Reasons to Care about the Impacts of Climate Change on Air Pollution

- Everyone is at risk
- Climate change will affect air pollution
- Changing air pollutant concentrations will affect the incidence of health outcomes
- Marginal changes in air quality can generate large changes in the incidence for a range of health outcomes
- Changes in health outcomes can be quantified and monetized
Presentation Overview

- How do we know air pollutants impact human health?
- Which pollutants impact human health?
- Which pollutants are affected by climate change?
- What are the health effects of air pollutants?
- Examples of benefit/impact estimates from changes in air quality
- Interdisciplinary thoughts/examples
Options for Determining if Air Pollutants Affect Human Health

- **Direct testing**
  - Observe physical results from controlled exposure using humans and/or animals

- **Evaluate relationships between health effects and air pollution data**
  - Episodic studies
  - Epidemiological studies
Direct Testing for Health Effects of Air Pollutants

- **Strengths:**
  - Support strong cause and effect relationships

- **Limitations:**
  - Human studies can only examine relatively mild and acute impacts
  - Animal results can only be seen as suggestive for human exposure
  - Differences in physiology and exposure limit animal to human extrapolation
Identifying the Health Effects of Air Pollutants by Evaluating Available Data

- Episodic studies
  - The “What just happened?” study
  - Typically involve high concentrations and sudden large changes in exposure
  - Results provide early evidence of air pollutants and health effects relationship
  - Difficult to extrapolate results to typical conditions
Episodic Studies: 1948 Donora, Pennsylvania

- What happened:
  - Pollution from the Donora Zinc Works smelting operation and other sources containing sulfur, carbon monoxide, and heavy metal dusts was trapped by weather conditions in the narrow Monongahela River valley
Air Pollution in Donora, Pennsylvania

Source: PBS
Air Pollution in Donora, Pennsylvania (cont.)

Source: NPR
What was it Like During the 1948 Donora Smog

- “Sometimes, (foot)balls that were punted were lost in the haze, not to be found”

- "I didn't realize the seriousness of it, but I thought it would affect the crowd at the football game. We had 50 pounds of hot dogs. I was worried about the hot dogs, the pop, buns, and candy [if no one showed up.]"
Direct Health Impacts of the 1948 Donora Smog

- In a town of 14,000
  - 20 dead
  - 6,000 sickened
December 1952 London Smog

Source: UK Met Office
1952 London Smog Impacts

- ~4,000 people were known to have died as a result of the smog, but it could be many more
- Many people experienced breathing problems
- Press reports claimed nearby cattle (Smithfield) were asphyxiated
- Travel was disrupted for days
Using Available Data to Identify/Estimate Impacts of Air Pollutants

- Epidemiological studies
  - Can consider fatal and nonfatal outcomes
  - There is an established history of study design, use, and interpretation of results
  - Different study designs allow for different degrees of modeling control
Types of Epidemiological Studies

- Cross sectional studies
  - Compare pollution levels and health effects at different locations
- Time series studies
  - Identify a population and evaluate health impacts as a function of pollution levels
Cross Sectional Studies

- Compare health impacts across multiple locations with levels of health stressor
  - Early studies compared annual mortality rates with average air pollution levels

- Strengths:
  - Use readily available data

- Weaknesses:
  - Hard to control for differences across locations
  - Snapshot provides more of a correlation than evidence of causation
Time Series Studies

- Evaluate air pollution and health outcome data within a population
- Strengths:
  - Use available data
  - The population serves as its own control
- Weaknesses:
  - Cannot evaluate development of chronic conditions
- Challenges
  - Controlling cyclical impacts (e.g., seasons)
Time Series Studies: Prospective Cohort Studies

- A special type of time series study:
  - Enroll a specific study population and follow them recording health events and exposure

- Strengths:
  - Interaction with individuals allows for control of individual characteristics
  - Can evaluate chronic conditions

- Challenges:
  - Need data to control for multiple individual confounders (smoking, income, race, diet, occupation)
Notable Cohorts for Air Pollution Studies

- **American Cancer Society Cancer Prevention Study:**
  - ~550,000 people enrolled nationwide in 1982

- **Harvard Six Cities Study:**
  - ~8,100 people enrolled in 1974
    - (Watertown, MA; Harriman, TN; St. Louis, MO; Steubenville, OH; Portage, WI; Topeka, KS)

- **Seventh-day Adventist Survey**
  - ~6,300 enrolled in So. California in 1977
Key Results from Prospective Cohort Studies

- Results from these studies have provided some of the strongest evidence of the health effects of air pollution for a number of severe health effects including
  - Mortality
  - Chronic bronchitis
Goal of the Epidemiological Study

