Exposure and Health Assessment of Agricultural Burning Smoke

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For Pullman and Spokane town meetings (June 7, 2004)
General Scientific Questions

Are episodes of increased particulate matter air pollution from agricultural burning associated with health effects in adults with asthma, as measured by:

- Increased pulmonary inflammation?
- Decrements in lung function?

Is pulmonary response modified by use of anti-inflammatory medication?
Study Location and Population

- Washington State University community, Pullman, WA.
- 33 adults, in the WSU community, with physician-diagnosed mild or moderate asthma
- Sample size was determined based on power simulations
Study Period

- ~60-day period (Sept 3-Nov 1, 2002)
- 2 monitoring sessions, each session consisting of 33 subjects and 30 days of monitoring period.
- 33 subjects: 16 Active and 17 on-call
  - Those subjects who are active in session 1 become on-call in session 2
Primary air measurements
Primary air measurements

Central Site Monitoring on WSU campus

- 12-hr PM$_{2.5}$ samples on quartz and Teflon filters with Harvard Impactor (8AM-8PM; 8PM-8AM)
- Real-time light scattering coefficient via nephelometer and DataRAM; PM$_{2.5}$ and PM$_{10}$ via TEOM; CO, CO$_2$, NO$_x$, SO$_2$, T, and RH
Ag burn episode declaration

- Initial criterion: 5 or more 30-min average PM$_{2.5}$ concentrations as measured by TEOM > 40 µg/m$^3$ during any 24-hour period.

- Sufficient indication of agricultural burning smoke impacts were detected based on
  - TEOM, DataRAM, and neph, visual observation, smell, current and predicted meteorological conditions, and burn calls in the surrounding region.
PM$_{2.5}$ concentrations at the central site in Sep 2002

9/11-15 Episode 1

9/25-26 episode 2 (missed)
PM$_{2.5}$ concentrations at the central site in Oct 2002

10/9-11 Episode 3 (sham)

10/17-19 Episode 4

10/24-26 episode 5 (missed)
# One-hour Nephelometer PM$_{2.5}$

between Sep and Oct 2002

<table>
<thead>
<tr>
<th>Range of PM$_{2.5}$</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 $\leq$ PM &lt; 20</td>
<td>1185</td>
<td>87</td>
</tr>
<tr>
<td>20 $\leq$ PM &lt; 30</td>
<td>154</td>
<td>11</td>
</tr>
<tr>
<td>30 $\leq$ PM &lt; 40</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>40 $\leq$ PM &lt; 50</td>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1365</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>N</th>
<th>Mean</th>
<th>Median</th>
<th>Min</th>
<th>Max</th>
<th>40$&lt;$ Peak $&lt;$ 80</th>
<th>Peak $\geq$ 80</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1464</td>
<td>11.1</td>
<td>7.7</td>
<td>-2.4</td>
<td>91.3</td>
<td>37</td>
<td>3</td>
</tr>
<tr>
<td>2001</td>
<td>1114</td>
<td>7.8</td>
<td>5.5</td>
<td>-2.6</td>
<td>206.9</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>2002</td>
<td>1365</td>
<td>11.0</td>
<td>9.0</td>
<td>-0.2</td>
<td>40.5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
PM$_{2.5}$ levels by source (12-h means)
PM$_{2.5}$ source contribution in Pullman (Sep-Oct 02)

- **Biomass burning**: 35%
- **Dust**: 38%
- **Vehicle exhaust**: 2%
- **Sulfate**: 20%
- **Cooking**: 1%
- **Unexplained**: 4%

*Based on chemical mass balance analysis*
Primary Hypothesis

Adults with mild to moderate asthma who are not using anti-inflammatory medication will show an increase in exhaled nitric oxide (eNO) associated with the peak 1-hr average of central site PM$_{2.5}$ during the previous 24 hours.
Secondary Hypotheses

These adults with asthma not using anti-inflammatory medication:

- Will show an increase in eNO associated with the peak 1-hr average of central site PM$_{2.5}$ during 24 hour period *one day prior* (1 day lag) to measurement.

