The Health Effects of Ambient Air Pollution

Understanding the Effects; Quantifying the Benefits

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Honolulu, Hawaii
April 4, 2005

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Health Effects of Ambient Air Pollution

- The Key Questions:
  - What are the effects?
  - How do the effects of different pollutants and components compare?
    - PM components (e.g. carbon vs. sulfate aerosol)
    - The Gases (e.g. ozone, sulfur dioxide)
  - How can we quantify the benefits?

Health Effects of Ambient Air Pollution

- Our Session Today:
  - Overview – Dan Greenbaum
  - The View from China – ZHU Tong, PKU
  - Quantifying mercury reduction benefits – Praveen Amar, NESCAUM
  - Discussion

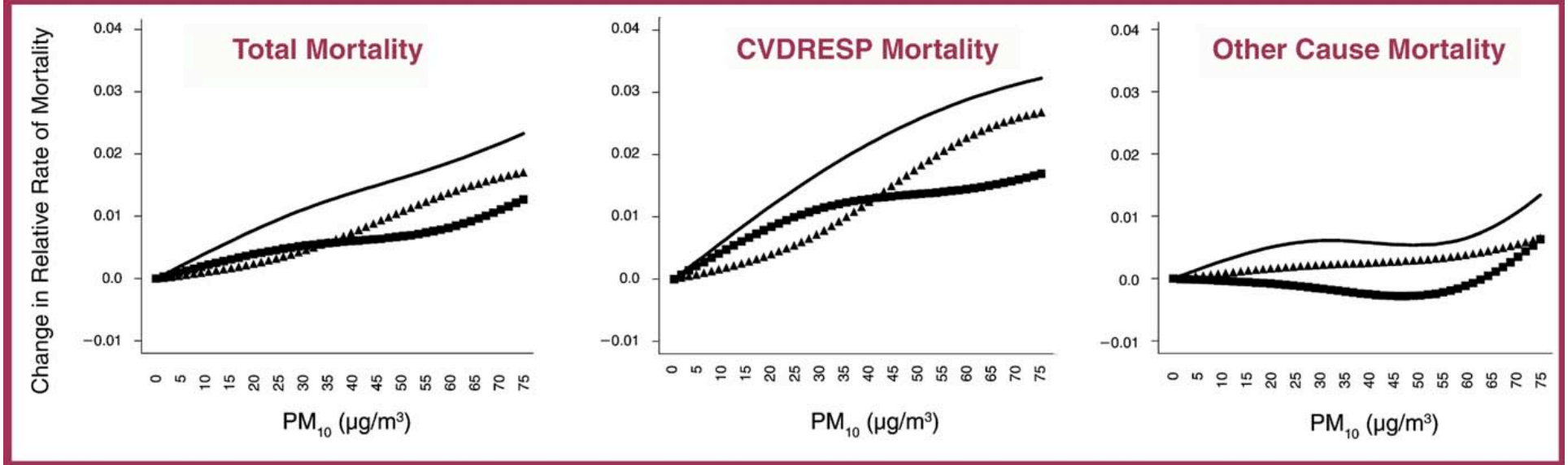
PM Health Effects

- High levels of PM (e.g. 500 μ/m^3) known to cause premature death
  - e.g. London 1952
- Studies in US, Europe, Asia, South America have found association of PM with death at much lower levels (<50 μ/m^3)
  - no evidence of a "threshold" (safe level)
- Recent progress toward identifying biological mechanisms for these effects
- Initial, non-systematic efforts to examine effects of different components

National Morbidity, Mortality and Air Pollution Study (NMMAPS)

Short Term Analysis (Daily) of Concentration - Response for the 20 Largest US Cities

