Tropospheric Ozone and Human Health

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• Brief history of air pollution and human health research
• Tropospheric ozone
• The relationship between ozone and mortality
  – Recent studies
  – Future research directions
Early Air Pollution and Human Health Research

Donora, PA 1948

LA, 1940’s and 50’s

Photos: DL Davis, 2002
Designer Smog Masks
(London 1950’s)

London 1952
10:30am

Source: National Archives
Cardiac Emergency Bed Service Applications for Greater London 1952

Source: Bell & Davis, *EHP* 2001

Source: NMMAPS, Johns Hopkins Bloomberg School of Public Health
Also in 1952: Discovery of Photochemical Smog

- Arie Haagen-Smit (1900 – 1977)
  - Began with study of vegetation damaged by air pollution
  - Discovered that tropospheric O₃ was
    - Not mainly from stratospheric intrusion
    - Not directly emitted but was formed through the chemical conversion of precursors
  - Suggested that O₃ and its precursors were the main constituents of LA smog
Tropospheric O$_3$ Chemistry
(very simplified)

VOCs + NO$_x$ + heat / sunlight $\rightarrow$ O$_3$

Precursors to ozone

Secondary pollutant
Anthropogenic Ozone Precursors

**VOC Sources**
- Motor Vehicles: 45%
- Industry / Commercial: 22%
- Consumer Solvents: 5%
- Other: 17%
- Utilities: 5%

**NO\textsubscript{x} Sources**
- Motor Vehicles: 56%
- Industry / Commercial / Residential: 22%
- Other: 17%

Source: *EPA 2003*
NO$_2$ and Health

- Health effects: irritation to throat and lungs, respiratory tract infection, exacerbation of asthma, lung function, possible increased susceptibility to allergens
- Children and asthmatics more susceptible
- Also a Criteria Pollutant
Volatile Organic Compounds (VOCS)

- Category of pollutants
- Gas
- Primary, secondary
- **Sources:** Biomass and fossil fuel combustion, construction materials, household chemicals (solvents), industry, biogenic sources
- **Health effects:** headache, dizziness, upper respiratory tract irritation, nausea, cancer
O$_3$ Isopleth Plot
Attainment and Nonattainment Areas in the U.S. 8-hour Ozone Standard

Source: EPA Greenbook
Health Impacts of Ozone

• Effects on lung function
• Respiratory symptoms
• Exacerbation of asthma
• Hospital admissions
• Emergency room visits
• Mortality?

Source: EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants*. 1996
Why divergent results for ozone and mortality?

- Potential reasons:
  - Differences in (and lack of) statistical power
  - Various statistical methods
  - Addressing of potential confounders
  - Underlying populations
  - Health care systems
  - Data quality
  - Others?
Why divergent results for ozone and mortality?

• Potential reasons:
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Confounders

• Potential confounder
  – Associated with the exposure of concern
  – Associated with the health endpoint
  – Not in the causal pathway

• Can create spurious associations or obscure real associations

Alcohol → ? → Lung Cancer
Confounding Example

• What is associated with both the exposure and the health outcome?
  – Could potentially be a confounder

Diagram:
- Smoking
  - Alcohol
  - Lung Cancer
  - ?

Exposure
Confounder
Potential Confounders for Ozone and Mortality

- Emissions Sources
- Ozone
- PM
- Mortality

Depends on question mark (?).
Approaches to Resolve Seemingly Conflicting Results

1) Meta-Analysis
   Combine results of previous efforts
   + Increased statistical power
   + Can explore differences in model specification, location, etc.
   - Publication bias

2) Multi-City Study
   Estimate the relationship in numerous locations
   + The above advantages
   + Lack of publication bias
   - Data intensive
1) Meta-Analysis Approach

- Systematically review the literature to find studies
- 144 effect estimates from 39 time-series studies
  - 38 in the U.S., 106 from outside the U.S.
- Combine the estimates using a Bayesian hierarchical model

\[
\hat{\beta}^s \mid \beta^s, \nu^s \sim N(\beta^s, \nu^s), s = 1, \ldots, S
\]

\[
\beta \mid \mu, \tau^2 \sim N(\mu, \tau^2)
\]

Plus sensitivity analysis to model structure and distributions . . .