- Develop quantitative/qualitative relationships that describe how exposure to the health stressor affects the incidence of the health outcome
  - Develop relationships that how characteristics of the event or individual affect the incidence of the health outcome
Typical Exposure-Response Calculation

- Health impact of pollutant is estimated by:

\[ \Delta y = y_0 \cdot (e^{\beta \cdot \Delta P} - 1) \]

- Where:
  - \( \Delta y \) is the change in incidence
  - \( y_0 \) is the baseline incidence
  - \( \beta \) is the estimated pollutant effect
  - \( \Delta P \) is the change in pollutant concentration

Source: P. Kinney, Columbia University
Types of Airborne Pollutants that Can Affect Human Health

- Naturally occurring
  - Particulate matter (dusts, wildfire smoke)
  - Ozone
  - Aeroallergens (pollens, molds)

- Anthropogenic
  - Hundreds of specific pollutants
  - Clean Air Act categories
    - Criteria pollutants
    - Hazardous air pollutants
    - Greenhouse gases
Clean Air Act Pollutants

- **Criteria pollutants**
  - The follow six pollutants with defined ambient concentration standards
    - Carbon monoxide
    - Lead
    - Nitrogen dioxide
    - Particulate matter
    - Ozone
    - Sulfur dioxide
Clean Air Act Pollutants (cont.)

- Toxic air pollutants
  - 187 specific pollutants identified in the 1990 Clean Air Act Amendments
  - Emissions standards vs concentration limits

- Greenhouse gases
  - In scope with the 2007 Supreme Court ruling and 2009 EPA Endangerment Finding
  - Control options being developed/evaluated
Potential Health Impacts from Air Pollutant Exposure

- **Morbidity**
  - Acute effects ranging in severity from minor activity restrictions, heart attacks, to hospitalizations/ER visits
  - New cases of chronic respiratory illness

- **Mortality**
  - Exposure linked to short-term and longer run increases in mortality

- New cancer cases
Which Categories of Air Pollutants are Sensitive to Climate Change?

- Pollutants whose formation and concentrations are sensitive to meteorological conditions (e.g., ozone, particulate matter, aeroallergens)

- Pollutants whose formation and concentrations are affected by climate sensitive processes (e.g., particulate matter from electricity generation, vehicle emissions, wildfires)
Ground-level Ozone Formation

Ozone formation

Sunlight

Oxygen (O₂) + Volatile Organic Compounds (VOC) + Nitrogen Oxides (NOx) → Ozone (O₃)

Source: P. Kinney, Columbia University
Air Pollutants that are Typically the Focus of Climate Change Discussions

- Some focus
  - Aeroallergens
- Considerable focus
  - Ozone
  - Particulate matter
Climate Change Impact on Aeroallergens: More and More Potent

- Pollen Production
  - 280 ppm: 4.8 g
  - 370 ppm: 10.9 g*
  - 600 ppm: 20.5 g*

- Antigen Amb a1 ELISA / mg protein
  - 280 ppm: 4490
  - 370 ppm: 5290
  - 600 ppm: 8180*

Source: L. Ziska, USDA
## Climate Change and Aeroallergens: Where is the Future Risk

### Allergenic pollen producers, Western weeds:

*Season: April through November*

<table>
<thead>
<tr>
<th>Weed</th>
<th>Western Weed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ragweed</td>
<td>Pigweed</td>
</tr>
<tr>
<td>Sagebrush</td>
<td>English plantain</td>
</tr>
<tr>
<td>Russian thistle</td>
<td>Fireweed</td>
</tr>
<tr>
<td>Marsh elder</td>
<td>Cocklebur</td>
</tr>
<tr>
<td>Yellow Dock</td>
<td>Lambsquarter</td>
</tr>
</tbody>
</table>

### Allergenic pollen producers, Mid-Western weeds:

*Season: May through October*

<table>
<thead>
<tr>
<th>Weed</th>
<th>Western Weed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ragweed</td>
<td>Pigweed</td>
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<td>Giant Ragweed</td>
<td>English plantain</td>
</tr>
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<td>Cocklebur</td>
</tr>
<tr>
<td>Lambsquarter</td>
<td></td>
</tr>
</tbody>
</table>

Source: L. Ziska, USDA
Climate Change and Aeroallergens: Where is the Future Risk (cont.)

