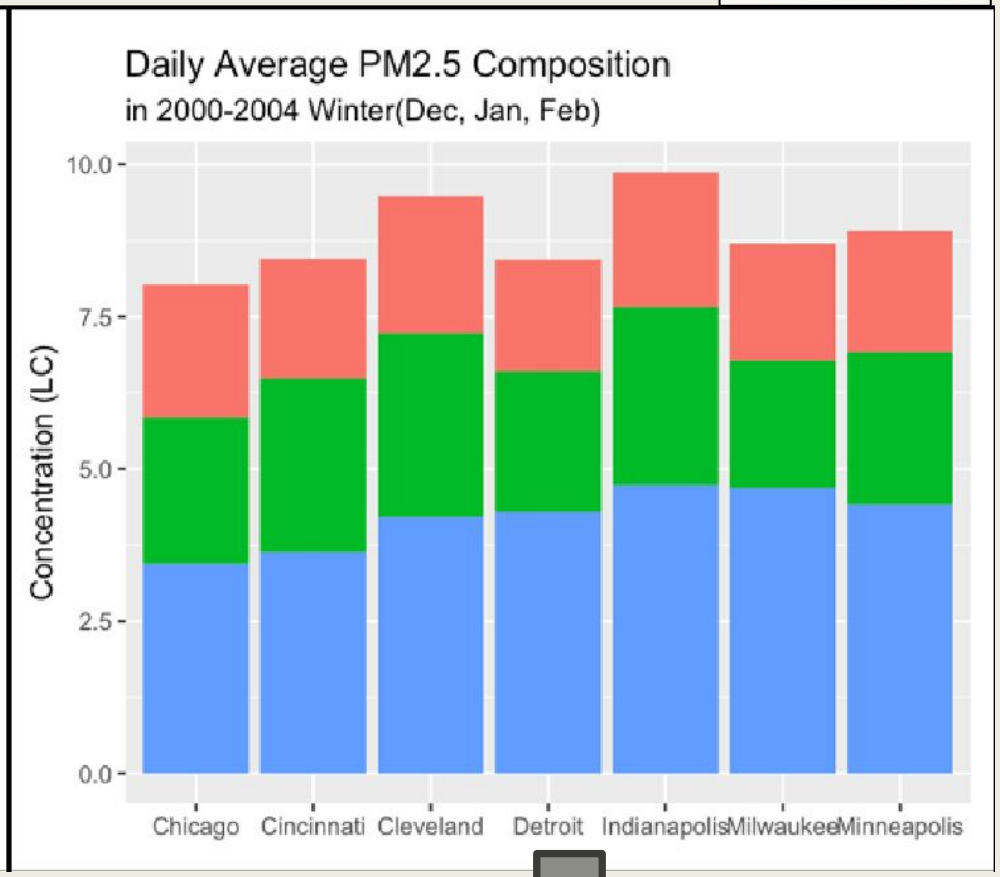


sulfate > ammonium > nitrate

nitrate > sulfate > ammonium

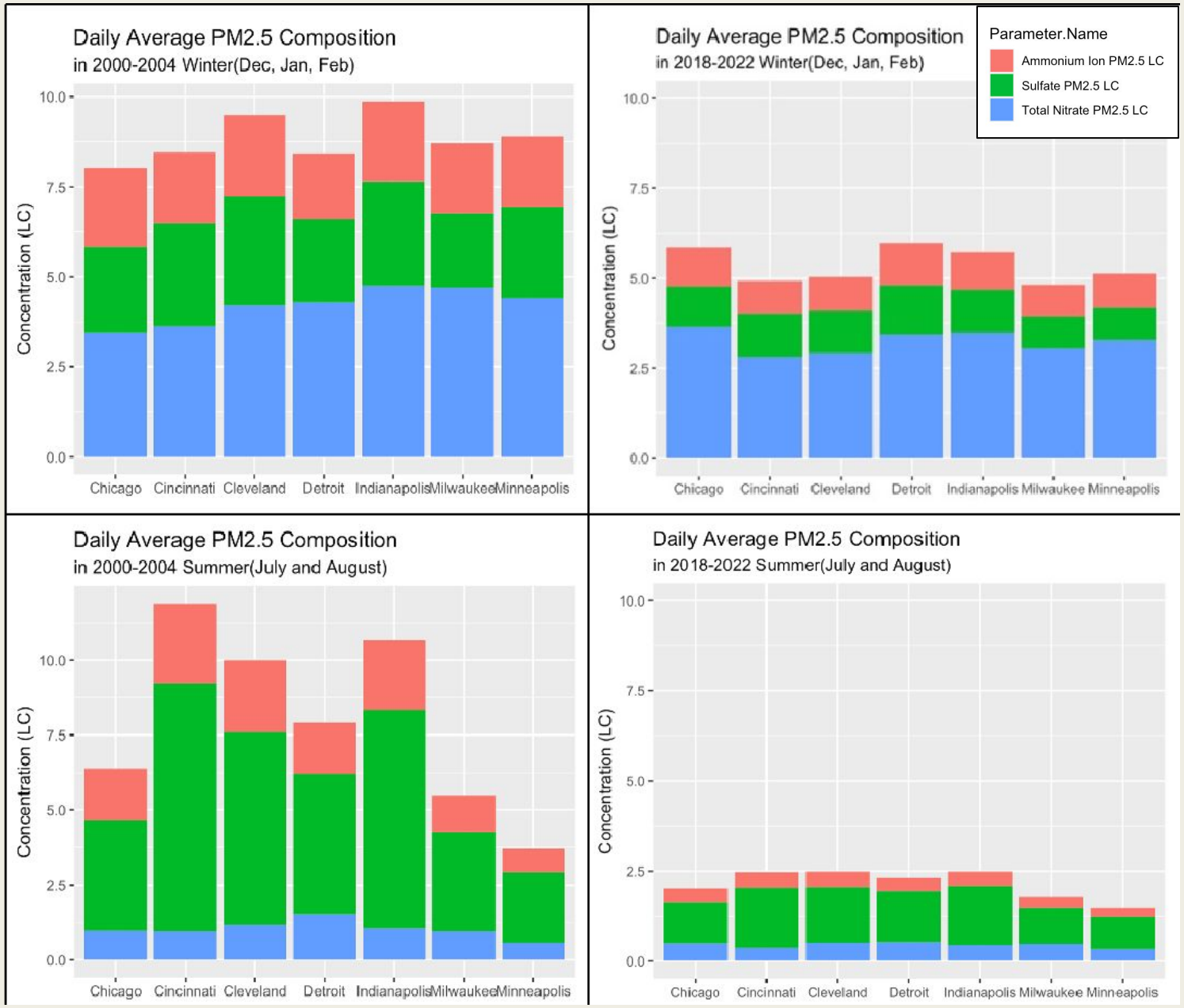
2000-2004





more $PM_{2.5}$ in the southern states than in the north
-more than 3 times as much in Cincinnati as in Minneapolis.

Sulfate is higher in southern states.
Nitrate is lowest in Chicago and Cincinnati and highest in Indianapolis.



In winter:

- Total concentration decreased a third from 2000-2004 to 2018-2022
  - Small in nitrate/large in sulfate/ammonium
- The relative proportion of sulfate and ammonium were similar in both periods, but the proportion of nitrate increased
- Highest concentrations: from Cleveland and Indianapolis to Chicago and Detroit (from south to north)

In summer:

- Total concentrations of three components decreased much more than those in winter
  - Largest in sulfate
- Highest: Cincinnati, Cleveland, Indianapolis (south)

