# Why we would be up a Creek Without CSN Data


## Ted Russell, Georgia Tech
## and a cast of hundreds from GIT, Emory and elsewhere

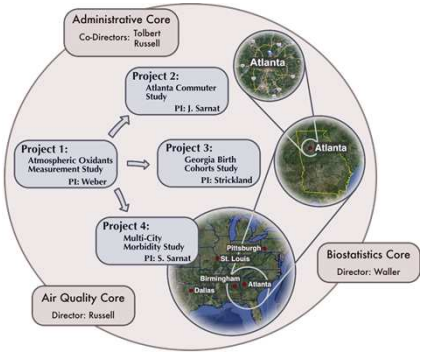
ROLLINS SCHOOL OF PUBLIC HEALTH
EMORY

Georgia Institute of Technology



This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # R83479901

# Special Thanks




- Colleagues Professors and students at Georgia Tech and Emory (and beyond)
  - Southeastern Center for Air Pollution Epidemiology (SCAPE)
- State of Georgia and other states for their great data
- Atmospheric Research and Analysis (ARA)
- Sources of support
  - Southern Company & Georgia Power
  - US EPA, DoT, NIH, USDA, NSF
  - Georgia EPD/DNR and DoT
  - ConocoPhillips and Phillips66
  - Health Effects Institute

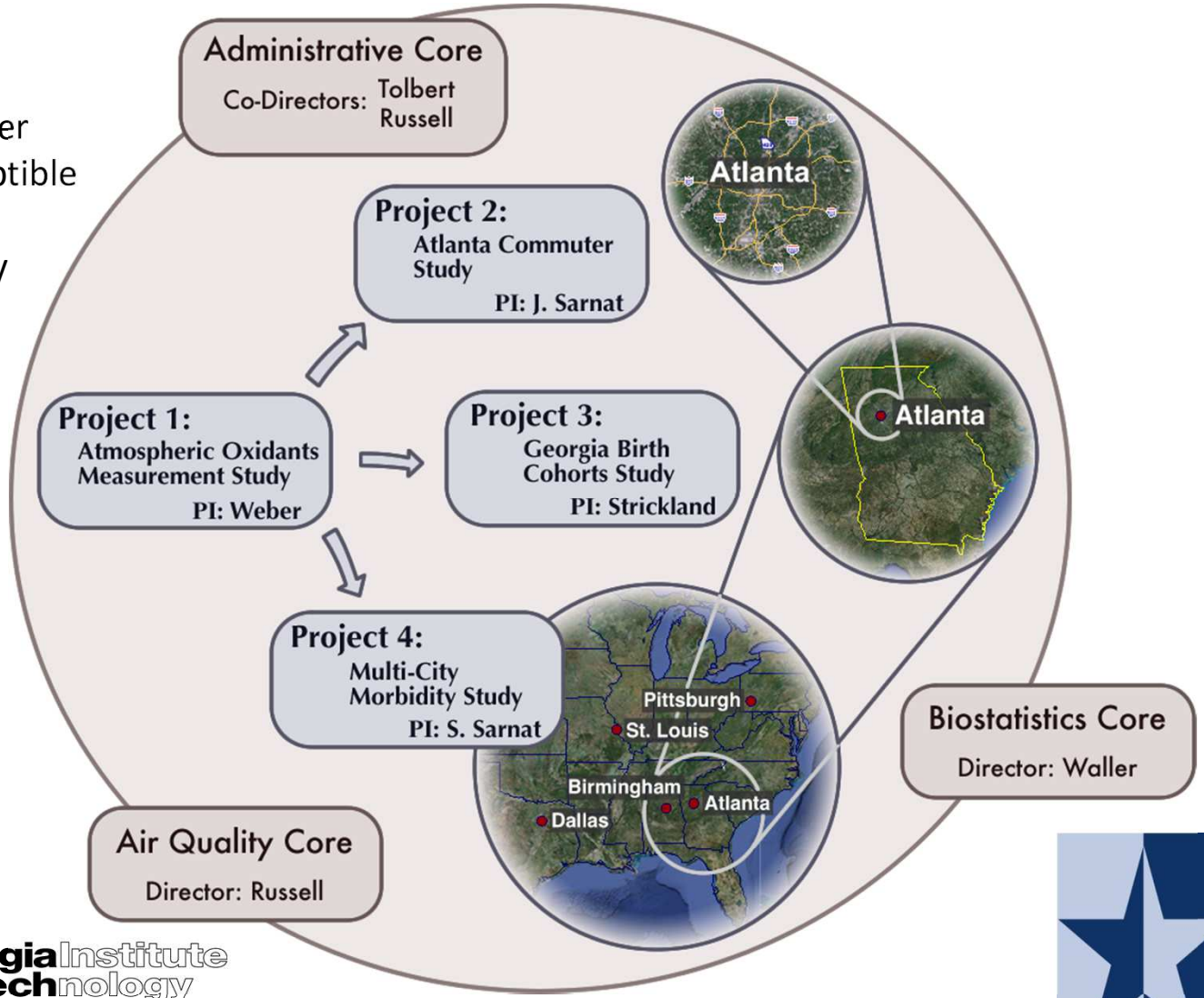
# Southeastern Center for Air Pollution and Epidemiology (SCAPE)

*Characterizing ambient air pollution mixtures and understanding their role in human health risks*

Co-Directors: Paige Tolbert, Emory, and Armistead (Ted) Russell, Georgia Tech

Key Features:

- Children and other vulnerable/susceptible populations
- Trans-disciplinary
- Multi-scale

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1998 Daily Max: 68.3 µg m-3
2013 Daily Max: 37.3 µg m-3

# Topics

- Air pollution and Health
- Uses of CSN data in research
  - Understanding sources
  - Assessing health impacts
- CSN modifications
- Inexpensive sensors
- Points to take home
  - Air pollution is a critical health concern
  - The CSN data set is a unique treasure
    - Variety of research applications
      - Impact decision making
    - Can be made more powerful
  - Embrace change

# AIR POLLUTION AND HEALTH

# Air Pollution Health Effects

## Respiratory

Coughing, wheezing, reduced lung function

Exacerbation of asthma, COPD

Lung cancer

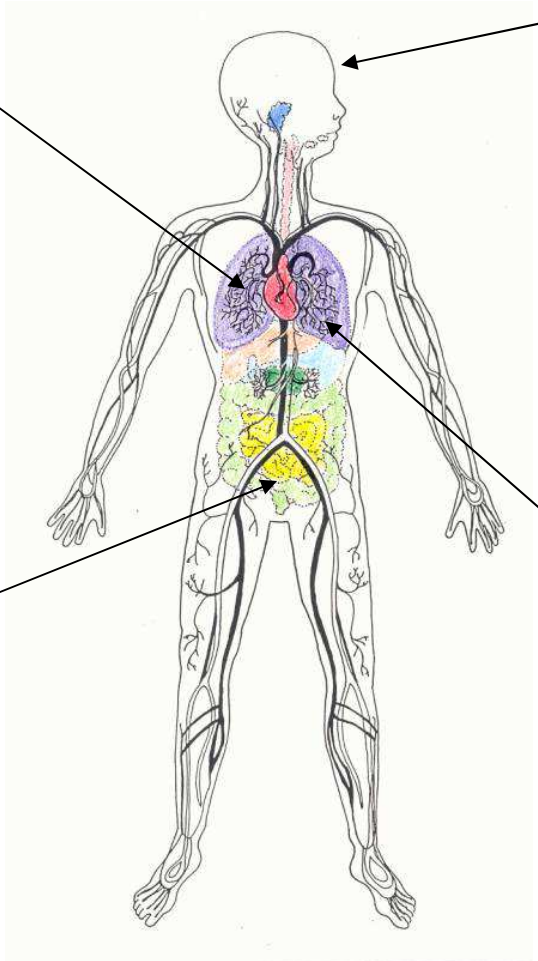
Respiratory mortality

## Reproductive

Low birth weight

Preterm births and intrauterine growth retardation (?)

Birth defects (?)



## Central Nervous

Stroke (?)

Cognitive effects(?)

## Cardiovascular

HRV reduction, dysrhythmias

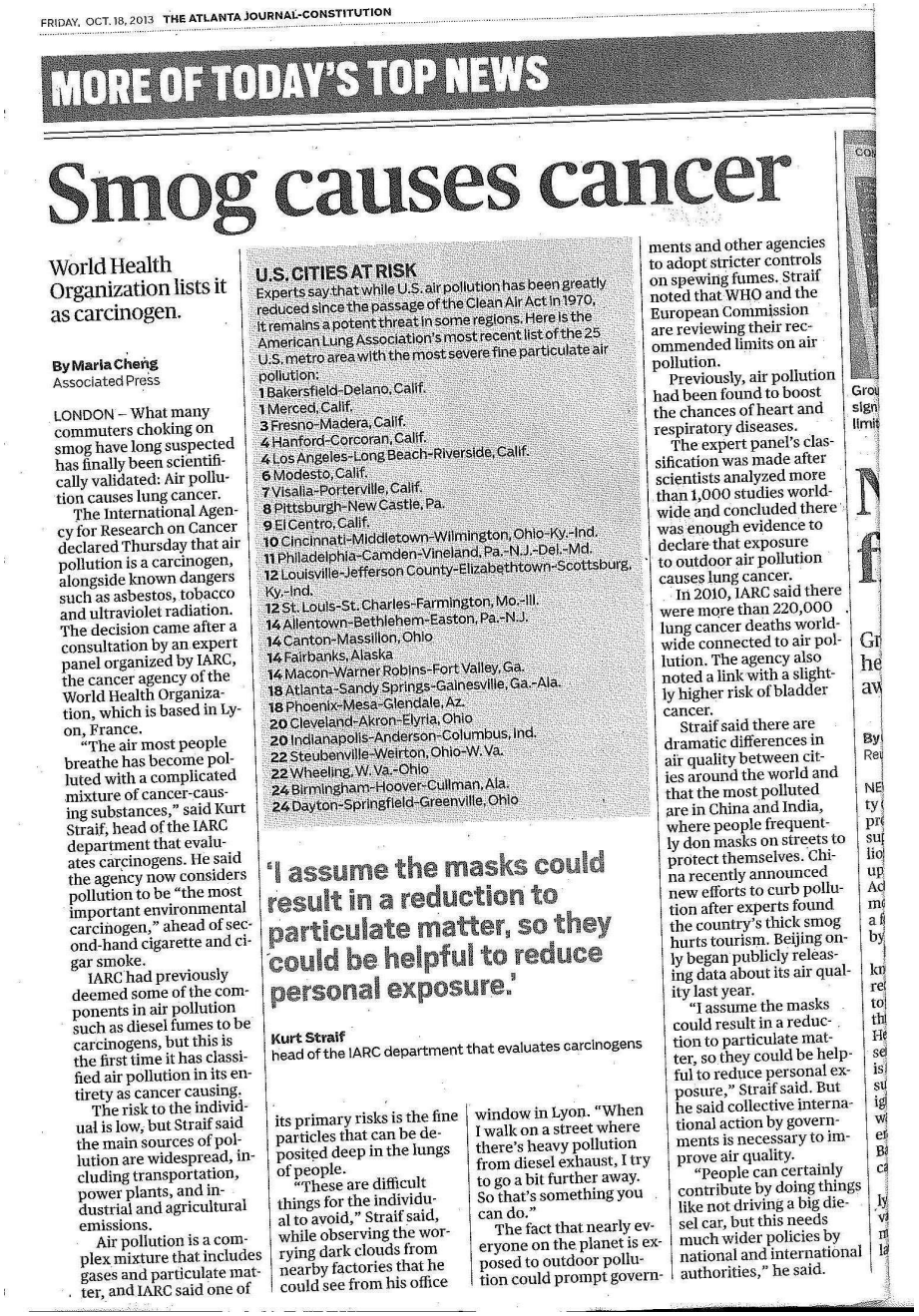
Systemic inflammation

Atherosclerosis

Myocardial infarctions (Heart Attacks)

CV mortality

# IARC: Smog is a Group 1 Carcinogen:





MORE OF TODAY'S TOP NEWS

## Smog causes cancer

World Health Organization lists it as carcinogen.

By Maria Cheng
Associated Press

LONDON – What many commuters choking on smog have long suspected has finally been scientifically validated: Air pollution causes lung cancer.

The International Agency for Research on Cancer declared Thursday that air pollution is a carcinogen, alongside known dangers such as asbestos, tobacco and ultraviolet radiation. The decision came after a consultation by an expert panel organized by IARC, the cancer agency of the World Health Organization, which is based in Lyon, France.

"The air most people breathe has become polluted with a complicated mixture of cancer-causing substances," said Kurt Straif, head of the IARC department that evaluates carcinogens. He said the agency now considers pollution to be "the most important environmental carcinogen," ahead of second-hand cigarette and cigar smoke.

IARC had previously deemed some of the components in air pollution such as diesel fumes to be carcinogens, but this is the first time it has classified air pollution in its entirety as cancer causing.

The risk to the individual is low, but Straif said the main sources of pollution are widespread, including transportation, power plants, and industrial and agricultural emissions.

Air pollution is a complex mixture that includes gases and particulate matter, and IARC said one of its primary risks is the fine particles that can be deposited deep in the lungs of people.

"These are difficult things for the individual to avoid," Straif said, while observing the worrying dark clouds from nearby factories that he could see from his office window in Lyon. "When I walk on a street where there's heavy pollution from diesel exhaust, I try to go a bit further away. So that's something you can do."

The fact that nearly everyone on the planet is exposed to outdoor pollution could prompt governments and other agencies to adopt stricter controls on spewing fumes. Straif noted that WHO and the European Commission are reviewing their recommended limits on air pollution.

Previously, air pollution had been found to boost the chances of heart and respiratory diseases.

The expert panel's classification was made after scientists analyzed more than 1,000 studies worldwide and concluded there was enough evidence to declare that exposure to outdoor air pollution causes lung cancer.

In 2010, IARC said there were more than 220,000 lung cancer deaths worldwide connected to air pollution. The agency also noted a link with a slightly higher risk of bladder cancer.

Straif said there are dramatic differences in air quality between cities around the world and that the most polluted are in China and India, where people frequently don masks on streets to protect themselves. China recently announced new efforts to curb pollution after experts found the country's thick smog hurts tourism. Beijing only began publicly releasing data about its air quality last year.

