The Steubenville Comprehensive Air Monitoring Program (SCAMP): A Case Study in Exposure Measurement

CONSOL ENERGY

Research & Development

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CONSOL Energy Inc.

- Began operations in 1864
- Headquartered in Upper St. Clair
- Largest U.S. producer of high-BTU bituminous coal
- Largest U.S. underground coal mining company
- One of the largest U.S. producers of coalbed methane
- Annual revenues: $2.2 billion

CONSOL Energy R&D

- Founded in 1947
- Located in South Park
- Research focuses on energy development, improving energy efficiency, and reducing pollution

Today's Discussion
SCAMP: A Case Study in Exposure Measurement

- Conceptualization
- Design
  - Important Considerations
  - Sampling and Measurement Issues
- Execution, Quality Assurance / Quality Control

Conceptualization

Fine Particulate Matter ($PM_{2.5}$)

- Nominal Definition: Airborne particles having a diameter less than 2.5 μm
  - (actually, "particles collected with an upper 50% cut point of 2.5 μm aerodynamic diameter and a specific, fairly sharp, penetration curve")
- Mixture of many substances with wide variety of chemical and physical properties
  - solids and liquids
  - different sizes (e.g., ultrafine, accumulation mode)
  - different chemical compounds
  - primary vs. secondary
- Primary exposure route: respiratory (inhalation)

$PM_{2.5}$ Health Endpoints

- Epidemiology studies have associated $PM_{2.5}$ with:
  - Mortality
  - Respiratory morbidity
  - Cardiovascular morbidity

- Toxicological link still unclear:
  - Total $PM_{2.5}$ mass?
  - Specific $PM_{2.5}$ size fraction?
  - Specific $PM_{2.5}$ chemical component(s)?

- Other important questions:
  - Acute vs. chronic exposure?
  - Confounding by co-pollutants?
  - Interaction with co-pollutants?

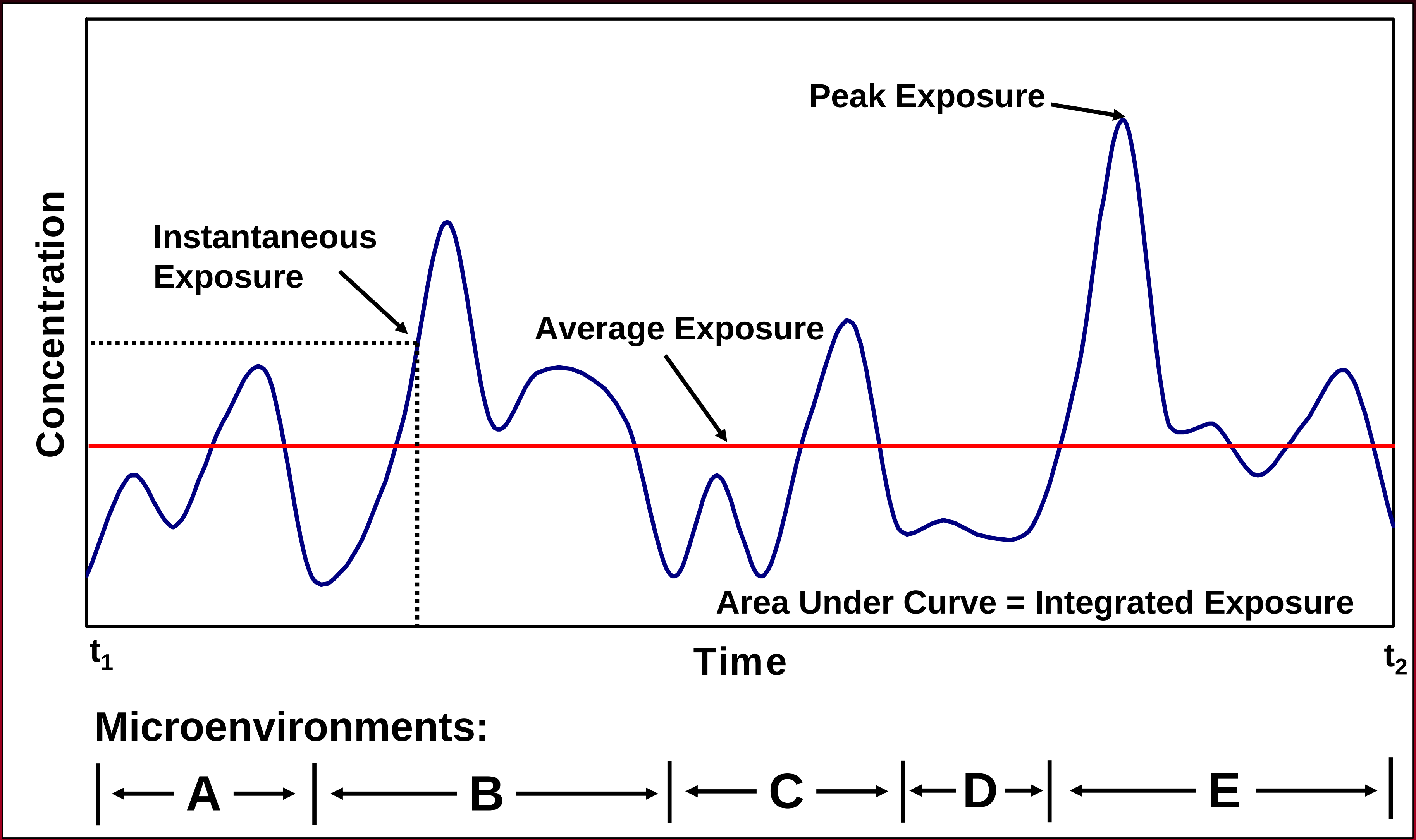
$PM_{2.5}$ – Relevance to CONSOL

- Coal combustion is considered a major source of fine particle precursors in the eastern U.S.
- EPA has promulgated standards under NAAQS for $PM_{2.5}$
  - 15 µg/m^3 (annual)
  - 65 µg/m^3 (daily)
- Implementation of the proposed standards could have a major impact on national and regional coal markets
- Sustainability – Economy, Environment, Society

Human Exposure - Concepts

- Contact between a human being and a chemical or agent
- Point of contact:
  - Visible external boundary of the person
    - e.g., skin, mouth, nostrils
  - Exchange boundaries where absorption occurs
    - e.g., lungs, skin, gastrointestinal tract
- Our example:
  - $PM_{2.5}$ (an air pollutant)
  - Primary Exposure Pathway: Respiratory (Inhalation)

Personal Exposure Through Space & Time



Indoor vs. Outdoor $PM_{2.5}$

Outdoor Sources

Power Plants
Automobiles
Diesel Engines
Steel Plants
Incinerators
Other Industries
Forest Fires
Fugitive Dust / Soil
Sea Salt

Indoor Sources

Cigarette Smoke
Food Cooking
Dusting
Vacuuming
Walking
Burning Candles
Re-suspension of dust
Combustion in Stoves / Heating Devices

$PM_{2.5}$ NAAQS and Many Epidemiology Studies are Based on Measurements Made at Centrally Located, Community Based Monitoring Sites, BUT . . .

Components of Personal Exposure to $PM_{2.5}$

$$E_{tot} = \underbrace{E_{ao} + E_{ai}}_{\text{Ambient Exposure}} + \underbrace{E_{ig} + E_{ir} + E_{pc}}_{\text{Non-ambient Exposure}}$$

Total Exposure (E_{tot})

ao	ambient $PM_{2.5}$ in outdoor microenvironments
ai	ambient $PM_{2.5}$ in indoor microenvironments
ig	$PM_{2.5}$ generated indoors
ir	$PM_{2.5}$ formed indoors by reaction of outdoor-generated pollutants
pc	"personal cloud" $PM_{2.5}$ that is not contained in indoor or outdoor measurements

$PM_{2.5}$ Concentration in an Indoor Microenvironment

Mass Balance:

Accumulation = In – Out + Generation – Consumption

$$dC_i/dt = \lambda P C_o - \lambda C_i + G_i - kC_i$$

C_i = concentration of $PM_{2.5}$ in indoor microenvironment ($\mu g\ m^{-3}$)

C_o = concentration of $PM_{2.5}$ in outdoor ambient air ($\mu g\ m^{-3}$)

λ = indoor/outdoor air exchange rate (h^{-1})

P = penetration factor

G_i = indoor $PM_{2.5}$ generation rate ($\mu g\ m^{-3}\ h^{-1}$)

k = removal rate (h^{-1})

Why Steubenville?

- "Dirtiest" of the Harvard Six Cities
  - Mean $PM_{2.5}$ Concentration = 29.6 µg/m^3, 1979-1985
  - Extensive $PM_{2.5}$ data record
- Major changes have occurred
  - Steubenville-Weirton MSA lost 4,200 manufacturing jobs in 1990s (decline of steel industry)
  - Population decreased by 7.4% in 1990s
- Likely a nonattainment area under $PM_{2.5}$ NAAQS

SCAMP

- Two-year comprehensive program for monitoring $PM_{2.5}$ and co-pollutants
- Steubenville, Ohio, and surrounding region
- May 2000 – May 2002
- Two major study components:
  - Indoor/Personal
    - Personal sampling of children and elderly volunteers
    - Indoor sampling in participants' homes
  - Outdoor
    - Participants' homes
    - Central site in Steubenville
    - Four remote sites located at cardinal compass points around Steubenville

Funding

U.S. DOE – National Energy Technology Laboratory

Ohio Coal Development Office

Electric Power Research Institute

American Petroleum Institute

National Mining Association

American Iron and Steel Institute

Edison Electric Institute

National Institute of Environmental Health Sciences

U.S. Environmental Protection Agency

CONSOL Energy Inc.

