National, Regional, Between-City, and Within-City Spatial Variability in Air Toxics

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Overall Approach

- Top Down
  - National Variability
  - Regional Variability
  - Between-city Variability
  - Within-city Variability
- Analyses
  - Visual
    - Box-plots
    - Proportional symbol maps
    - Bar charts
  - Statistical
    - Concentration ranges
    - Spatial Coefficients of Variation (CV)
    - Ratios of concentrations
      - Mean:median
      - 75^{th} to 25^{th} percentile

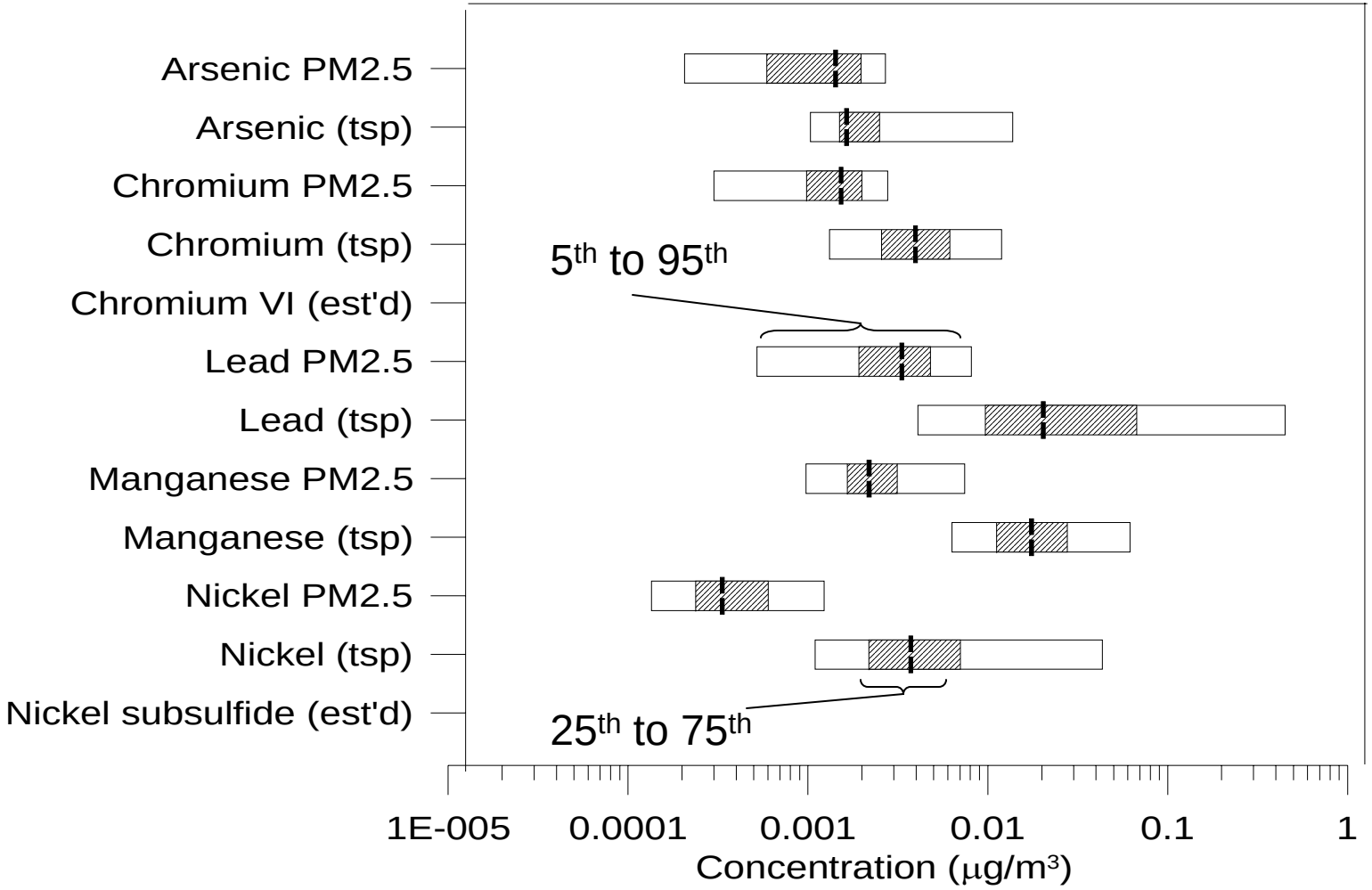
Spatial Variability – Site-averages

- Site-average = the mean of annual average concentrations for a given site and pollutant between 2000 and 2003
- The mean value of up to four annual averages was used to remove the possible influence of climatology (e.g., a hot year)
- 2000-2003 were chosen because
  - these data are most reflective of current concentrations
  - data are available at more sites
  - longer time periods may result in errors because of trends (previous talk)

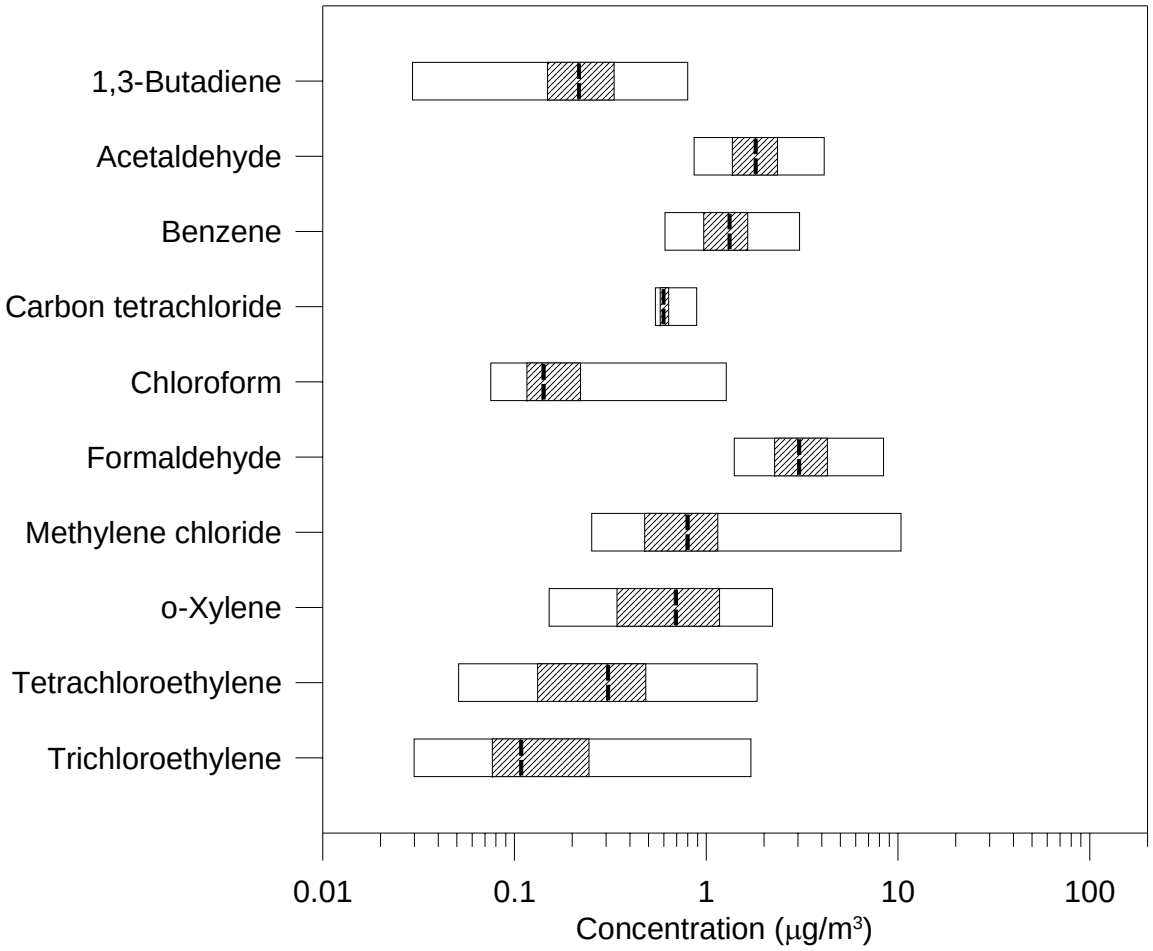
National Variability In Concentrations – Approach

- Quantify and display the urban concentration ranges of air toxics from 2000 to 2003
- Quantify and display the MDL ranges from 2000 to 2003 to assess how well we can quantify the lower range of concentrations
- Compare concentration ranges to 10^{-6} cancer benchmarks

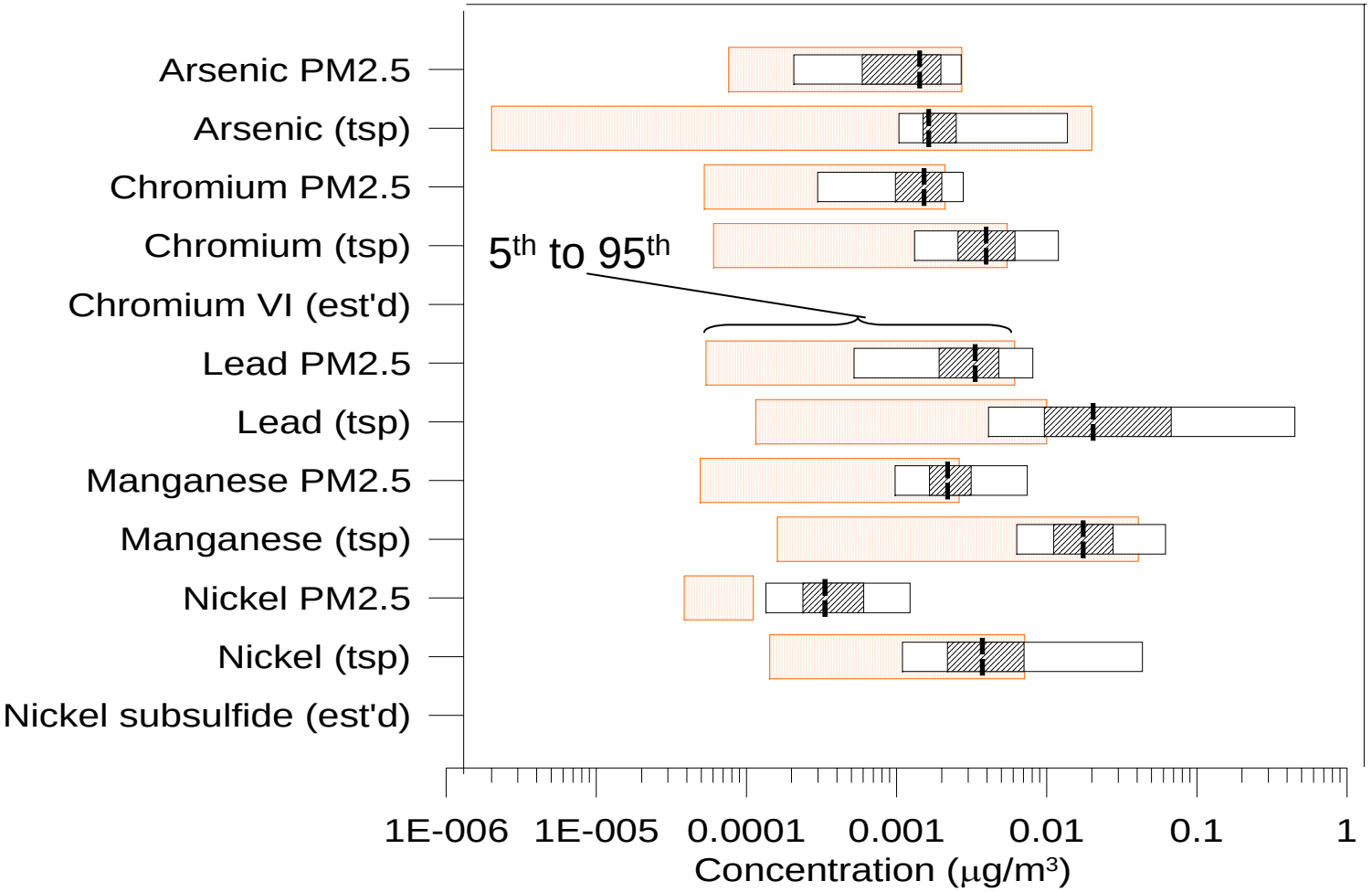
National Urban Concentration Ranges (1 of 2)



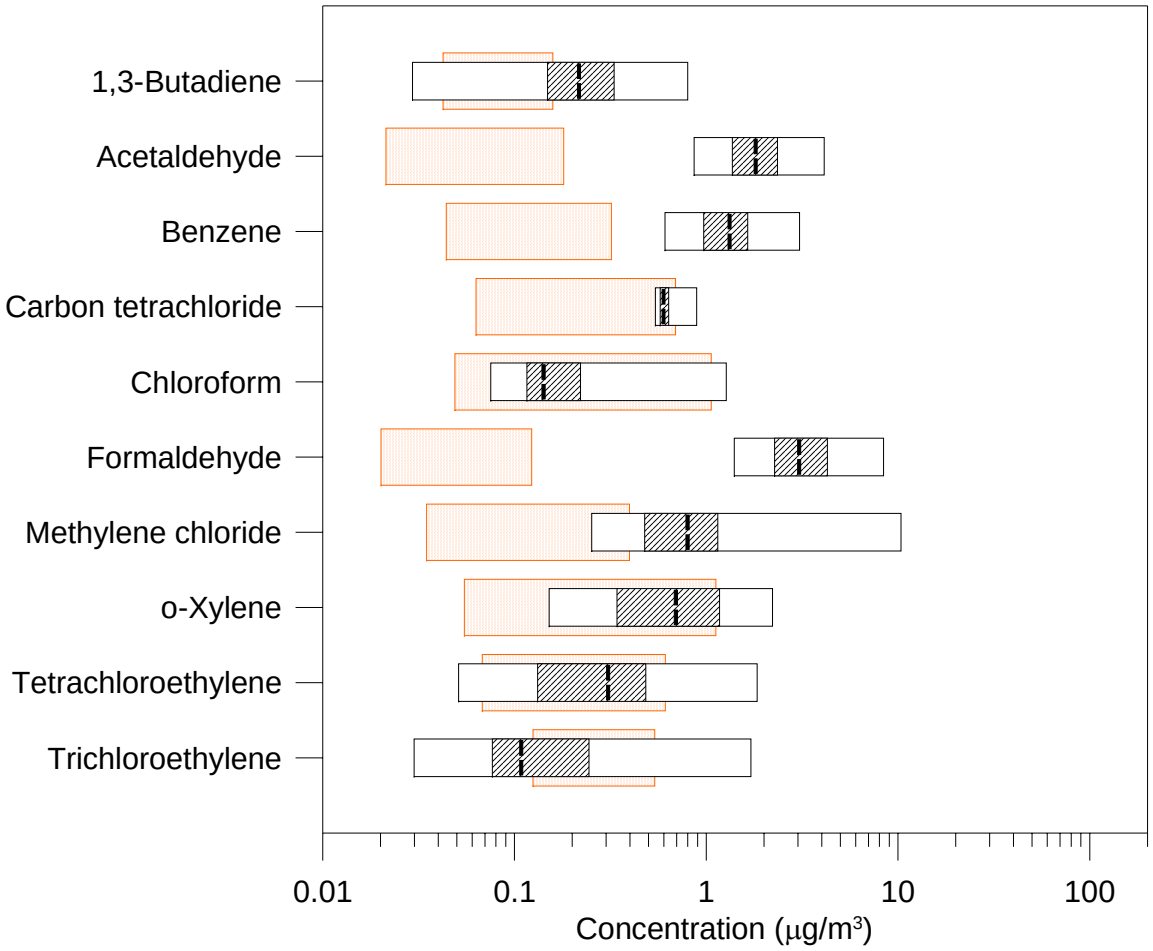
National Urban Concentration Ranges (2 of 2)