- Will show a decrease in lung function as measured by MEF and FEV1 associated with prior 24-hr and 1-day lagged peak 1-hr average of central site PM$_{2.5}$.

- Will show higher eNO and lower lung function (MEF, FEV1) on ag-burn episode days compared to non-episodic days.
Health Measures

- Exhaled nitric oxide (eNO), a sensitive marker for inflammation in the lungs
- Lung function tests
  - FEV$_1$: forced expiratory volume in 1 second, an estimate of airflow obstruction
  - MEF: mid-expiratory flow, a measure of airflow from the small airways
Health Effects Assessment

Active subjects – 3 lab visits/week

- Breath samples for eNO
- Coached pulmonary function tests (Micro DL)
- Symptom/medication and time-activity diaries

On-call subjects – 3 lab visits/episode

- 3 consecutive-day lab visits (eNO, PFT, urine samples) during an “episode”
- Symptoms
# Subjects Health Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>33</td>
<td>22</td>
<td>11</td>
</tr>
<tr>
<td>Female</td>
<td>21</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>Age (years)</td>
<td>24 (18,52)</td>
<td>23.5 (18,47)</td>
<td>25 (18,52)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.7 (1.5, 2)</td>
<td>1.7 (1.5, 2)</td>
<td>1.7 (1.6, 1.9)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>75 (48, 159)</td>
<td>76 (48, 159)</td>
<td>73 (52, 127)</td>
</tr>
<tr>
<td>BMI</td>
<td>24 (18, 55)</td>
<td>24 (18, 55)</td>
<td>26 (19, 44)</td>
</tr>
<tr>
<td>Subj-days, All</td>
<td>611</td>
<td>405</td>
<td>206</td>
</tr>
<tr>
<td>Subj-days, with eNO</td>
<td>610</td>
<td>404</td>
<td>206</td>
</tr>
<tr>
<td>Subj-days, with LF</td>
<td>607</td>
<td>404</td>
<td>203</td>
</tr>
</tbody>
</table>

Note: Median and range given for quantitative variables
### Subject Symptom Reporting

<table>
<thead>
<tr>
<th></th>
<th>Anti-Inflammatory Medications</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Missing data</td>
<td>25 (6%)</td>
<td>16 (8%)</td>
</tr>
<tr>
<td><strong>Asthma severity code</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No worsening</td>
<td>342 (84%)</td>
<td>141 (68%)</td>
</tr>
<tr>
<td>1-3 mild periods of worsening</td>
<td>31 (8%)</td>
<td>38 (18%)</td>
</tr>
<tr>
<td>4 or more mild periods of worsening</td>
<td>7 (2%)</td>
<td>8 (4%)</td>
</tr>
<tr>
<td>1 or more severe worsening</td>
<td>0</td>
<td>3 (1%)</td>
</tr>
<tr>
<td><strong>Contacted provider for asthma</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Missed class/work because of asthma</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rescue inhaler use (puffs/day)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>366 (90%)</td>
<td>168 (82%)</td>
</tr>
<tr>
<td>1</td>
<td>12 (3%)</td>
<td>11 (5%)</td>
</tr>
<tr>
<td>2</td>
<td>2 (1%)</td>
<td>11 (5%)</td>
</tr>
</tbody>
</table>
Health Effect Model

- Mixed Effects Model
- Covariates (predictors):
  - Central Site Exposure Measure
  - Gender, Age, BMI, Medication, interaction between medication & exposure
  - Temperature, \( T^2 \), RH, \( RH^2 \)
- Controlled for repeated subject
### Health Effects Results