SCAMP Goals

- Compare urban $PM_{2.5}$ concentration / composition with remote $PM_{2.5}$ concentration / composition
- Study associations among $PM_{2.5}$, co-pollutants, and weather conditions
- Provide a comprehensive database for use in epidemiological and transport studies and in compliance program development

SCAMP Goals

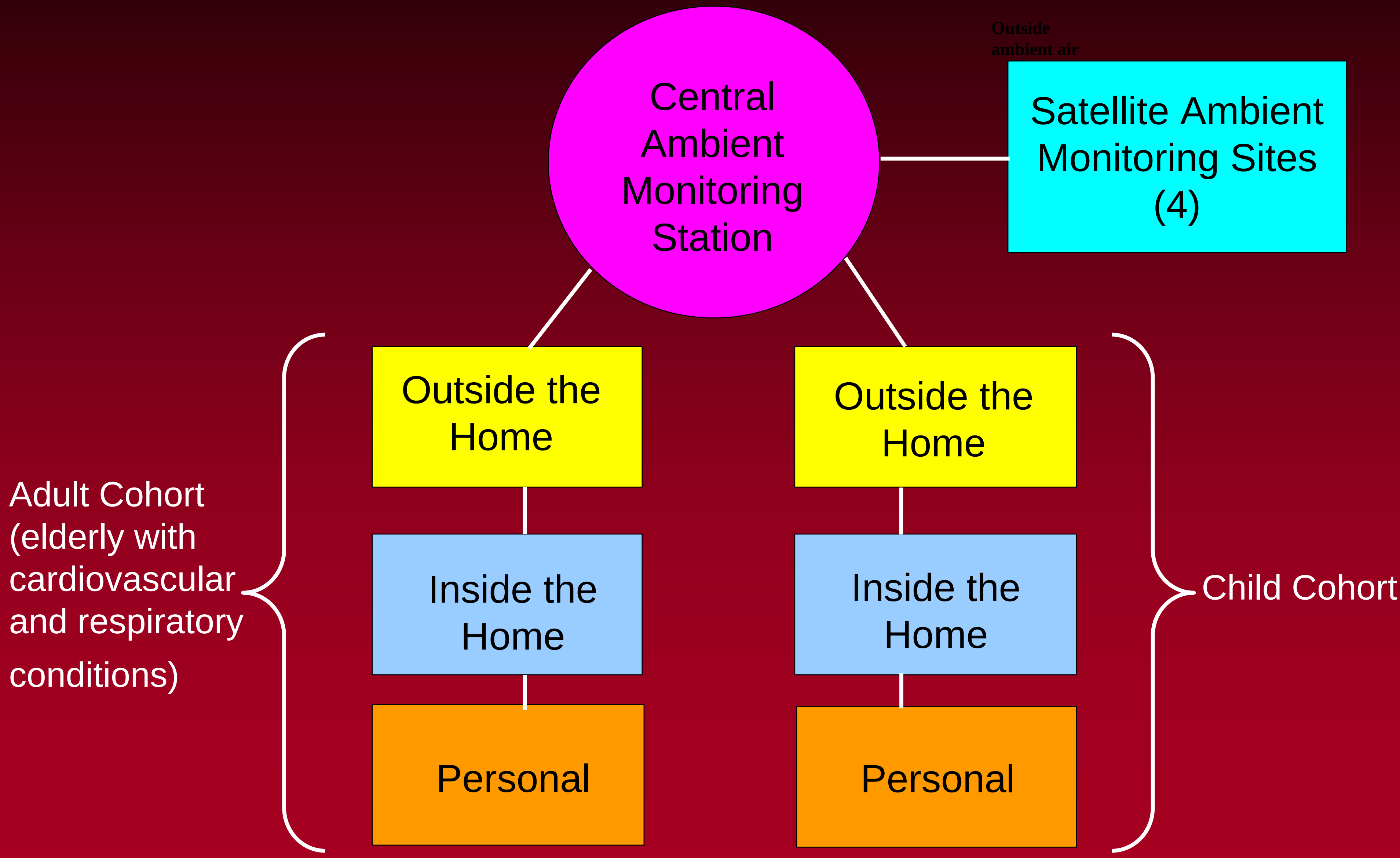
- Characterize indoor, outdoor, and personal exposure to $PM_{2.5}$ and gaseous pollutants for cohorts of older adults and children

- Determine and compare the composition of personal, indoor, and outdoor $PM_{2.5}$, and identify factors affecting the relationship between personal exposure and outdoor composition

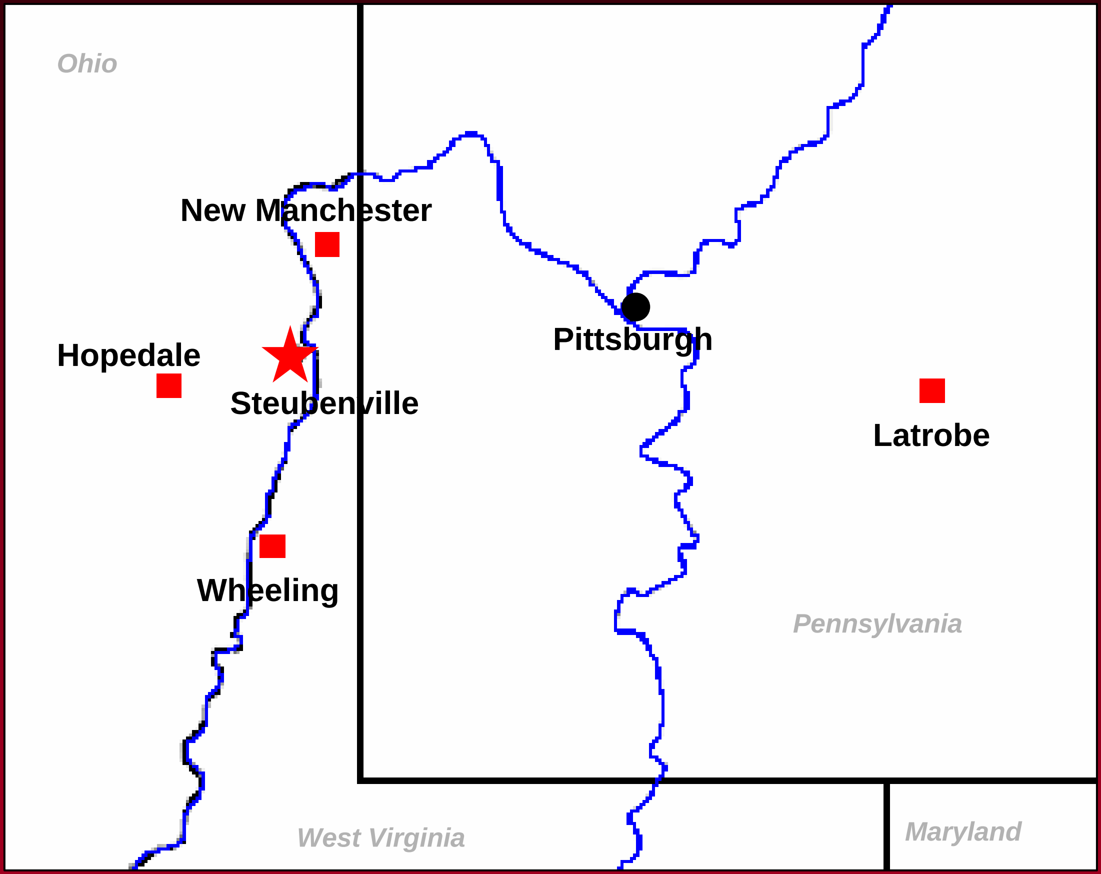
- Provide exposure measurements for concurrent study of air pollution and cardiovascular health