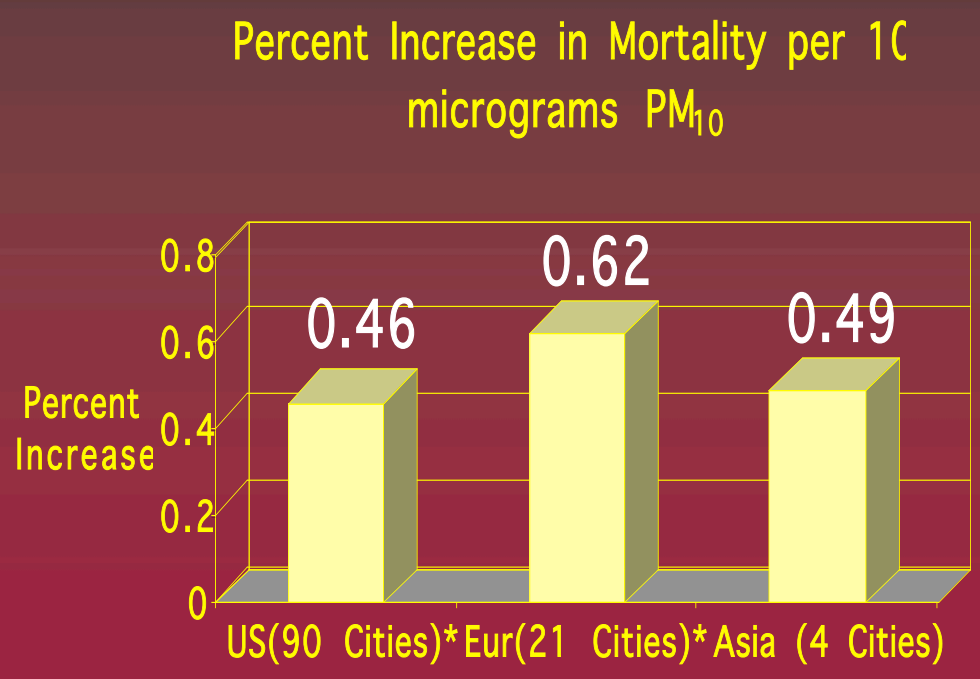
(Daniels et al HEI 2004)



EVIDENCE FROM ASIA:

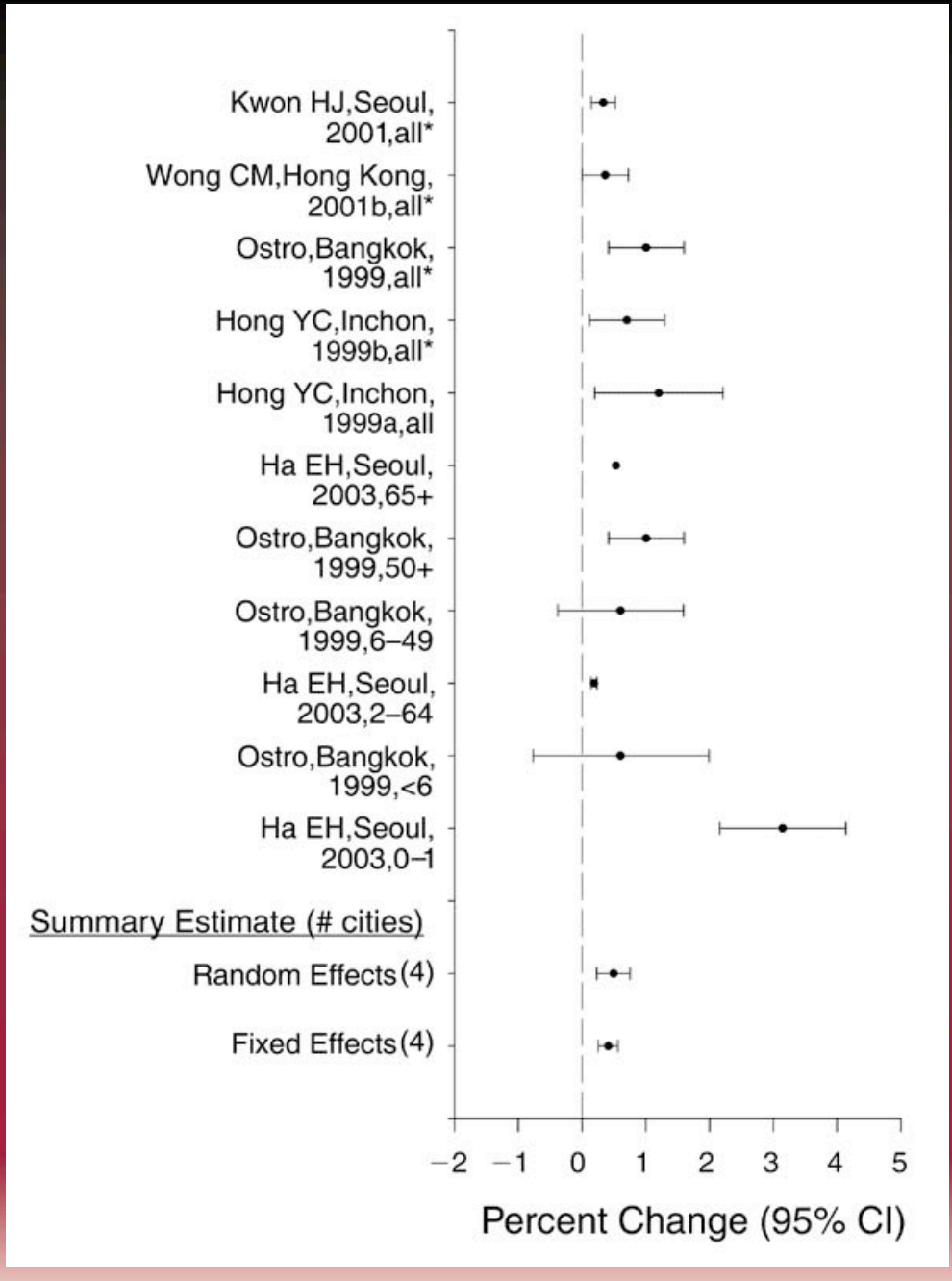
*HEI Meta-Analysis of Asian Studies of Daily Mortality/Hospital Admissions (**P**ublic Health and **A**ir **P**ollution in **A**sia (PAPA) 2004)*