<table>
<thead>
<tr>
<th>Response</th>
<th>Pollutant</th>
<th>Not on Meds.</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>eNO (ppb)</td>
<td>1-h max PM$_{2.5}$</td>
<td>0.79 (-0.90, 2.48)</td>
<td>0.26 (-1.45, 1.96)</td>
</tr>
<tr>
<td>eNO</td>
<td>1-h max PM$_{2.5}$ (lagged 1 day)</td>
<td>0.35 (-1.33, 2.04)</td>
<td>-0.46 (-2.39, 1.47)</td>
</tr>
<tr>
<td>MEF (l/min)</td>
<td>1-h max PM$_{2.5}$</td>
<td>0.54 (-0.71, 1.79)</td>
<td>0.54 (-1.01, 2.09)</td>
</tr>
<tr>
<td>MEF</td>
<td>1-h max PM$_{2.5}$ (lagged 1 day)</td>
<td>0.20 (-1.74, 2.14)</td>
<td>1.30 (-0.61, 3.20)</td>
</tr>
<tr>
<td>FEV$_1$ (ml)</td>
<td>1-h max PM$_{2.5}$</td>
<td>3.92 (-4.70, 12.55)</td>
<td>4.82 (-6.66, 16.31)</td>
</tr>
<tr>
<td>FEV$_1$</td>
<td>1-h max PM$_{2.5}$ (lagged 1 day)</td>
<td>4.41 (-11.0, 19.86)</td>
<td>8.50 (-9.80, 26.80)</td>
</tr>
</tbody>
</table>
### Health Effects Results: episodes

#### eNO effects (ppb)

<table>
<thead>
<tr>
<th></th>
<th>Real Episode</th>
<th>Non-episode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>3.6 (-1.5, 8.8)</td>
<td>0</td>
</tr>
<tr>
<td>Declared</td>
<td>5.7 (-3.9, 15.2)</td>
<td>0</td>
</tr>
<tr>
<td>Not declared</td>
<td>0.2 (-4.4, 4.7)</td>
<td>0</td>
</tr>
</tbody>
</table>

#### FEV$_1$ effects (ml)

<table>
<thead>
<tr>
<th></th>
<th>Real Episode</th>
<th>Non-episode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>22 (-12.2, 56.2)</td>
<td>0</td>
</tr>
<tr>
<td>Declared</td>
<td>-1.8 (-45.1, 41.6)</td>
<td>0</td>
</tr>
<tr>
<td>Not declared</td>
<td>38.2 (-7.2, 83.5)</td>
<td>0</td>
</tr>
</tbody>
</table>
### Health Effects Results: episodes

**MEF effects (L/min)**

<table>
<thead>
<tr>
<th></th>
<th>Real Episode</th>
<th>Non-episode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>2.5 (-1.9,7.0)</td>
<td>0</td>
</tr>
<tr>
<td>Declared</td>
<td>-2.9 (-6.9,1.0)</td>
<td>0</td>
</tr>
<tr>
<td>Not declared</td>
<td>3.4 (-2.5,9.4)</td>
<td>0</td>
</tr>
</tbody>
</table>
Discussion: Why Were Effects Not Observed?

Several potential reasons:

- Young adults with asthma less susceptible?
- Timing of Health Measures
- No effects
- Low and infrequent exposures
- Uncertainties in exposure assessment
Strengths of Study

- Health outcomes
  - Exhaled nitric oxide
  - Pulmonary function

- Exposures measured dominated by agricultural burning
  - hourly maximum PM$_{2.5}$
  - 1 day lagged PM$_{2.5}$
  - episodes
Study Limitations

- Adults with asthma were chosen based on feasibility, population base, residential and monitoring locations.
- Difficult to precisely define agricultural burning component.
- Low peak exposure levels.
- Diurnal and spatial exposure variation.
Refinements in Exposure Assessment

Address uncertainties due to:
- Spatial variation
- Diurnal variation
- Individual activities
Outdoor Sites (Marked with red IDs)
24-h Outdoor PM$_{2.5}$ (in µg/m$^3$), Oct 17-18
6-d Outdoor PM$_{2.5}$ (in $\mu$g/m$^3$), Oct 26-Nov 1
Ratio of home outdoor to central site PM$_{2.5}$ at 7 outdoor sites