Design

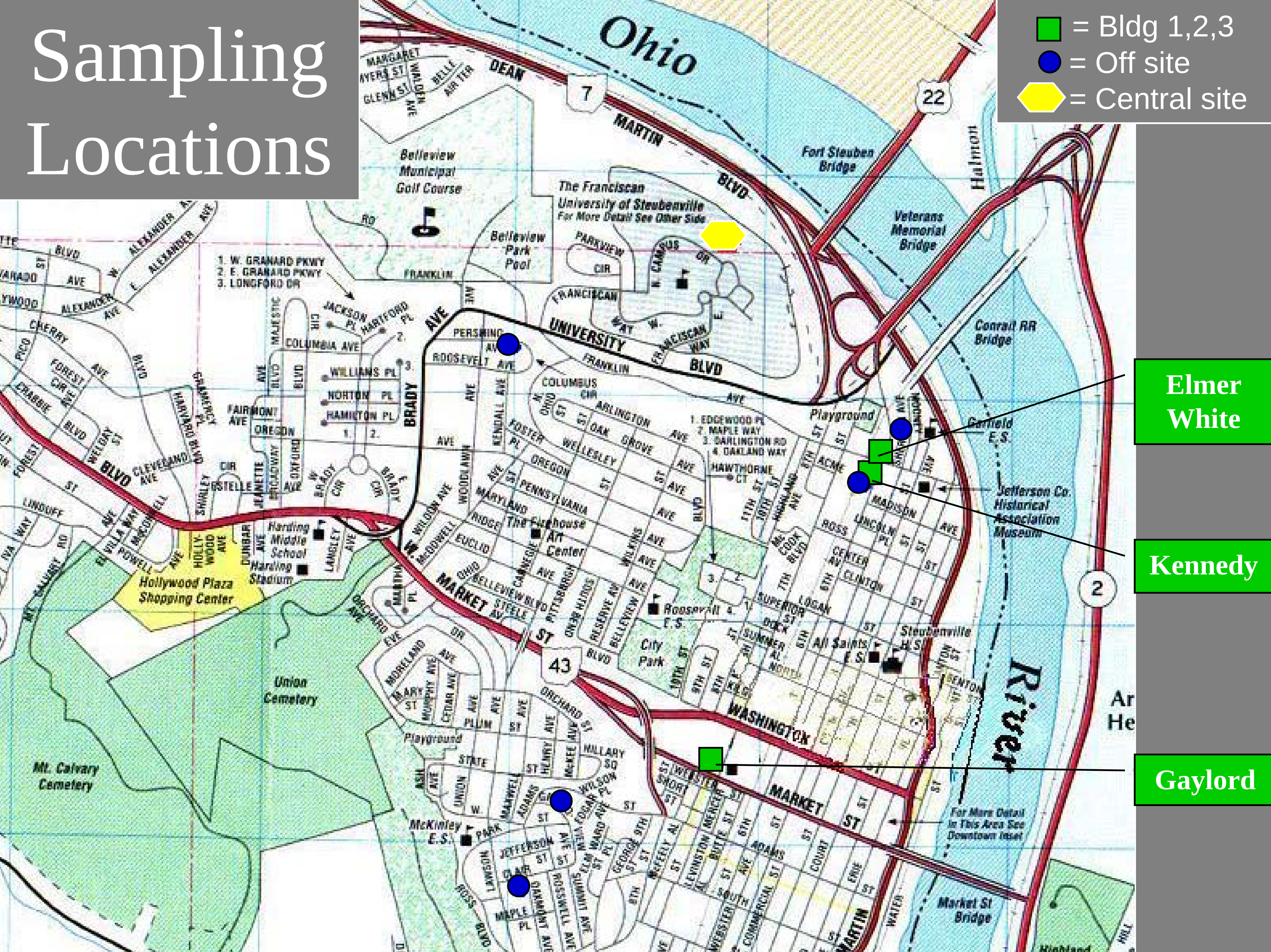
SCAMP Exposure Measurement Design



SCAMP Outdoor Ambient Monitoring Sites

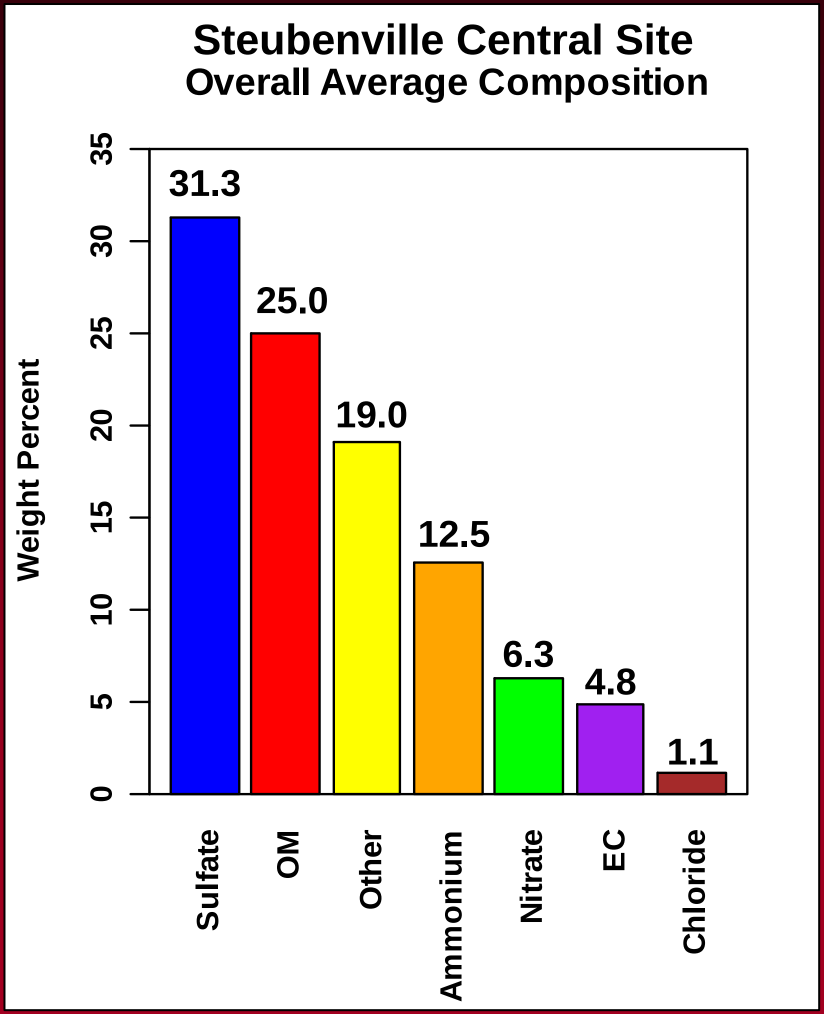


Sampling Locations



Design:
Important Considerations

$PM_{2.5}$ Composition



OM Component:

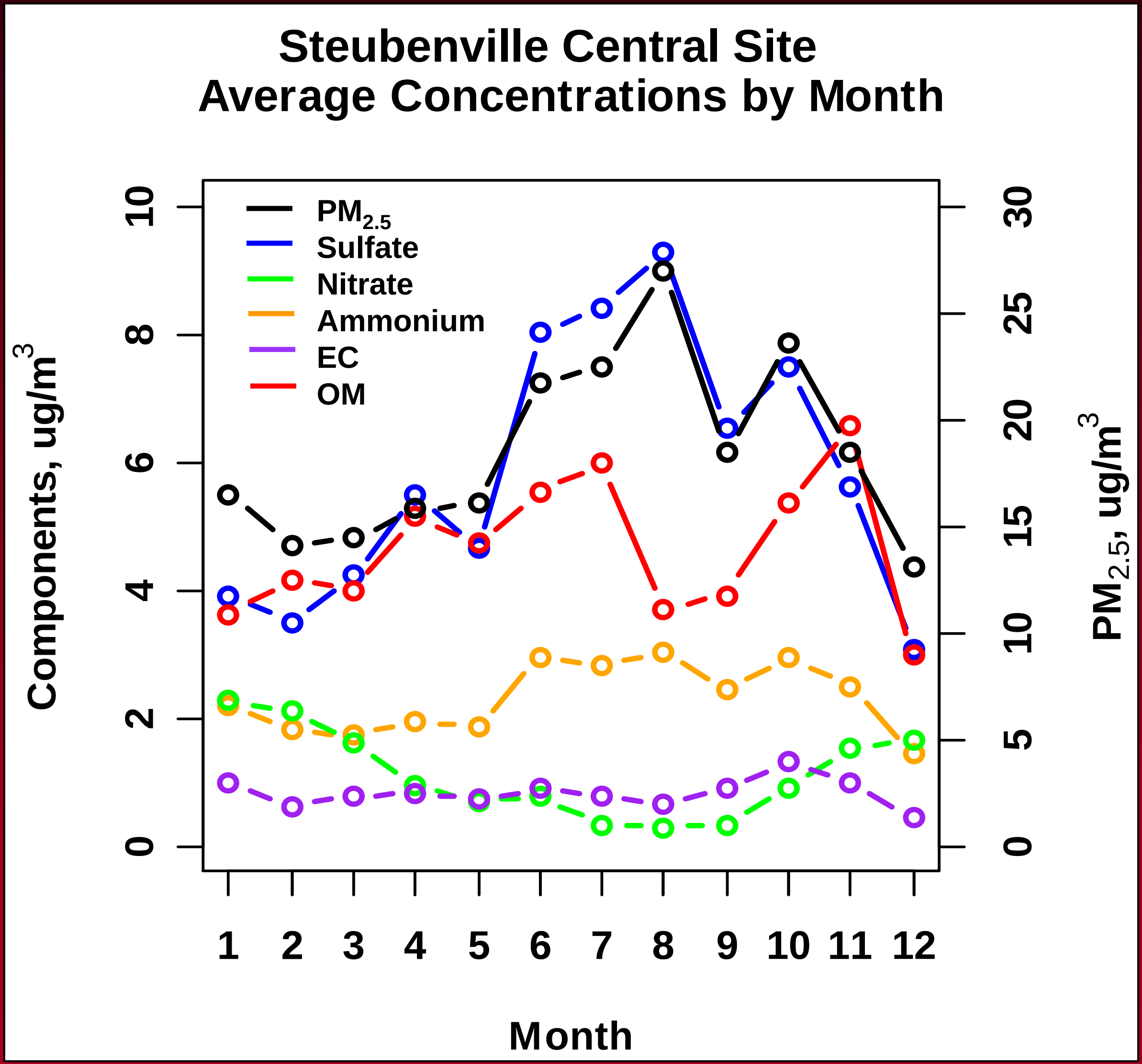
Hundreds to thousands of different chemical compounds

"Other" Component:

Crustal material
Trace elements
Particle-bound water

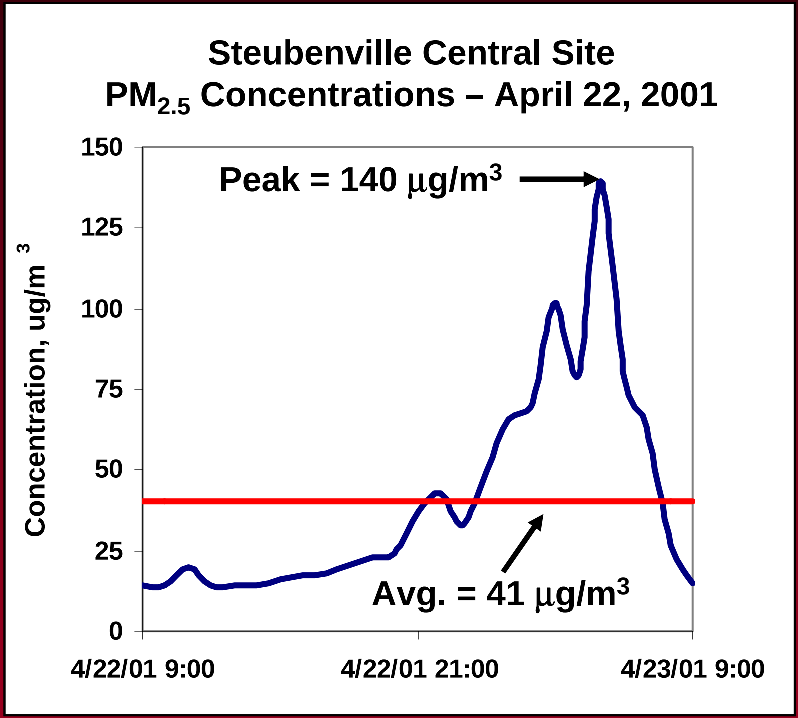
Temporal Resolution/Frequency/Duration

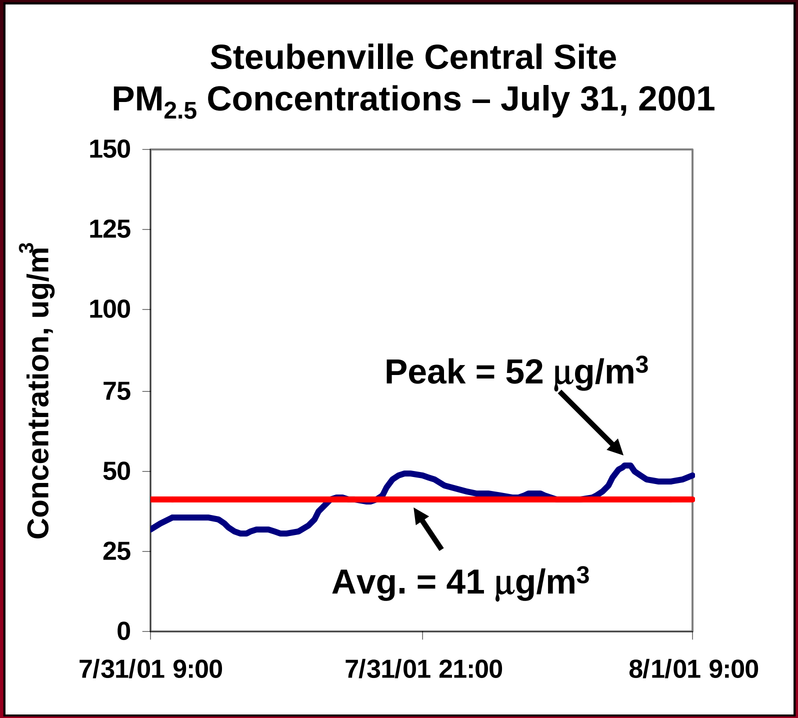
Seasonal Variability



Temporal Resolution/Frequency/Duration

Other Considerations

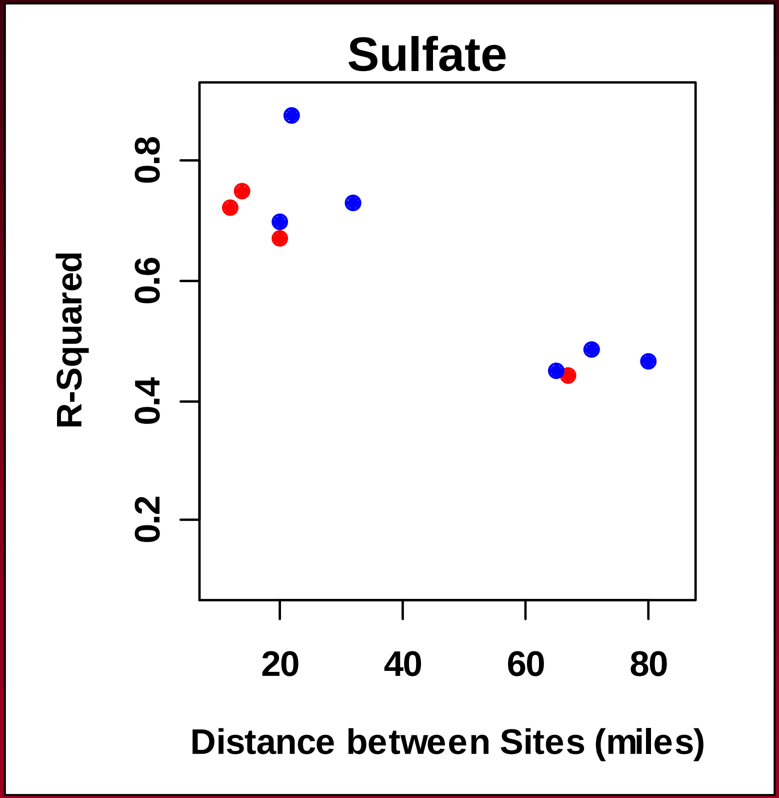


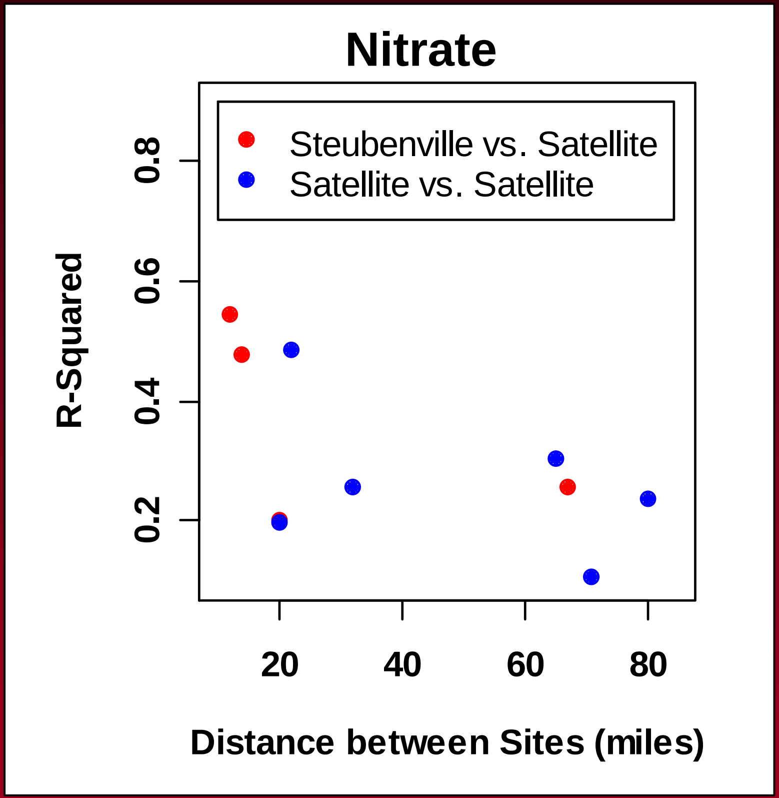


- Chronic vs. acute exposure
- Frequency and duration of episodes
- Effect of averaging

Spatial Variability

Compositional Dependence





Spatial Variability

Siting Considerations

$PM_{2.5}$ Monitor Siting Requirements – EPA Quality Assurance Guidance Document 2.12:

- Unobstructed air flow for at least 2 m in all directions
- Sampler inlet located 2 to 15 m above ground level
- Collocated sampler inlets spaced 1 to 4 m, vertical elevations within 1 m of each other