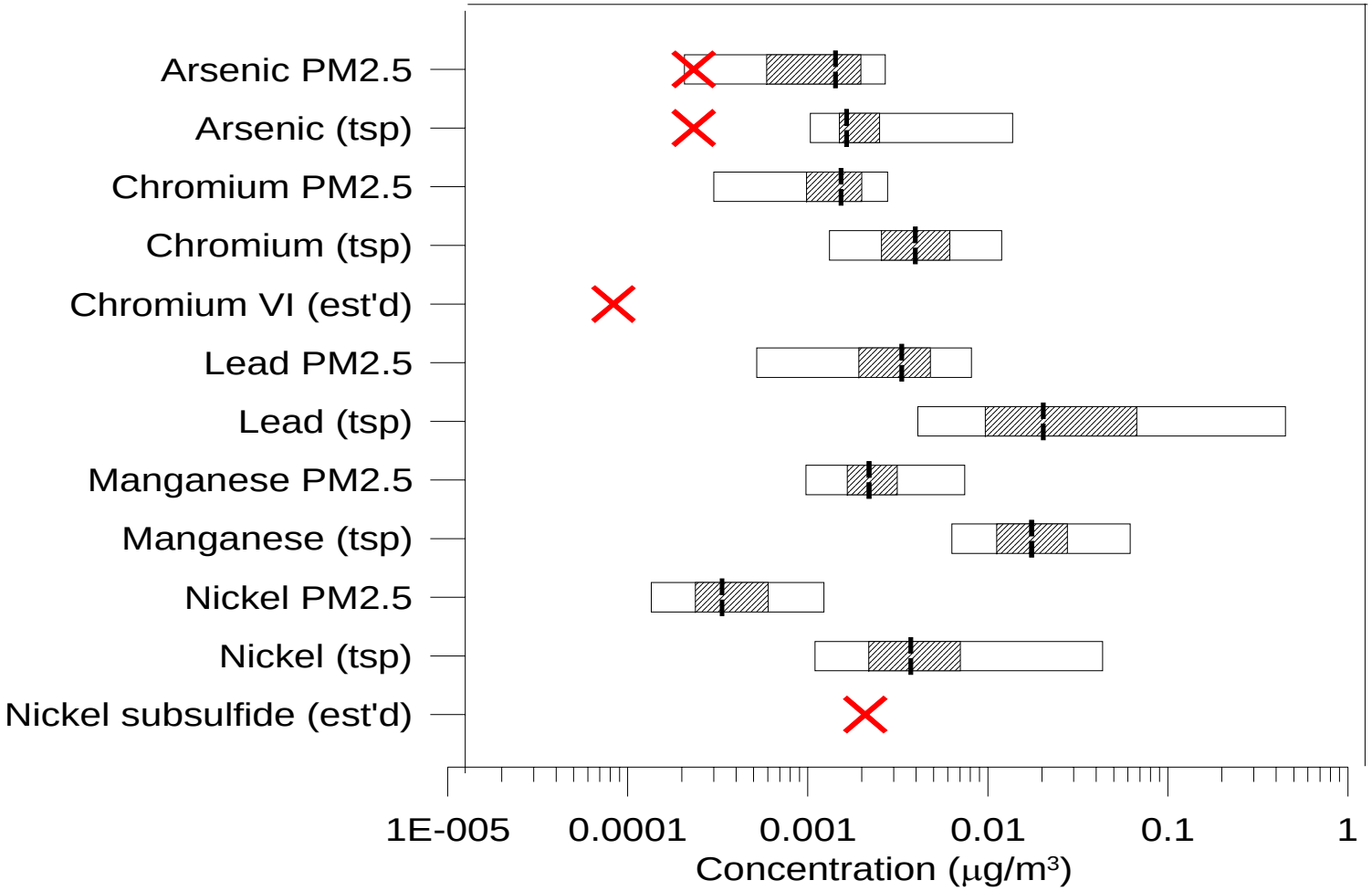
National Urban Concentration Ranges and MDL Ranges (1 of 2)



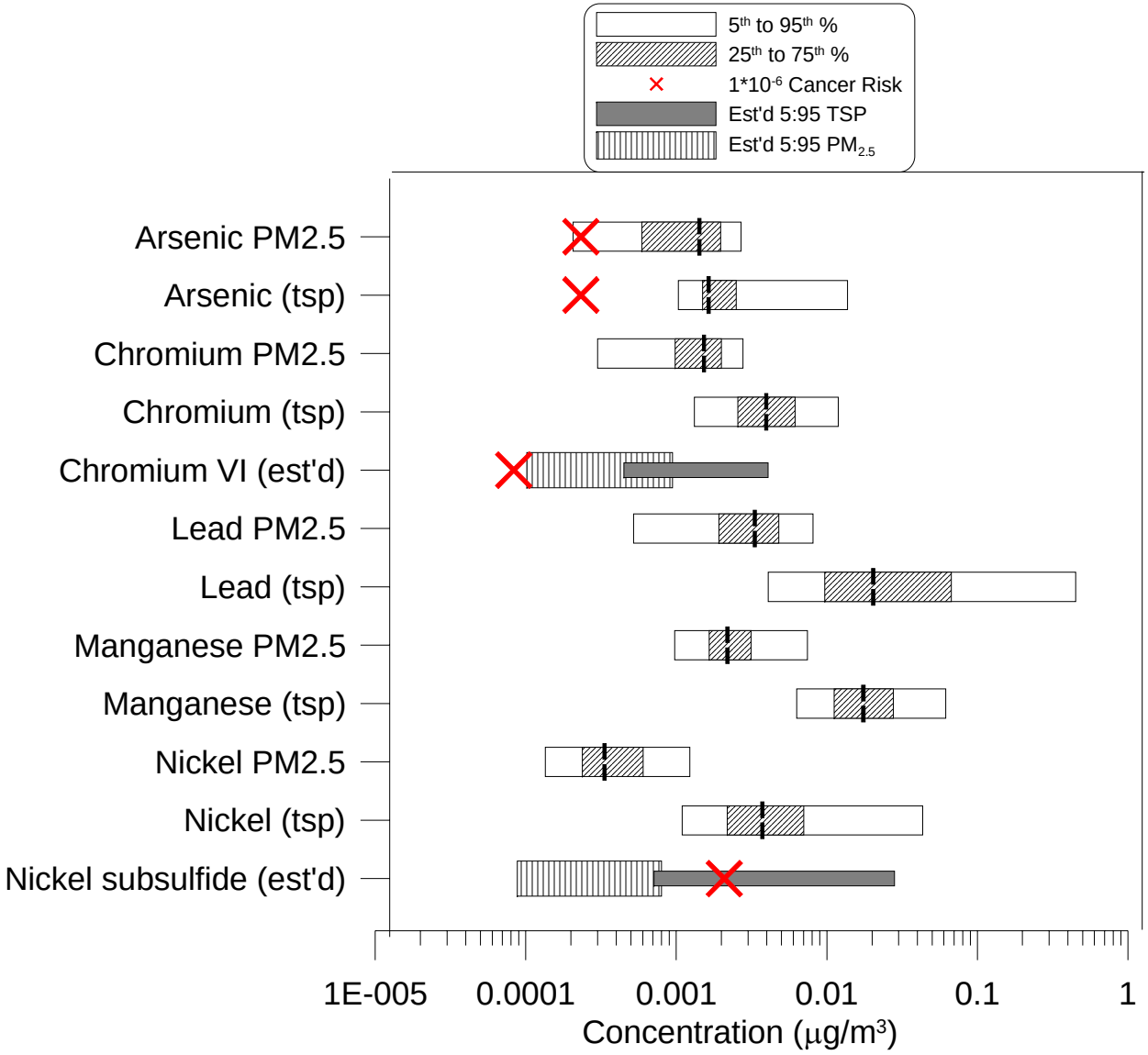
National Urban Concentration Ranges and MDL Ranges (2 of 2)



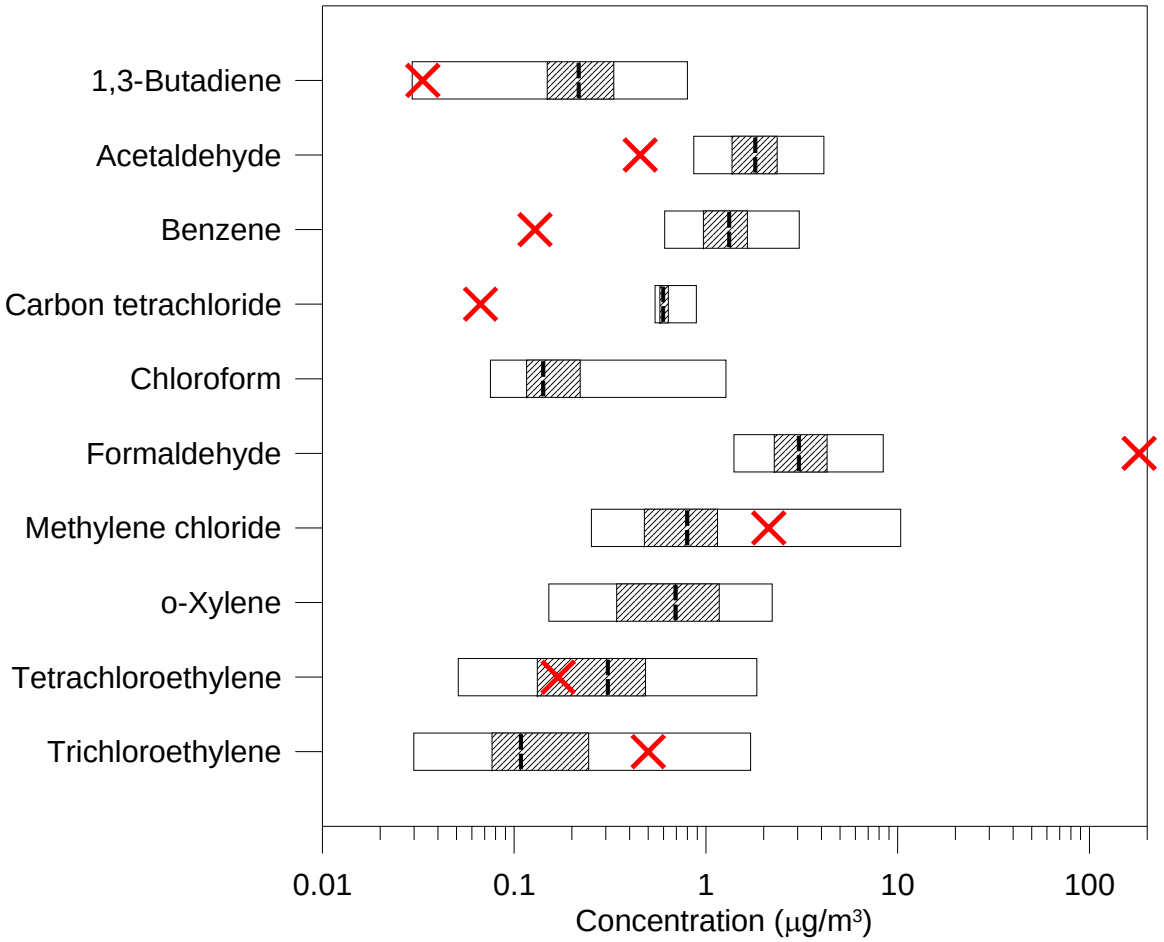
National Urban Concentration Ranges and $1*10^{-6}$ Cancer Benchmarks (1 of 3)



National Urban Concentration Ranges and $1*10^{-6}$ Cancer Benchmarks (2 of 3)



National Urban Concentration Ranges and $1*10^{-6}$ Cancer Benchmarks (3 of 3)

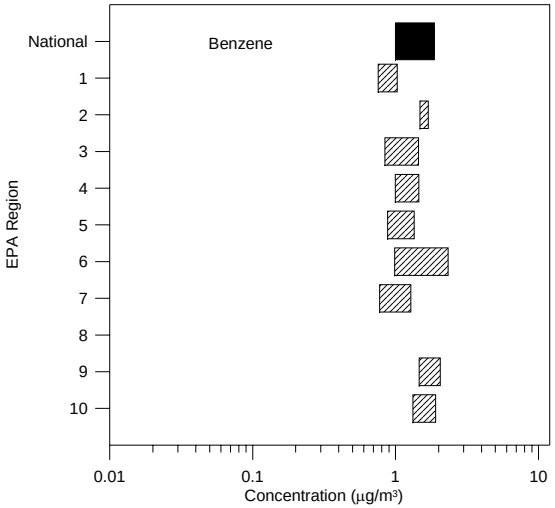


National Urban Concentration Ranges – Conclusions

- Concentration ranges show that most HAPs are highly variable.
- Many pollutants have ranges that are skewed high (i.e., urban concentrations are not normally distributed).
- MDLs for many air toxics are too high to characterize the low end of urban concentration ranges.
- Many air toxics urban concentrations are above 10^{-6} cancer benchmark values.

Regional Variability

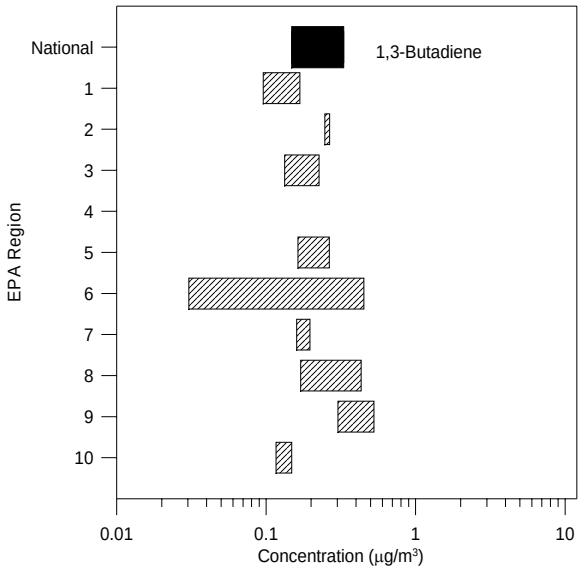
Box plots of interquartile ranges for each region are shown in the next few slides.