"I assume the masks could result in a reduction to particulate matter, so they could be helpful to reduce personal exposure," Straif said. But he said collective international action by governments is necessary to improve air quality.

"People can certainly contribute by doing things like not driving a big diesel car, but this needs much wider policies by national and international authorities," he said.

### U.S. CITIES AT RISK

Experts say that while U.S. air pollution has been greatly reduced since the passage of the Clean Air Act in 1970, it remains a potent threat in some regions. Here is the American Lung Association's most recent list of the 25 U.S. metro area with the most severe fine particulate air pollution:

1 Bakersfield-Delano, Calif.
1 Merced, Calif.
3 Fresno-Madera, Calif.
4 Hanford-Corcoran, Calif.
4 Los Angeles-Long Beach-Riverside, Calif.
6 Modesto, Calif.
7 Visalia-Porterville, Calif.
8 Pittsburgh-New Castle, Pa.
9 El Centro, Calif.
10 Cincinnati-Middletown-Wilmington, Ohio-Ky.-Ind.
11 Philadelphia-Camden-Vineland, Pa.-N.J.-Del.-Md.
12 Louisville-Jefferson County-Elizabethtown-Scottsburg, Ky.-Ind.
12 St. Louis-St. Charles-Farmington, Mo.-Ill.
14 Allentown-Bethlehem-Easton, Pa.-N.J.
14 Canton-Massillon, Ohio
14 Fairbanks, Alaska
14 Macon-Warner Robins-Fort Valley, Ga.
18 Atlanta-Sandy Springs-Gainesville, Ga.-Ala.
18 Phoenix-Mesa-Glendale, Az.
20 Cleveland-Akron-Elyria, Ohio
20 Indianapolis-Anderson-Columbus, Ind.
22 Steubenville-Weirton, Ohio-W. Va.
22 Wheeling, W. Va.-Ohio
24 Birmingham-Hoover-Cullman, Ala.
24 Dayton-Springfield-Greenville, Ohio

**'I assume the masks could result in a reduction to particulate matter, so they could be helpful to reduce personal exposure.'**

**Kurt Straif**
head of the IARC department that evaluates carcinogens

Atlanta Journal Constitution, Oct. 18, 2013

# A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010
## Lim et al., 2012, Lancet

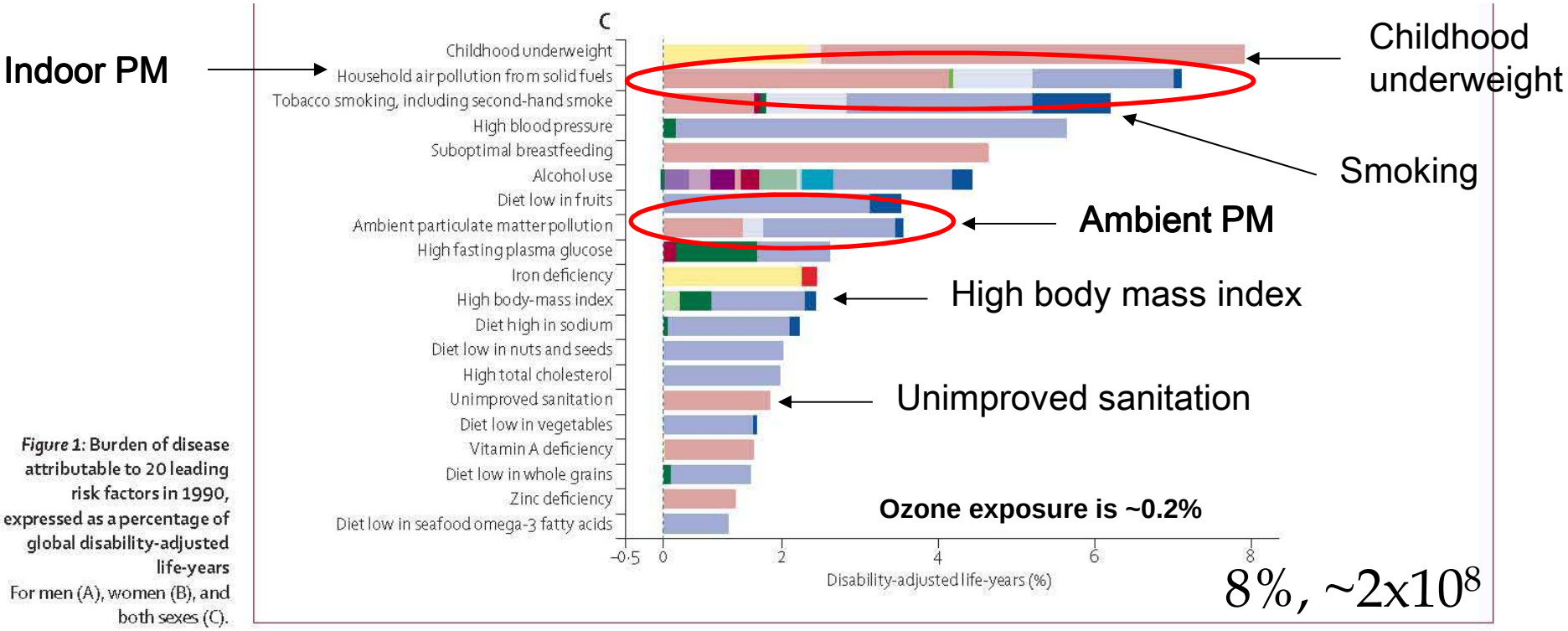


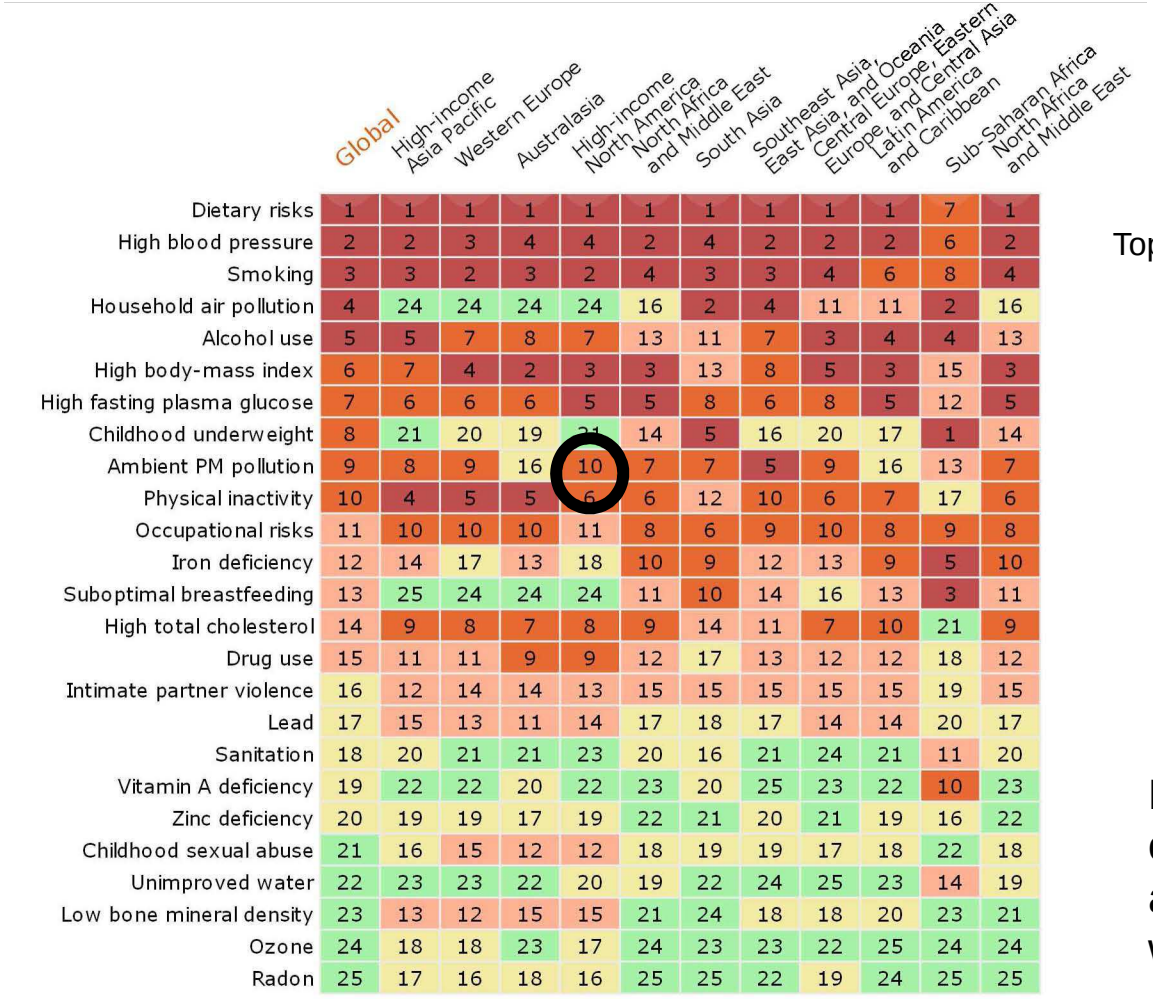

*Figure 1:* Burden of disease attributable to 20 leading risk factors in 1990, expressed as a percentage of global disability-adjusted life-years
For men (A), women (B), and both sexes (C).

# Disability Adjusted Life Years Lost by Risk Factor

Colors indicate related health disorder (e.g., cancer, cardiovascular disease)

(AP ~7 million related deaths/yr)

# Environmental Impacts on Global Disease: Factors Leading to Premature Death (2010)



| | Global | High-income Asia Pacific | Western Europe | Australasia | High-income North America | North Africa and Middle East | South Asia | Southeast Asia, East Asia, and Oceania | Central Europe, Eastern Europe, and Central Asia | Latin America and Caribbean | Sub-Saharan Africa | North Africa and Middle East |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dietary risks | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 7 | 1 |
| High blood pressure | 2 | 2 | 3 | 4 | 4 | 2 | 4 | 2 | 2 | 2 | 6 | 2 |
| Smoking | 3 | 3 | 2 | 3 | 2 | 4 | 3 | 3 | 4 | 6 | 8 | 4 |
| Household air pollution | 4 | 24 | 24 | 24 | 24 | 16 | 2 | 4 | 11 | 11 | 2 | 16 |
| Alcohol use | 5 | 5 | 7 | 8 | 7 | 13 | 11 | 7 | 3 | 4 | 4 | 13 |
| High body-mass index | 6 | 7 | 4 | 2 | 3 | 3 | 13 | 8 | 5 | 3 | 15 | 3 |
| High fasting plasma glucose | 7 | 6 | 6 | 6 | 5 | 5 | 8 | 6 | 8 | 5 | 12 | 5 |
| Childhood underweight | 8 | 21 | 20 | 19 | 21 | 14 | 5 | 16 | 20 | 17 | 1 | 14 |
| Ambient PM pollution | 9 | 8 | 9 | 16 | 10 | 7 | 7 | 5 | 9 | 16 | 13 | 7 |
| Physical inactivity | 10 | 4 | 5 | 5 | 6 | 6 | 12 | 10 | 6 | 7 | 17 | 6 |
| Occupational risks | 11 | 10 | 10 | 10 | 11 | 8 | 6 | 9 | 10 | 8 | 9 | 8 |
| Iron deficiency | 12 | 14 | 17 | 13 | 18 | 10 | 9 | 12 | 13 | 9 | 5 | 10 |
| Suboptimal breastfeeding | 13 | 25 | 24 | 24 | 24 | 11 | 10 | 14 | 16 | 13 | 3 | 11 |
| High total cholesterol | 14 | 9 | 8 | 7 | 8 | 9 | 14 | 11 | 7 | 10 | 21 | 9 |
| Drug use | 15 | 11 | 11 | 9 | 9 | 12 | 17 | 13 | 12 | 12 | 18 | 12 |
| Intimate partner violence | 16 | 12 | 14 | 14 | 13 | 15 | 15 | 15 | 15 | 15 | 19 | 15 |
| Lead | 17 | 15 | 13 | 11 | 14 | 17 | 18 | 17 | 14 | 14 | 20 | 17 |
| Sanitation | 18 | 20 | 21 | 21 | 23 | 20 | 16 | 21 | 24 | 21 | 11 | 20 |
| Vitamin A deficiency | 19 | 22 | 22 | 20 | 22 | 23 | 20 | 25 | 23 | 22 | 10 | 23 |
| Zinc deficiency | 20 | 19 | 19 | 17 | 19 | 22 | 21 | 20 | 21 | 19 | 16 | 22 |
| Childhood sexual abuse | 21 | 16 | 15 | 12 | 12 | 18 | 19 | 19 | 17 | 18 | 22 | 18 |
| Unimproved water | 22 | 23 | 23 | 22 | 20 | 19 | 22 | 24 | 25 | 23 | 14 | 19 |
| Low bone mineral density | 23 | 13 | 12 | 15 | 15 | 21 | 24 | 18 | 18 | 20 | 23 | 21 |
| Ozone | 24 | 18 | 18 | 23 | 17 | 24 | 23 | 23 | 22 | 25 | 24 | 24 |
| Radon | 25 | 17 | 16 | 18 | 16 | 25 | 25 | 22 | 19 | 24 | 25 | 25 |

Top 25 risk factors out of 67.