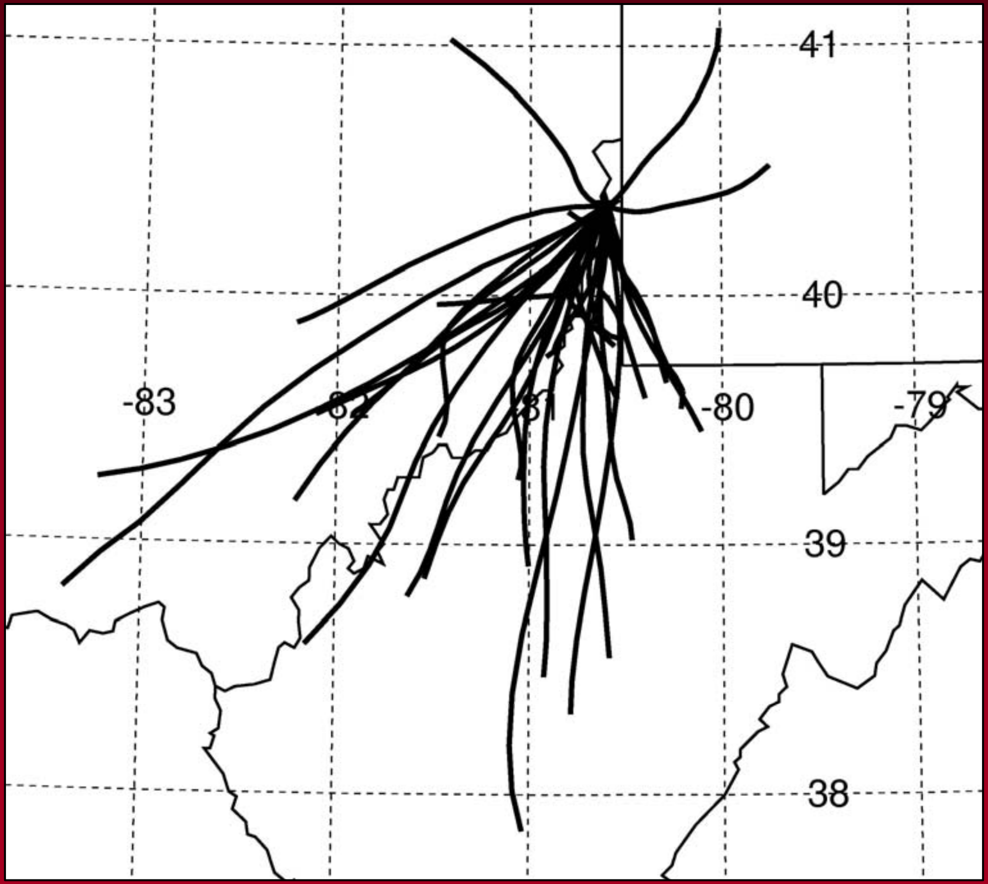
Other Considerations:

- Proximity to Sources
- Elevation / Prominent Geographical Features
- Safety / Electrical / Security

Other Potentially Important Variables

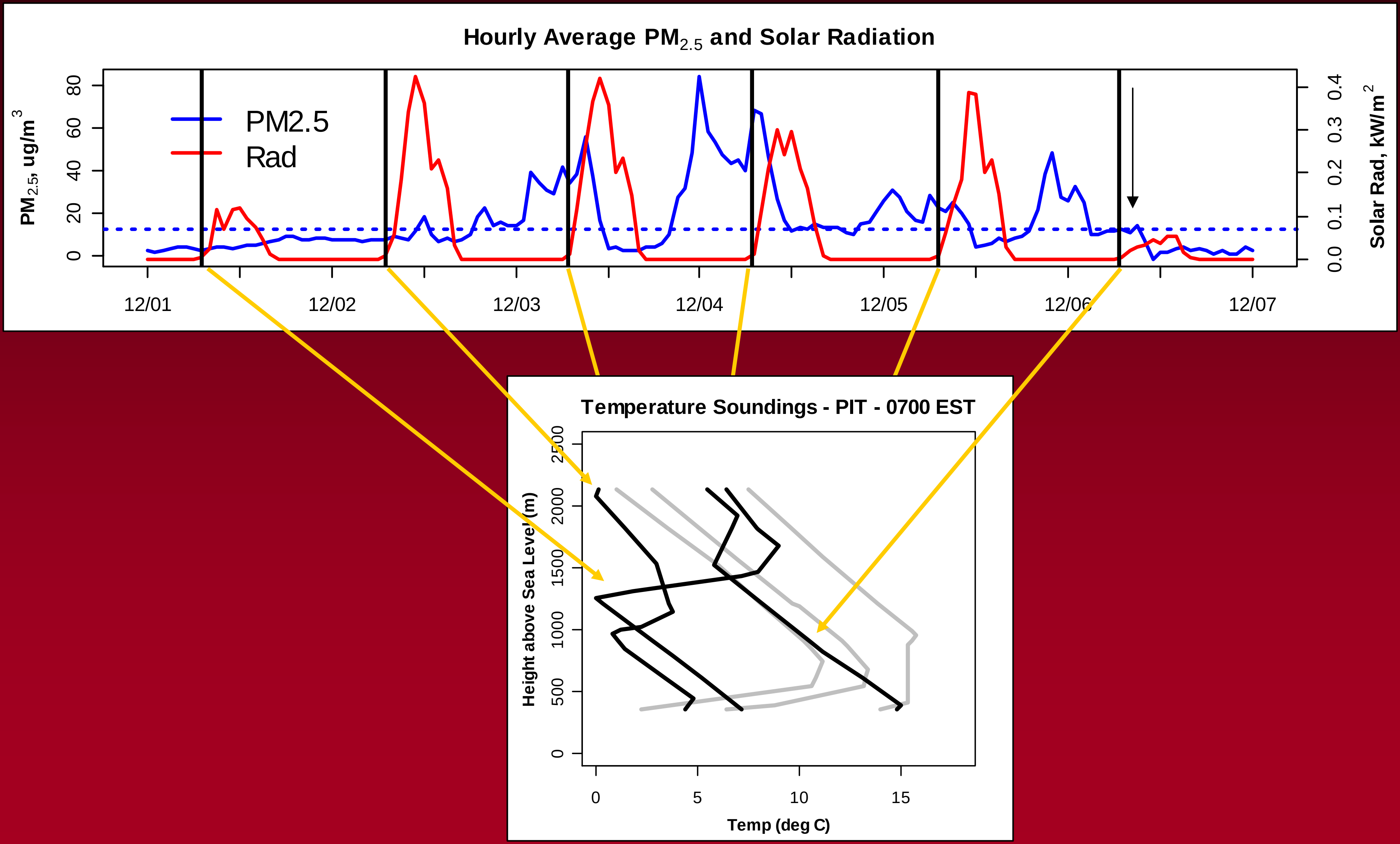
Transport / Wind Direction

12-h Backward Trajectories from Steubenville for Hours with $PM_{2.5}$ Concentrations > 65 $\mu g/m^3$



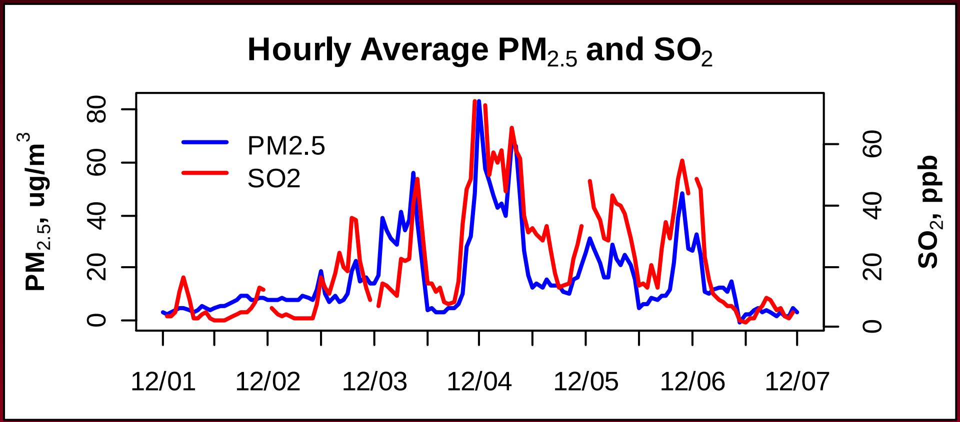
Other Potentially Important Variables

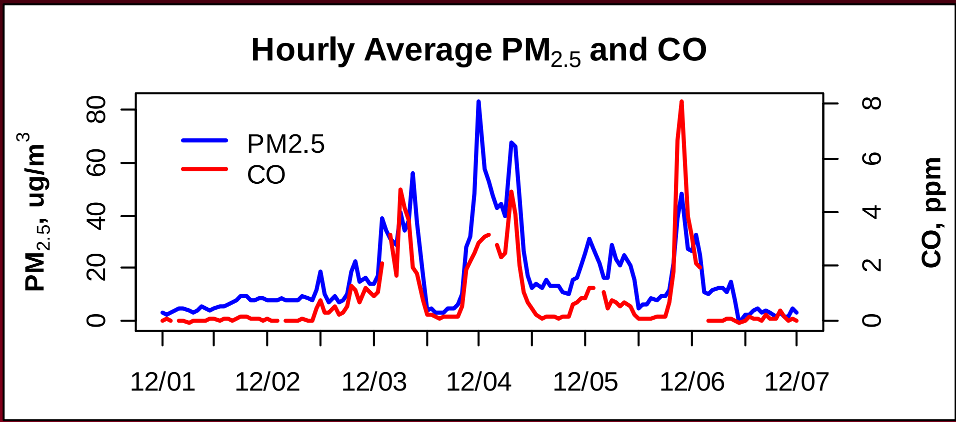
Frontal Systems and Temperature Inversions