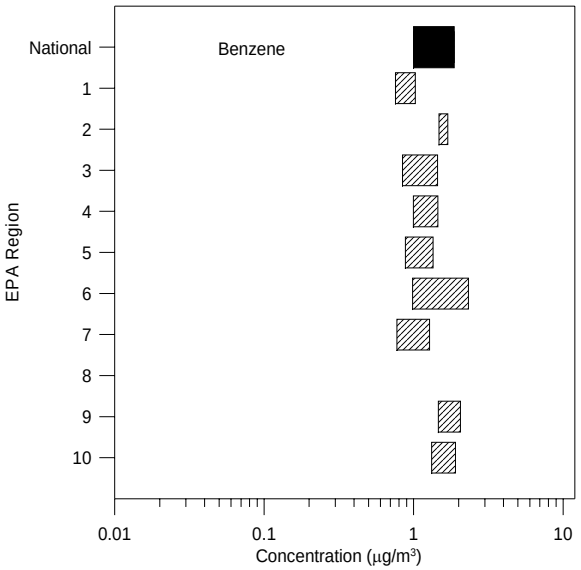
Regional Variability – Approach

- Quantify and display typical concentrations by EPA region.
- Identify regional trends in chemically similar pollutants
- Check for urban and rural differences

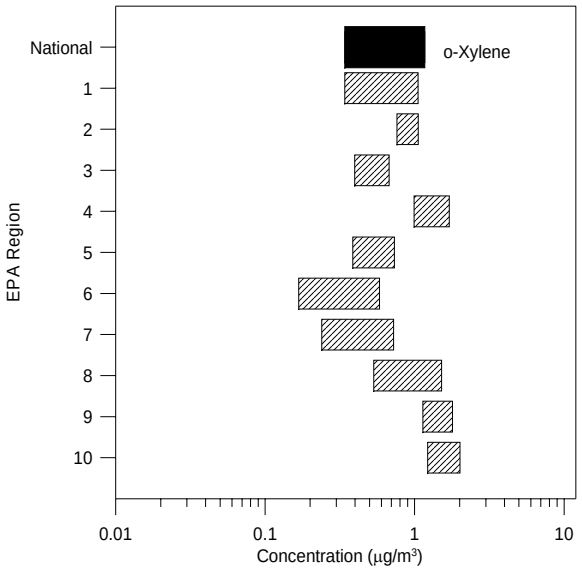
Regional Variability – Gaseous HAPs (1 of 3)



1,3-Butadiene



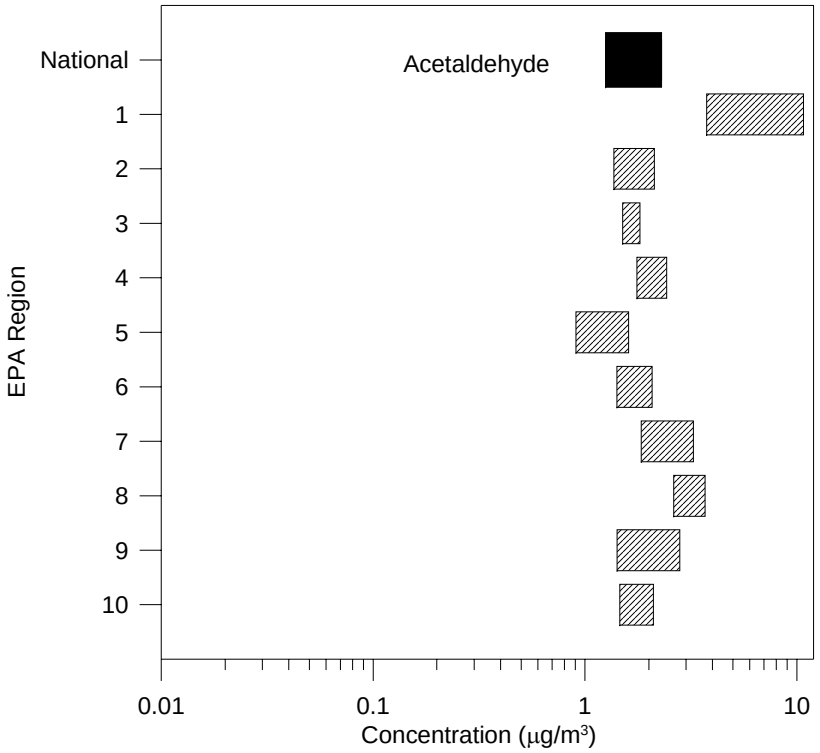
Benzene



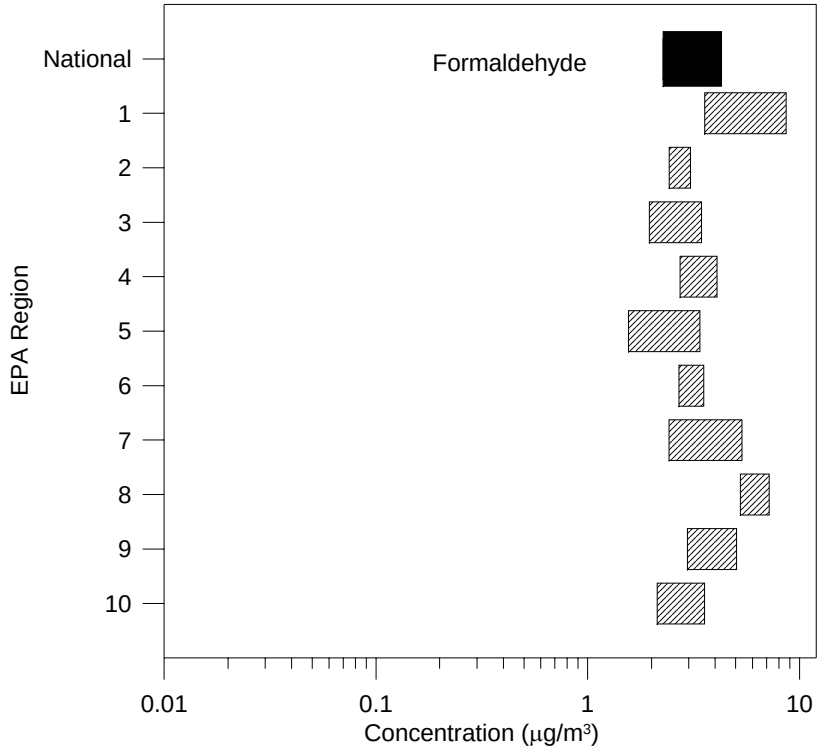
o-Xylene

Concentrations in Region 9 are slightly higher than the national average for all three species. Not much regional variability for benzene, slightly more for o-xylene, and a bit more for 1,3-butadiene.

Regional Variability – Gaseous HAPs (2 of 3)



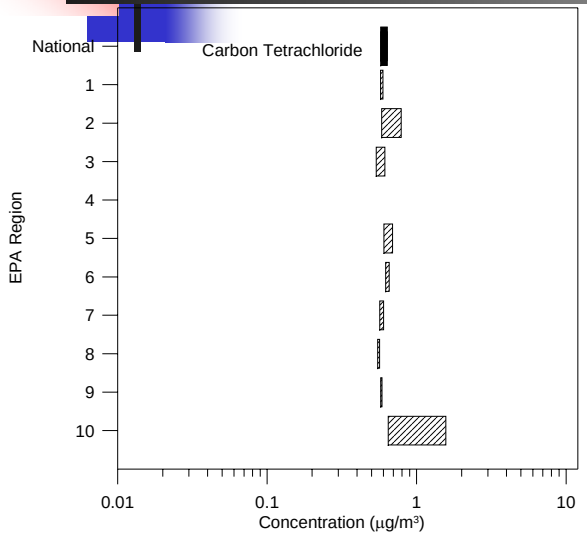
Acetaldehyde



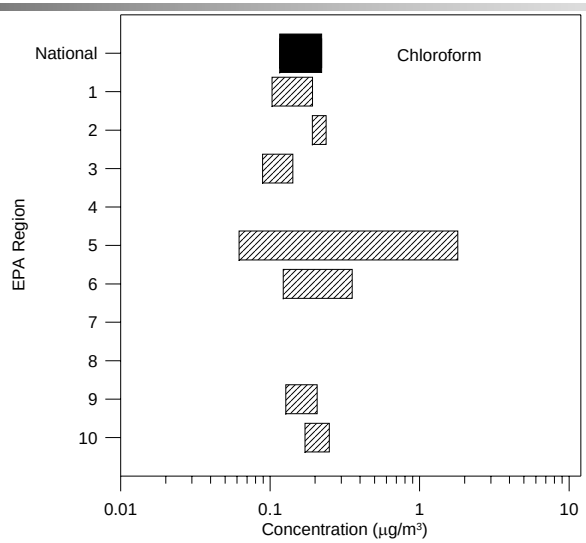
Formaldehyde

Concentrations in Regions 1 and 8 are based on just a few sites that have higher concentrations than those seen in other regions.

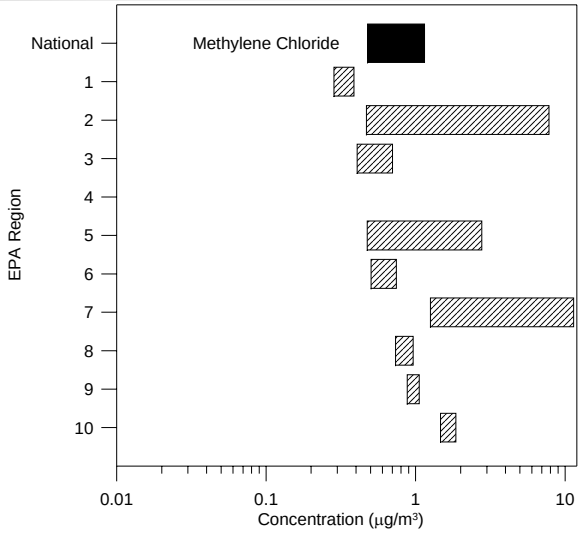
Regional Variability – Gaseous HAPs (3 of 3)



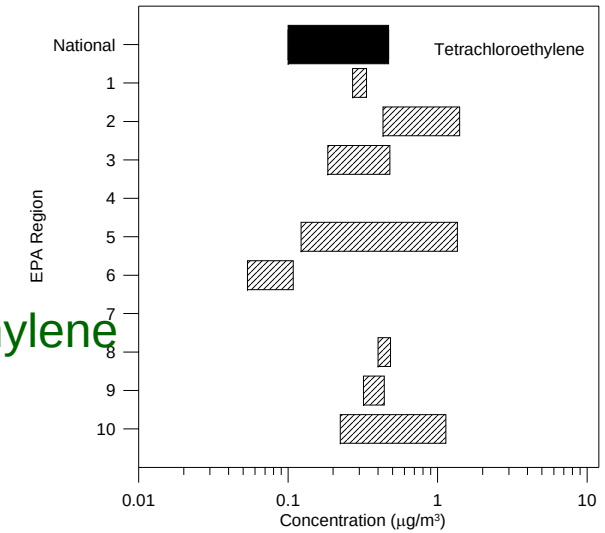
Carbon Tetrachloride



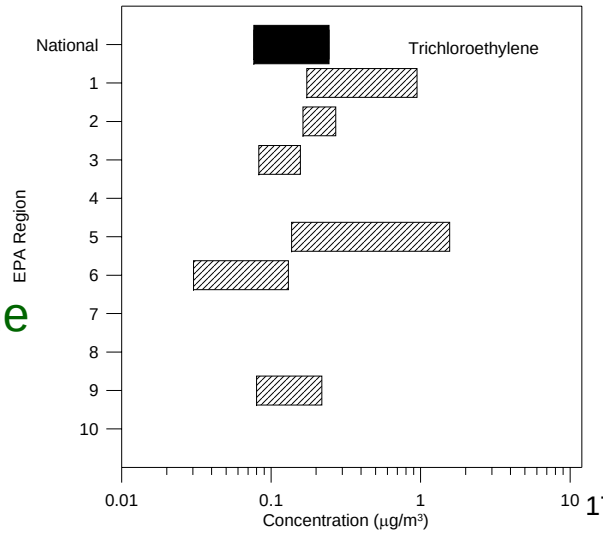
Chloroform



Methylene Chloride

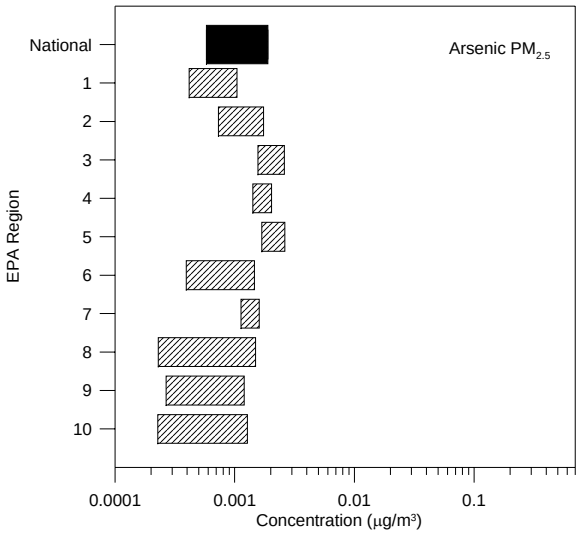


Tetrachloroethylene

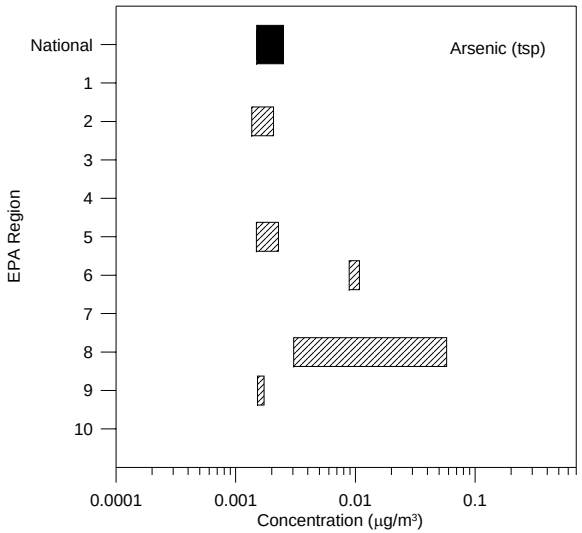


Trichloroethylene

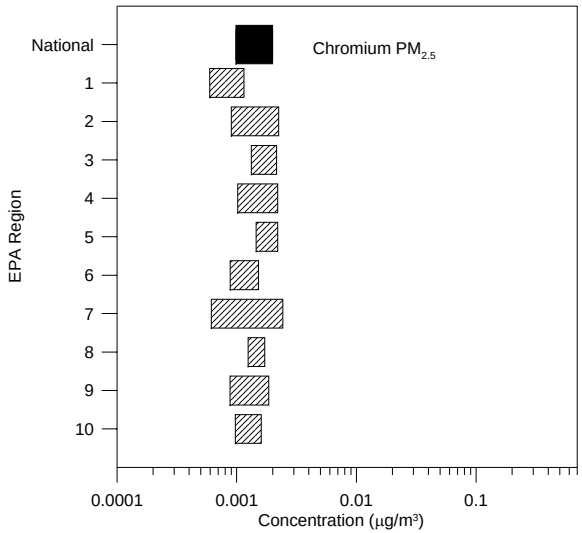
Regional Variability – PM Metals (1 of 2)



Arsenic $PM_{2.5}$



Arsenic (tsp)

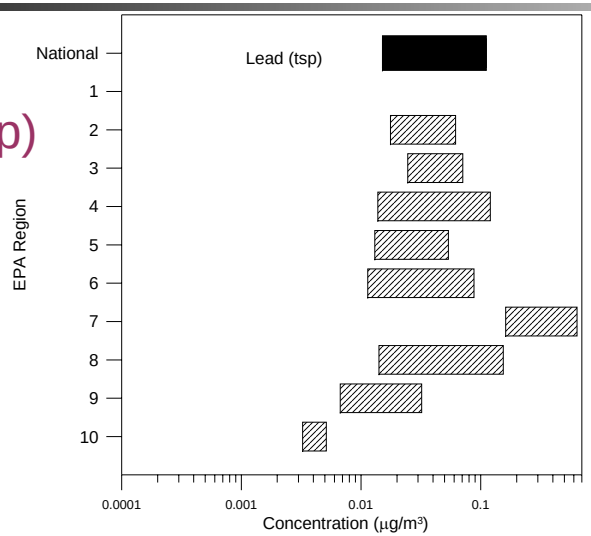


Chromium $PM_{2.5}$

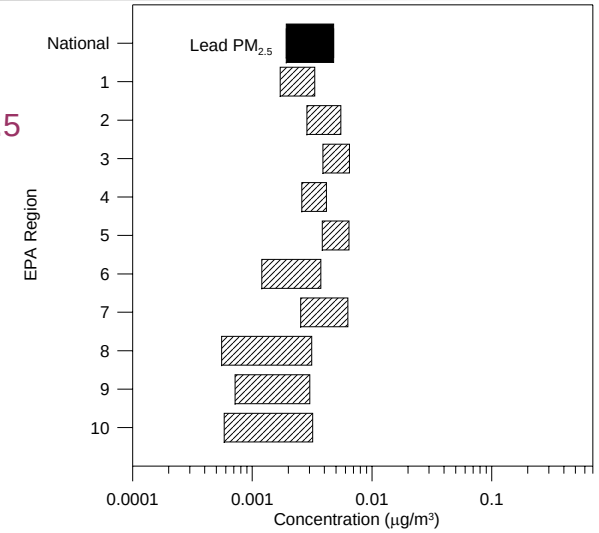
Arsenic and Chromium $PM_{2.5}$ concentrations are higher in the Midwest, southeast, and mid-Atlantic regions. Arsenic (tsp) concentrations in Region 8 are dominated by a site in Helena, Montana.