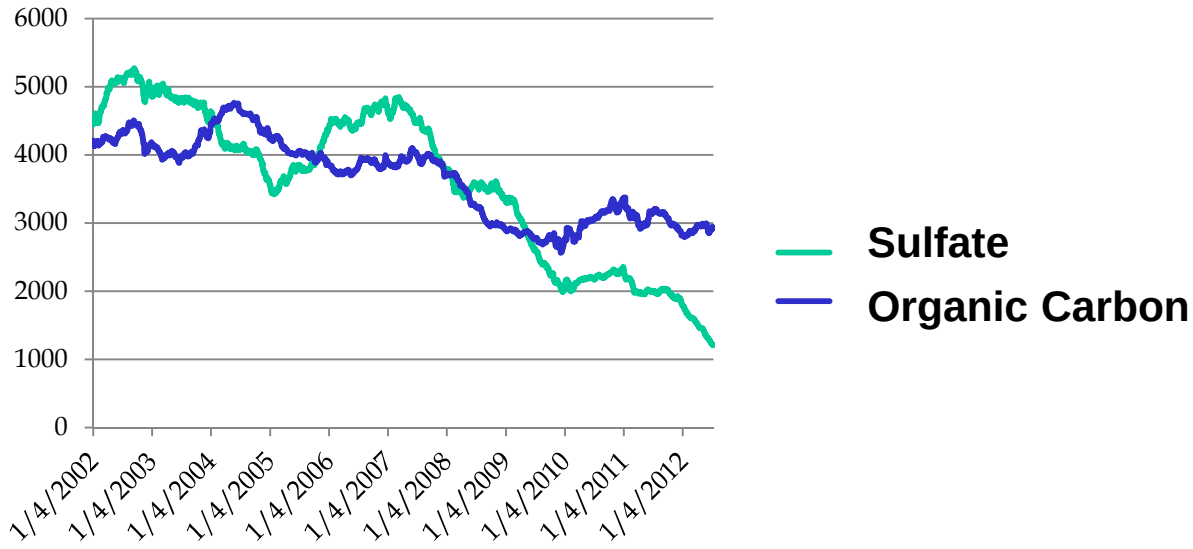
Does not include other effects such as asthma, lost work and school…

# Research applications of CSN data

- Understanding atmospheric chemical dynamics
  - Linkages between species
- Assessing effectiveness of controls
- Air quality model evaluation
  - These models have a huge role in air quality management, and we want to make sure they are up to the job
- Understanding what sources are responsible for PM problems (and other species as well)
  - Source apportionment
- Health studies
  - PM is not a single species and health effects are suspected of being species-related
- Source apportionment and health
  - Ultimately, you control sources to improve health
- … and more.

# Atmospheric Dynamics
# Chemical Linkages: OC and Sulfate

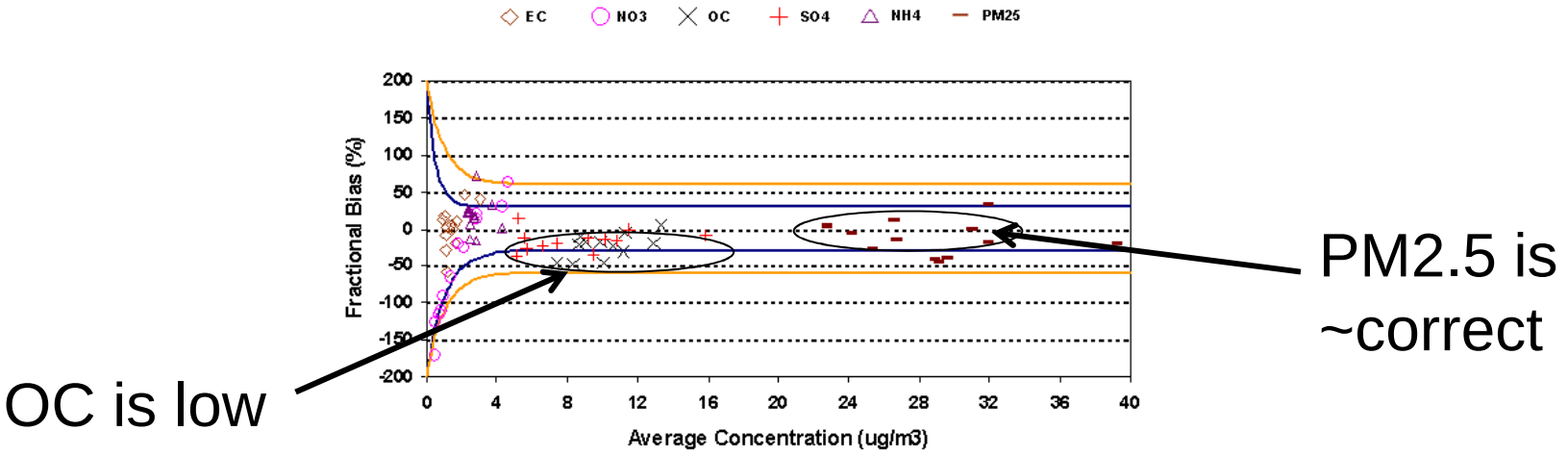
- Do anthropogenic emissions reductions affect biogenic PM formation
  - Analysis of trends in OC and sulfate in Atlanta suggest linkage:




- Supports laboratory and intensive field experiments
  - Without such corroboration it is difficult to assess importance
  - This is knock your socks off cool.

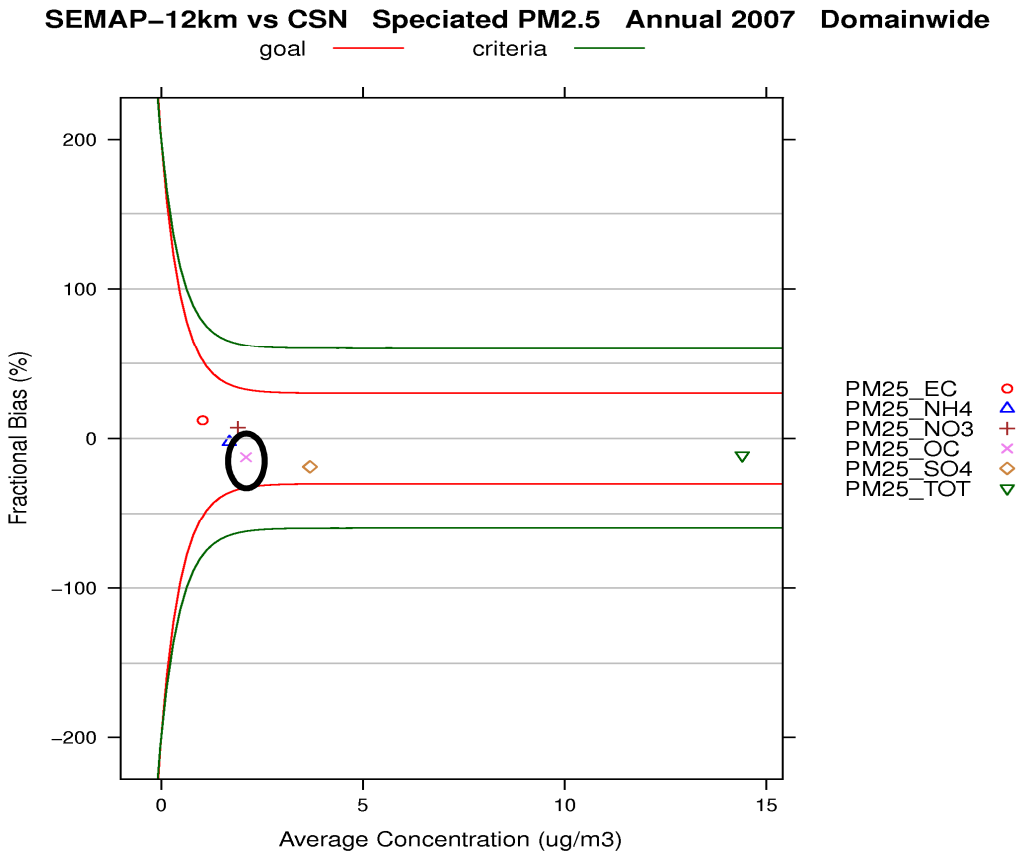
# Air Quality Model Evaluation

- Air quality models play a huge role in atmospheric research and air quality planning
  - How well do they work?




- While some species captured, simulated OC continues to be low most of the time
  - Without speciated data, would not know why PM is off
    - Or if there is a problem when PM looks good.
  - Became major research focus

# And what happened?




Removed much of bias (but a bit more to go)

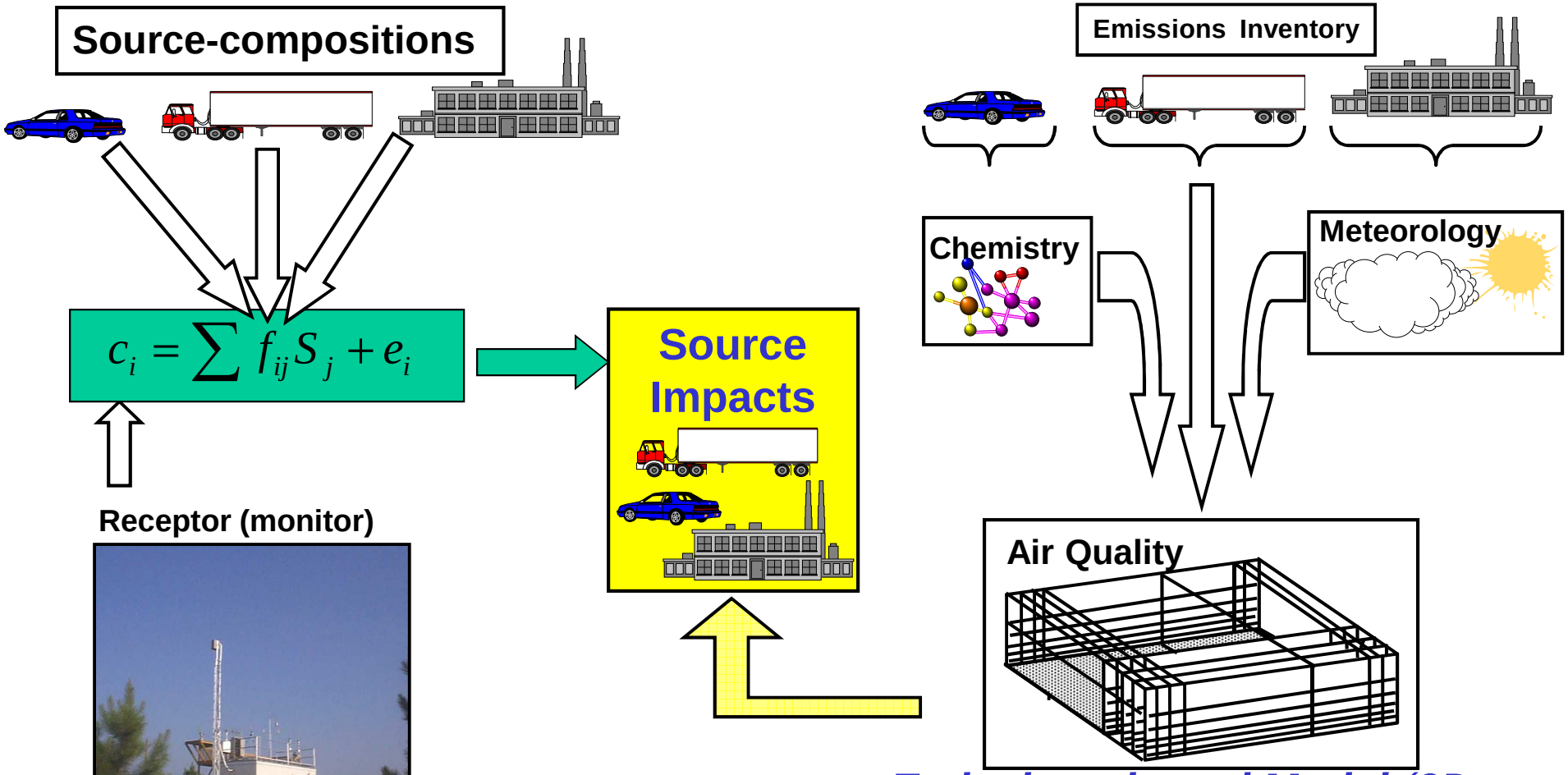
➔ Without speciated data, we would be ~clueless

# WHAT SOURCES CONTRIBUTE TO PM2.5?

# Source Apportionment

- Health, ecosystem and atmospheric science researchers want to know the source of pollutants
- Air quality managers need to know which sources to control: we control sources, not species in the atmosphere
- However, we can not directly measure source impacts
  - Various methods to estimate source impacts➔
    - **"source apportionment"**
      - Receptor based (uses measurements directly)
        - » Chemical mass balance (CMB), PMF, UNMIX
      - Emissions-based air quality models
        - » CMAQ, CAMx

# Source Apportionment
# Receptor vs. Emissions-Based Models




***Receptor Model:***
***CMB, PMF, UNMIX…***

***Emissions-based Model*** *(3D Chemical Transport Model (CTM):*

*CMAQ, CAMx, STEM, GEOS-Chem…)*

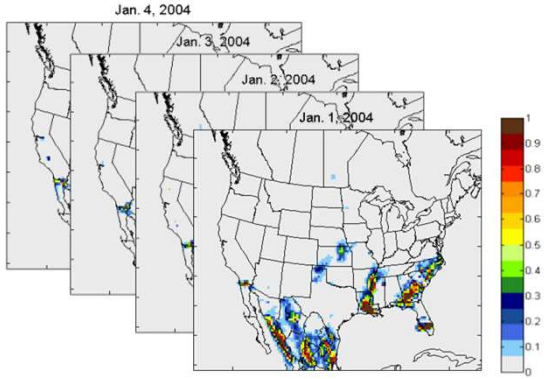
# Problems

- Models give different results
- Emissions-based model source impacts
  - Do not fully agree with measurements
  - Are based on uncertain inputs
  - …
- Receptor models
  - Do not agree between methods (PMF, CMB…)
  - Do not fully explain observations
  - Do not identify all of the sources in an area
  - …
- Neither
  - Incorporate all the data
    - CMB does not use emissions and met data
    - CTMs don't directly use observational data
  - **Can be evaluated by direct observation**

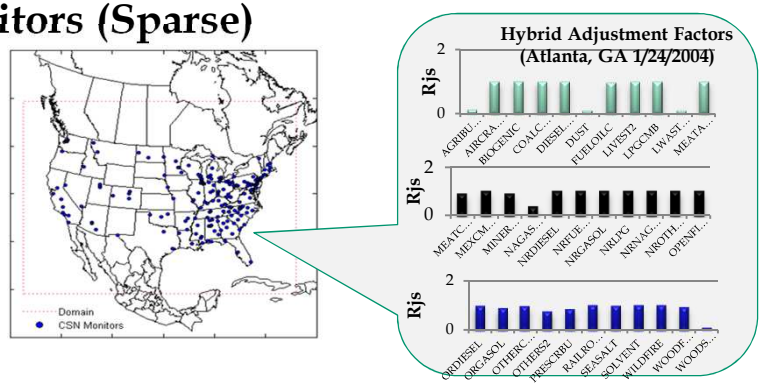
Solution (partial?):Hybrid methods

# CMAQ-CMB Hybrid-Kriging Approach

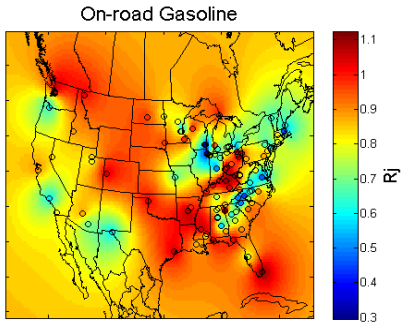
## 1. CMAQ Source Impacts (Daily)