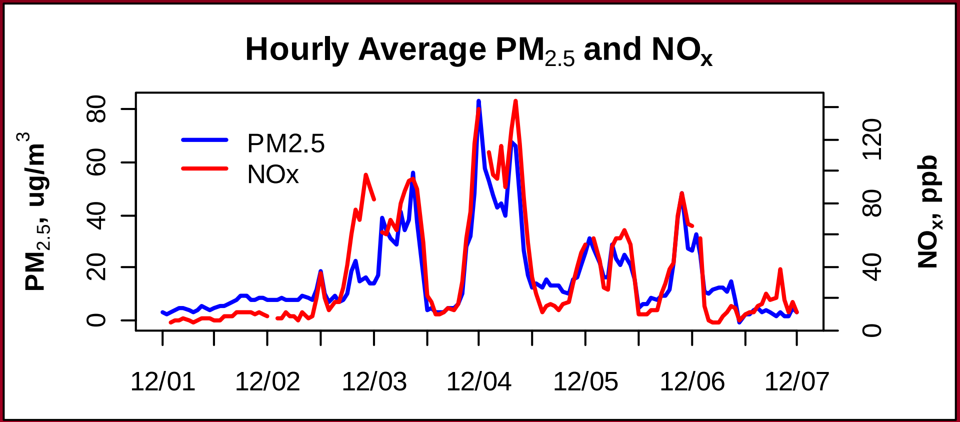


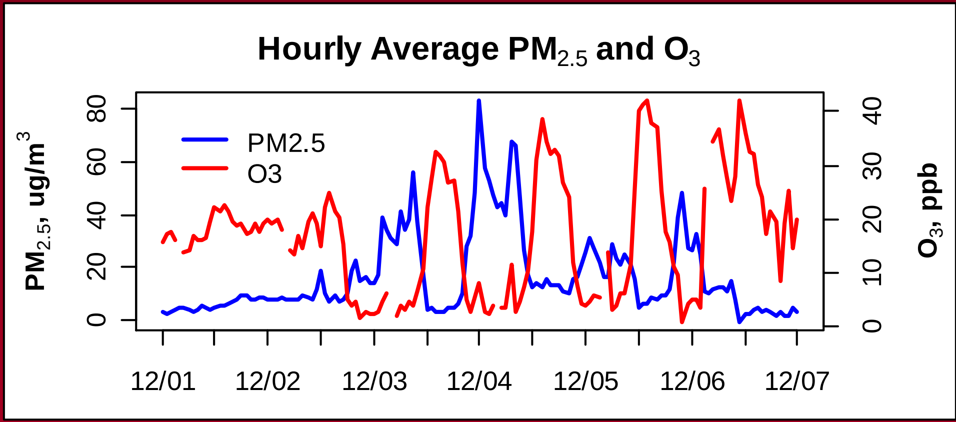
Other Potentially Important Variables

Gaseous Co-Pollutants



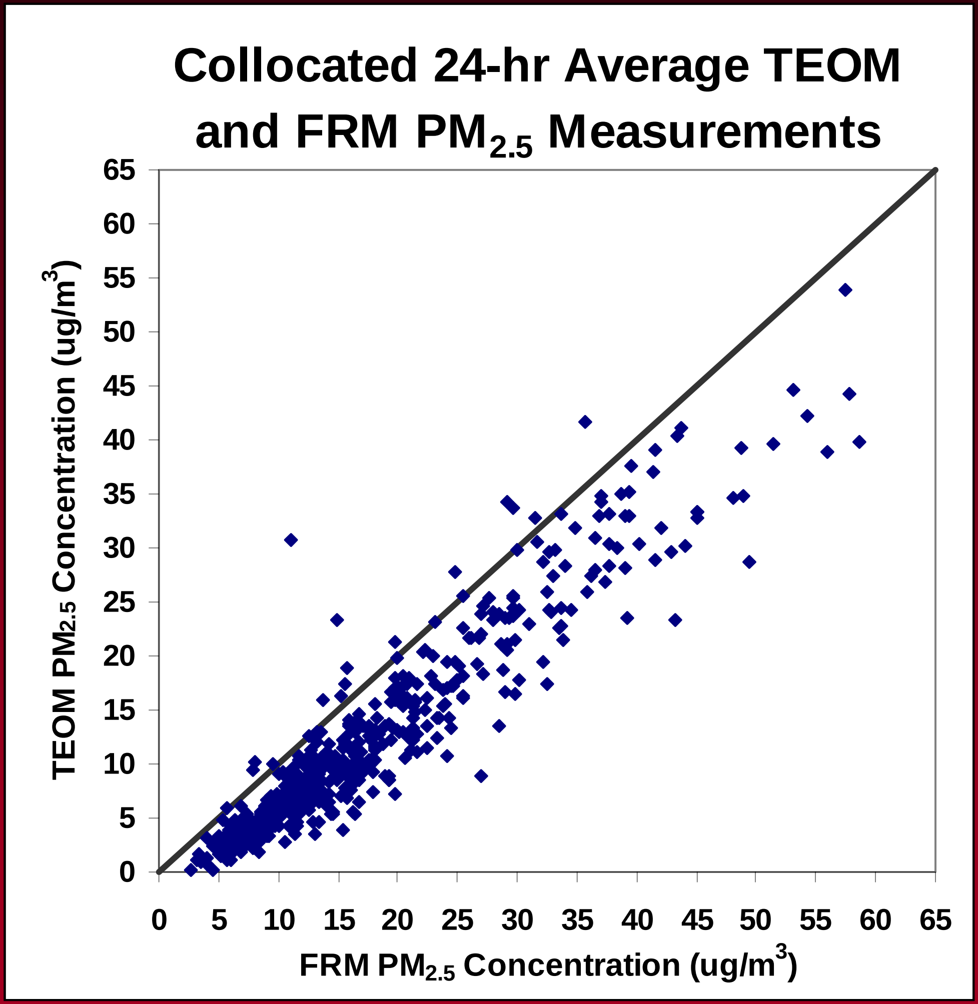






Design:
Sampling and Measurement Issues

$PM_{2.5}$ Sampler Issues



Bias of TEOM Relative to FRM (in $\mu g/m^3$)

FRM Conc.	Rel. Bias
6.6	-3.7
11.4	-4.7
17.8	-5.6
28.6	-5.8
43.2	-8.4

$PM_{2.5}$ Sampler Issues

Potential Sources of Measurement Error in the $PM_{2.5}$ FRM:

- No denuders to scrub reactive gases
- No backup filters to collect revolatilized material
- No blank correction procedure to account for contamination during handling / storage

Important Points – Sampler Selection:

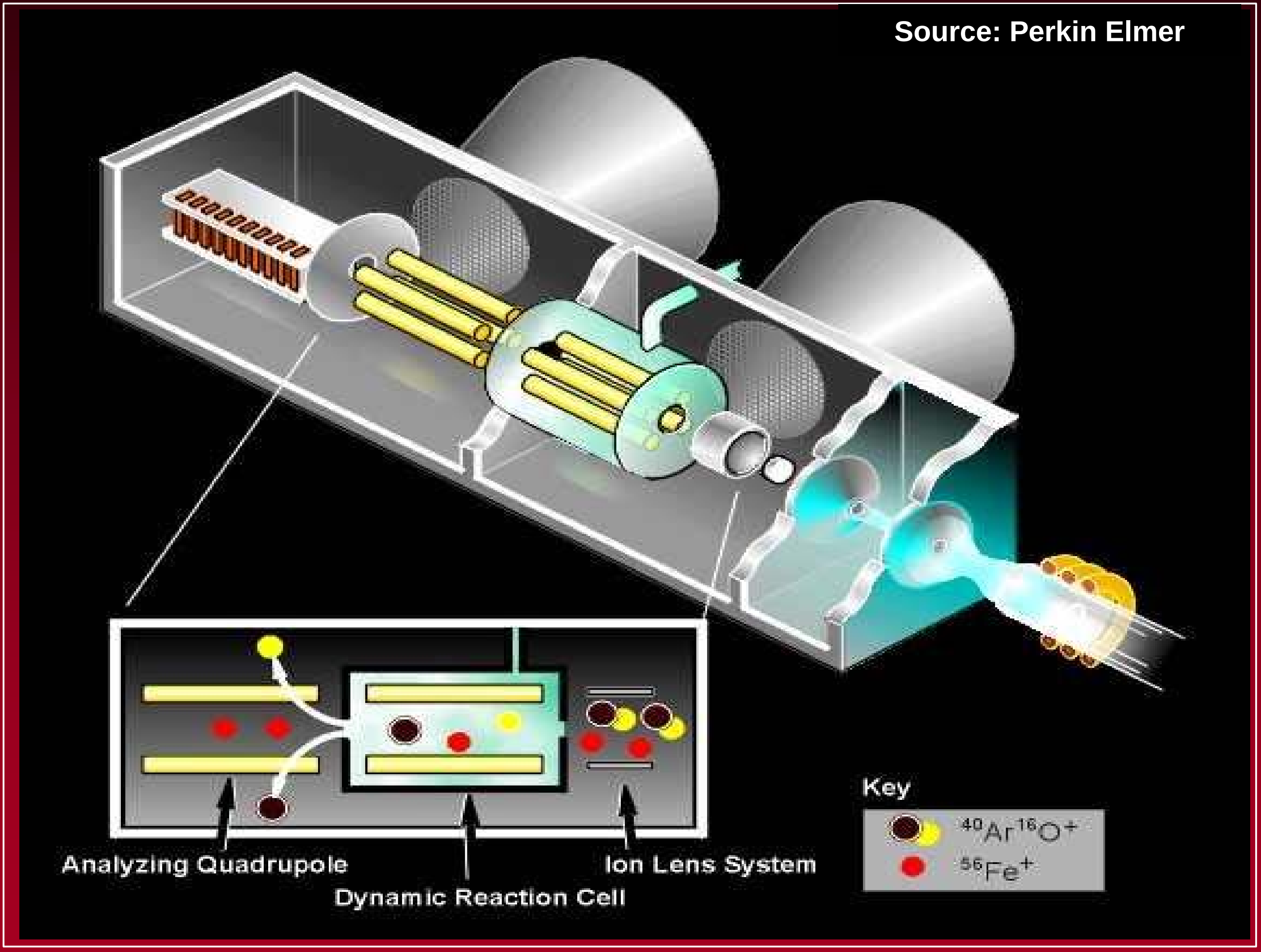
- Integrated vs. Continuous
- Accuracy and Precision
  - Difference between measured / true ambient values
  - Comparability among different methods
- Cost / Labor Requirements