Regional Variability – PM Metals (2 of 2)

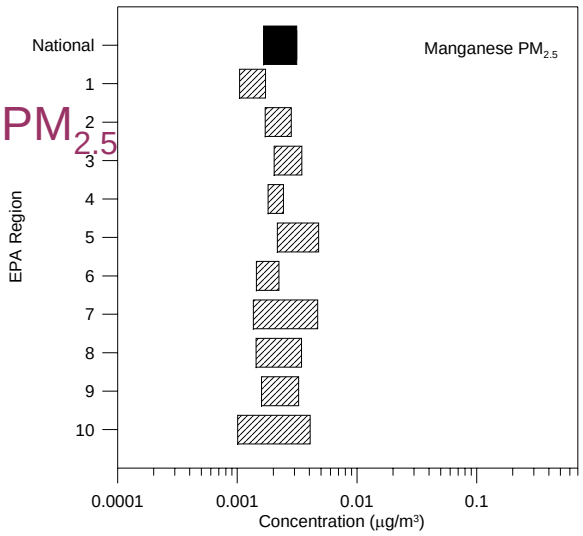
Lead (tsp)



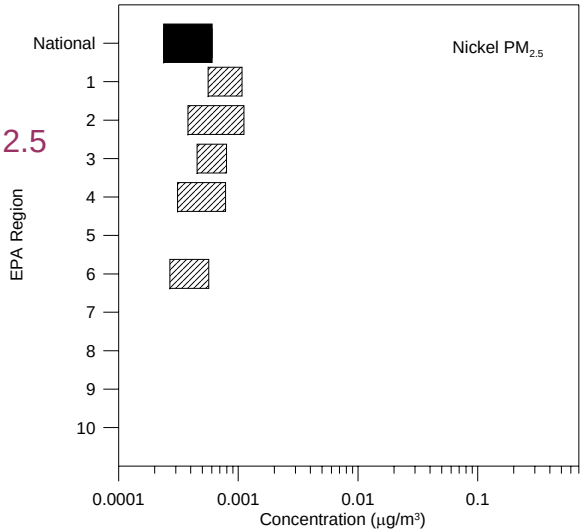
Lead $PM_{2.5}$



Manganese $PM_{2.5}$



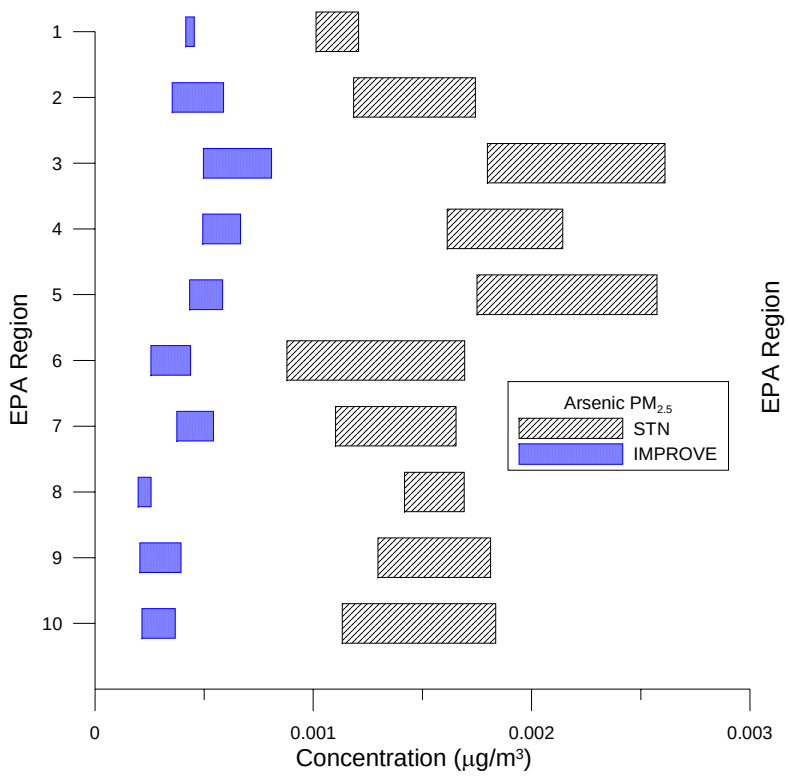
Nickel $PM_{2.5}$



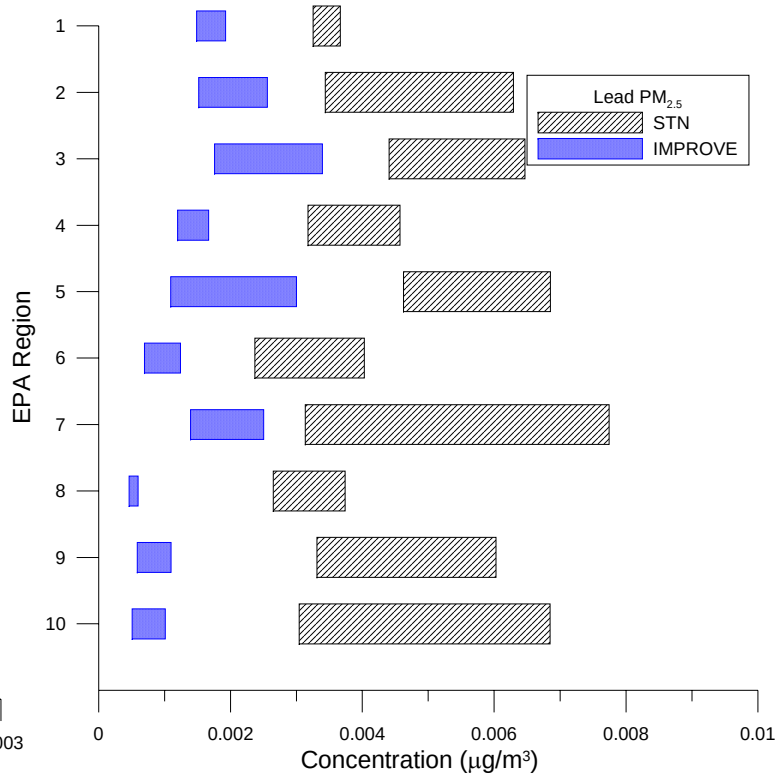
Urban and Rural Differences (1 of 2)…

Comparison of Speciation Trends Network (STN – urban) and Interagency Monitoring of Protected Visual Environments (IMPROVE) network interquartile concentration ranges by EPA region.

Arsenic $PM_{2.5}$



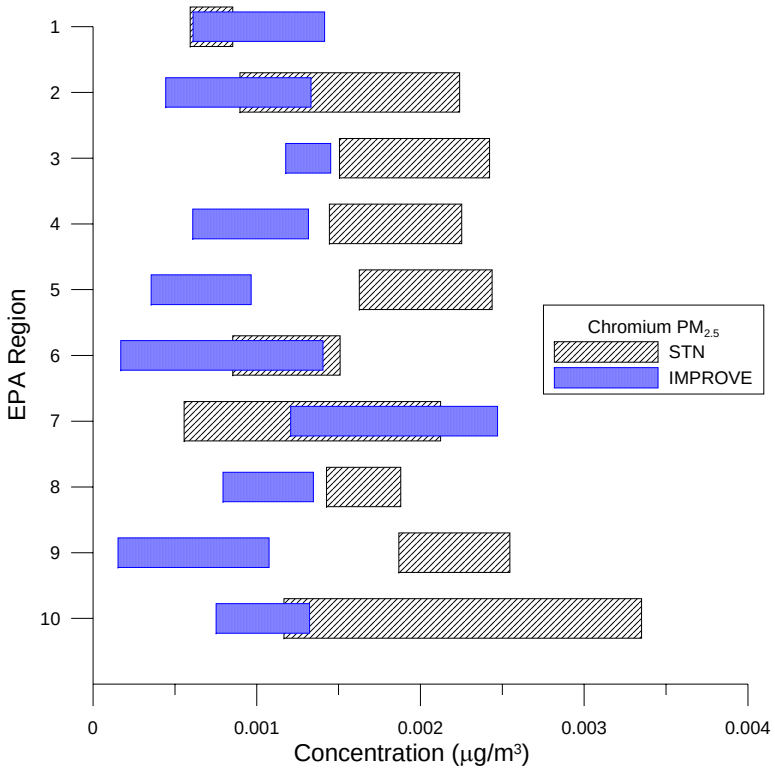
Lead $PM_{2.5}$



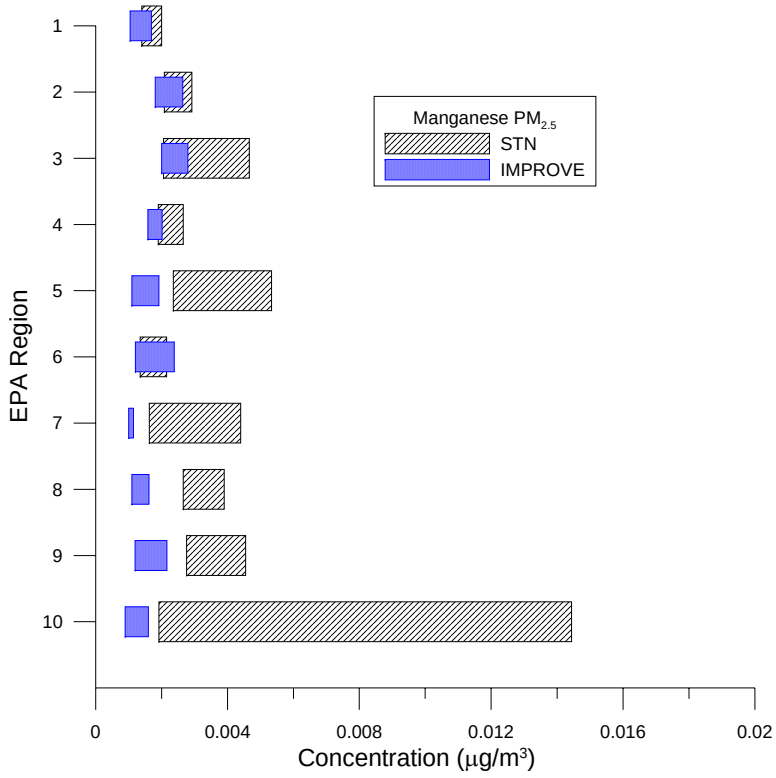
Urban and Rural Differences (2 of 2)…

Comparison of Speciation Trends Network (STN – urban) and Interagency Monitoring of Protected Visual Environments (IMPROVE) network interquartile concentration ranges by EPA region.

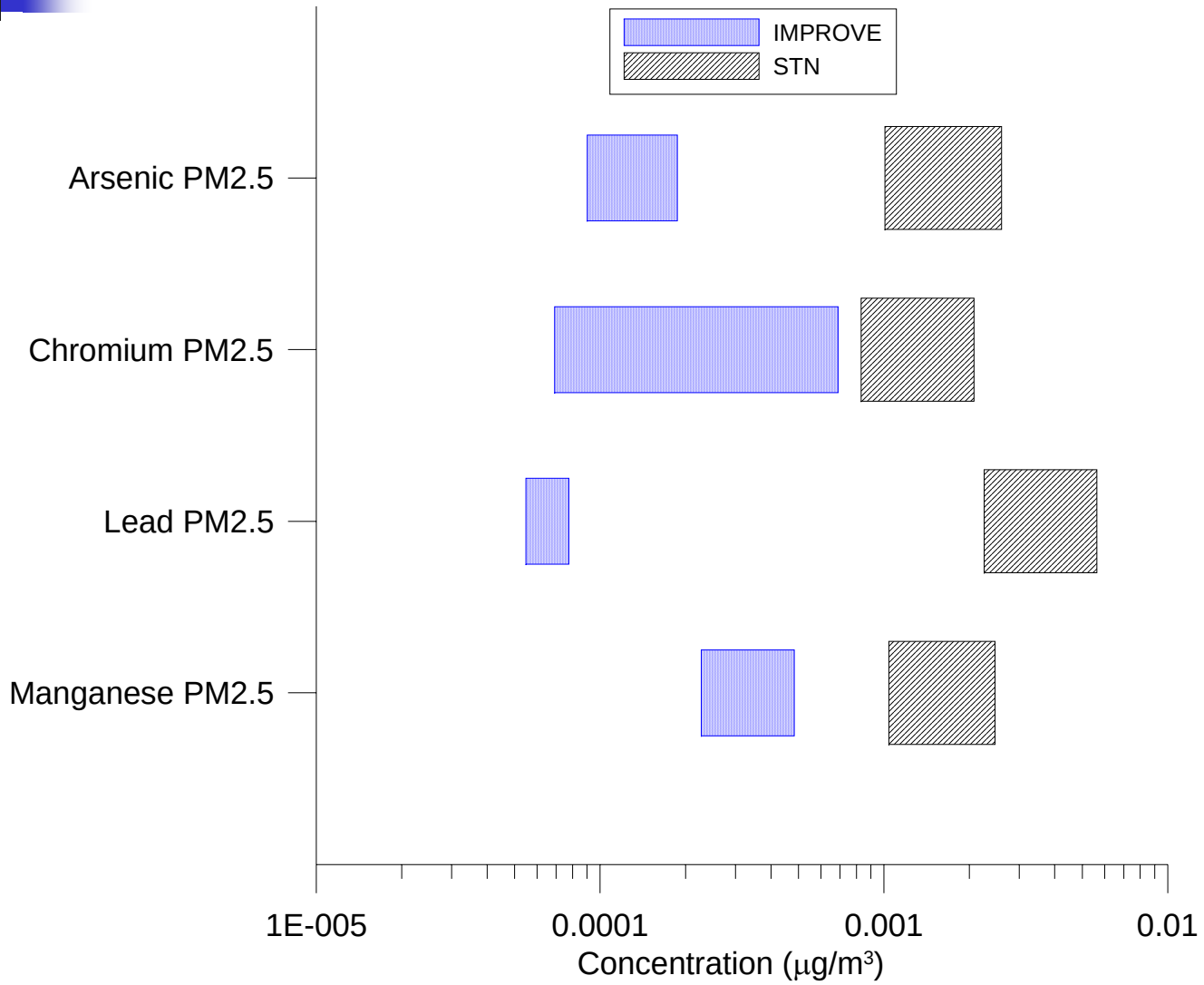
Chromium $PM_{2.5}$



Manganese $PM_{2.5}$



Are Urban and Rural Differences Real? – MDLs



Regional Variability – Conclusions

- Air toxics concentrations varied by region.
- Some regions had high (or low) concentrations of chemical groups, but no one region had high concentrations of all air toxics

Between-City Variability – Questions

- How much do concentrations vary between cities?
- What is the relative variability of different pollutants between cities?
- What are the implications of this variability?

