Why we would be up a Creek Without CSN Data

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

**Central Nervous**
- Stroke (?)
- Cognitive effects (?)

**Reproductive**
- Low birth weight
- Preterm births and intrauterine growth retardation (?)
- Birth defects (?)

**Cardiovascular**
- HRV reduction, dysrhythmias
- Systemic inflammation
- Atherosclerosis
- Myocardial infarctions (Heart Attacks)
- CV mortality
IARC: Smog is a Group 1 Carcinogen:

World Health Organization lists it as carcinogen.

By Marielle Thein
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 asbestos, cigarette and cigar smoke.

IARC had previously deemed some of the components in air pollution such as diesel fumes to be carcinogenic, 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 worryingly 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 smoking 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 due to 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."

Kurt Straif, head of the IARC department that evaluates carcinogens, said.

"I don't know that they would be effective. But it's better than doing nothing. 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.
Lim et al., 2012, Lancet

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)

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Global</th>
<th>High-income Asia Pacific</th>
<th>Western Europe</th>
<th>Australasia</th>
<th>High-income North America and Middle East</th>
<th>South Asia</th>
<th>South-East Asia, Pacific and Oceania</th>
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</tbody>
</table>

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:

  ![Graph showing trends in OC and sulfate](image)

  - Sulfate
  - Organic Carbon


• 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

OC is low

PM2.5 is ~correct
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

Source-compositions

Receptor (monitor)

Emissions Inventory

Meteorology

Chemistry

Air Quality

Emissions-based Model (3D Chemical Transport Model (CTM):
CMAQ, CAMx, STEM, GEOS-Chem…)

Receptor Model:
CMB, PMF, UNMIX…

\[ c_i = \sum f_{ij} S_j + e_i \]
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)

4. Temporal Interpolation of Adjustment Factors

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

Community Multi-scale Air Quality (CMAQ)\(^{1}\) Model
Decoupled Direct Method (DDM) $^{\S}$

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

\(^{\S}\) Napelenok et al., *Atm Env* (2006)
Hybrid Method

Hybrid CMAQ-CMB Source Apportionment Model

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

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

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

- Spatially interpolate $R_{js}$ 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

\[ \text{Original Impact} \times R_j = \text{Adjusted Impact} \]

\[ SA_{i,j}^{\text{base}} \times R_j = SA_{i,j}^{\text{adj}} \]
• 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
## Sources Quantified

### 36 Source Categories

<table>
<thead>
<tr>
<th>Combustion</th>
<th>On-road</th>
<th>Non-road</th>
<th>Biomass Burning</th>
<th>Others</th>
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Results

Impacts on PM$_{2.5}$

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<th>Original Impacts</th>
<th>Hybrid-Kriging Adjusted Impacts</th>
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Dust

Concentration ($\mu$g m$^{-3}$)
Results

Impacts on PM$_{2.5}$

- Biomass burning and dust impacts are reduced significantly.
  - Inventories are averaged.
  - Sources are highly variable and uncertain.

Biomass Burning

Dust
Results

Impacts on PM$_{2.5}$

Original Impacts  Hybrid-Kriging Adjusted Impacts

Traffic-Related

Coal Combustion

Concentration ($\mu g m^{-3}$)
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.
## Domain-Averaged Source Contributions

January 2004

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<th>Rank</th>
<th>CMAQ-DDM</th>
<th>Hybrid-Kriging</th>
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<td>Woodstoves</td>
<td>Biogenics 13%</td>
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<td>3</td>
<td>Coal Combustion</td>
<td>Livestock 12%</td>
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<td>4</td>
<td>Biogenics</td>
<td>Fuel Oil Combustion 8%</td>
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<td>5</td>
<td>Livestock</td>
<td>Others 6%</td>
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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 sparser

• 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*

*A key is many sensors together.
Hyderabad India

EBAM (10 min) — PM3 (10 min)

EBAM (ug/m³)
Shinyei (ug/m³)

PM1
R² = 0.72
PM2
R² = 0.71
PM3
R² = 0.75
PM avg
R² = 0.73
Atlanta Freeway PM Emission Factor Estimate

Emissions Factor = \frac{\Delta \text{PM}}{\Delta \text{CO}_2}

= 0.079 \ \mu g \ m^{-3} \ \text{PM}/ \text{ppmCO}_2

= 0.39 \ \text{g PM/kg}

Grieshop et al: \ 0.031- \ 1.06 \ \text{LDV/HDDV}
Atlanta Freeway BC Emission Factor Estimate

Emissions Factor = \( \frac{\Delta BC}{\Delta CO_2} \)

= 0.044 \( \mu g \) m\(^{-3}\) BC/ppmCO\(_2\)

= 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