Trace Element Analysis - Issues

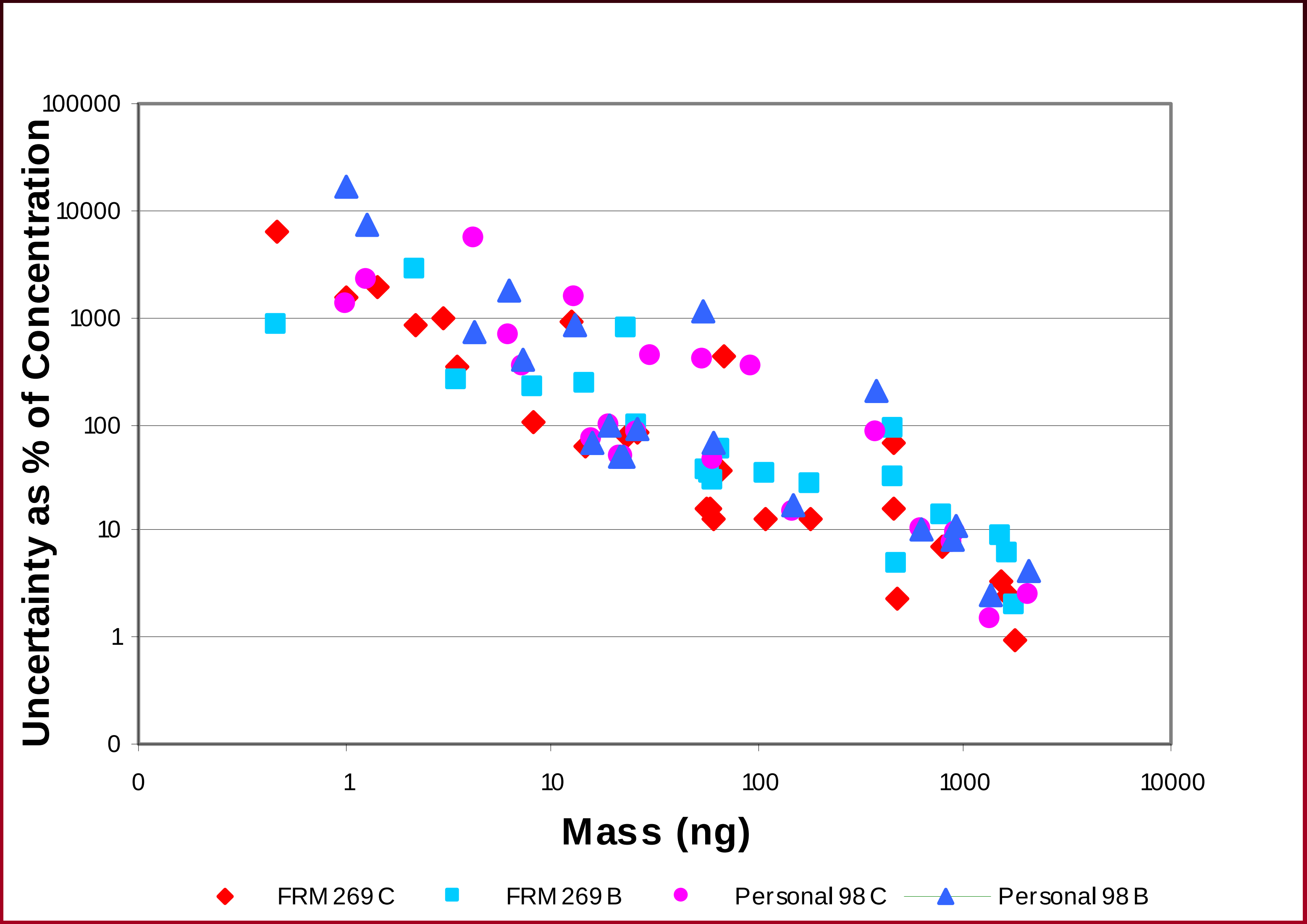
- **X-ray Fluorescence**
  - **Advantages**
    - Non-destructive
    - Dissolution not necessary
    - Good precision for major elements
  - **Disadvantages**
    - Sensitivity
    - Limited applications at masses < 20 amu

- **Conventional ICP-MS**
  - **Advantages**
    - Sensitivity-ppt
    - Speed
    - Widely Applicable
  - **Disadvantages**
    - Destructive
    - Dissolution required
    - <u>Molecular interferences</u>

Dynamic Reaction Cell ICP-MS



Trace Element Analysis - Limitations with XRF

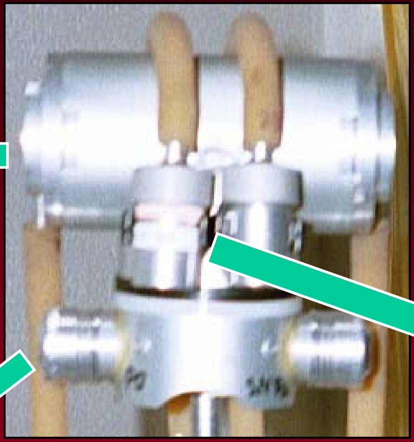


Personal and Indoor Sampling

Outside the Home Sampling

Harvard Multi-Pollutant Monitor

2 x $PM_{2.5}$ PEMs



NO_2/SO_2 and O_3
Ogawa badges
(passive samplers)

EC/OC and SO_4^{2-}
Mini-PEMs

Personal Sampling – Issues and Limitations

- Recruitment of subjects
- Does the behavior of the participant change?
- Personal Samplers:
  - Do they effectively measure the exposure?
  - Gases – significant biases versus federal reference and equivalent monitors, high blanks, detection limits, passive sampling technology
- Integrated – not real-time, short-term transient exposure information is limited (inferred through activity diary)
- Expensive and labor intensive

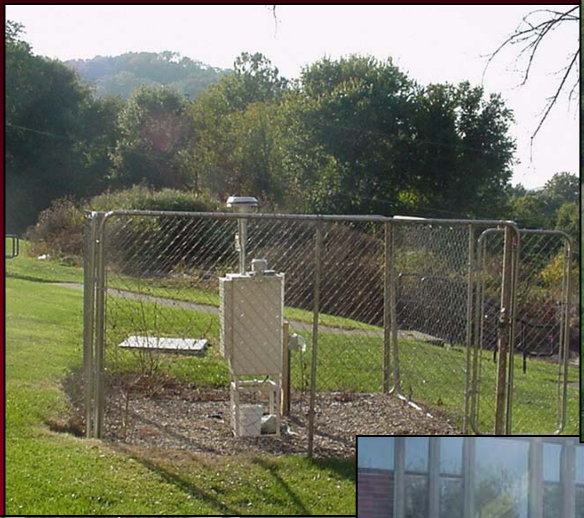
Steubenville Site

- $PM_{2.5}$ FRM
  - Mass (1/1 $days^{-1}$)
  - Ions (1/4)
  - Water-soluble elements (1/4)
- $PM_{2.5}$ Speciation Sampler
  - EC, OC (1/4)
  - Acid-digestible elements (1/4)
- $PM_{2.5}$ TEOM
  - Mass (continuous)
- PM_{10} FRM
  - Mass (1/1)
  - Ions (1/1)
  - Water-soluble elements (1/1)

- FRM or FEM Gas Analyzers
  - SO_2, CO, NO_x, O_3 (continuous)
- 10-m Meteorological Tower
  - Weather Conditions (continuous)
- Burkard Volumetric Spore Trap
  - Pollen and Mold Spores (1/1)

Satellite Sites

- $PM_{2.5}$ FRM
  - Mass (1/1 $days^{-1}$)
  - Ions (1/4)
  - Water-soluble elements (1/4)




Personal and Indoor Monitoring

Adult Study Participants:

- 32 adults (29 women, 3 male)
- 53-90 years; average age 70.5 years
- All current non-smokers; 15 past smokers (1 participant living w/smoker, 4 have guests that smoke occasionally)
- 27 reported health condition (e.g., chest pain, hypertension, CHF, COPD, cough, phlegm) during screening questionnaire
- Reside mostly in three government-subsidized buildings
  - Kennedy (16), Gaylord (5), Elmer White (5)
  - Private homes (5), townhouse (1)
- Linked to concurrent NIEHS/EPA-funded HRV study

Children's Study Participants:

- 15 children
- Living in non-smoking households

Measurements:

- Indoor and outdoor particulate and gaseous concentrations
- Personal exposure measurements
- Air exchange rates
- Time/activity diaries, housing questionnaires
- Fine particles: $PM_{2.5}$, EC/OC, SO_4^{2-}, NO_3^-, water-soluble and total elements
- Gases: O_3, SO_2, NO_2
- Health Monitoring (Adults): clinic visits, questionnaires, EKG's, breath analysis