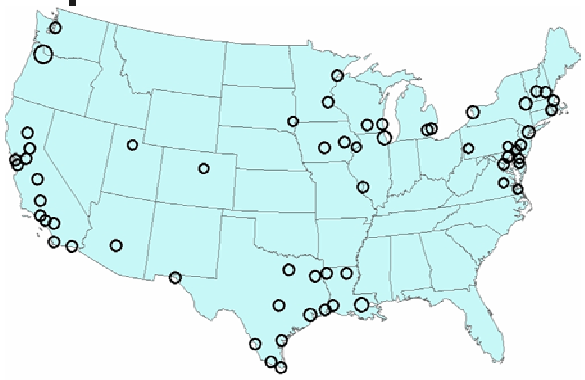
Citywide Averages

- Citywide averages were calculated by taking the arithmetic mean of all site-averages within the boundaries of a Metropolitan Statistical Area (MSA)
- Only one site-average was required for a citywide average to be considered valid

Between-City Variability – Approach

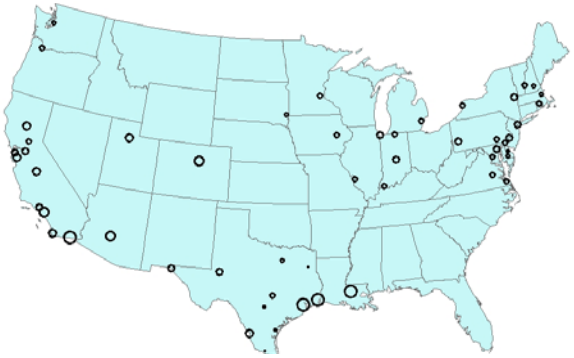
- Identify pollutants with large differences in citywide averages using proportional symbol maps
- Quantify between-city variability
  - Coefficient of Variations (CVs)
  - Other metrics

Spatial Variability In Citywide Average Concentrations of Gases

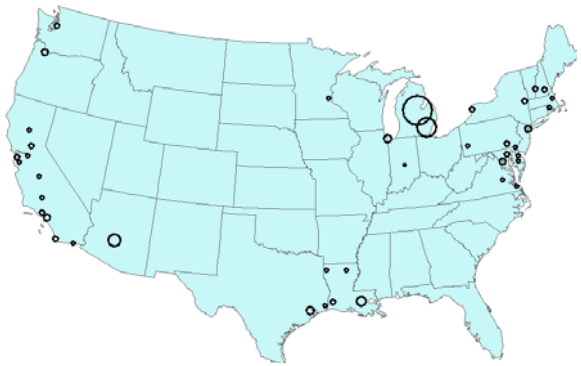


Carbon Tetrachloride; low

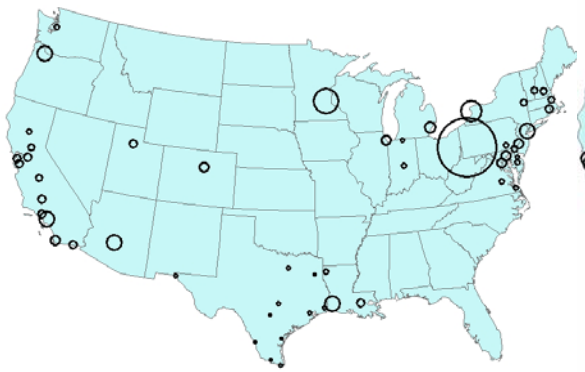
o-Xylene; medium



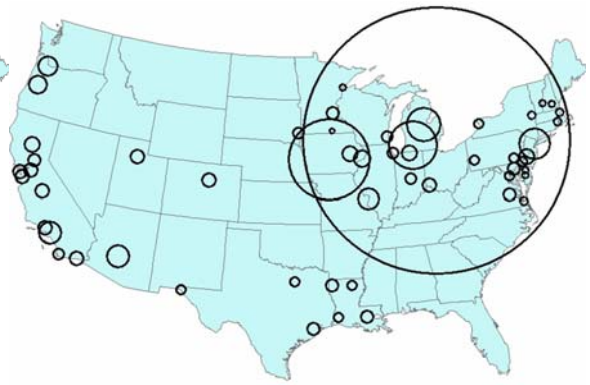
1,3-Butadiene; high



Chloroform; high



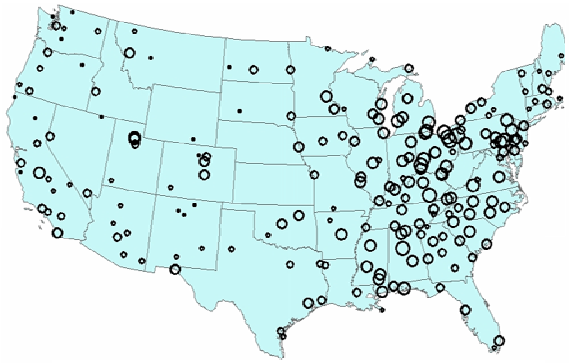
Tetrachloroethylene; high



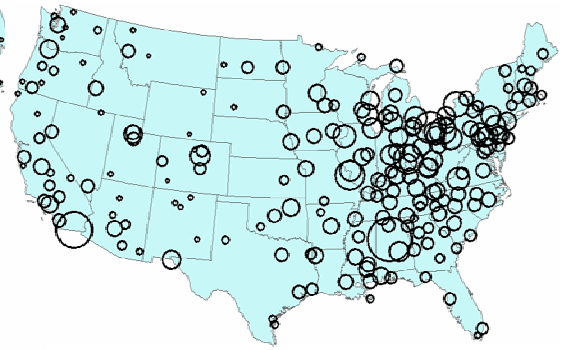
Methylene Chloride; high

Note, circles on all maps represent the same concentration scale.

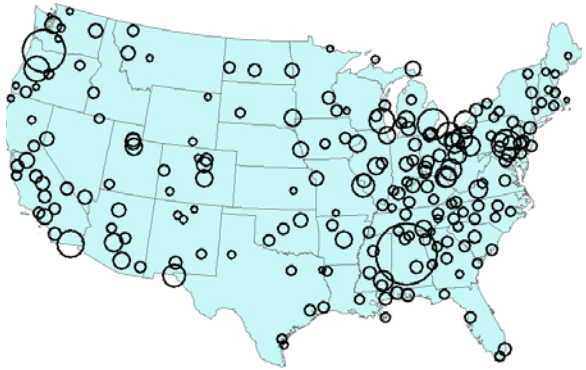
Spatial Variability In Citywide Average Concentrations of PM Metals



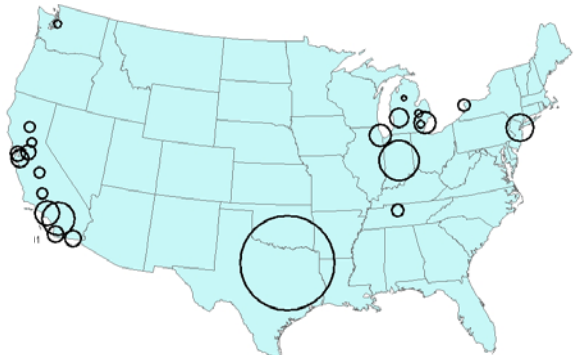
Arsenic $PM_{2.5}$; medium



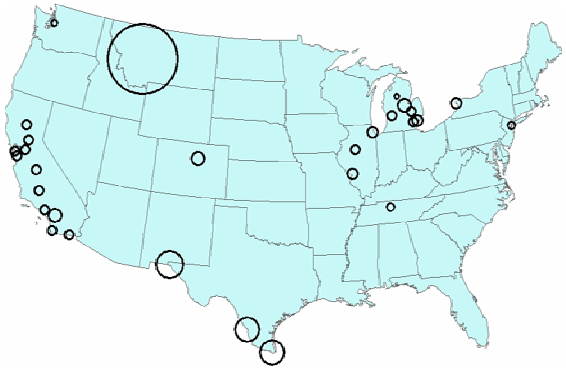
Lead $PM_{2.5}$; medium



Manganese $PM_{2.5}$; medium



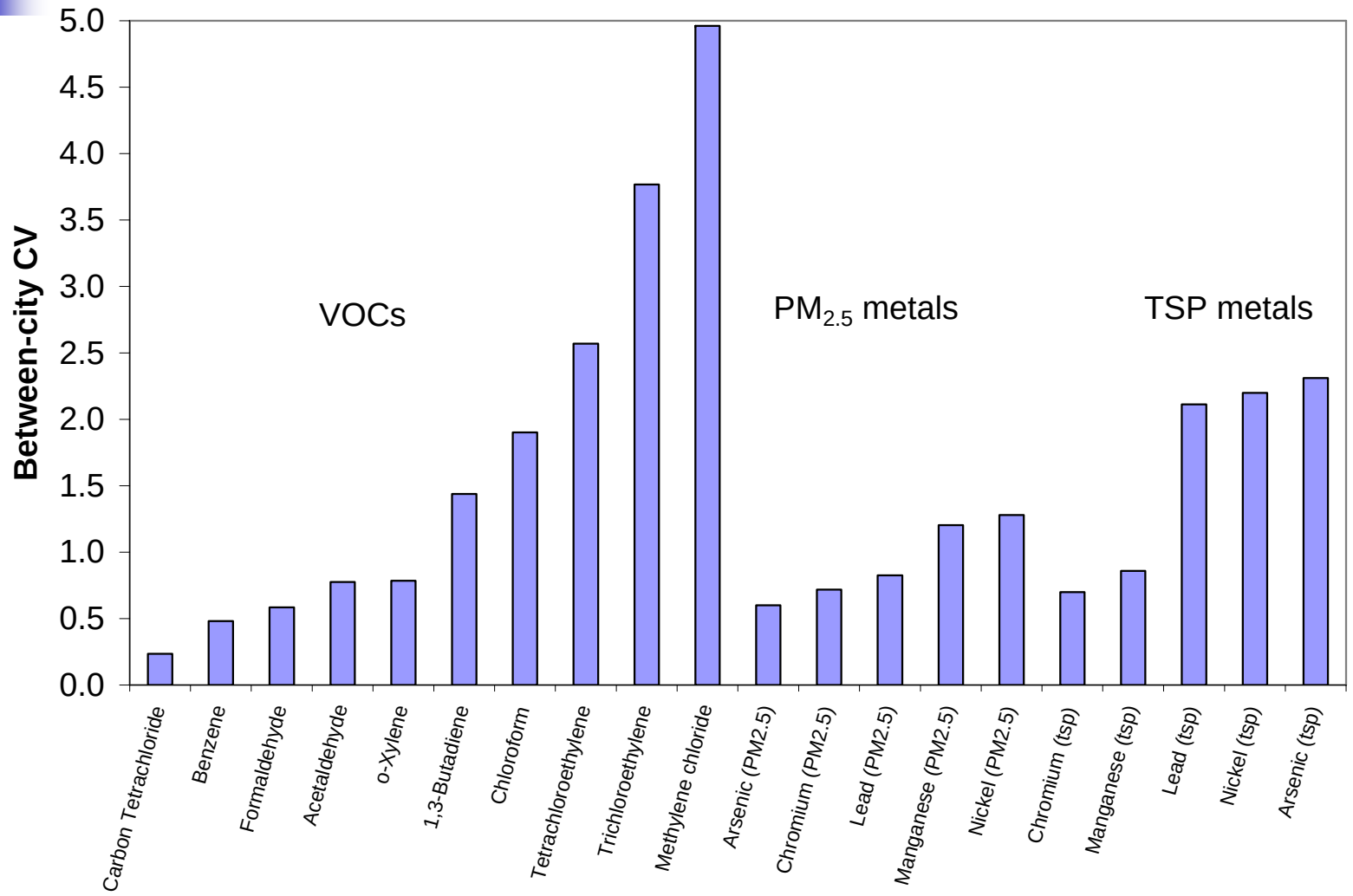
Nickel (tsp); high



Arsenic (tsp); high

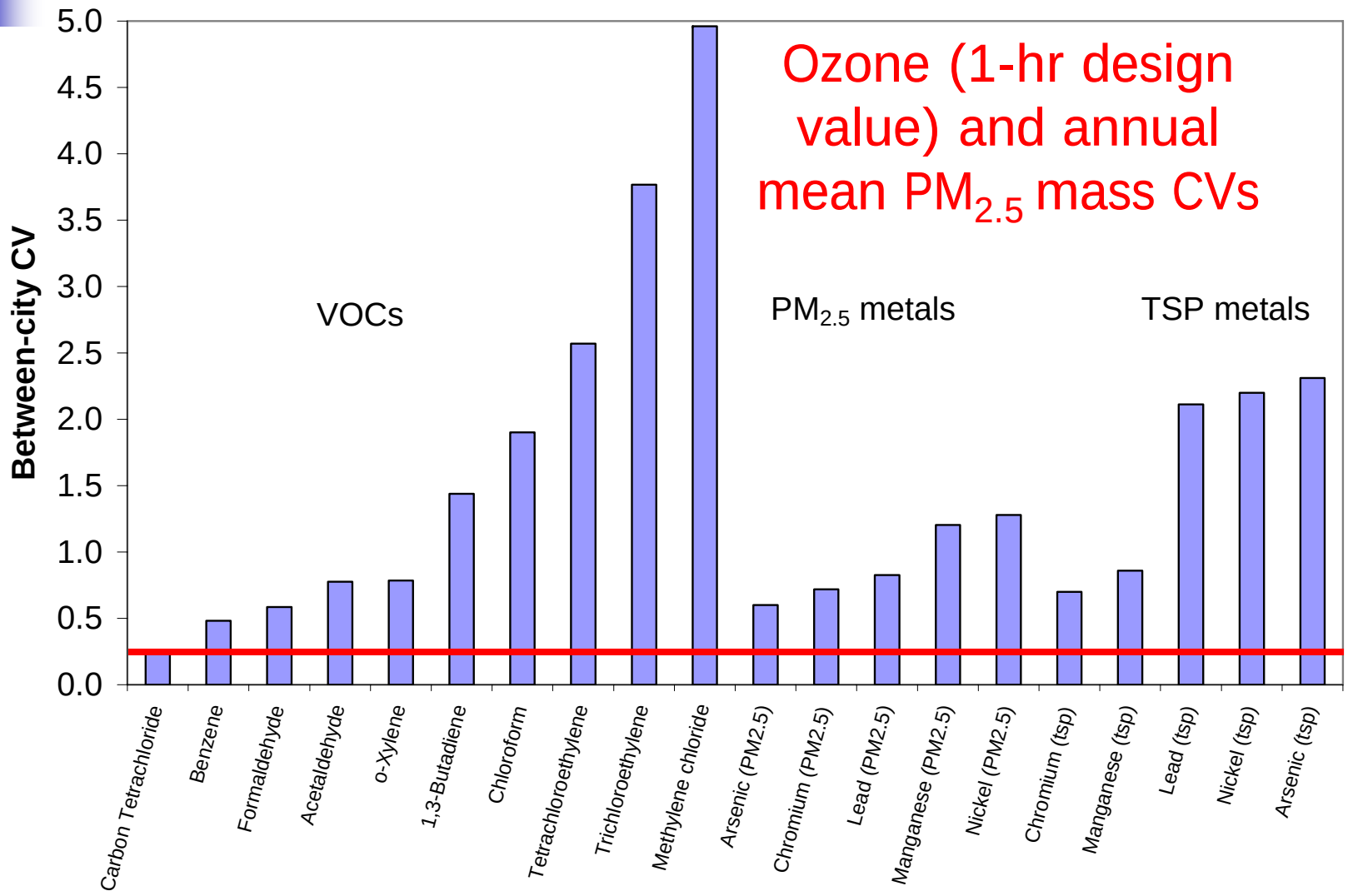
Note, circles on all maps represent the same concentration scale.