## 2. Hybrid CMAQ-CMB Analysis at CSN Monitors (Sparse)

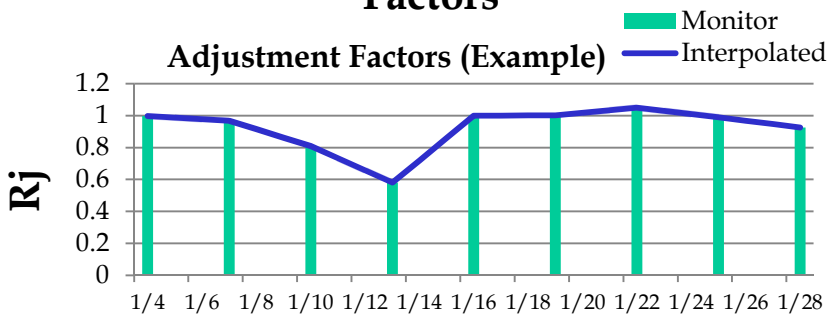



## 3. Spatial Interpolation of Adjustment Factors (Kriging)




January 4, 2004

## 4. Temporal Interpolation of Adjustment Factors

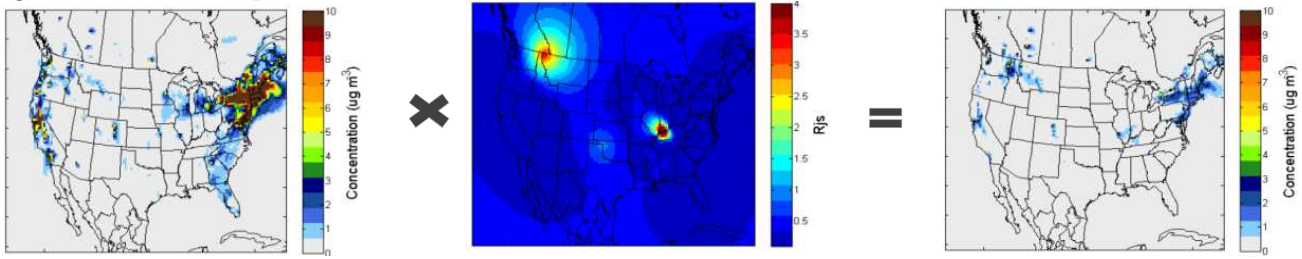



## 5. Adjust CMAQ Source Impact Spatial Fields (Daily, Spatially Dense)

Original Woodstove Impact

Woodstove Adjustment Factors

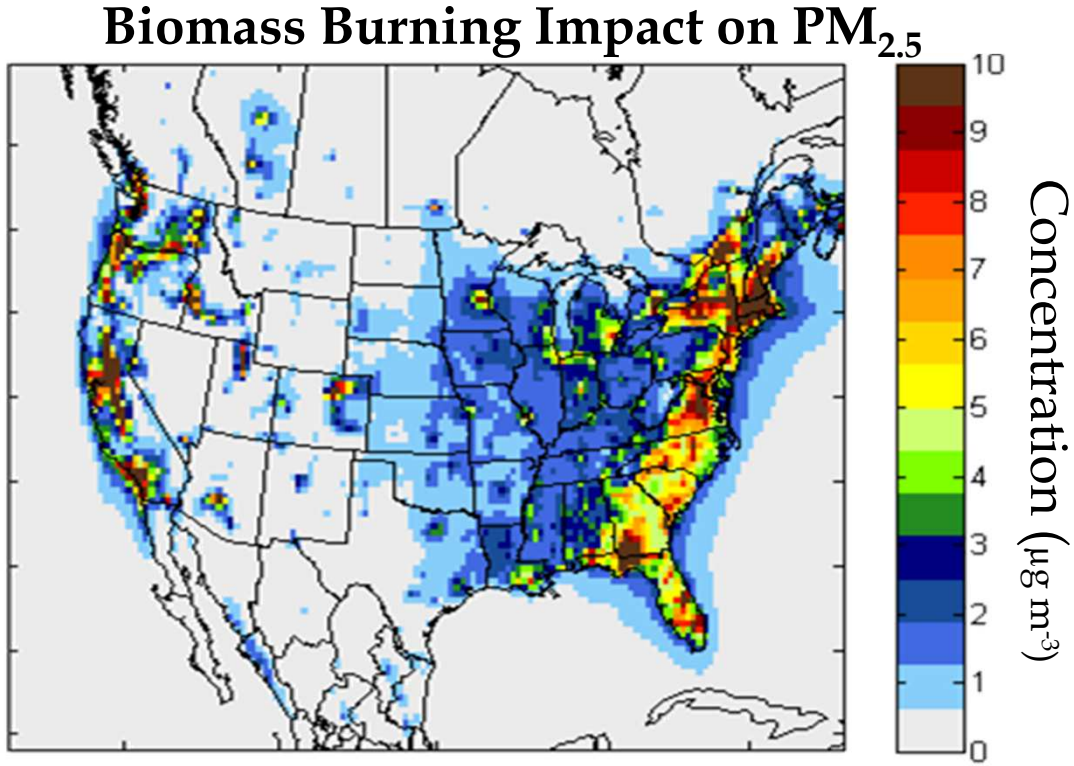
Adjusted Woodstove Impact



# CMAQ-DDM

## Community Multi-scale Air Quality (CMAQ)[ŧ] Model Decoupled Direct Method (DDM) [ş]

- Source impact sensitivities
- Source apportionment fields
- Results do not agree with speciated CSN observations




Jan. 2004 Average

[ŧ] Byun and Schere, *Appl Mech Rev* (2006)

[ş] Napelenok et al., *Atm Env* (2006)

# Hybrid Method

## Hybrid CMAQ-CMB Source Apportionment Model

$$X^2 = \sum_{i=1}^{N} \left[ \frac{\left[ \left( c_i^{obs} - c_i^{sim} \right) - \sum_{j=1}^{J} SA_{i,j}^{base} \left( R_j - 1 \right) \right]^2}{{\sigma_{obs}}^2 + {\sigma_{CTM}}^2} \right] + \Gamma \sum_{j=1}^{J} \frac{\ln(R_j)^2}{{\sigma_{\ln(R_j)}}^2}$$

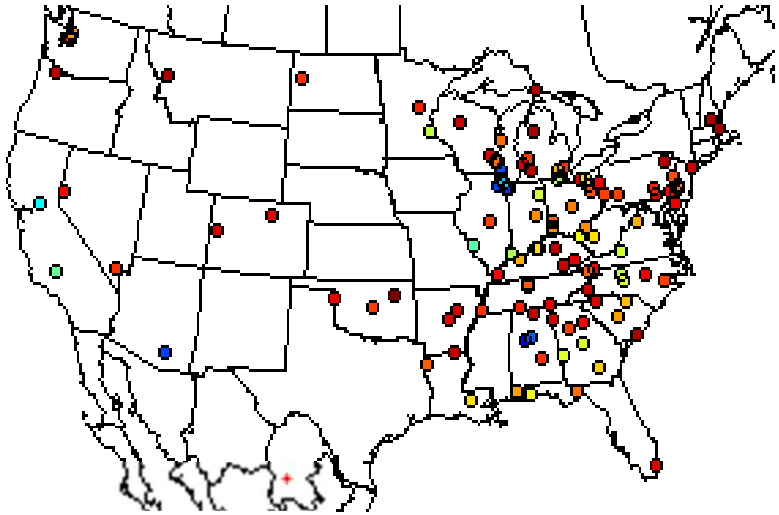
| | | | |
|---|---|---|---|
| i, j | species, sources | $R_j$ | source impact adjustment factors (*j x 1)* |
| $c_i^{obs}$, $c_i^{sim}$ | observed and CMAQ-simulated concentrations (*i x 1)* | $\sigma_{obs}$, $\sigma_{CTM}$, $\sigma_{\ln(R_j)}$ | uncertainty of measurement, CMAQ-simulated concentrations, emissions respectively |
| $SA_{i,j}^{base}$ | original CAMQ-simulated source impacts (*i x j)* | $\Gamma$ | weighting term to balance first and second terms; Hu et al. tested sensitivity to choice of $\Gamma$ |

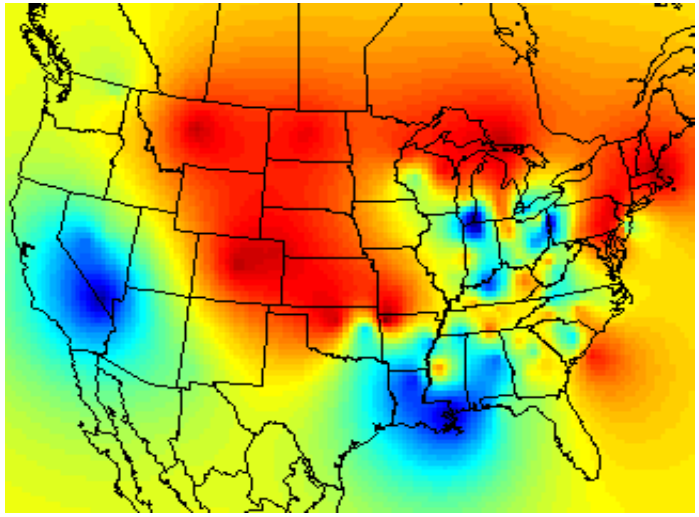
Hu et al. (2014), *Atmos .Chem. and Phys., 14,* 5415-5431 .

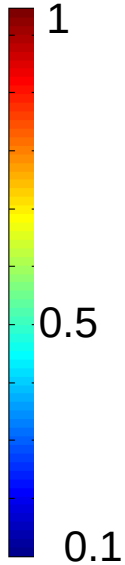
# Spatial Interpolation

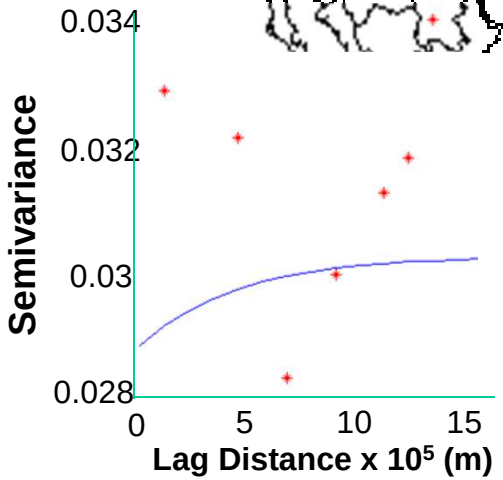
- Spatially interpolate Rjs determined for each CSN location for each observation day.