Allergenic pollen producers, Southern weeds:
Season: April through November

- Ragweed
- Marsh elder
- Yellow Dock
- Giant Sagebrush
- Pigweed
- Cocklebur
- Lambsquarter
- English plantain

Allergenic pollen producers, Northeast weeds:
Season: May through September

- Ragweed
- Giant Ragweed
- Marsh elder
- Pigweed
- Mugwort
- English plantain
- Russian thistle
- Cocklebur
- Lambsquarter

Source: L. Ziska, USDA
“Why Should We Care”: Air Pollution Benefits from Title IV of 1990 CAAA

Source: Chestnut and Mills, 2005
“Why Should We Care?” (cont.)

### National estimates of annual (2010) health benefits as a result of Title IV related PM$_{2.5}$ reductions

<table>
<thead>
<tr>
<th>Avoided health effects</th>
<th>Number of cases of avoided health effects*</th>
<th>Monetary value (millions US 2000 dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US</td>
<td>Canada</td>
</tr>
<tr>
<td>Mortality (adults)</td>
<td>17,000</td>
<td>1000</td>
</tr>
<tr>
<td>Infant mortality (children less than 1)</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>Chronic bronchitis (adults)</td>
<td>10,400</td>
<td>600</td>
</tr>
<tr>
<td>Nonfatal heart attacks (adults)</td>
<td>22,800</td>
<td>1200</td>
</tr>
<tr>
<td>Respiratory hospital admissions (all ages)</td>
<td>8300</td>
<td>400</td>
</tr>
<tr>
<td>Cardiovascular hospital admissions (adults)</td>
<td>10,800</td>
<td>600</td>
</tr>
<tr>
<td>Emergency room visits for asthma (children)</td>
<td>14,100</td>
<td>600</td>
</tr>
<tr>
<td>Acute bronchitis (children)</td>
<td>26,600</td>
<td>1100</td>
</tr>
<tr>
<td>Asthma exacerbations (children with asthma)</td>
<td>28,200</td>
<td>1200</td>
</tr>
<tr>
<td>Upper respiratory symptoms (children with asthma)</td>
<td>338,200</td>
<td>15,200</td>
</tr>
<tr>
<td>Lower respiratory symptoms (children)</td>
<td>287,300</td>
<td>12,200</td>
</tr>
<tr>
<td>Minor restricted activity days (adults)</td>
<td>12,130,300</td>
<td>636,100</td>
</tr>
<tr>
<td>Work loss days (adults)</td>
<td>2,090,400</td>
<td>109,600</td>
</tr>
<tr>
<td>Total monetary value</td>
<td>$108,148</td>
<td>$6416</td>
</tr>
</tbody>
</table>

Source: Chestnut and Mills, 2005
Air Pollution Change in 2050 From Climate Change

- GISS for meteorology with the A1B emission scenario (business as usual)
- Regionally downscaled with MM5
- Emissions change from 2001 inventory only if sensitive to meteorology
- 2001 emissions inventory run through CMAQ for air quality results
- Health effects calculated with BenMap
- Source: Tagaris et al., *Environmental Science and Technology*, 2009
Air Pollution Change in 2050 From Climate Change (cont.)

Source: Tagaris et al. 2009
Air Pollution Change in 2050 From Climate Change (cont.)

Source: Tagaris et al. 2009
Air Pollution Change in 2050 From Climate Change (cont.)

- Examples of the quantified health impacts
  - Premature mortality:
    - Particulate matter: 3,711 (1377 - 6066)
    - Ozone: 279 (111 – 462)
  - Chronic bronchitis
    - Particulate matter: 2,438 (386, 4552)
  - School loss days
    - Ozone: ~1,430,000 (485,000, 2,520,000)
Air Pollution Change in 2050 From Climate Change (cont.)

- Monetized value of the quantified health impacts:
  - ~$22 billion/year
  - Monetized results driven by changes in mortality
    - Value per avoided/incurred death monetized in EPA air quality assessments ~$6M - $7M
    - Value of statistical life (VSL)
Conclusions

- Climate change will affect ambient concentrations of a number of air pollutants
- The impact will likely vary by pollutant and location
- In general, conditions will get worse
- This will have significant health impacts
- These impacts represent a cost of climate change and, if avoided, a benefit of the associated mitigation action
Promoting Interdisciplinary Work: Thoughts

- Incorporate other disciplines in projects (e.g., economists, ecologists)
- Read with depth and breadth
- Don’t be afraid to ask:
  - “What if we…?”
  - “Could we…”
- Don’t be afraid to be wrong
Interdisciplinary Example

- Northeast city needs to comply with an order to address a combined sewer overflow problem
- Options:
  - Heavy concrete based infrastructure effort
  - Increase urban vegetation, permeable paving
- Interdisciplinary benefit
  - Vegetation increase significant enough to:
    - improve urban heat, air quality
    - Reduce GHG emissions
- Result: quantified and monetized health benefits