Quantifying Between-City Variability – CVs



Coefficient of Variation (CV) = Standard deviation/mean

Quantifying Between-City Variability

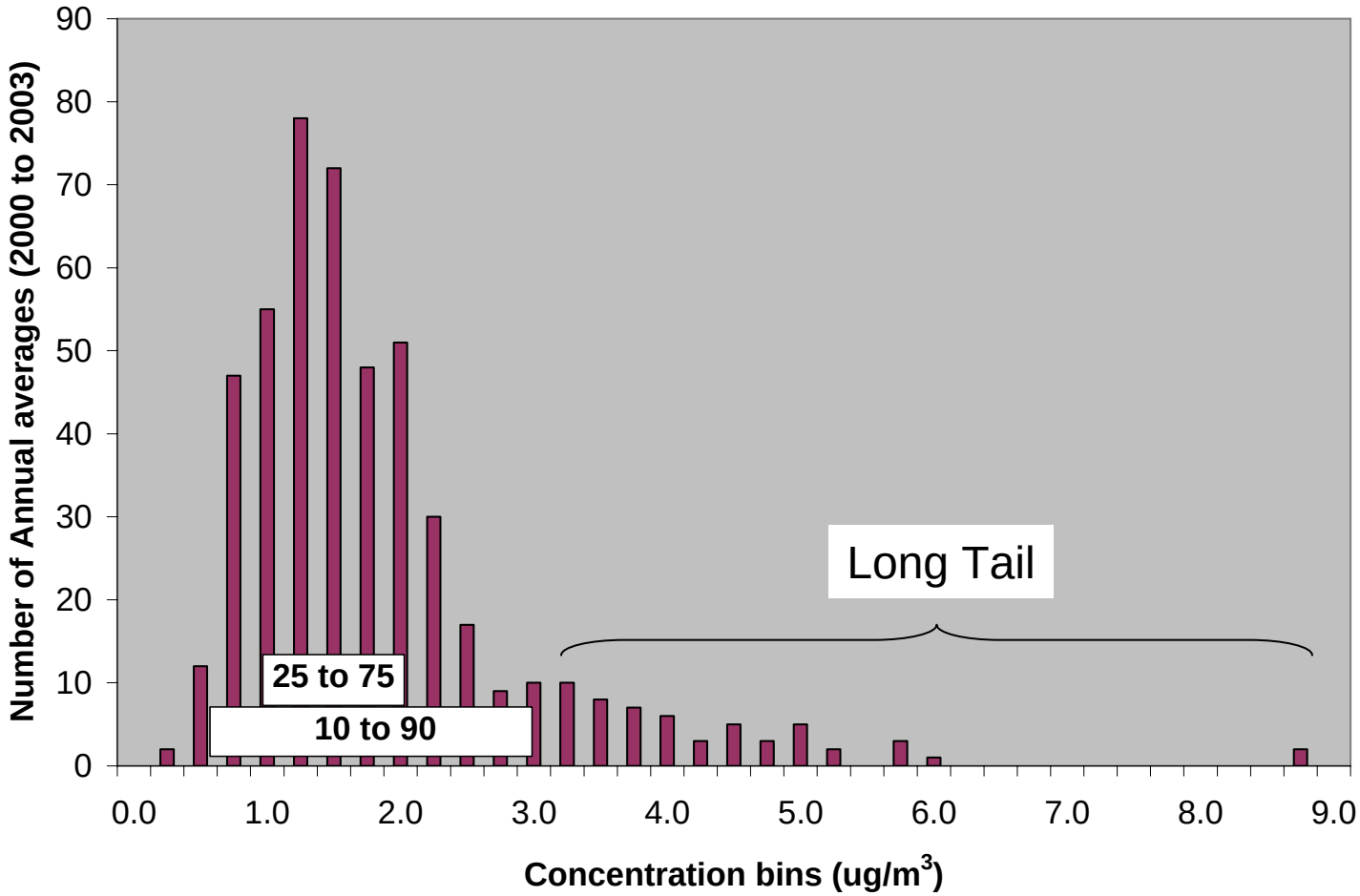


Between-city Spatial Variability Categories

Low	Medium	High
Carbon Tetrachloride	Formaldehyde	Chloroform
Benzene	Arsenic $PM_{2.5}$	Lead (tsp)
	Chromium (tsp) and $PM_{2.5}$	Nickel (tsp)
	Acetaldehyde	Arsenic (tsp)
	o-Xylene	Tetrachloroethylene
	Lead $PM_{2.5}$	Trichloroethylene
	Manganese (tsp) and $PM_{2.5}$	Methylene Chloride
	Nickel $PM_{2.5}$	
	1,3-Butadiene	

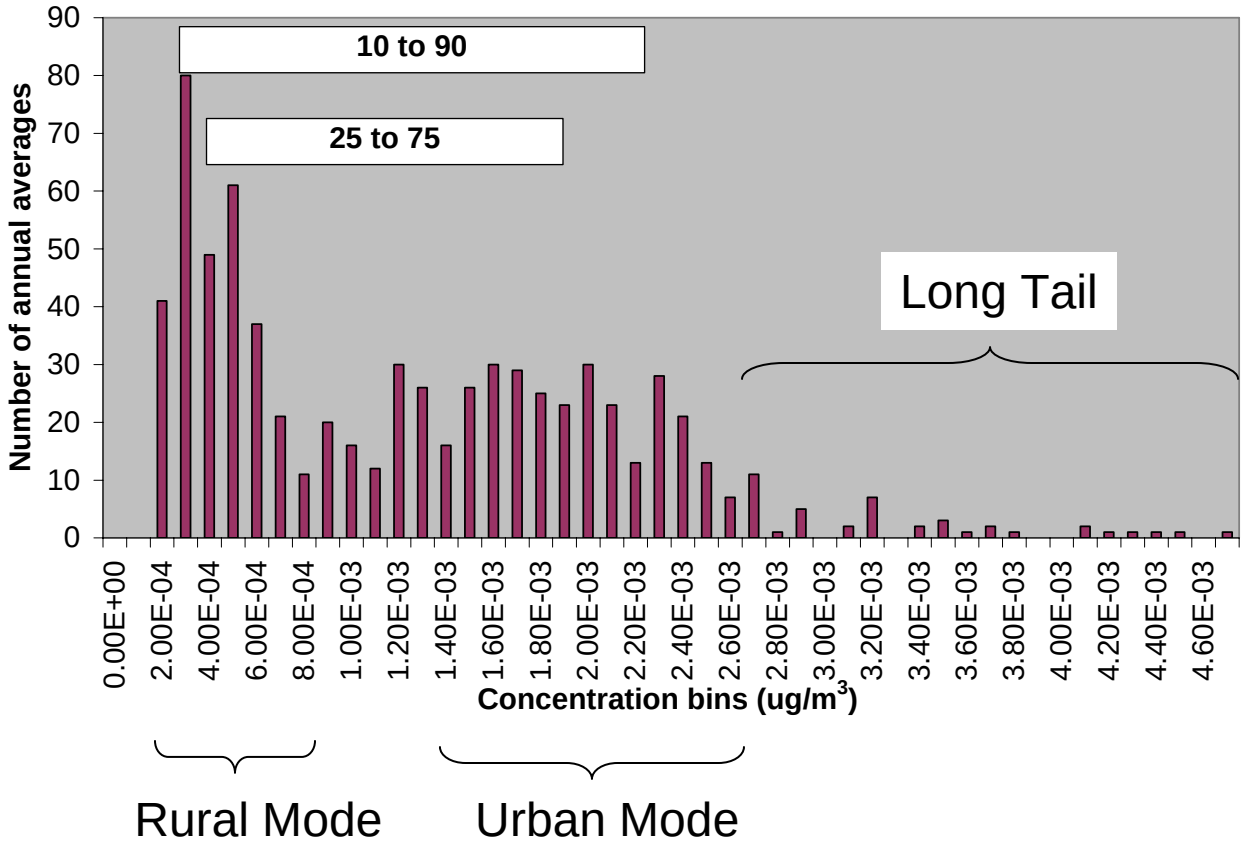
Note, pollutants are arranged in order of increasing spatial variability (i.e., Methylene Chloride had the highest variability).

Is CV a Good Metric for Spatial Variability? (1 of 4)



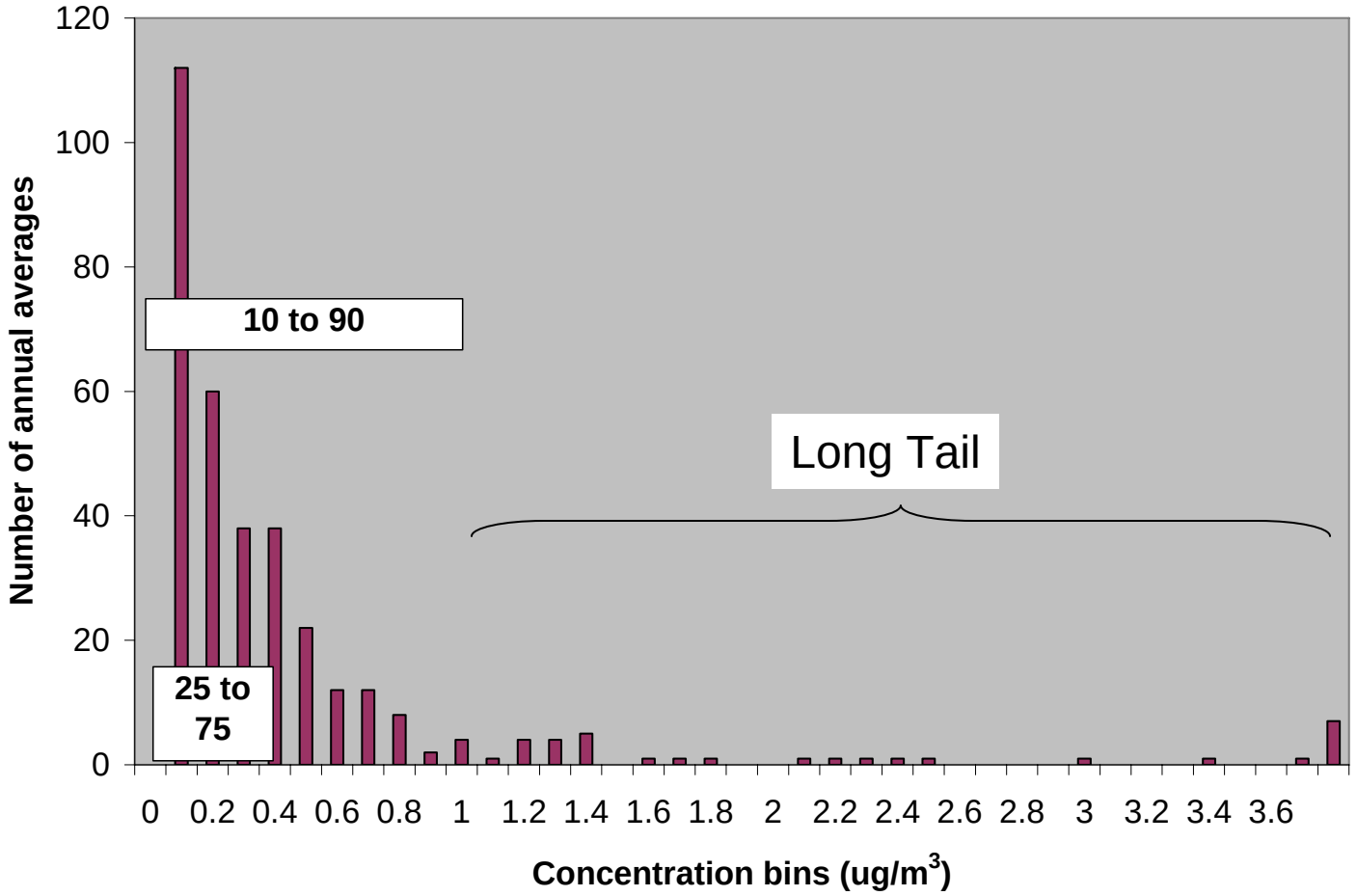
- Distribution of benzene annual averages from 2000 to 2003. The distribution is not normal.
- Boxes show the 25th to 75th percentile range and the 10th to 90th percentile range.

Is CV a Good Metric for Spatial Variability? (2 of 4)



- Distribution of arsenic $PM_{2.5}$ annual averages from 2000 to 2003.
- The distribution is bimodal because of urban and rural measurements.

Is CV a Good Metric for Spatial Variability? (3 of 4)



- Distribution of tetrachloroethylene annual averages from 2000 to 2003.
- The distribution is highly skewed, which will result in higher CV values.
- CV may not be a good measure of spatial variability.

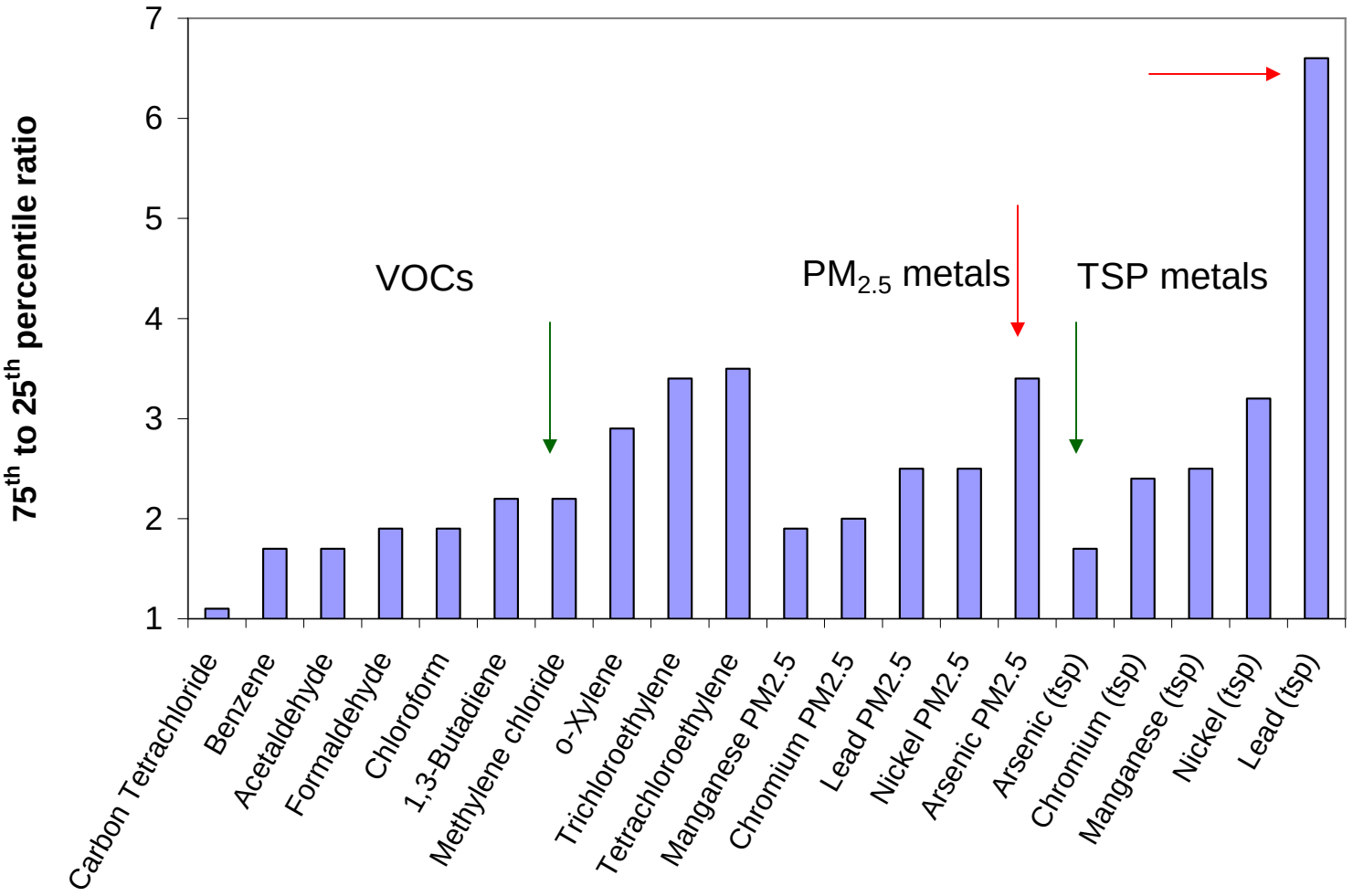
Is CV a Good Metric for Spatial Variability? (4 of 4)

- CV may be a poor statistical measure of between-city spatial variability because of the skewed distribution of citywide average concentrations.
  - A few high concentrations can skew CV values.
  - The high citywide average concentrations are likely real.
- Do other metrics give different results?