**Natural Gas Combustion Jan. 16, 2004**





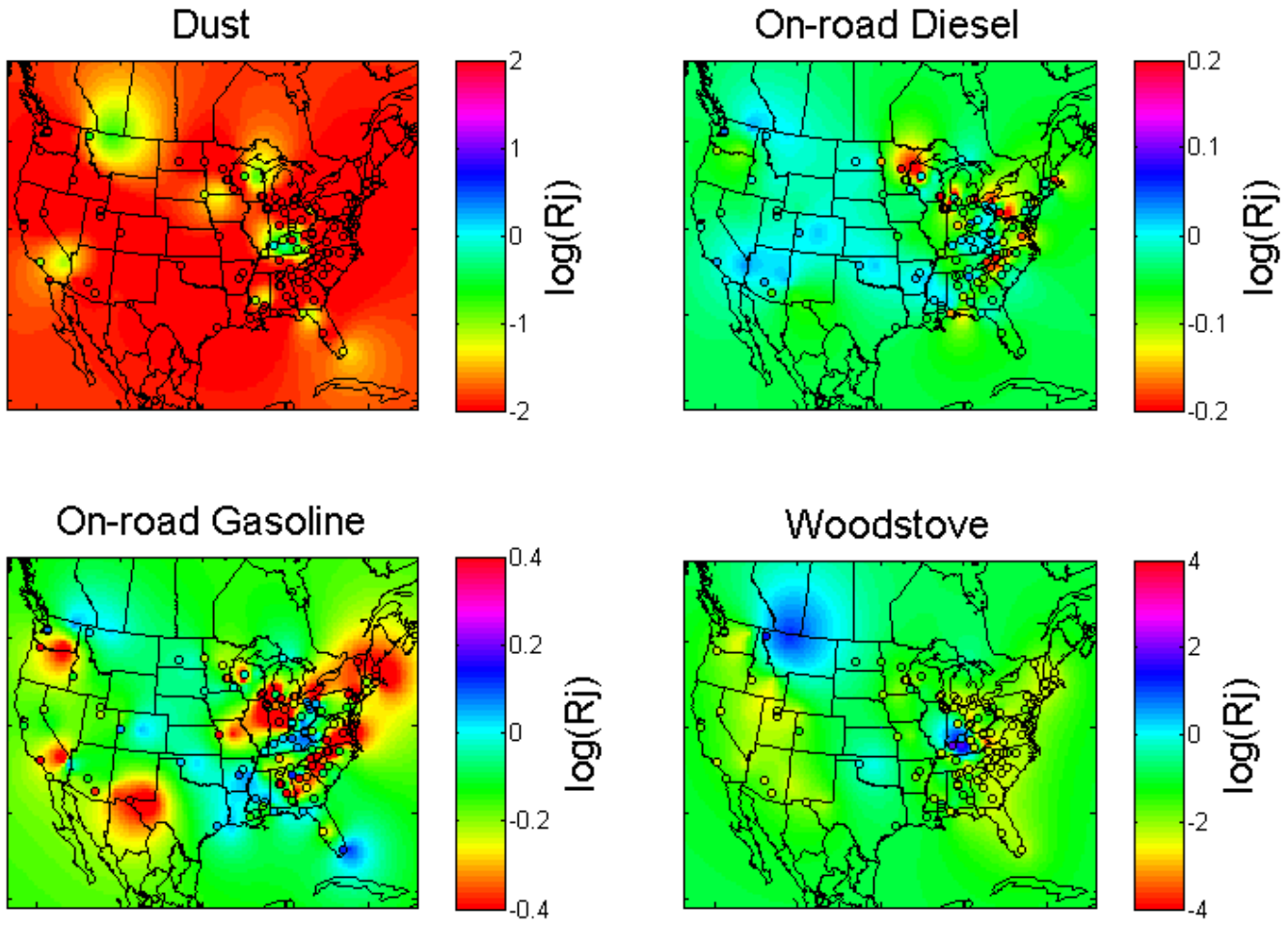



- Ordinary kriging
- Exponential model

# Temporal Interpolation

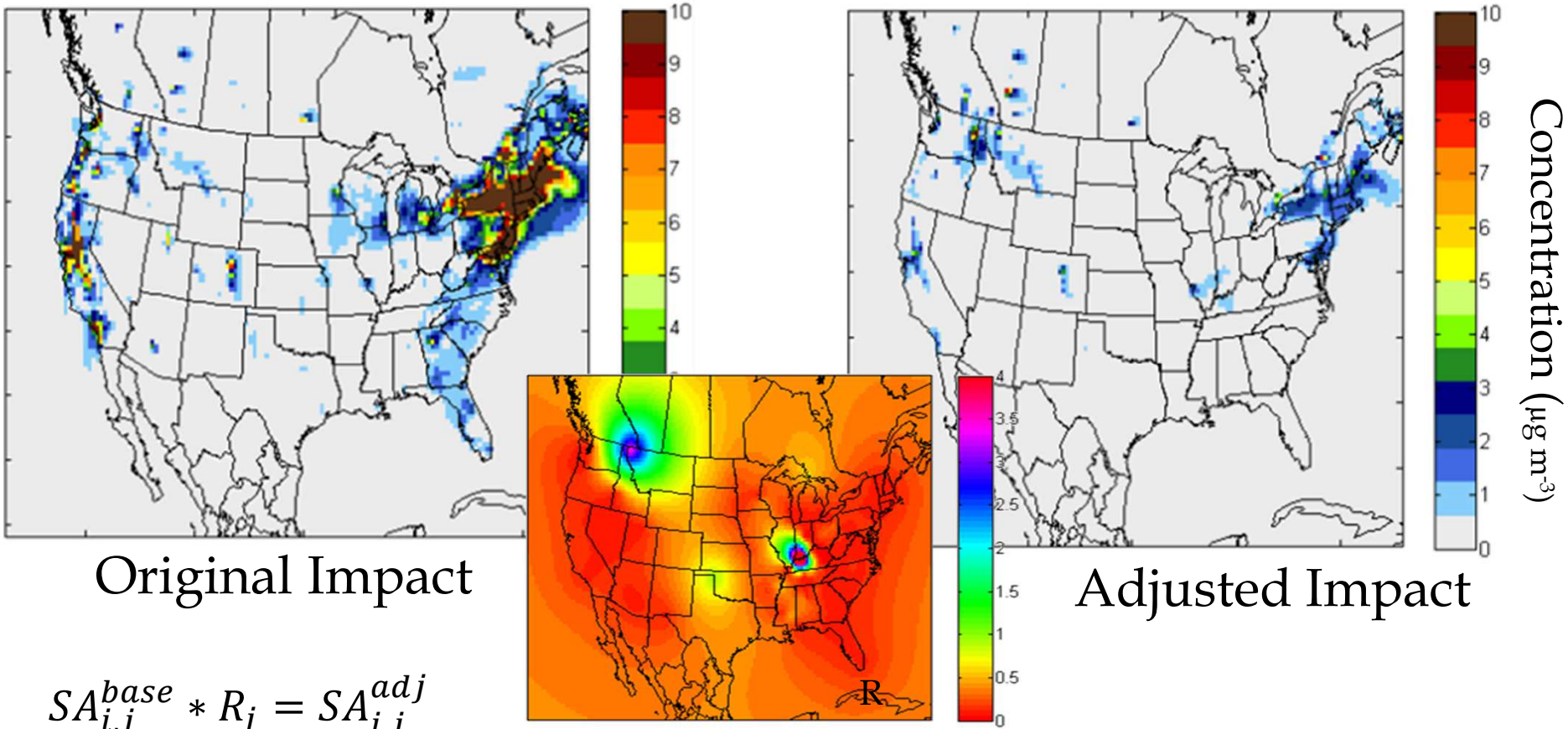
- Speciated data not available every day



# Daily Adjustment

- Adjust original source impact fields with hybrid adjustment factors

**Woodstove Impact Jan. 4, 2004**




Original Impact

Adjusted Impact

$$SA_{i,j}^{base} * R_j = SA_{i,j}^{adj}$$

Adjustment Factors

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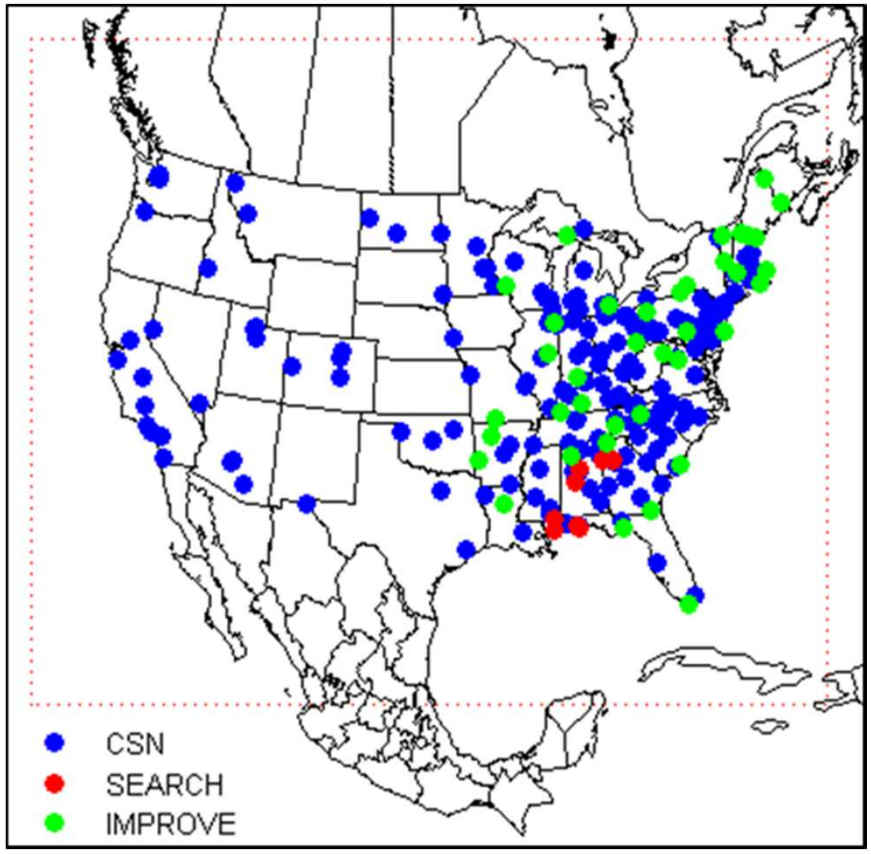
# Application

- Domain: Continental U.S.
- Spatial resolution: 36-km
- Observation data:
  - CSN Network
  - Total PM2.5 mass, 5 ions, 35 metals
  - 1-in-3/6 day availability
- Model Inputs
  - Emissions: NEI 2002
- Evaluate using IMPROVE and SEARCH data



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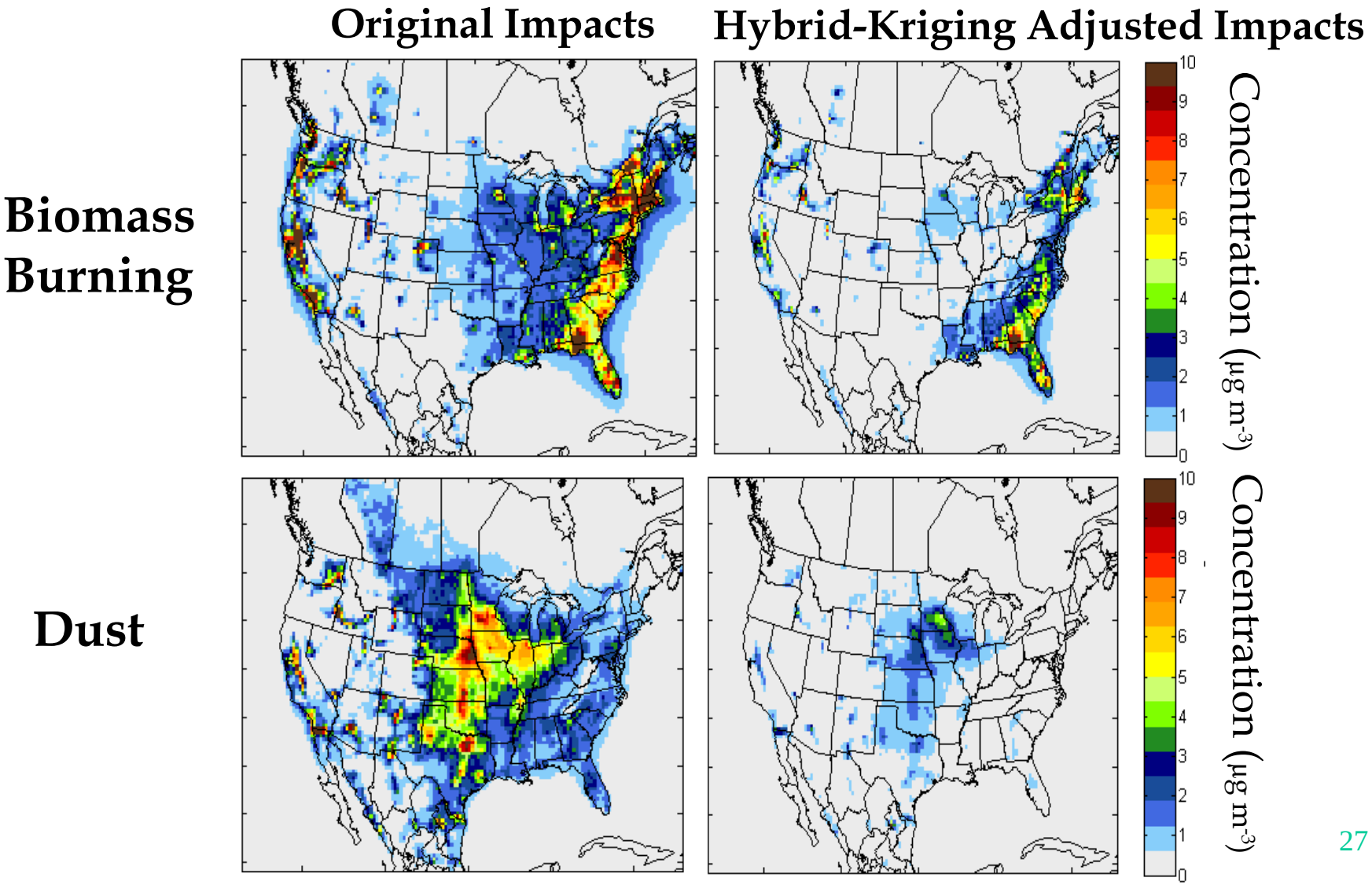
# Sources Quantified

## 36 Source Categories

| Combustion | On-road | Non-road | Biomass Burning | Others |
|---|---|---|---|---|
| Coal | Diesel | Aircraft | Agricultural | Biogenic |
| Diesel | Gasoline | Diesel | Open Fires | Dust |
| Fuel Oil | | Fuel Oil | Prescribed | Livestock |
| Liquid | | Gasoline | Lawn Waste | Metal |
| Petroleum Gas | | Liquid Petroleum | Wildfires | Production |
| Other | | Gas | Woodfuel | Meat Cooking |
| Mexican Sources | | Natural Gas | Woodstove | Mineral |
| | | Other | | Production |
| | | Railroad | | Seasalt |
| | | | | Solvents |
| | | | | Other |

# Results

## Impacts on $PM_{2.5}$

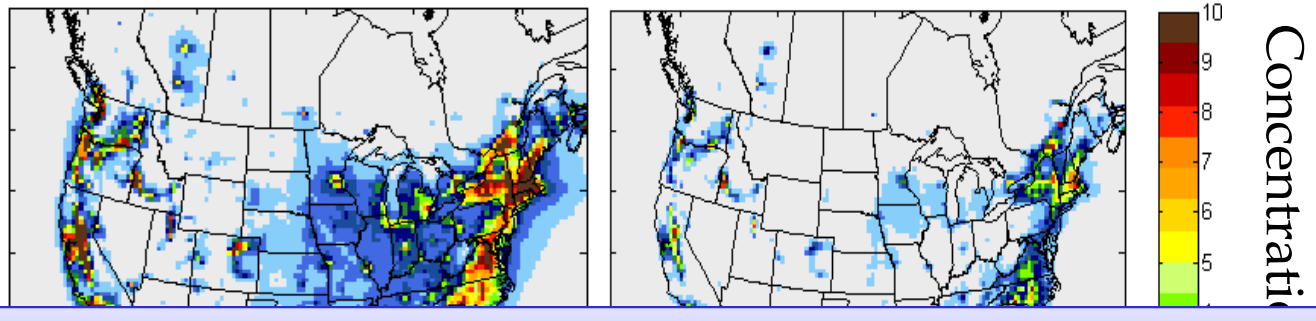


# Results

## Impacts on $PM_{2.5}$

**Original Impacts** **Hybrid-Kriging Adjusted Impacts**

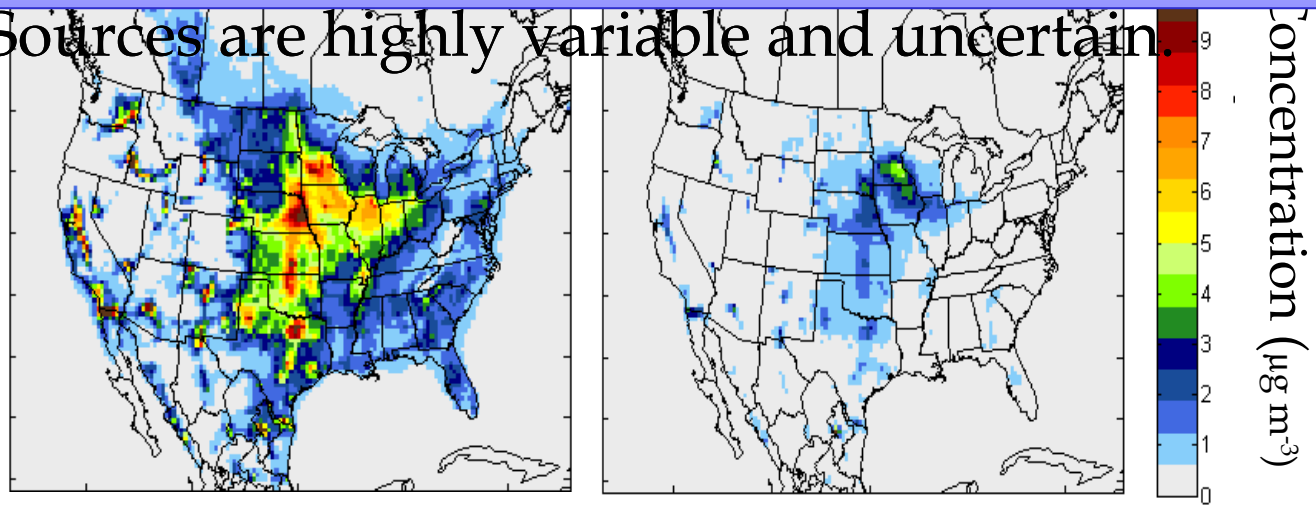
**Biomass Burning**



Biomass burning and dust impacts are reduced significantly.