<table>
<thead>
<tr>
<th>Sampling Period</th>
<th>Average Home Outdoor PM$<em>{2.5}$/Central site PM$</em>{2.5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct 4-11</td>
<td>0.0</td>
</tr>
<tr>
<td>Oct 11-17</td>
<td>0.2</td>
</tr>
<tr>
<td>Oct 17-18</td>
<td>0.4</td>
</tr>
<tr>
<td>Oct 18-19</td>
<td>0.6</td>
</tr>
<tr>
<td>Oct 19-26</td>
<td>0.8</td>
</tr>
<tr>
<td>Oct 26-Nov 1</td>
<td>1.0</td>
</tr>
<tr>
<td>Oct 26-Nov 1</td>
<td>1.2</td>
</tr>
<tr>
<td>Oct 26-Nov 1</td>
<td>1.4</td>
</tr>
<tr>
<td>Oct 26-Nov 1</td>
<td>1.6</td>
</tr>
<tr>
<td>Oct 26-Nov 1</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Locations:
- **BJJ**
- **B02**
- **DOE**
- **B16**

**Central**

**Graph Legend**
- **Home outdoor PM$_{2.5}$/Central site PM$_{2.5}$**

**Graph X-axis**
- Sampling period (24 h-168 h)

**Graph Y-axis**
- Home outdoor PM$_{2.5}$/Central site PM$_{2.5}$

**Graph Key Points**
- **BJJ**
- **B02**
- **DOE**
- **B16**

**Graph Analysis**
- The ratio of home outdoor to central site PM$_{2.5}$ varies significantly across different sampling periods, with notable peaks and troughs.
- **BJJ** shows the highest variability, especially around Oct 17-18.
- **B02** and **DOE** exhibit moderate fluctuations, with **DOE** showing a slight decrease towards Oct 26-Nov 1.
- **B16** maintains a relatively stable ratio throughout the period, with slight increases towards the end.

**Conclusion**
- The data indicates substantial differences in PM$_{2.5}$ levels between home and central sites, with significant variations over time.
- Further analysis might reveal specific environmental factors influencing these differences.

**Note**
- The graph provides a visual representation of the data, with key points marked for each location across different sampling periods.
Personal Exposure Assessment

- Time-activity diary
  - From every subject every day, 10-min resolution

- Personal sampling:
  - 2/d, 2 HPEMs/subject (Teflon for XRF, quartz for EC/OC)
Central site vs. Personal PM$_{2.5}$

$R^2 = 0.09$, $n=63$
Personal vs. central site tracers: Sulfur and levoglucosan (LG)

- Central-site Sulfur (µg/m³)
- Personal Sulfur (µg/m³)

- Central-site LG (µg/m³)
- Personal LG (µg/m³)

\[ R^2 = 0.08, n = 21 \]

\[ R^2 = 0.42, n = 40 \]
Total Personal Exposure ($E_t$) Model

$$E_t = E_{ag} + E_{ig} + \text{“personal cloud”}$$

**Exposure to ambient generated PM:**

$$E_{ag} = \alpha C_a$$

**Exposure to indoor generated PM:**

$$E_{ig} = (1-y)(C_{ig})$$

$\alpha$ = “attenuation factor” = $[y + (1-y)(F_{inf})]$

$C_a$ = ambient (outdoor) concentration

$y$ = fraction of time spent outdoors

$C_{ig}$ = indoor-generated concentration = $C_i - C_a(F_{inf})$
Performance of personal exposure estimates

**Attenuation factor estimated by sulfur tracer**

- 0.4
- 0.6
- 0.8
- 1.0
- 1.2
- 1.4
- 1.6
- 1.8

**Attenuation factor estimated by ME**

- 0.5
- 0.6
- 0.7
- 0.8
- 0.9
- 1.0
- 1.1
- 1.2

\[ R^2 = 0.72, \ n = 11 \]

**Personal levoglucosan (µg/m³)**

- 0.00
- 0.02
- 0.04
- 0.06
- 0.08
- 0.10
- 0.12
- 0.14
- 0.16
- 0.18
- 0.20

**Estimated Eab (µg/m³)**

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8

\[ R^2 = 0.39, \ n = 28 \]
Sensitivity Analysis:
Responses to last 12-h central-site LG