Other Measures of Spatial Variability

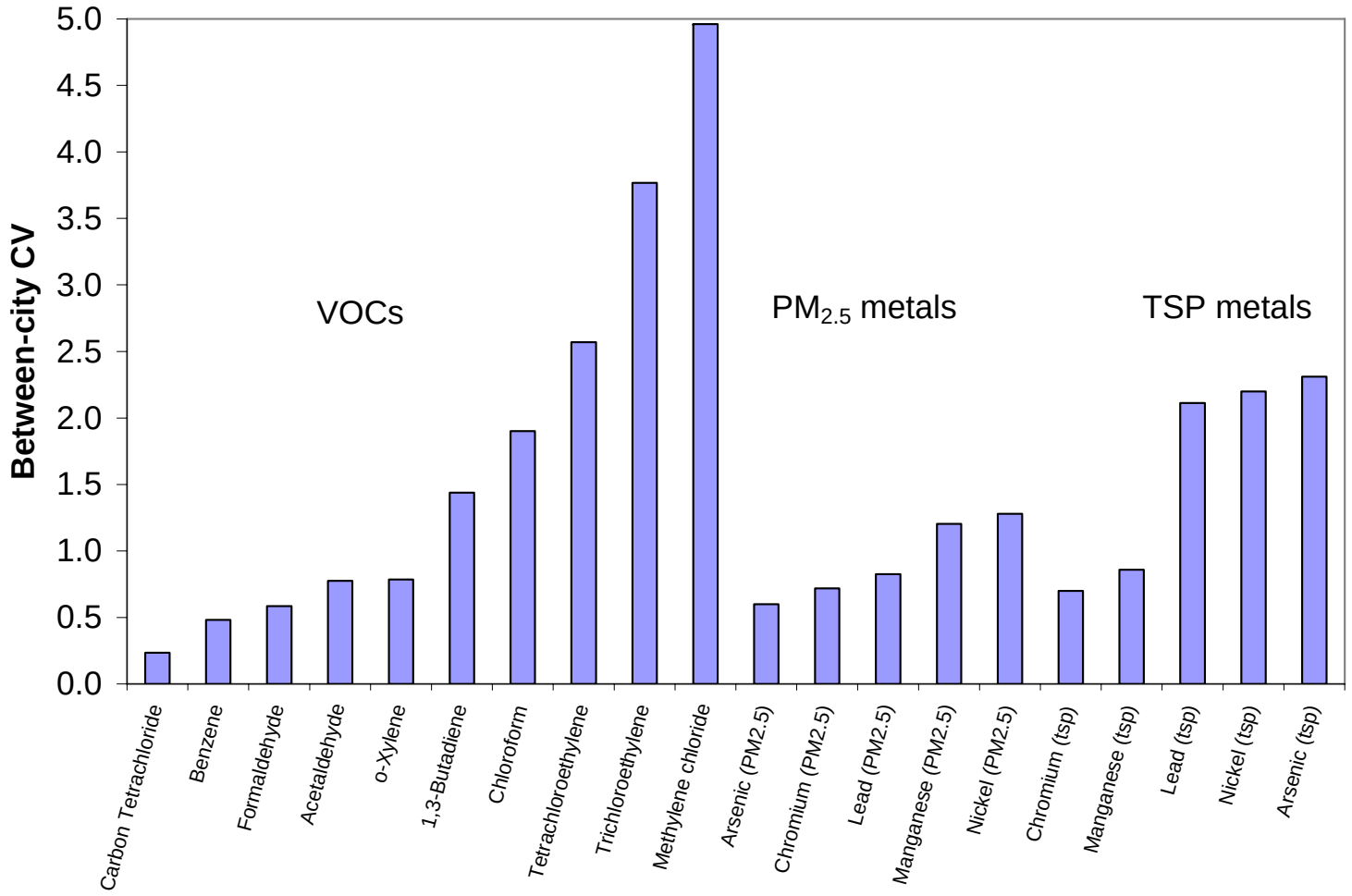
- Ratio of 75^{th} to 25^{th} percentile concentrations (or 95^{th} to 5^{th}, etc.)
  - Characterizes the typical range of concentrations. Higher numbers indicate greater variability.
  - Is not influenced by high outliers
- Ratio of mean to median concentrations
  - Indicates skew in distribution

Between-City Variability – 75th to 25th Percentile Ratios

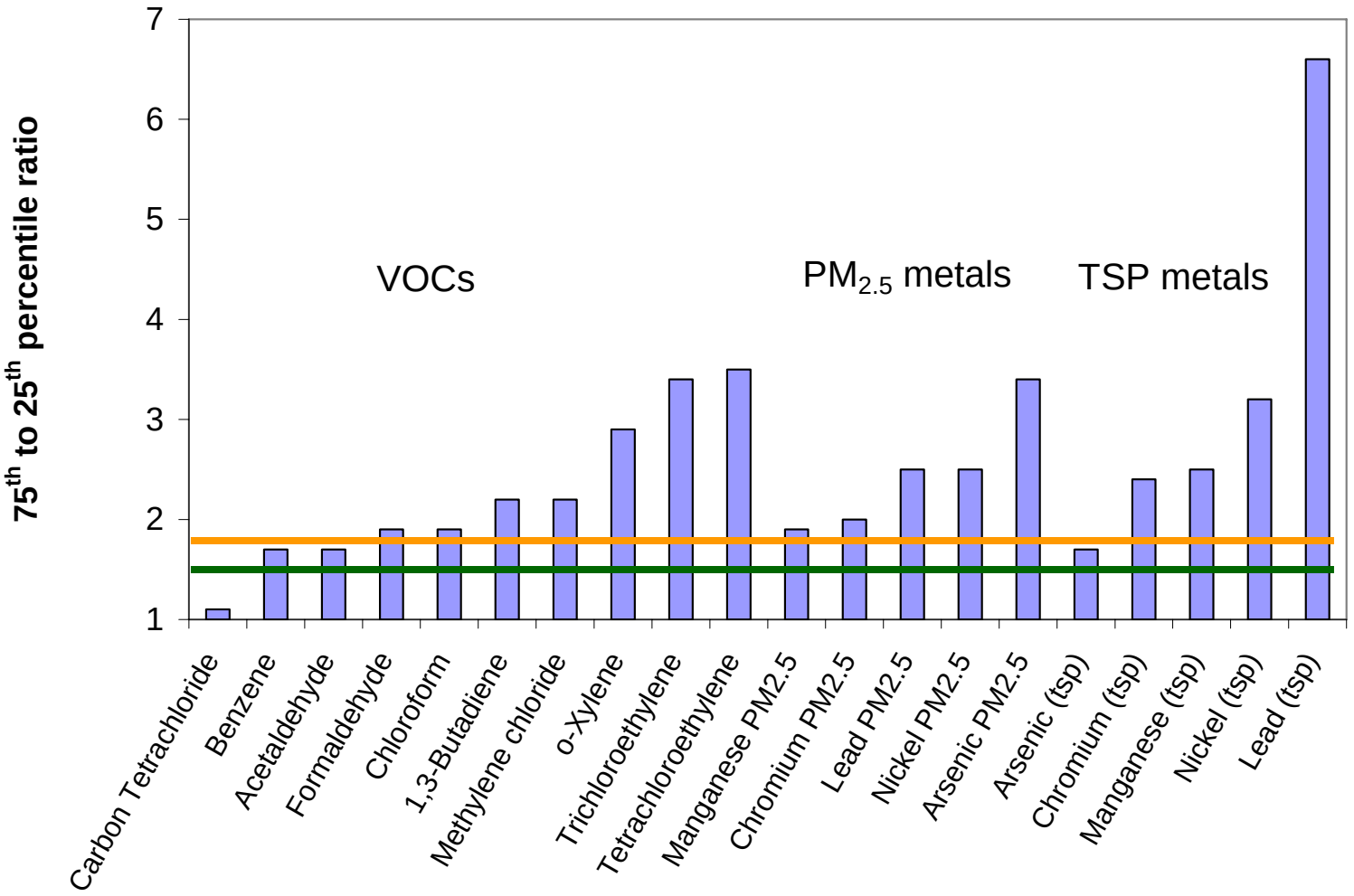


- Species with green arrows had higher variability when quantified by CV.
- Species with red arrows had lower variability.
- Overall the changes were not large and CV is "good enough" to quantify between-city variability.

Quantifying Between-City Variability – CVs



Between-City Variability: 75th to 25th Percentile Ratios Comparison



- 75th to 25th percentile ration of the 1-hr ozone design values is shown in green (1.17).
- 75th to 25th percentile ratio of the $PM_{2.5}$ mass annual average concentration shown in orange (1.37).

Between-City Variability Conclusions

- Concentrations of air toxics are more variable between cities than ozone or $PM_{2.5}$ concentrations
- Air toxics do not have one type of between-city variability
  - Micro-, middle-, and neighborhood-scale air toxics may include tsp metals, methylene chloride, or tetrachloroethylene.
  - Urban-scale air toxics may include benzene or formaldehyde.
  - Global-scale air toxics include carbon tetrachloride.
- More monitors may be necessary to characterize air toxics concentrations

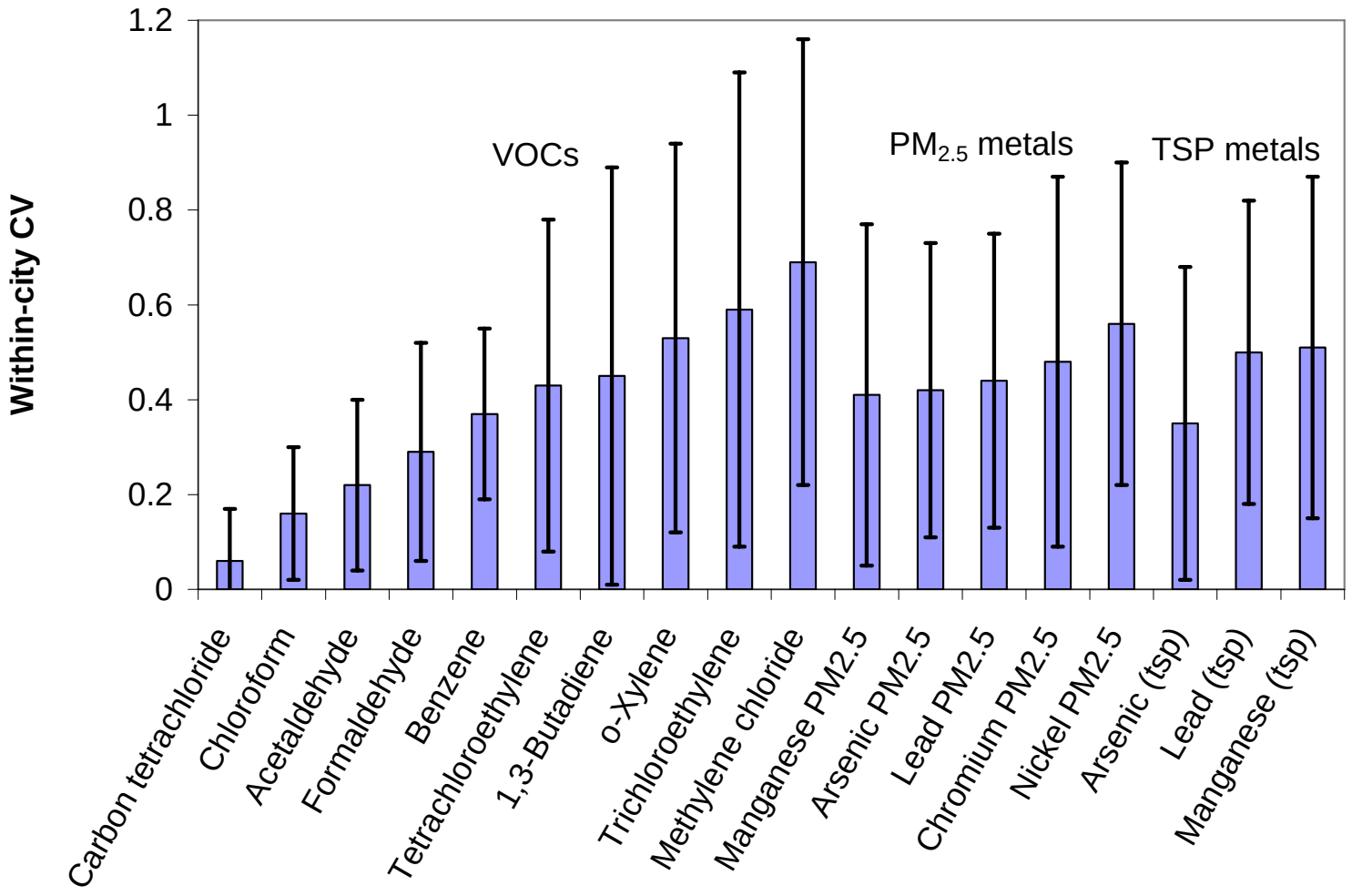
Within-City Variability – Questions

- How much do concentrations vary within cities?
- Is within city variability consistent between cities for a given pollutant?
- Is within city variability consistent between pollutants in the same city?