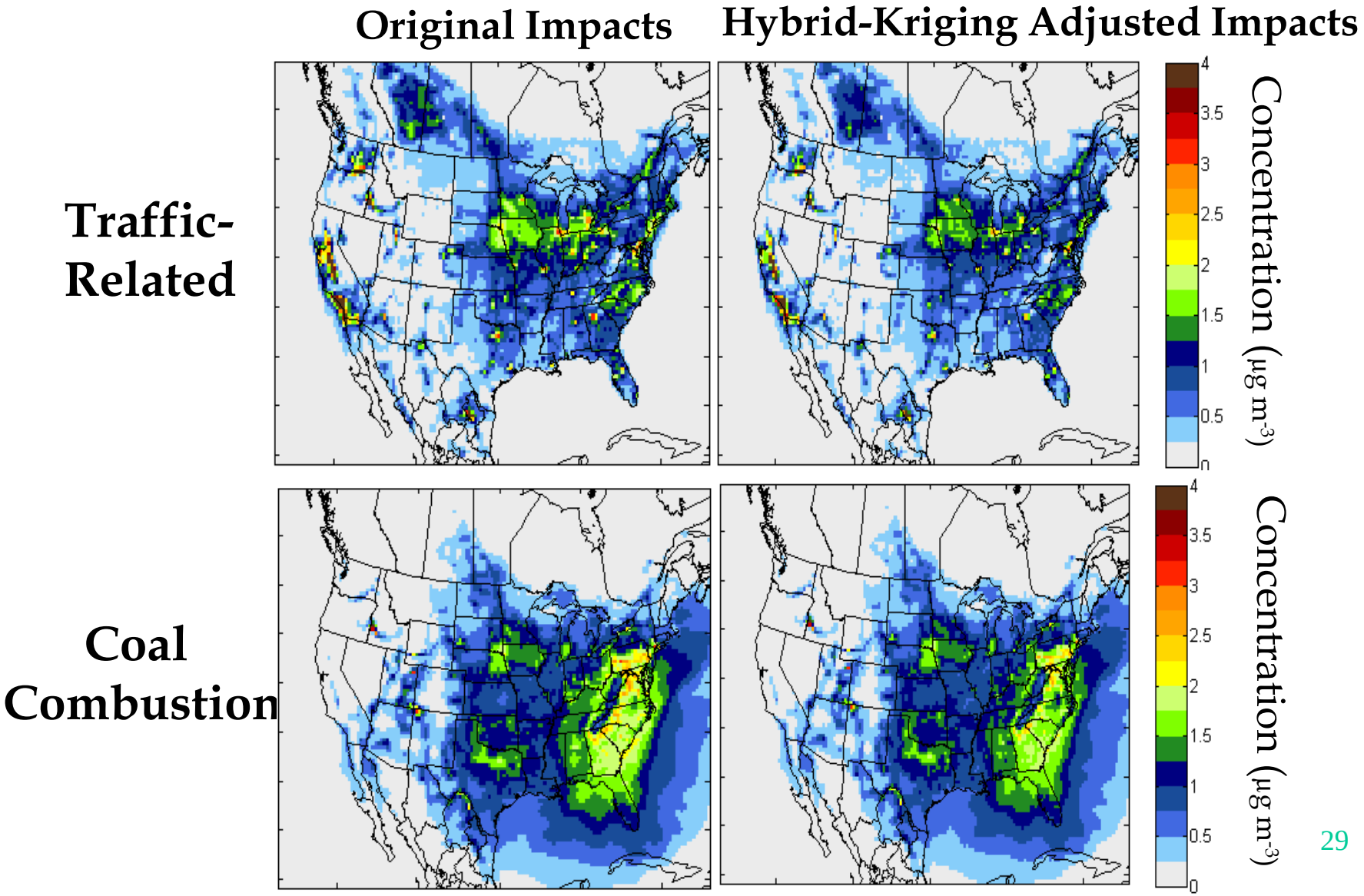
- Inventories are averaged.
- Sources are highly variable and uncertain.

**Dust**



# Results

## Impacts on $PM_{2.5}$



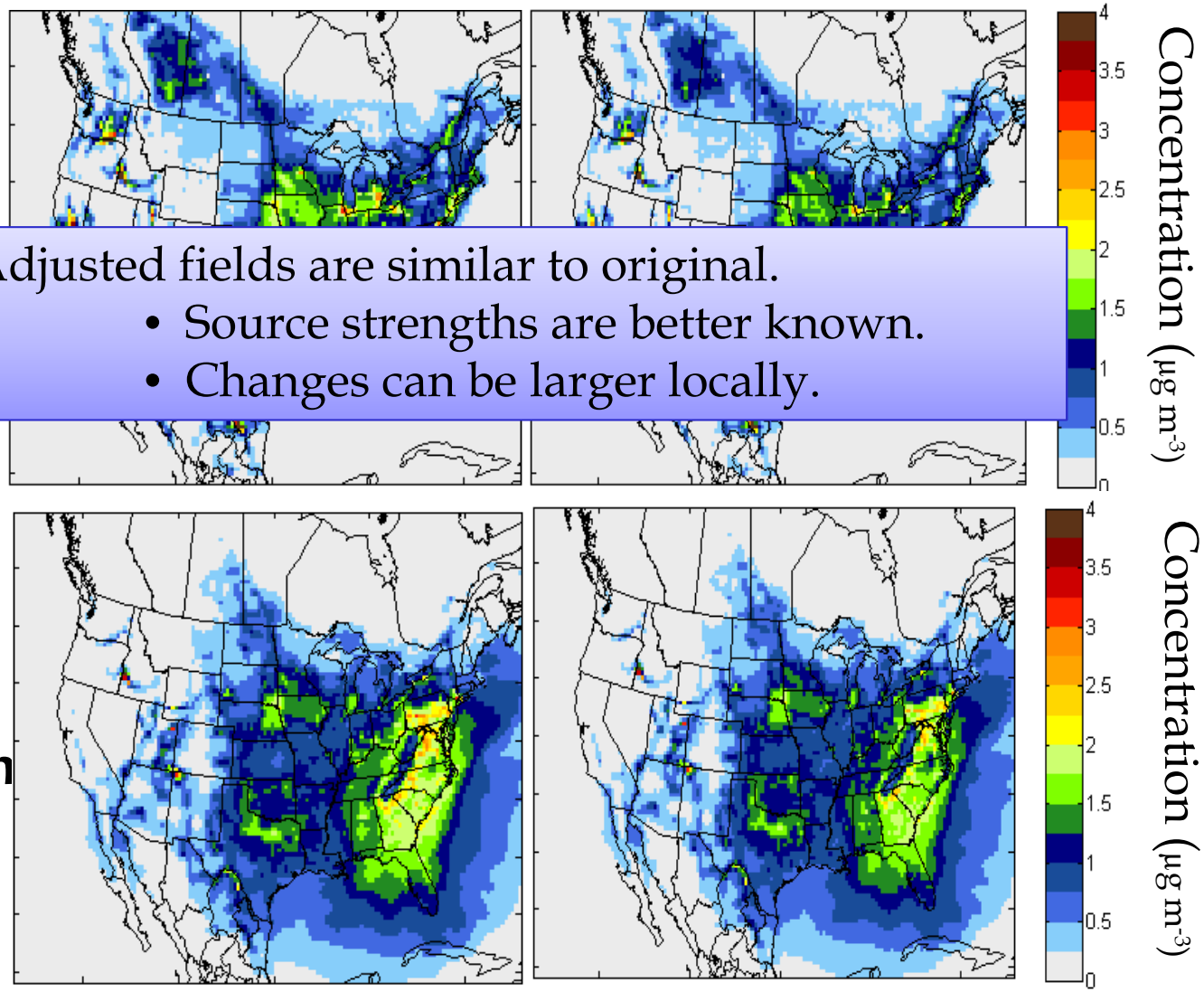
# Results

## Impacts on $PM_{2.5}$

**Original Impacts** **Hybrid-Kriging Adjusted Impacts**

**Traffic-Related**

**Coal Combustion**




Adjusted fields are similar to original.

- Source strengths are better known.
- Changes can be larger locally.

# Results

## Domain-Averaged Source Contributions

### January 2004

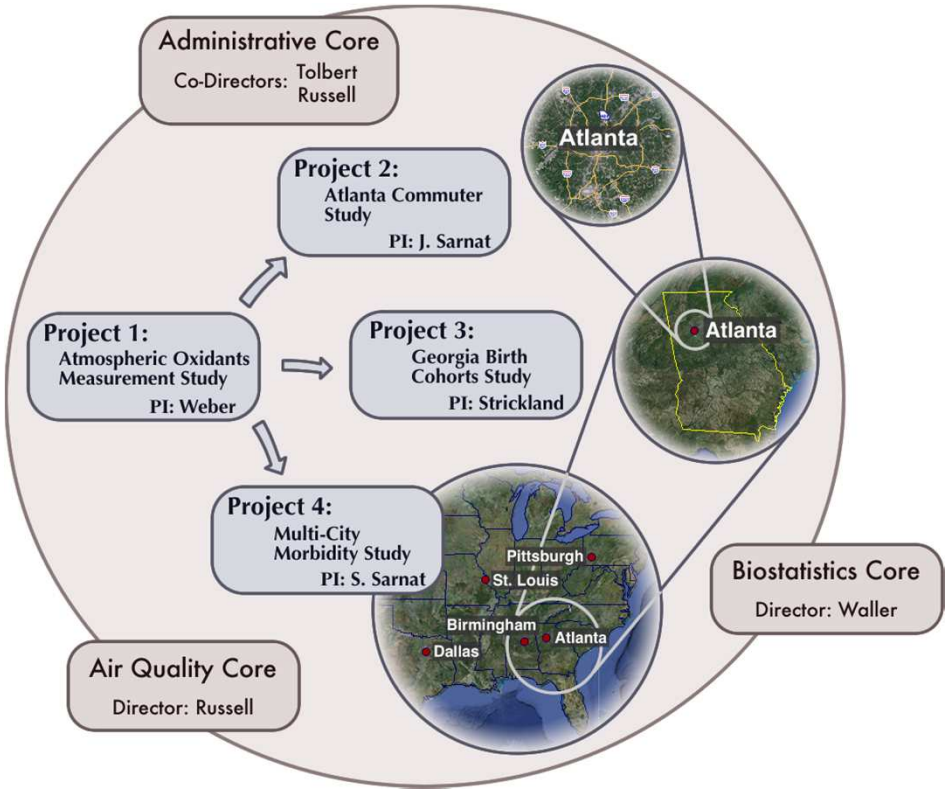
| Rank | CMAQ-DDM | | Hybrid-Kriging | |
|---|---|---|---|---|
| 1 | Dust | 20% | Coal Combustion | 14% |
| 2 | Woodstoves | 12% | Biogenics | 13% |
| 3 | Coal Combustion | 9% | Livestock | 12% |
| 4 | Biogenics | 9% | Fuel Oil Combustion | 8% |
| 5 | Livestock | 8% | Others | 6% |

Livestock impacts available only because of $NH_4$ measurements

# What this provides…

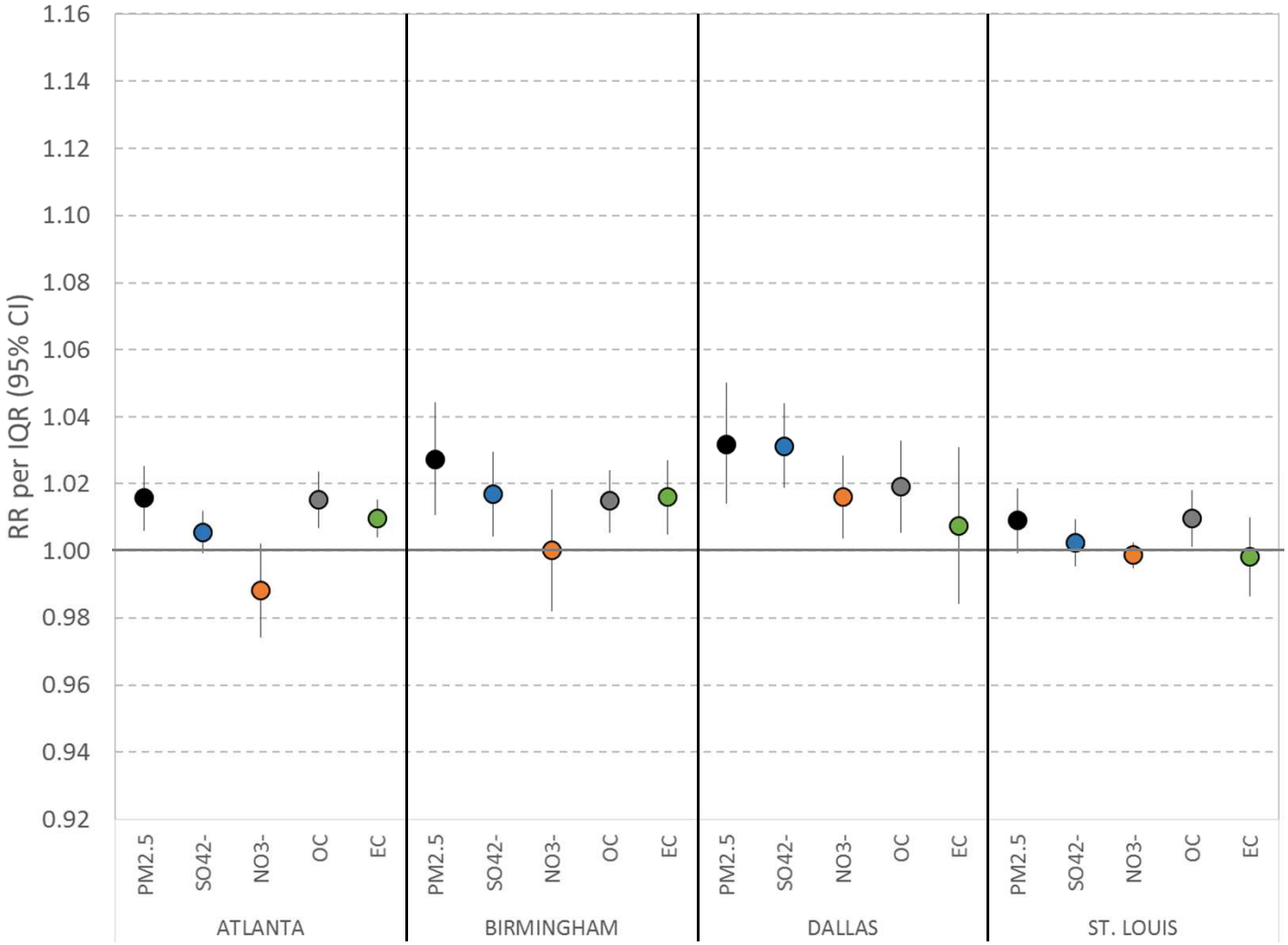
- Now have hourly, spatially complete, species and source impact fields that account for observations, chemistry, meteorology and emissions
  - Driven by both observations and knowledge of the atmospheric species dynamics