- 28 recent daily time series studies examined in depth
- Studies find effects of air pollution on rate of death, illness
  - ~0.5% increase per 10 μg/m^3 of PM_{10}
  - High levels of air pollution in Asian cities (>100 μg/m^3), imply a substantial public health impact
- *Limitations*
  - Small number of cities
  - Not geographically representative (poorest, most polluted countries under-represented)



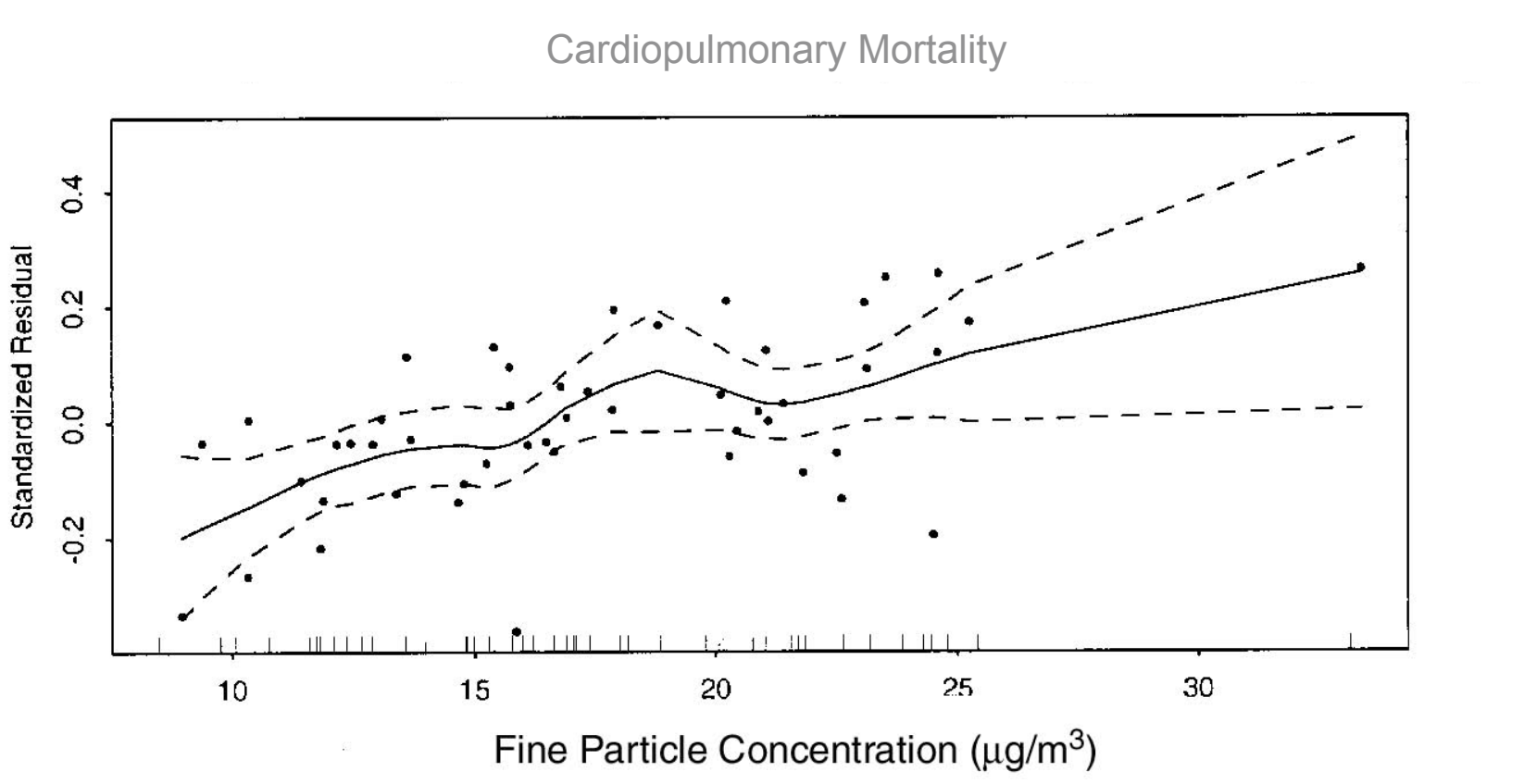
*** Estimates Using Pre-GAM Results (without revision)**