* 95% confidence interval shown
* No effects observed with 1-d lag
Sensitivity Analysis:
Responses to last 12-h mean indoor PM$_{2.5}$

* 95% confidence interval shown
* No effects observed with 12-h lag
Sensitivity Analysis:
Responses to last 12-h PM$_{2.5}$ exposure originated from outdoor sources

* 95% confidence interval shown
* No effects observed with 12-h lag
Conclusions – Health Assessment

- Adverse health effects were not observed in association with observed particulate matter concentrations in adults with asthma
  - These results should be interpreted with caution due to uncertainties and limitations
Slides will be available on the PM Center Website

http://depts.washington.edu/pmcenter/res_projects.html
Acknowledgement

- Study subjects
  - EPA/Northwest Research Center for Particulate Air Pollution and Health Effects
  - WA Department of Ecology
  - U.S. EPA Region 10
## Sensitivity Analysis: within subject differences

<table>
<thead>
<tr>
<th>Response</th>
<th>Pollutant</th>
<th>Overall</th>
<th>Not on meds</th>
</tr>
</thead>
<tbody>
<tr>
<td>eNO (ppb)</td>
<td></td>
<td>0.69 (-0.54, 1.93)</td>
<td>0.15 (-1.27, 1.56)</td>
</tr>
<tr>
<td>FEV1 (ml)</td>
<td>1-h maximum PM(_{2.5})</td>
<td>8.00 (-0.06, 16.06)</td>
<td>8.86 (-2.04, 19.75)</td>
</tr>
<tr>
<td>MEF (l/min)</td>
<td></td>
<td>0.63 (-0.44, 1.71)</td>
<td>0.63 (-0.82, 2.08)</td>
</tr>
</tbody>
</table>
Sensitivity Analysis: with nephelometer data only

<table>
<thead>
<tr>
<th>Response</th>
<th>Pollutant</th>
<th>Overall</th>
<th>Not on meds</th>
</tr>
</thead>
<tbody>
<tr>
<td>eNO (ppb)</td>
<td>1-h max PM&lt;sub&gt;2.5&lt;/sub&gt;</td>
<td>0.93 (-1.48, 3.33)</td>
<td>1.16 (-1.90, 4.23)</td>
</tr>
<tr>
<td></td>
<td>1-h max PM&lt;sub&gt;2.5&lt;/sub&gt;, lagged 1 day</td>
<td>0.24 (-2.21, 2.69)</td>
<td>0.48 (-2.98, 3.94)</td>
</tr>
<tr>
<td>MEF (l/min)</td>
<td>1-h max PM&lt;sub&gt;2.5&lt;/sub&gt;</td>
<td>0.46 (-1.18, 2.11)</td>
<td>0.07 (-1.95, 2.09)</td>
</tr>
<tr>
<td></td>
<td>1-h max PM&lt;sub&gt;2.5&lt;/sub&gt;, lagged 1 day</td>
<td>-0.80 (-3.18, 1.58)</td>
<td>0.50 (-2.04, 3.04)</td>
</tr>
<tr>
<td>FEV1 (ml)</td>
<td>1-h max PM&lt;sub&gt;2.5&lt;/sub&gt;</td>
<td>1.53 (-9.60, 12.65)</td>
<td>1.64 (-14.0, 17.29)</td>
</tr>
<tr>
<td></td>
<td>1-h max PM&lt;sub&gt;2.5&lt;/sub&gt;, lagged 1 day</td>
<td>-2.35 (-22.3, 17.62)</td>
<td>2.76 (-21.7, 27.19)</td>
</tr>
</tbody>
</table>
Comparisons of PM$_{2.5}$ Measurements at central site (12-h averages)

R$^2$ = 0.69

R$^2$ = 0.66

Neph vs. HI$_{2.5}$

TEOM$_{2.5}$ vs. HI$_{2.5}$