# USING CSN DATA AND SOURCE APPORTIONMENT IN SPECIES-SOURCE-HEALTH ANALYSES



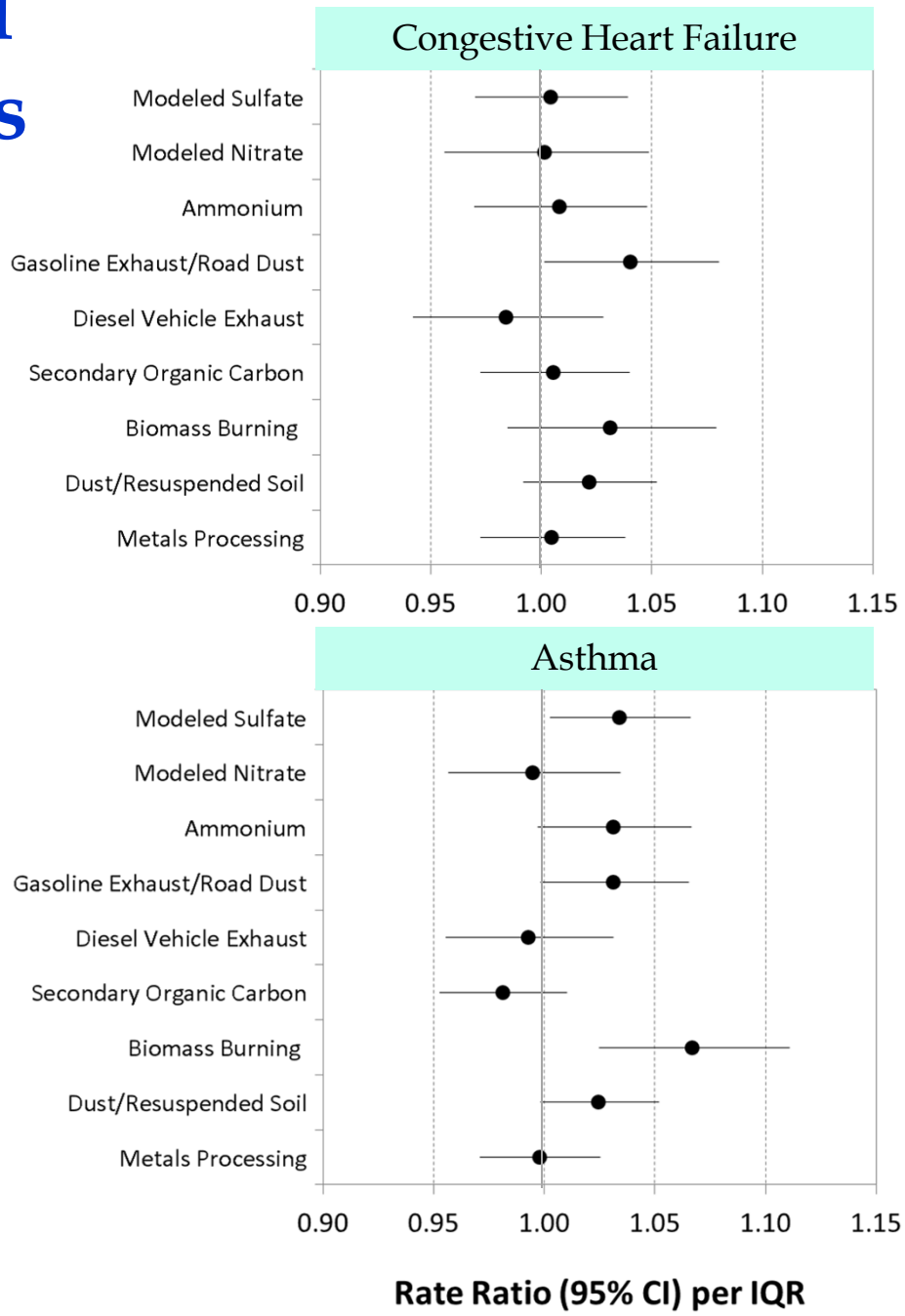
# $PM_{2.5}$ Components and Respiratory ED Visits

*[CMAQ-Fused PWAs]*



# Source Mixtures and ED Visits in St. Louis

- Application of daily ensemble SA outputs in epidemiologic models
- Sulfate, mobile sources, biomass burning, and dust sources generally showed strongest associations



# CSN Network Modifications

- Hate to see reductions in the CSN network, but
- Redesigning the network is appropriate
  - Some sites are more informative than others
  - Value of information decreasing in some cases/sites
- Focus on more comprehensively instrumented sites is very good
  - Can use the other types of data to develop a more comprehensive understanding of sources and air quality impacts
    - Some source apportionment methods use non-PM data
    - Health studies benefit from having multiple pollutant measurements at the same location(s)
  - Embrace this change
    - Build on it

# What is there not to like about the CSN?

- Spatial coverage
  - Getting sparcer
- Temporal coverage
  - 1-in-3 or 1-in-6
    - Limits health analyses
  - 24-hour average measurements
    - Hinders more complete understanding about
      - Atmospheric dynamics
      - Sources
      - Potential health impacts
- Researchers do not use the data enough

## Potential (partial) Solution: Inexpensive monitors/networks

# Low Cost Sensors

- Rapid development of low cost sensors
  - PM ($12-…)
    - Limited speciation
  - Gases
    - Ozone, NOx, CO, CO2, …
- Do They Work?
  - Depends on the question
    - Low accuracy and low precision suffices in some cases
      - Is my air bad?
    - Higher accuracy may be required in other cases
      - Am I in attainment?
      - What are the health impacts of a specific pollutant
    - Lots of data can make up for deficiencies.
  - Interesting applications

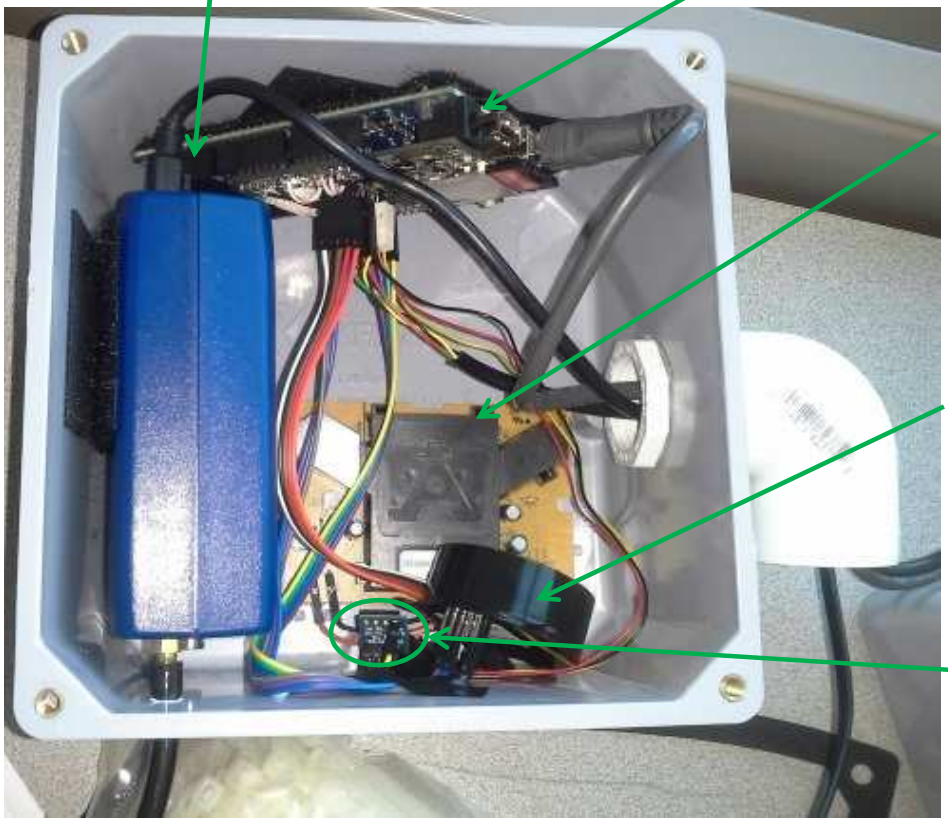
# Georgia Tech Multisensor Unit (Karoline Johnson and Mike Bergin)

- Developing various inexpensive multisensor units
- Deployed in
  - Atlanta
    - Lab roof
    - Near Road
  - India
  - China
- Used to develop emission factors
  - Deployed near freeway
  - Used CO2 (to get fuel use), PM and BC
  - Imagine, getting emission factors for a few $1000.