Evidence from Asia: PM10 and All Cause Mortality



American Cancer Society Cohort

HEI Reanalysis Results
(Krewski, et al)

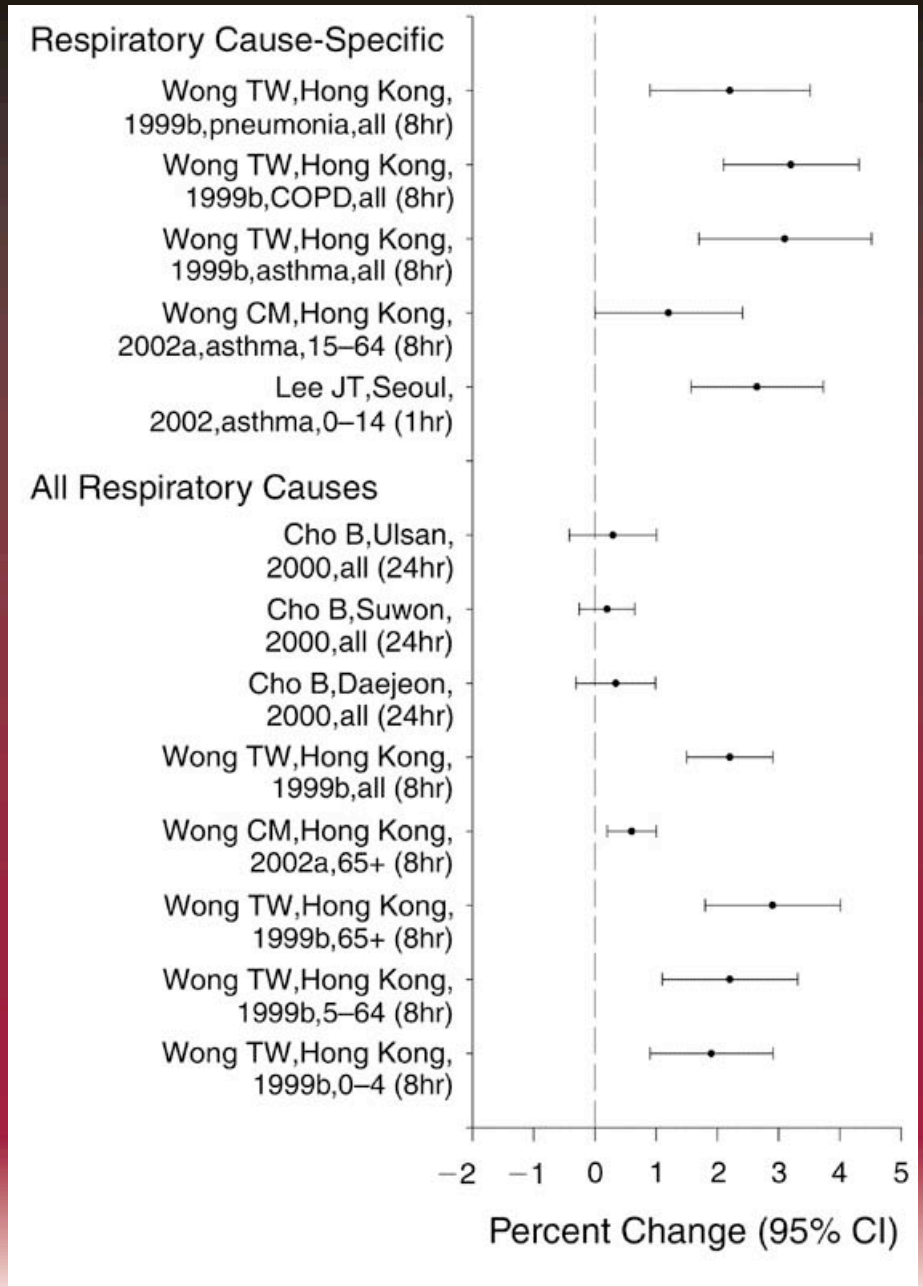


Ozone Health Effects

- Known to cause inflammation in respiratory tract
- Reduces ability to breathe (lung function) for some people