Within-City Variability – Approach

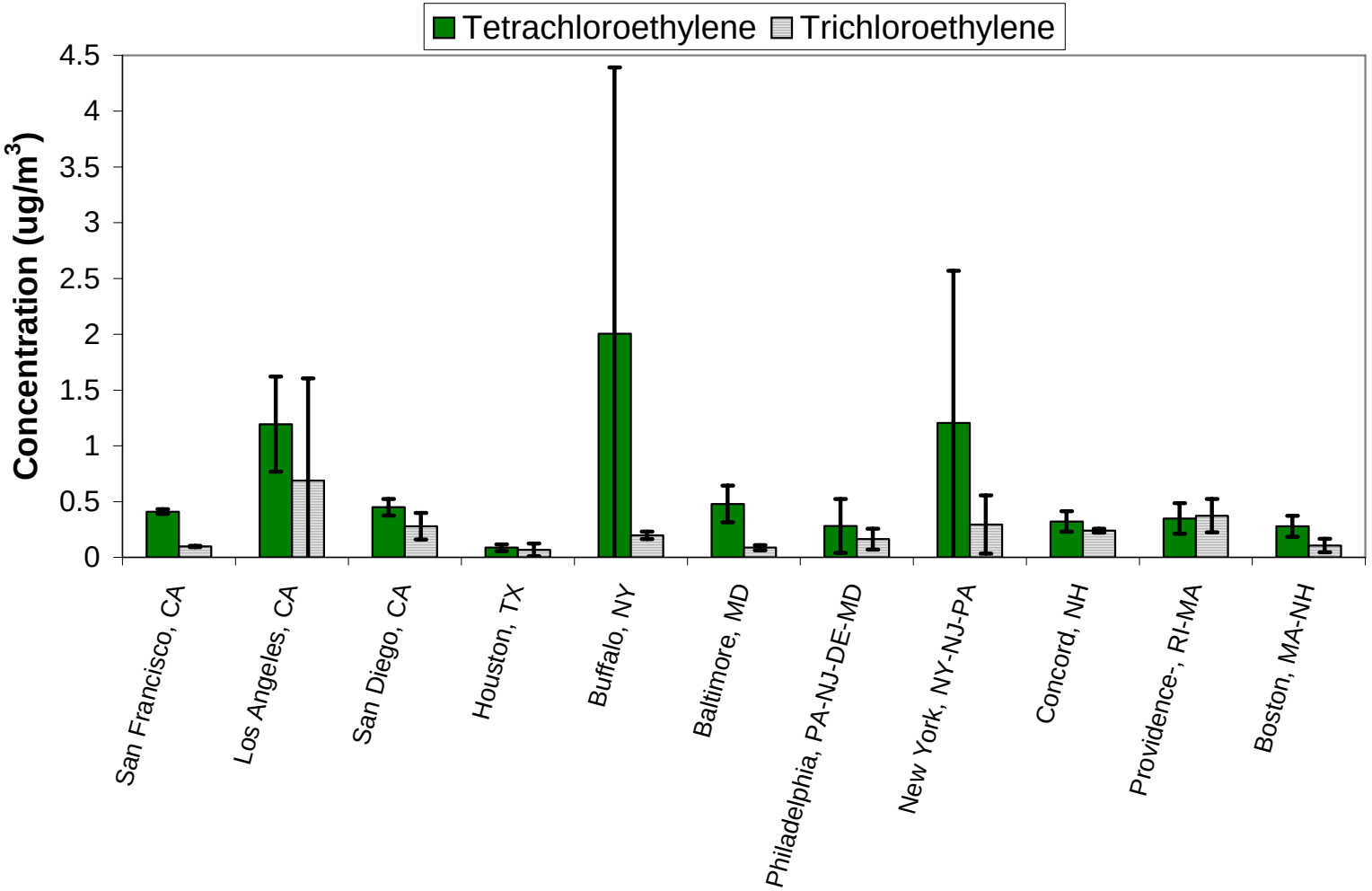
- Calculate CVs for each pollutant within each city with at least two site-averages.
  - Determine the mean CV for each pollutant within cities.
  - Determine the standard deviation of the CV for each pollutant within cities.
- Compare within-city CVs for pollutants between cities and pollutants.

Within-City CVs

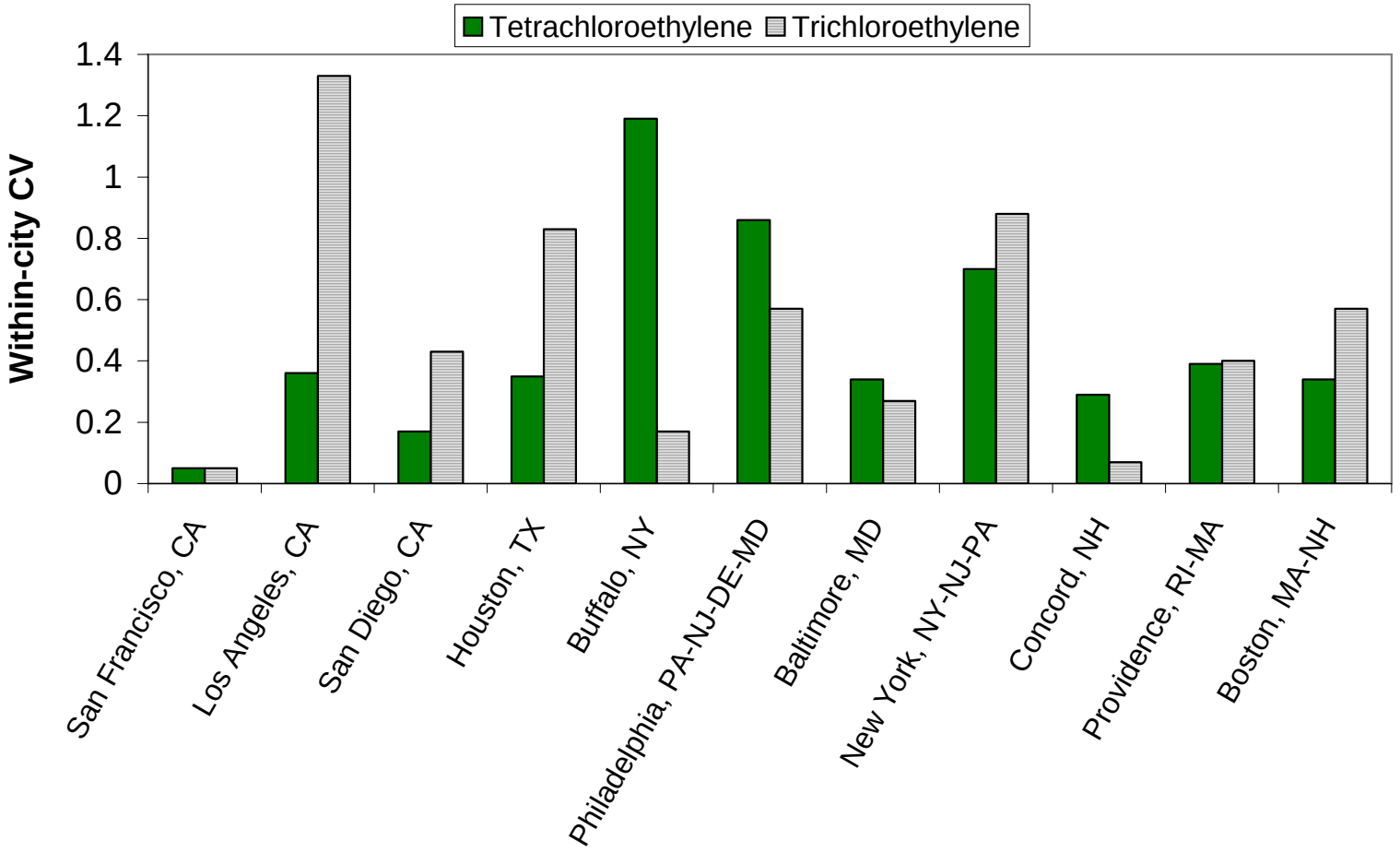


- Within-city CVs are typically lower than between-city CVs.
- Concentrations of air toxics vary by about a factor of two to three on average within cities.
- However, significant variability exists between cities.

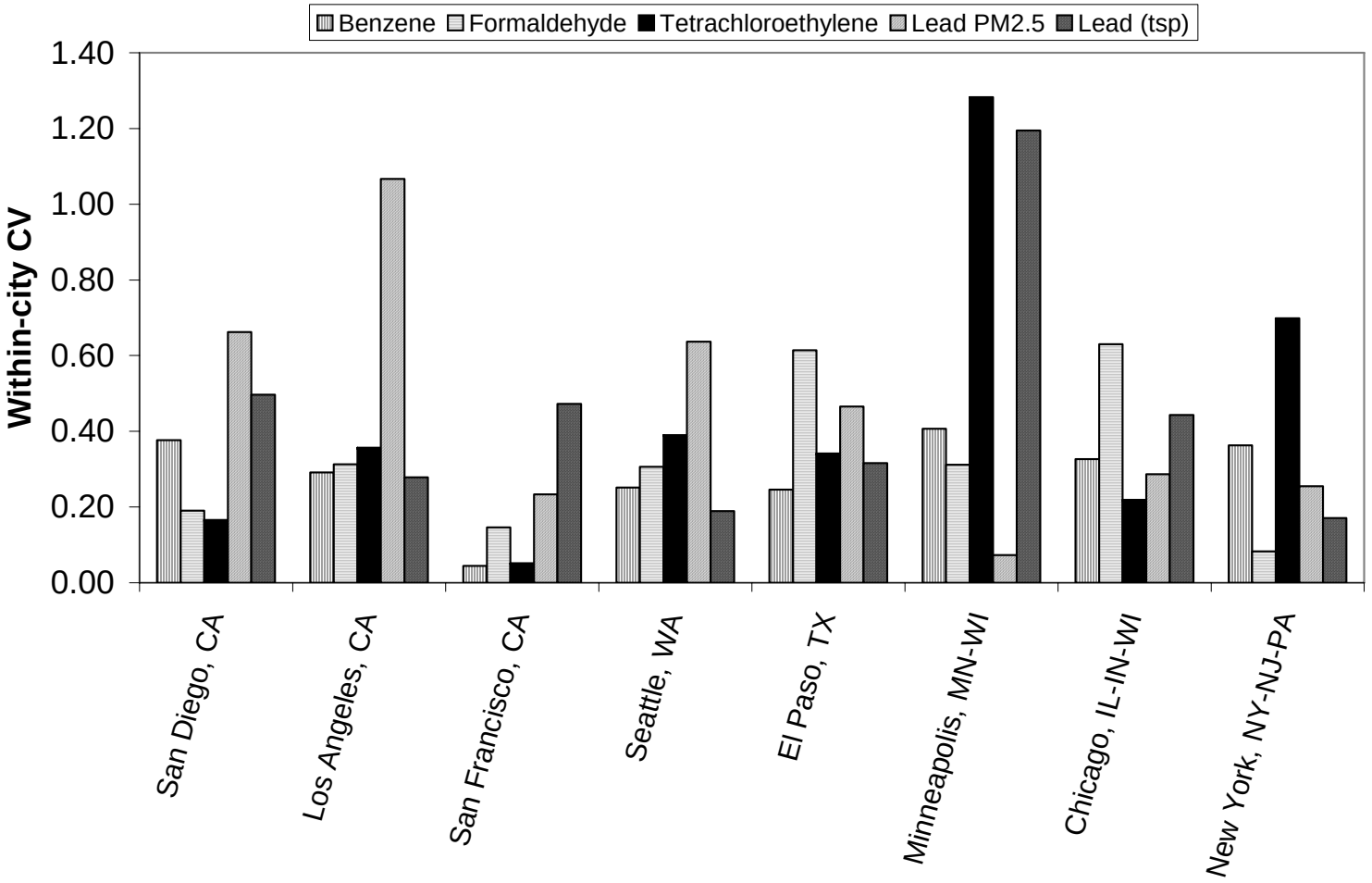
Within-City Variability – Mean and Standard Deviations Concentrations



Within-City CVs – City Comparisons (1 of 2)



Within-City CVs – City Comparisons (2 of 2)



Within-City Comparisons – Conclusions

- The within-city representativeness of a given monitor is *pollutant-* and *location-specific* for air toxics.
  - The within-city variability of a given pollutant is not consistent across cities.
  - The within-city variability of one pollutant is not necessarily consistent with other chemically similar pollutants.
- The within-city variability of air toxics may require more monitors than criteria pollutants for adequate characterization.

Spatial Variability – Lessons Learned

- Most air toxics are highly spatially variable, much more so than ozone or $PM_{2.5}$.
  - Air toxics concentrations may require more monitors for characterization.
  - Models may require speciated and highly spatially resolved emissions inventories.
- No one city or region had high concentrations of all selected air toxics.
  - High air toxics concentrations are pollutant- and location-specific.

Between-City Statistics

Pollutant	Variability	Number of MSAs	Between-city CV	Mean: Median	75: 25	Mean	25%	Median	75%
Carbon Tetrachloride	Low	61	0.2	1.1	1.1	6.4E-01	5.7E-01	6.0E-01	6.4E-01
Benzene	Low	83	0.5	1.1	1.7	1.4E+00	9.7E-01	1.3E+00	1.6E+00
Formaldehyde	Medium	71	0.6	1.2	1.9	3.6E+00	2.2E+00	3.1E+00	4.3E+00
Arsenic $PM_{2.5}$	Medium	203	0.6	1.0	3.4	1.4E-03	5.8E-04	1.4E-03	2.0E-03
Chromium (tsp)	Medium	25	0.7	1.2	2.4	4.8E-03	2.6E-03	4.0E-03	6.2E-03
Chromium $PM_{2.5}$	Medium	204	0.7	1.1	2.0	1.6E-03	9.9E-04	1.5E-03	2.0E-03
Acetaldehyde	Medium	71	0.8	1.2	1.7	2.1E+00	1.4E+00	1.8E+00	2.3E+00
o-Xylene	Medium	69	0.8	1.3	2.9	8.5E-01	3.9E-01	6.7E-01	1.1E+00
Lead $PM_{2.5}$	Medium	210	0.8	1.1	2.5	3.7E-03	1.8E-03	3.3E-03	4.6E-03
Manganese (tsp)	Medium	37	0.9	1.3	2.5	2.3E-02	1.1E-02	1.8E-02	2.8E-02
Manganese $PM_{2.5}$	Medium	213	1.2	1.4	1.9	3.0E-03	1.7E-03	2.2E-03	3.1E-03
Nickel $PM_{2.5}$	Medium	67	1.3	1.6	2.5	5.4E-04	2.4E-04	3.3E-04	6.0E-04
1,3-Butadiene	Medium	56	1.4	1.5	2.2	3.1E-01	1.5E-01	2.1E-01	3.2E-01
Chloroform	High	41	1.9	2.1	1.9	3.1E-01	1.2E-01	1.4E-01	2.2E-01
Lead (tsp)	High	60	2.1	4.3	6.6	7.7E-02	9.6E-03	1.8E-02	6.4E-02
Nickel (tsp)	High	24	2.2	2.4	3.2	8.9E-03	2.2E-03	3.7E-03	7.1E-03
Arsenic (tsp)	High	29	2.3	2.8	1.7	4.6E-03	1.5E-03	1.6E-03	2.5E-03
Tetrachloroethylene	High	52	2.6	2.2	3.5	6.5E-01	1.4E-01	2.9E-01	4.8E-01
Trichloroethylene	High	45	3.8	4.3	3.4	5.1E-01	7.4E-02	1.2E-01	2.5E-01
Methylene chloride	High	56	5.0	5.8	2.2	4.5E+00	5.1E-01	7.8E-01	1.1E+00

Within-City Statistics

Pollutant	Variability	Mean within-city CV	Standard Deviation of within-city CV	Number of MSAs
Carbon tetrachloride	Low	0.06	0.11	28
Chloroform	Low	0.16	0.14	14
Acetaldehyde	Low	0.22	0.18	26
Formaldehyde	Low	0.29	0.23	26
Arsenic (tsp)	Medium	0.35	0.33	12
Benzene	Medium	0.37	0.18	34
Manganese $PM_{2.5}$	Medium	0.41	0.36	52
Arsenic $PM_{2.5}$	Medium	0.42	0.31	48
Tetrachloroethylene	Medium	0.43	0.35	24
Lead $PM_{2.5}$	Medium	0.44	0.31	51
1,3-Butadiene	Medium	0.45	0.44	26
Chromium $PM_{2.5}$	Medium	0.48	0.39	45
Lead (tsp)	Medium	0.50	0.32	30
Manganese (tsp)	Medium	0.51	0.36	14
o-Xylene	Medium	0.53	0.41	31
Nickel $PM_{2.5}$	Medium	0.56	0.34	10
Trichloroethylene	Medium	0.59	0.50	17
Methylene chloride	High	0.69	0.47	22

Acronyms

- CV = Coefficient of Variation
- HAP = Hazardous air pollutant (i.e., air toxics)
- IMPROVE = Interagency Monitoring of Protected Visual Environments
- MDL = Method Detection Limit (sometimes minimum detection limit)
- MSA = Metropolitan Statistical Area
- PM = Particulate matter
- SD = Standard deviation
- STN = Speciation Trends Network
- tsp = total suspended particulate