Execution,
Quality Assurance /
Quality Control

QA/QC

- PROJECT IMPLEMENTATION
- SAMPLING – EPA Quality Assurance Guidelines 2.12
- FILTER HANDLING - Chain of custodies, cold storage
- WEIGHING – Maintain controlled environment for temp, humidity, dust, static, external round robins for equivalency
- CHEMICAL ANALYSIS – standard methods, external round robins for competency
- DATA INTEGRITY – data review, database, independent audits
- DATA ANALYSIS – data flagging, data validation, blank correction, statistical (in)significance, peer review

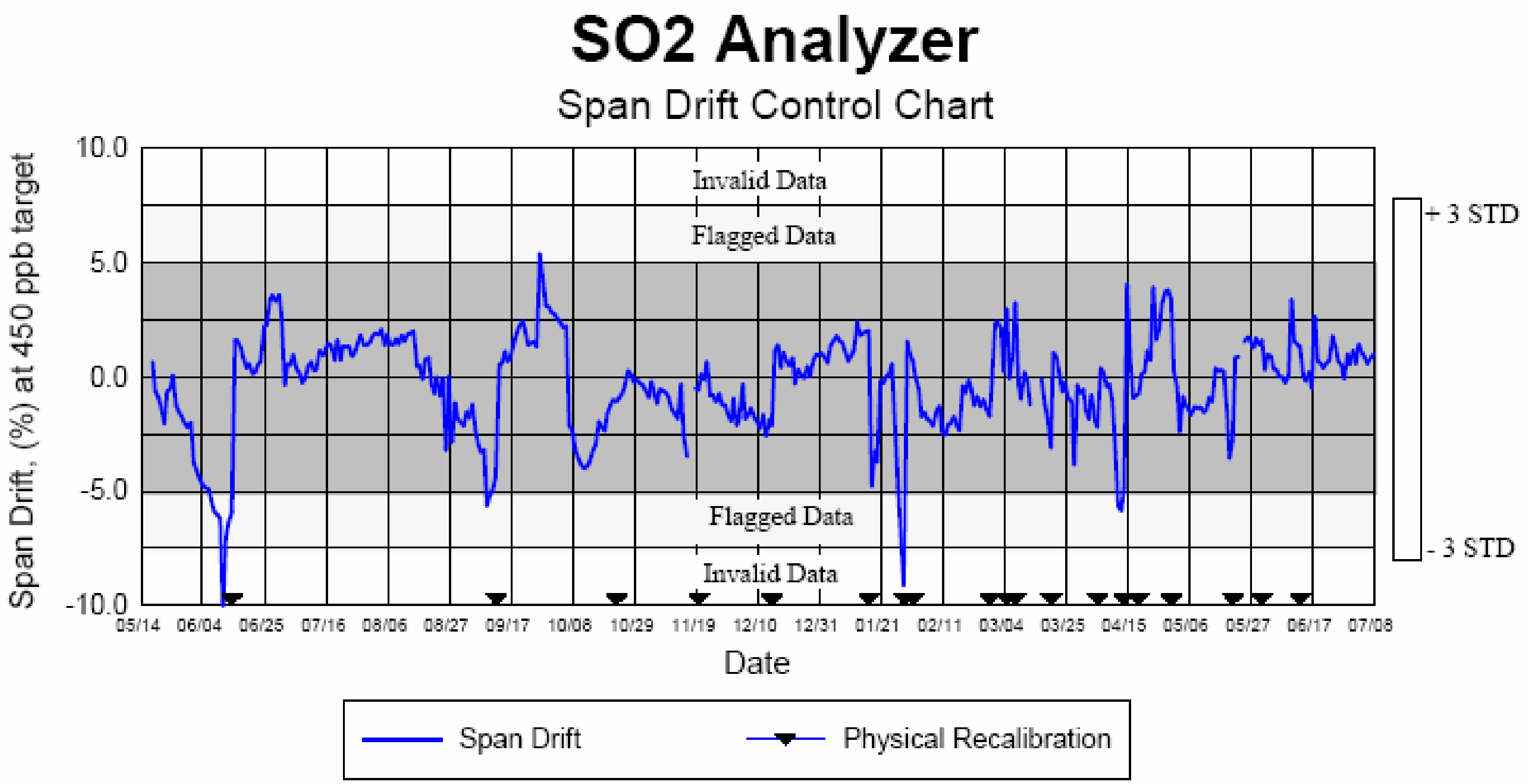
➢ **BALANCE COST, EFFECTIVENESS, COMPLIANCE**

QA/QC

$PM_{2.5}$ Filter Management

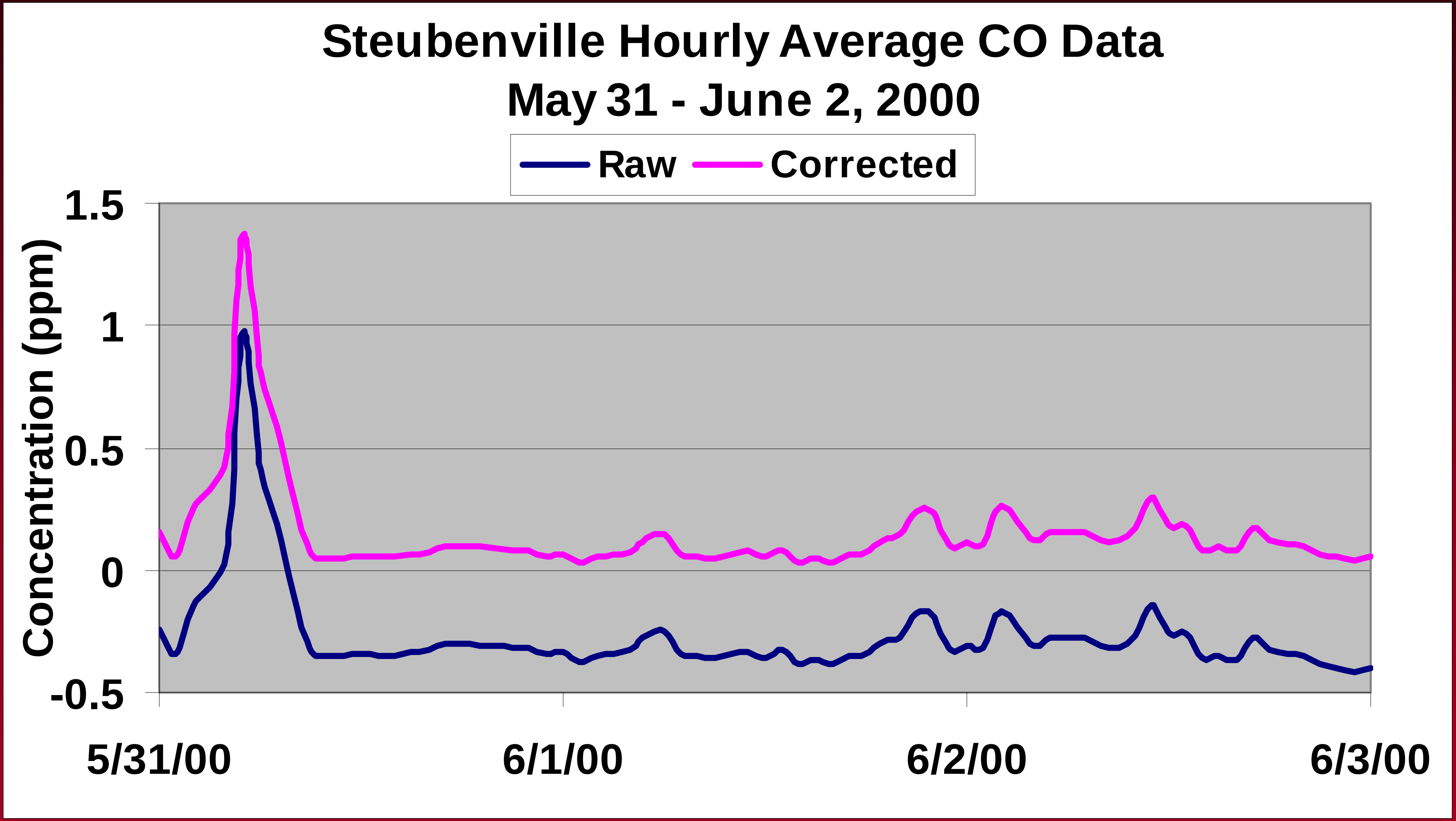
- Need to deploy filters to 5 sites from 2 labs for everyday sampling for 2 years through a (3) state area
- Filters must be recovered within 96 hours of sampling event
- Filter cassettes are expensive. Can’t buy an unlimited amount. Need to clean and re-use fleet.
- Filters need to be back weighed within 30 days
- Filter handling/protocol very restrictive to prevent contamination and minimize artifacts
- Need to maintain coordination, timeliness, custody and control
- Outcome: **<u>Cost to implement ~ 100K. THAT IS WHY MONITORING AGENCIES ARE >>>>> Continuous</u>**

QA/QC
Gas Analyzers – Control Charts



QA/QC

Gas Analyzers – Accounting for Drift



Summary

- Conceptualization
- Design
  - Important Considerations
  - Sampling and Measurement Issues
- Execution, Quality Assurance / Quality Control

Plus . . .

- Data Analysis
- Reporting
- Project Management
- Keep Up With the Science