- Increases hospitalization for asthma, other lung diseases
- Recent systematic evidence of effects on premature mortality
- Effects have been demonstrated for short term exposure, long term effects are less certain

Evidence from Asia: Ozone and Respiratory Hospital Admissions

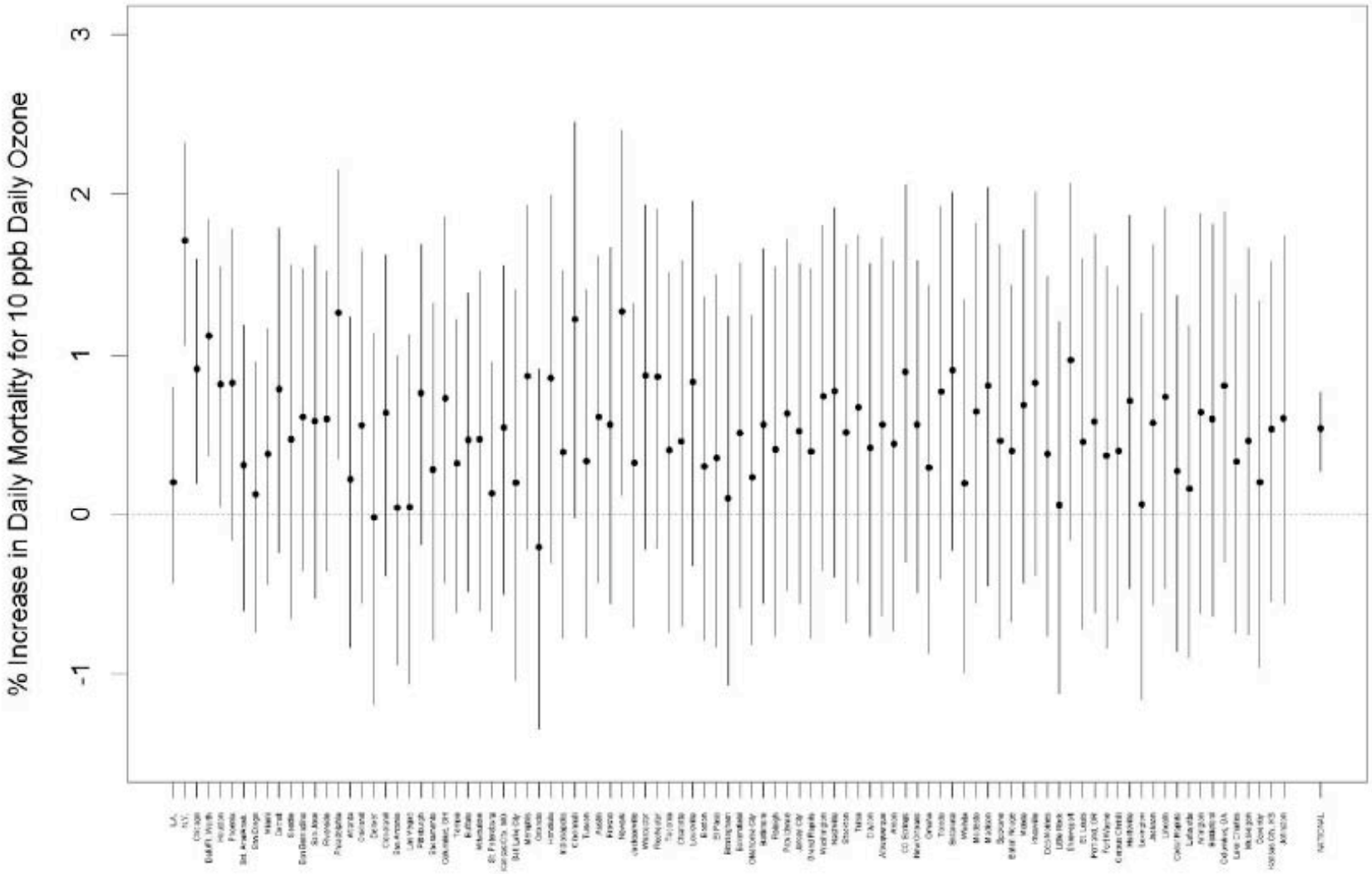
(PAPA, 2004)



