The Public Health Impact of Air Pollution and Climate Change

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Outline

- The Clean Air Act
- National Data Sets
- Air Pollution and Health
- Climate Change, Heat Waves, and Health
- Future Research Directions
The Clean Air Act (CAA)

- The Clean Air Act is one of most important laws for protecting public health and the environment in the United States
- The CAA requires the EPA administrator to set National Ambient Air Quality Standards (NAAQS) for pollutants for which air-quality criteria are listed. By intent, the NAAQS must protect susceptible groups within the U.S. population with an “adequate margin of safety”

Particulate Matter is a complex mixture of very small particles and liquid droplets. It is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles.
The Regulatory Process

CAA → NAAQS → Attainment designation → State Implementation Plan (SIP)

EPA Integrated Risk Assessment

Air Pollution Epidemiology (Mathematical Modelling)

National Data Sets

THE NATIONAL MORBIDITY MORTALITY, AND AIR POLLUTION STUDY (NMMAPS), 1987-2006

THE MEDICARE COHORT AIR POLLUTION STUDY (MCAPS), 1999-2010
Linking National Data Sets

- Air Pollution data (EPA)
- Health data (Medicare, NCHS)
- Weather data (NOAA)

National Morbidity Mortality Air Pollution Study
1987—2006
The National Medicare Cohort Study, 1999-2010 (MCAPS)

• Medicare data include:
  – Billing claims for everyone over 65 enrolled in Medicare (~48 million people),
    • date of service
    • disease (ICD 9)
    • age, gender, and race
    • place of residence (zip code)

MCAPS study population: 204 counties with populations larger than 200,000 (11.5 million people)
Statistical Methods for the analysis of time series data

Estimate + bounds
(% increase per 10 units PM$_{2.5}$)

Percentage change in Emergency Hospital Admission rate for cardiovascular disease per 10 $\mu g/m^3$ in Particulate Matter

Peng et al 2008 JAMA
\[ H = (\exp(\beta \times \Delta x) - 1) \times N \]

Relative risk
Reduction in PM_{2.5}
Number of hospital admissions for the year 2002

**Table 2.** Annual Reduction in Admissions Attributable to a 10-\(\mu g/m^3\) Reduction in the Daily PM_{2.5} Level for the 204 Counties in 2002

<table>
<thead>
<tr>
<th>Cause-Specific Hospital Admissions</th>
<th>Annual No. of Admissions</th>
<th>Annual Reduction in Admissions (95% PI)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerebrovascular disease</td>
<td>226,641</td>
<td>1,836 (680 to 2,992)</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td>70,061</td>
<td>802 (42 to 1,254)</td>
</tr>
<tr>
<td>Ischemic heart disease</td>
<td>346,082</td>
<td>1,523 (69 to 2,976)</td>
</tr>
<tr>
<td>Heart rhythm</td>
<td>169,627</td>
<td>967 (17 to 1,951)</td>
</tr>
<tr>
<td>Heart failure</td>
<td>246,598</td>
<td>3,156 (1,923 to 4,389)</td>
</tr>
<tr>
<td>COPD</td>
<td>108,812</td>
<td>990 (196 to 1,785)</td>
</tr>
<tr>
<td>Respiratory tract infection</td>
<td>226,620</td>
<td>2,085 (629 to 3,241)</td>
</tr>
</tbody>
</table>

Abbreviations: COPD, chronic obstructive pulmonary disease; PI, posterior interval; PM_{2.5}, particulate matter of less than or equal to 2.5 \(\mu m\) in aerodynamic diameter.

*Per 10-\(\mu g/m^3\) reduction in PM_{2.5}.

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**Ozone and Short-term Mortality in 95 US Urban Communities, 1987-2000**

Michelle L. Bell, PhD
Aidan McDermott, PhD
Scott L. Zeger, PhD
Jonathan M. Samet, MD
Francesca Dominici, PhD

**Context:** Ozone has been associated with various adverse health effects, including increased rates of hospital admissions and exacerbation of respiratory illnesses. Although numerous time-series studies have estimated associations between day-to-day variation in ozone levels and mortality counts, results have been inconclusive.

**Objective:** To investigate whether short-term (daily and weekly) exposure to ambient ozone is associated with mortality in the United States.

**November 17 2004**
Rigorous statistical modeling has played a key role in environmental policy

- From US EPA NAAQS Criteria Document 1996: "Many of the time-series epidemiology studies looking for associations between O3 exposure and daily human mortality have been difficult to interpret because of methodological or statistical weaknesses, including the failure to account for other pollutants and environmental effects."

- From US EPA Criteria Document 2006: "While uncertainties remain in some areas, it can be concluded that robust associations have been identified between various measures of daily O3 concentrations and increased risk of mortality."
Do cities with bigger improvements in air quality have bigger improvements in health, measured by life expectancy?

**Fine-Particulate Air Pollution and Life Expectancy in the United States**

**Pope, Ezzati, Dockery**

January, 2009

**Epidemiology**

January, 2013

The Effect of Air Pollution Control on Life Expectancy in the United States: An Analysis of 545 US counties for the period 2000-2007

Correia, Pope, Ezzati, Dockery, Dominici

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We found that an average decrease of 1.56 micrograms per cubic meter in PM$_{2.5}$ is associated with increased in life expectancy of a 0.84 years.