Source: Bell et al., *Epidemiology* 2005
<table>
<thead>
<tr>
<th>Cause</th>
<th>Percent Increase (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.87% (0.55, 1.18%)</td>
</tr>
<tr>
<td>CVD</td>
<td>1.11% (0.68, 1.53%)</td>
</tr>
<tr>
<td>Respiratory</td>
<td>0.47% (-0.51, 1.47%)</td>
</tr>
</tbody>
</table>
Other New Meta-Analyses


% Increase in Daily Mortality for 10 ppb in Daily O₃

-1.0 0.0 1.0 2.0

Lag 0  Lag 1

Provided a single lag
Provided multiple lags

Publication bias?
Selected Meta-Analysis Results

- 144 effect estimates from 39 time-series studies
- Strong statistically significant association identified between ozone and mortality for total deaths and cardiovascular disease
- Implied relationship between ozone and respiratory disease mortality
- Large heterogeneity in individual study estimates
- Strong indications of publication bias
2) Multi-City Study

- Time-series study to investigate short-term exposure to ambient ozone (up to a week)
- 95 large urban U.S. communities (40% of the U.S. population)
- 14 years of daily data from 1987 to 2000
  - Some cities monitor O$_3$ for part of the year
- Uniform analysis framework for all cities
- Total and Cardiovascular/Respiratory mortality

Source: Bell et al., *JAMA* 2004
Hierarchical Approach

• Stage 1
  – Estimate the relationship between ozone and mortality within each city

• Stage 2
  – Combine the city-specific estimates to generate a national estimate, taking into account the uncertainty of each city’s estimate
Stage 1: Community-Specific Model

Mortality for a given city on a given day

\[ \ln(E[\mu_t^c]) = \sum_{l=0}^{L} \beta_l^c x_{t-l}^c + \gamma^c DO\text{W}_t^c + S_t^c (time_t, df_t) \]

Ozone levels on that day and previous days

Temperature

\[ + S_T^c (T_t^c, df_T) + S_{T_{1,3}}^c (T_{t-1,t-3}^c, df_{T_{1,3}}) \]

Heat waves

Dew point on that day and recent days

\[ + S_D^c (D_t^c, df_D) + S_{D_{1,3}}^c (D_{t-1,t-3}^c, df_{D_{1,3}}) \]
Community-Specific Bayesian Estimates

95 city-specific responses

% Increase in Daily Mortality for 10 ppb Daily Ozone

Overall Estimate
Total Mortality
CVD + Respiratory Mortality

% Increase in Daily Mortality for 10 ppb Daily O₃

Lag 0  Lag 1  Lag 2  Lag 3

SINGLE LAG MODELS DISTRIBUTED LAG MODELS
Exclude Days with High Temperatures

- Results robust to exclusion of high temperature days
- Effects range from: 0.50% (0.25, 0.75%) to 0.55% (0.30, 0.80%)
Sensitivity to Adjustment by PM$_{10}$

Adjusted for PM$_{10}$ (lag 1)

Without PM Adjustment
(using only days with PM data)

X = National Average Effect
Selected Multi-City Study Results

- 95 U.S. urban communities over 14 years
- Identified a strong statistically significant association between ozone and mortality
- Effects present for $O_3$ on the present day, previous day, and up to about a week
- Effects similar for all age groups considered
- Results robust to adjustment by PM$_{10}$, degrees of freedom for smooth functions of time, and temperature
- Association present even when considering only days below EPA’s current standard
Compare Meta-Analysis and Multi-City Results

% Increase in Mortality for 10 ppb Daily Ozone

- Meta-Analysis
- Multi-City

Total
Resp
CVD
CVD Resp
Mortality now (tentatively) included as a health endpoint.

Source: EPA. *Air Quality Criteria for Ozone and Related Photochemical Oxidants DRAFT*. 2005
Future Research Directions

- Ozone threshold studies
Future Research Directions

• Ozone threshold studies
• Climate change and ozone

Summer Ozone Levels (2050’s vs. 1990’s)
Future Research Directions

- Ozone threshold studies
- Climate change and ozone
- Particulate matter speciation
- Mortality and air pollution in Latin American urban centers

Summer Ozone Levels (2050’s vs. 1990’s)
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