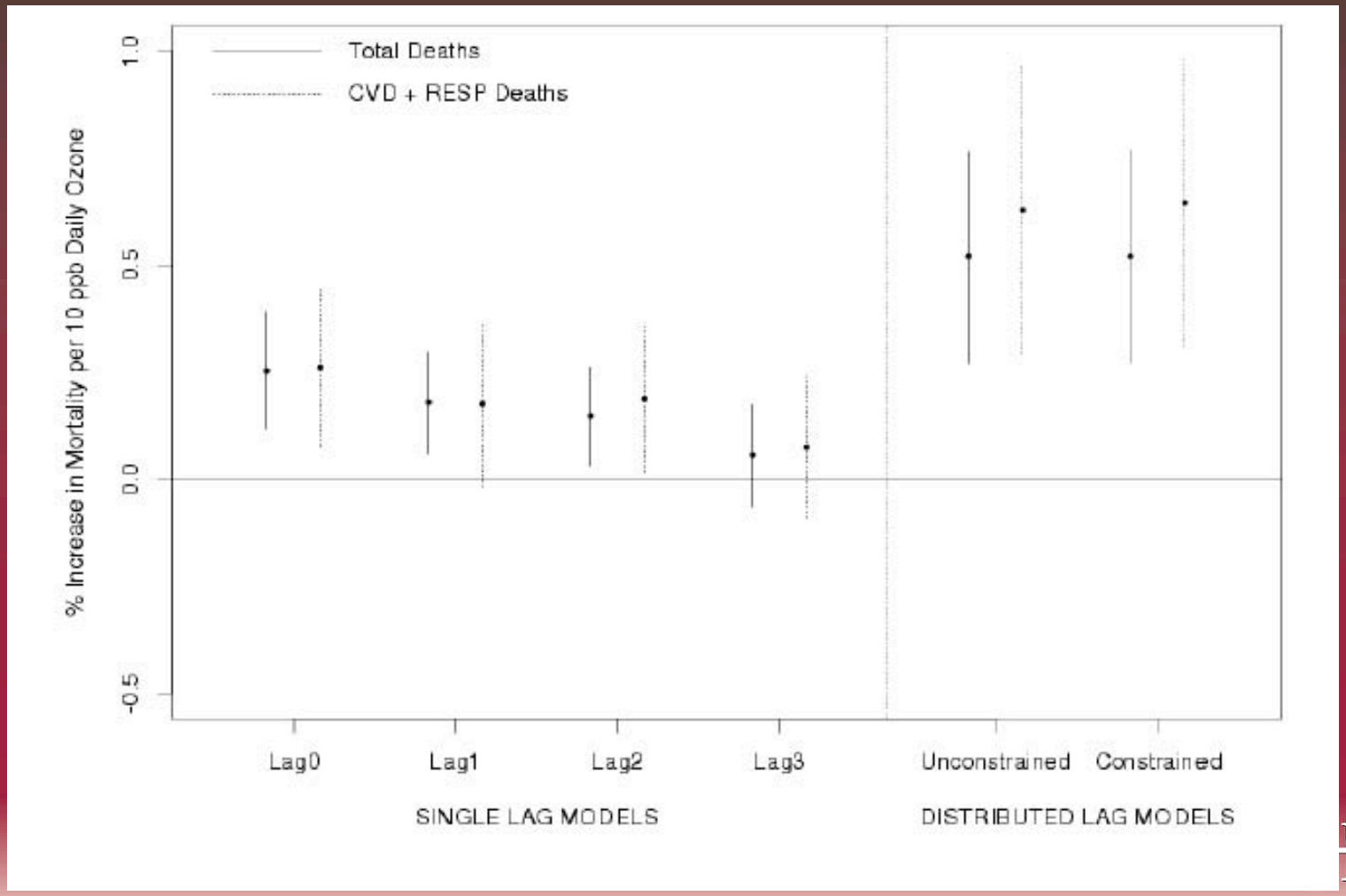
Ozone Effects on Mortality
95 US Cities (Bell, et al 2004)