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**The New York Times**

Want to Live Longer? Breathe Clean Air

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**E.P.A. Sets a Lower Limit for Soot Particles in the Air**

By JOHN M. BRODER

Published: December 14, 2012

- **New NAAQS for PM$_{2.5}$ in 2013**: The agency, acting under a court deadline, set an annual standard of 12 micrograms per cubic meter of air, a significant tightening from the previous standard of 15 micrograms, set in 1997, which a federal court found too weak to adequately protect public health. The new standard is in the middle of the range of 11 to 13 micrograms per cubic meter that the E.P.A.’s science advisory panel recommended.
Health Impacts of Extreme Heat in the US

Heat Index, Total Deaths due to Heat in Chicago,
July 12 to July 19, 1995
(Semenza et al NEJM, 1996)

Whitman et al. 1997
What is a Heat Wave?

- There is no generally agreed upon definition of a heat wave
- Exceedances of percentiles of the temperature distribution
- Exceedances of specific absolute temperature levels
- Continuous stretches of high temperature
- High humidity
**Statistical Model for Present-day Risk**  
(May – October, 1987-2005)

\[
\log E[Y_t] = f(\text{weather}_t) + g(\text{pollution}_t, \text{season}_t)
\]

- Average temperature
- Maximum temperature
- Temperature in the previous week
- Humidity

\[
RR = \frac{1}{n} \sum_{t} \frac{\hat{f}(\text{weather}_t) I(\text{hw}_t = 1)}{t} = \frac{1}{n} \sum_{t} \frac{\hat{f}(\text{weather}_t) I(\text{hw}_t = 0)}{t}
\]

- Average number of deaths on heat wave days
- Average number of deaths on non-heat wave days

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**A National Study of Heat Waves and Mortality**

Log Relative Risks of Mortality and 95% HPD Associated with a Heat Wave Day: Results are shown for the largest 105 cities using data for the period 1987 to 2005. Results are grouped by geographical region and within each group are plotted as a function of the longitude (south to north)

Bobb, Dominici, Peng, Biometrics 2011
1943 counties in the United States with at least 5 summers of near-complete (>95%) daily temperature data during 1999 to 2010. 23.7 million fee-for-service Medicare beneficiaries (aged ≥65 years) per year (85% of all Medicare enrollees).
Our future?
Health Impacts of Climate Change

- While the present-day health effects of hot temperatures have been fairly well characterized, the extent to which future changes in the heat wave distribution will affect human health has not been as extensively studied.
- We estimate the excess mortality associated with heat waves in Chicago for 2081–2100 under several global climate change scenarios.
- We are interested in partitioning the uncertainty into: 1) statistical variation; 2) climate models, and 3) and climate change scenarios.

Analysis Schematic and Data Integration

Databases for current conditions
- Health status (Mortality)
- Environmental conditions
  - Weather
  - Air Pollution

Present-day heat wave mortality risk

Future conditions
- Population growth
- Mortality rate
- Adaptation

Future Heat Wave Excess Mortality

Global climate models
- Projection 1
- Projection 2
- ...

Spatial Downscaling
- Local projection 1
- Local projection 2
- ...

Future heat waves
Expected number of excess deaths during a given heat wave period

$$ED_{hw} = N \times (RR - 1) \times L$$

- For the period 1987-2005, there were a total of 14 heat waves (0.7 per year) an average length of 9.2 days
- For the period 2081-2100, under scenario A2, we predicted 4 heat waves event per year for an average length of 19 days (under the climate model = cnm.cm3)

Annual excess mortality attributable to heat waves events, 2081-2100

We estimated an annual excess mortality attributable to heat waves ranging between 166 to 2217 deaths per year.

Under the A2 scenario, 5 of the 7 climate models project that the annual mortality from heat waves will be similar to or greater than the mortality from the devastating 1995 heat wave.

Peng et al 2011, EHP
Assumptions

- Constant rate of mortality on non-heat wave days
- No interaction between exposure to air pollution and heat
- No adaptation

Are we becoming less vulnerable to heat? (Bobb, Peng, Bell, and Dominici 2014 EHP)

Figure 3: National temporal trends in the risk of heat-related mortality from 1987 to 2005. a, National average excess number of deaths per 1000 attributable to each $10^{\circ} F$ increase in temperature plotted over time. Shaded bands indicate 95% posterior intervals (PI). b, Same as in a but with results stratified by age group.
Why the excess number of deaths associated with each heat wave are declining over time?

- Higher AC prevalence
- Air pollution levels have declined
- Prevention and treatment of cardiovascular diseases have improved
- Extensive heat-health warning systems and public health response programs have been implemented in several US cities
- Other factors that might contribute to declining risk of heat-related mortality include: 1) changes in activity patterns (e.g., less time spent outside), changes in the built environment (e.g., more green spaces), physiological adaptations, and greater awareness of the dangers of extreme heat

Approach to quantifying future health impacts of heat waves (and other adverse weather events) in a changing climate

Diagram showing a flow from Greenhouse gas emissions scenario to Climate, and then to Future excess Mortality, with factors like Population growth, Global & regional climate models, and Assumptions on future conditions.
**Temperature**

**Ozone**

**PM$_{2.5}$**

**Fires**

**Human Health**

**Climate Change**

Exposure Response

Joint effects

Adaptation

Susceptibility

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**Summary**

- **What is known**
  - Air pollution, even at lower levels, is still affecting human health
  - Climate change threatens public health by affecting several environmental stressors jointly
  - Air pollution (especially O$_3$) is likely to be affected
- **What is not known**
  - Resiliency and vulnerability to changing exposures (e.g., extreme heat, higher pollution) in some populations
  - Which chemical components of fine particulate matter are harmful and what are the best air pollution control strategies
  - Co-benefits (and co-costs) of policies
Thanks

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  - Michelle Bell, Yale
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- EPA RD 83479801 (Koutrakis)
- EPA R834894 (Dominici)
- NIH R01 ES019560 (Peng)
- NIH R21 ES020152 (Peng)
- NIH R21 ES021427(Bell)
- HEI 4909 (Dominici/Zigler)

References

Questions?