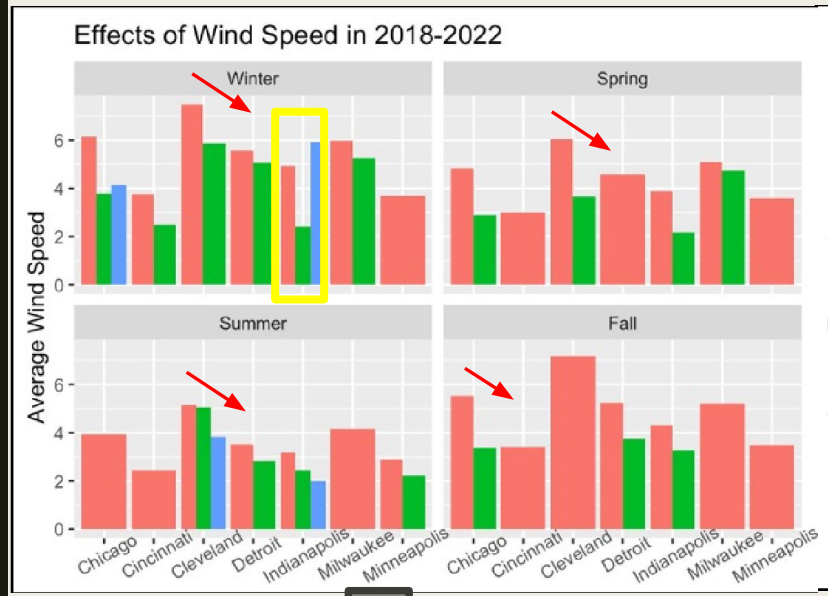
Meteorology

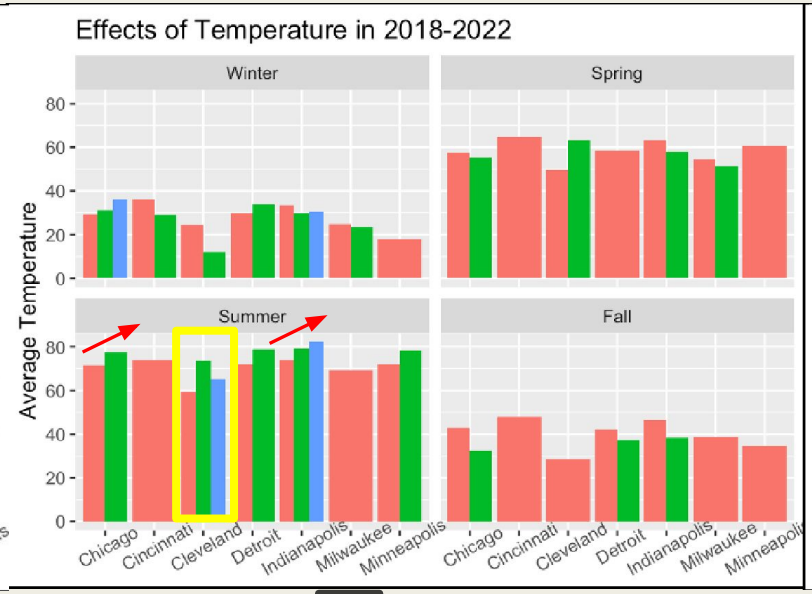
Wind Speed/Temperature/Relative Humidity

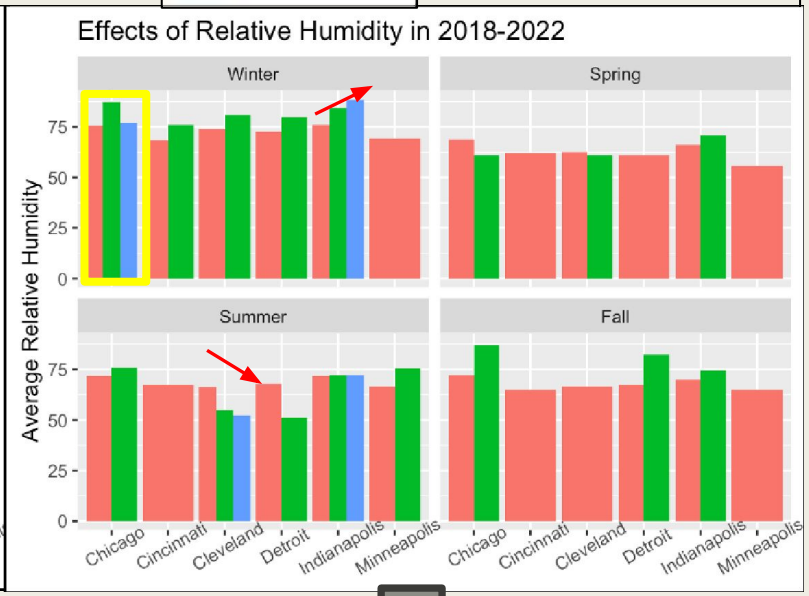
Exception: small number of data, larger emissions or wind blowing from larger sources to the city in high concentration days