# Multisensor Box*

microAeth-
Black Carbon

Arduino-micro
controller



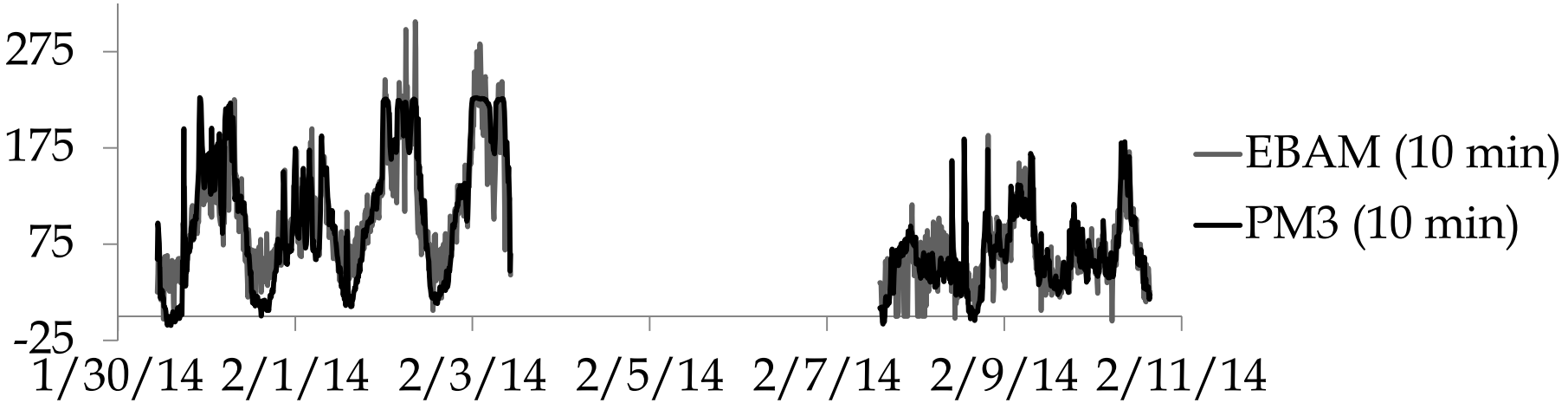
Shinyei-
PM
sensor

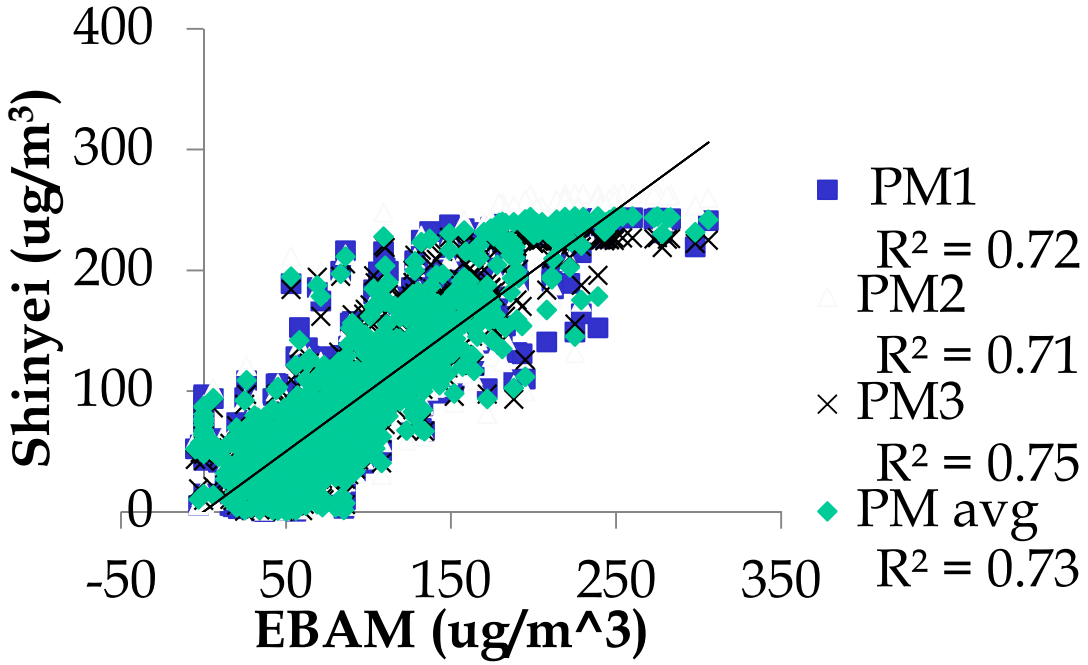
COZIR-
$CO_2$
Sensor

temperature
and
humidity
sensor

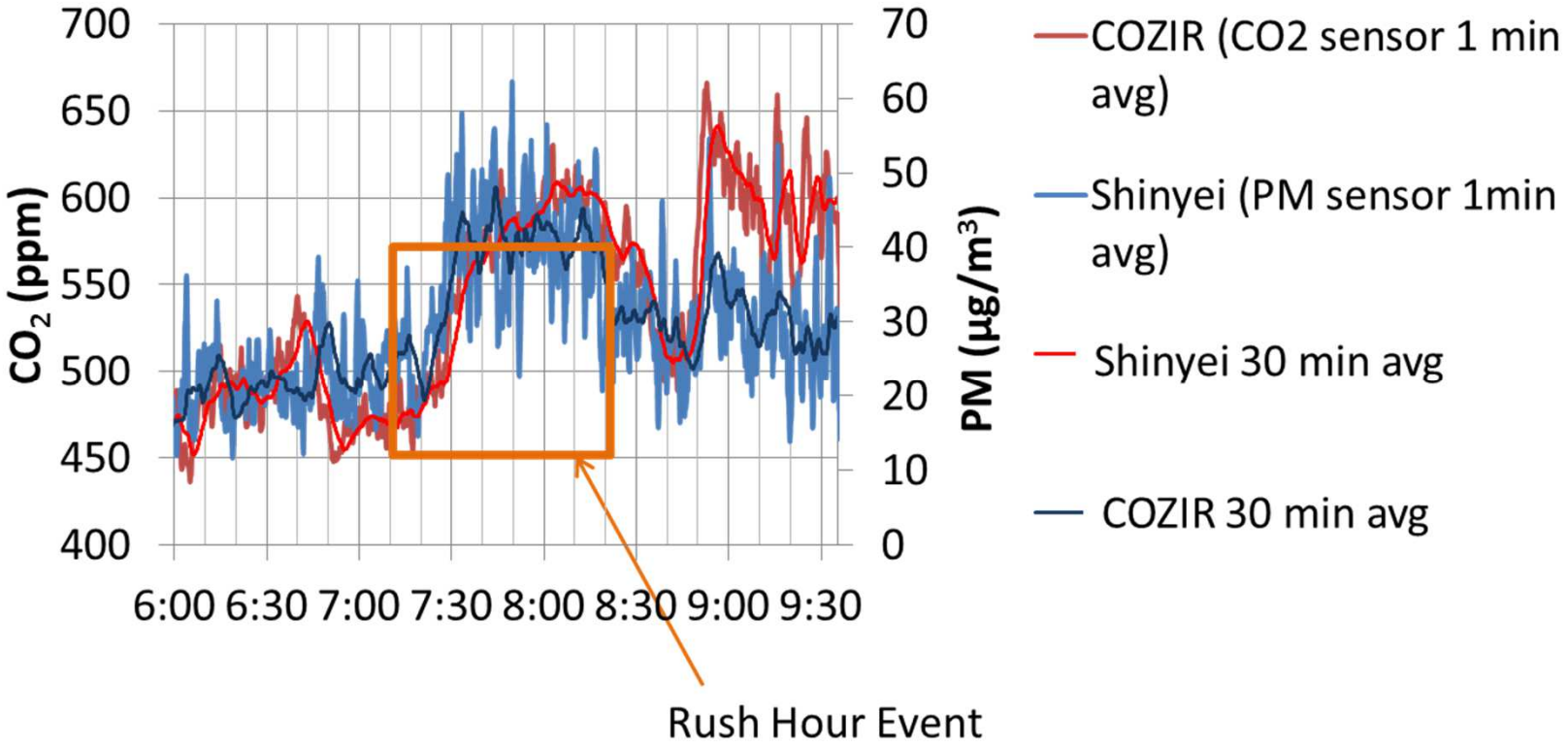
*A key is many sensors together.

# Hyderabad India



# Atlanta Freeway PM Emission Factor Estimate



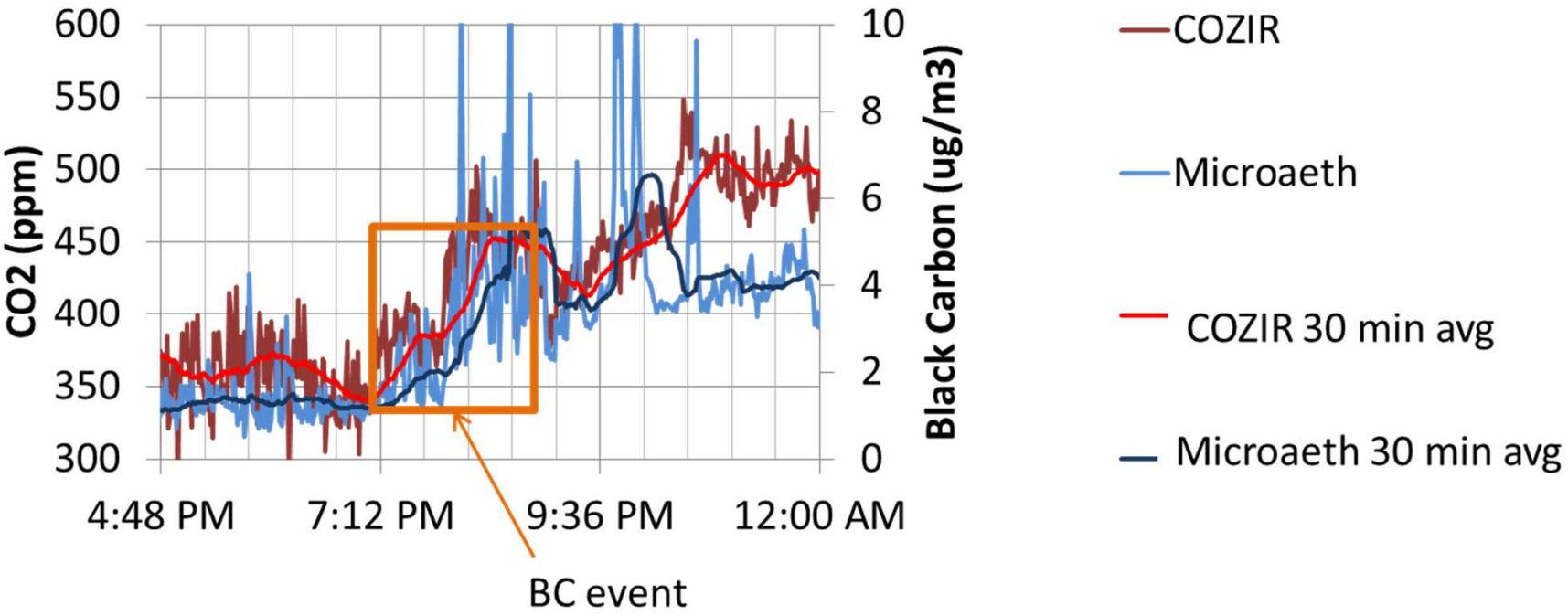

Emissions Factor = $\Delta PM/\Delta CO_2$

= 0.079 µg $m^{-3}$ PM/ppm$CO_2$

= 0.39 g PM/kg

Grieshop et al: 0.031- 1.06 LDV/HDDV

# Atlanta Freeway BC Emission Factor Estimate




Emissions Factor = $\Delta BC/\Delta CO_2$

= 0.044 μg $m^{-3}$ BC/ppm$CO_2$

= 75 mg BC/kg fuel

Grieshop et al : 27- 440 LDV/HDDV

# LC Monitors

- What power!
  - Extend the information from current networks
  - Doing an emissions estimate with a $7000 box (which should get cheaper: most of the cost in for BC)
  - Embrace this advancing capability
- Problems with LC monitors
  - Quality varies
  - Need to have reference monitors around for calibration and assessment
  - Do not give much information on PM species.

# Opportunity

- We are looking to get access to archived Teflon filters, e.g., from FRM measurements, for advanced source apportionment analysis.
  - Extending the source apportionment work we are currently conducting to provide increased information on some major sources
- If interested and want more information, please contact me:
  - ar70@ce.gatech.edu

# Summary

- Air quality, worldwide, is a serious health concern
- CSN data is a treasure
  - Chemical detail and long term nature give CSN data real power for research
  - Without it, we really would not be able to quantify the impact of specific sources to PM or assess effectiveness of controls
  - Key to identifying which sources have greatest health implications
  - Can be made more powerful
    - Continuous monitoring
    - Additional instrumentation at sites
- Embrace changes
  - Network changes emphasizing high value locations with increased instrumentation
  - Low cost monitors to extend power of “routine” monitoring

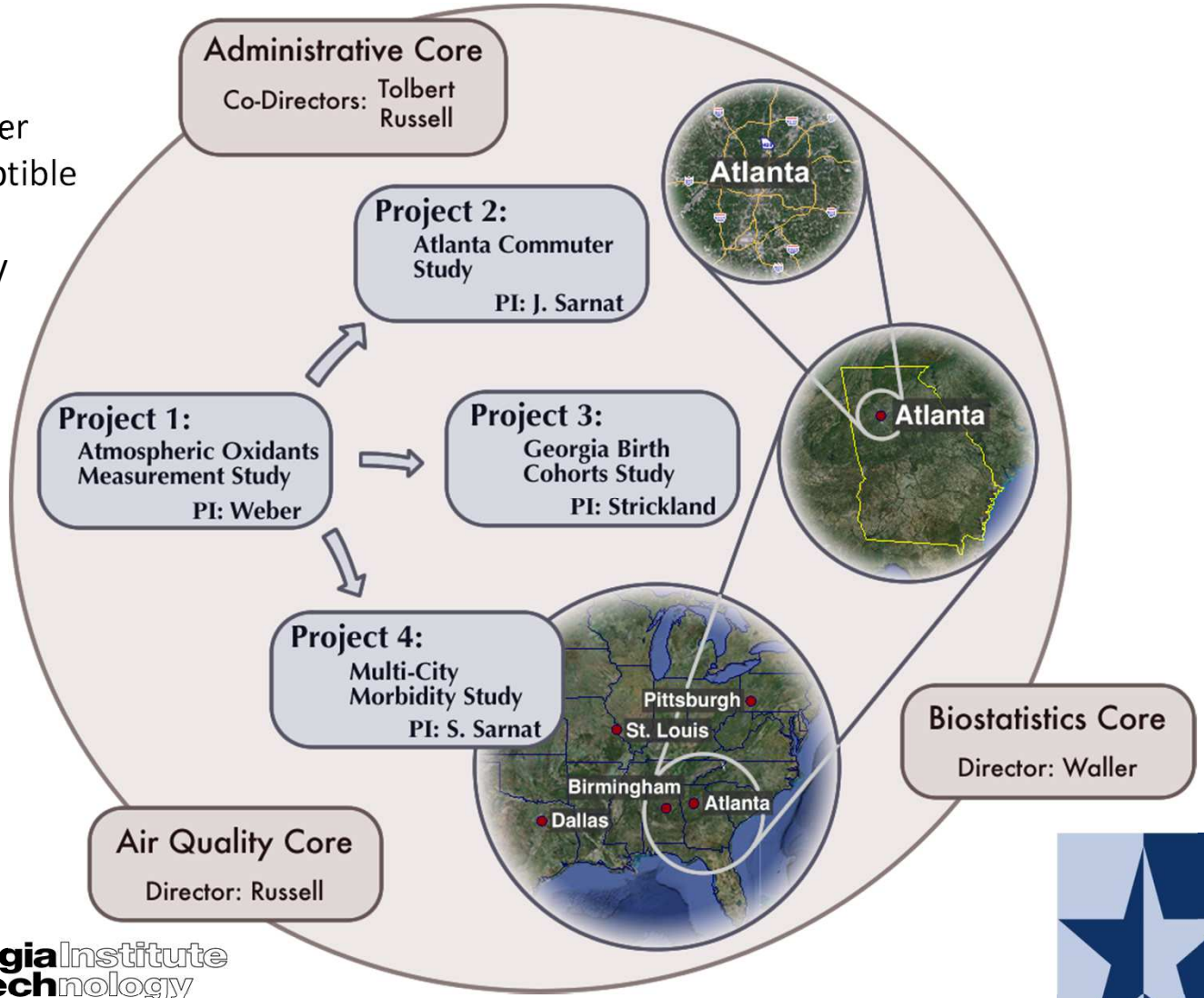
# Southeastern Center for Air Pollution and Epidemiology (SCAPE)

*Characterizing ambient air pollution mixtures and understanding their role in human health risks*

Co-Directors: Paige Tolbert, Emory, and Armistead (Ted) Russell, Georgia Tech

Key Features:

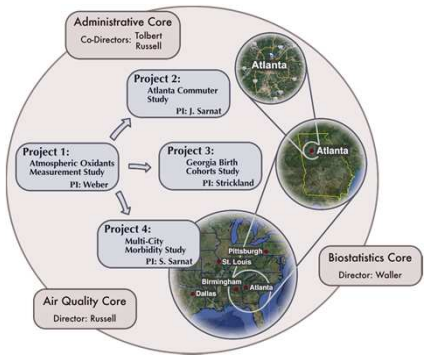
- Children and other vulnerable/susceptible populations
- Trans-disciplinary
- Multi-scale




ROLLINS SCHOOL OF PUBLIC HEALTH EMORY

Georgia Institute of Technology

This research is funded by U.S. EPA - Science To Achieve Results (STAR) Program
Grant # RD83479901


Administrative Core
Co-Directors: Tolbert
Russell
Project 2:
Atlanta Commuter
Study
PI: J. Sarnat
Project 1:
Atmospheric Oxidants
Measurement Study
PI: Weber
Project 3:
Georgia Birth
Cohorts Study
PI: Strickland
Project 4:
Multi-City
Morbidity Study
PI: S. Sarnat
Air Quality Core
Director: Russell
Biostatistics Core
Director: Waller
Atlanta
Atlanta
Pittsburgh
St. Louis
Birmingham
Dallas
Atlanta