PM Concentration
low con
med con
high con

low con: <= 25 ug/m^3
med con: > 25 ug/m^3 <= 35 ug/m^3
high con: > 35 ug/m^3





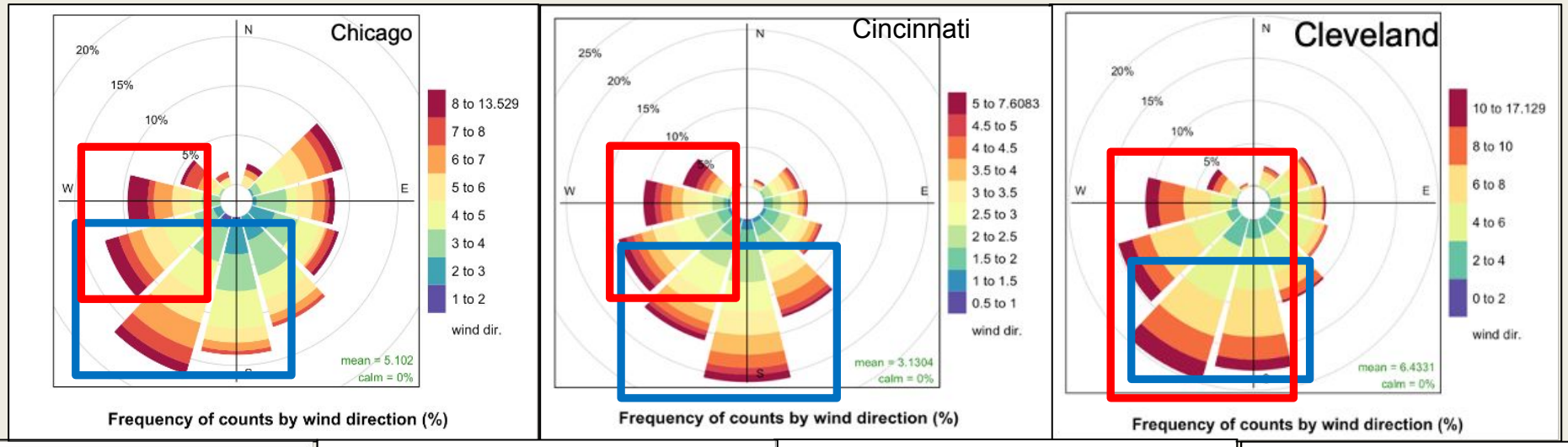


The higher wind speed is, the lower $PM_{2.5}$ concentration is in all seasons, and wind speed was lower in summer than in winter.

In summer, the higher temperature is, the higher $PM_{2.5}$ concentration is.

In summer, the lower relative humidity is, the higher concentration is, while in winter, the higher relative humidity is, the higher concentration is.

Meteorology – Wind Direction



Winds were most frequently from south side of the city.
High $PM_{2.5}$ concentrations mostly came from west side of the city.

CONCLUSION

$PM_{2.5}$ concentration decreased dramatically over these 20 years, while it started to increase again recently.
EPA has proposed to lower the annual standard and is taking comments on lowering 24-hour standard.

Dominant component in summer: OC (2018-2022) ; sulfate (2000-2004)
Dominant component in winter: nitrate
Sulfate concentration is higher in southern states.

The higher wind speed is, the lower $PM_{2.5}$ concentration is.
The higher temperature is, the higher $PM_{2.5}$ concentration is in summer.
The lower relative humidity is, the higher concentration is in summer, while in winter, the higher relative humidity is, the higher concentration is.
High $PM_{2.5}$ concentrations mostly came from west side of the city.

THANKS!