FIGURE 4. Community-Specific Bayesian Estimates Obtained Under a Constrained Distributed Lag Model

NOTE: This distributed lag model reflects the percent increase in mortality for a 10 ppb increase in ozone over the previous week.



Ozone Effects on Mortality
95 US Cities
(Approximately 0.5% increase in mortality /10ppb)

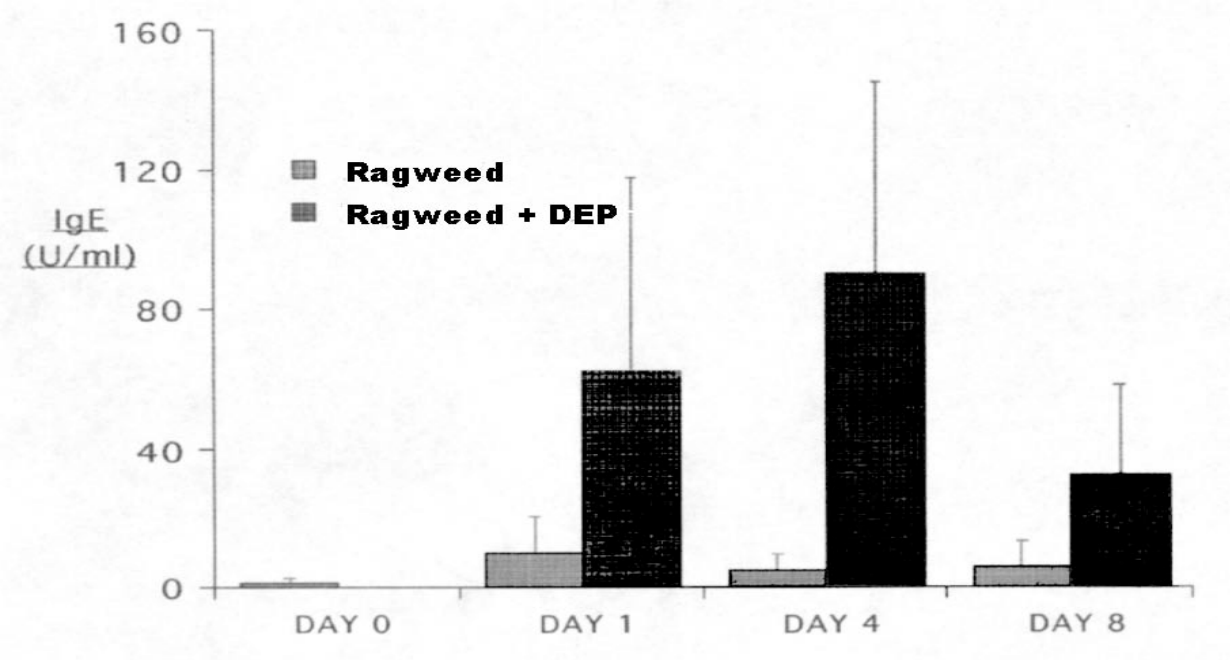


"Carbon" Effects

- A Number of acute and long-term effects have been attributed to carbon compounds
  - Black carbon, CO, Hydrocarbons
- A range of respiratory and cardiovascular effects, e.g.
  - Allergy exacerbation
  - Lung Cancer
  - Premature Mortality

Example: Acute "Carbon" Effects
Diesel and Allergy

- Does diesel exacerbate allergic response in humans? (High dose experiments by Diaz-Sanchez, 1999)
- Limited data base available; HEI has new studies underway

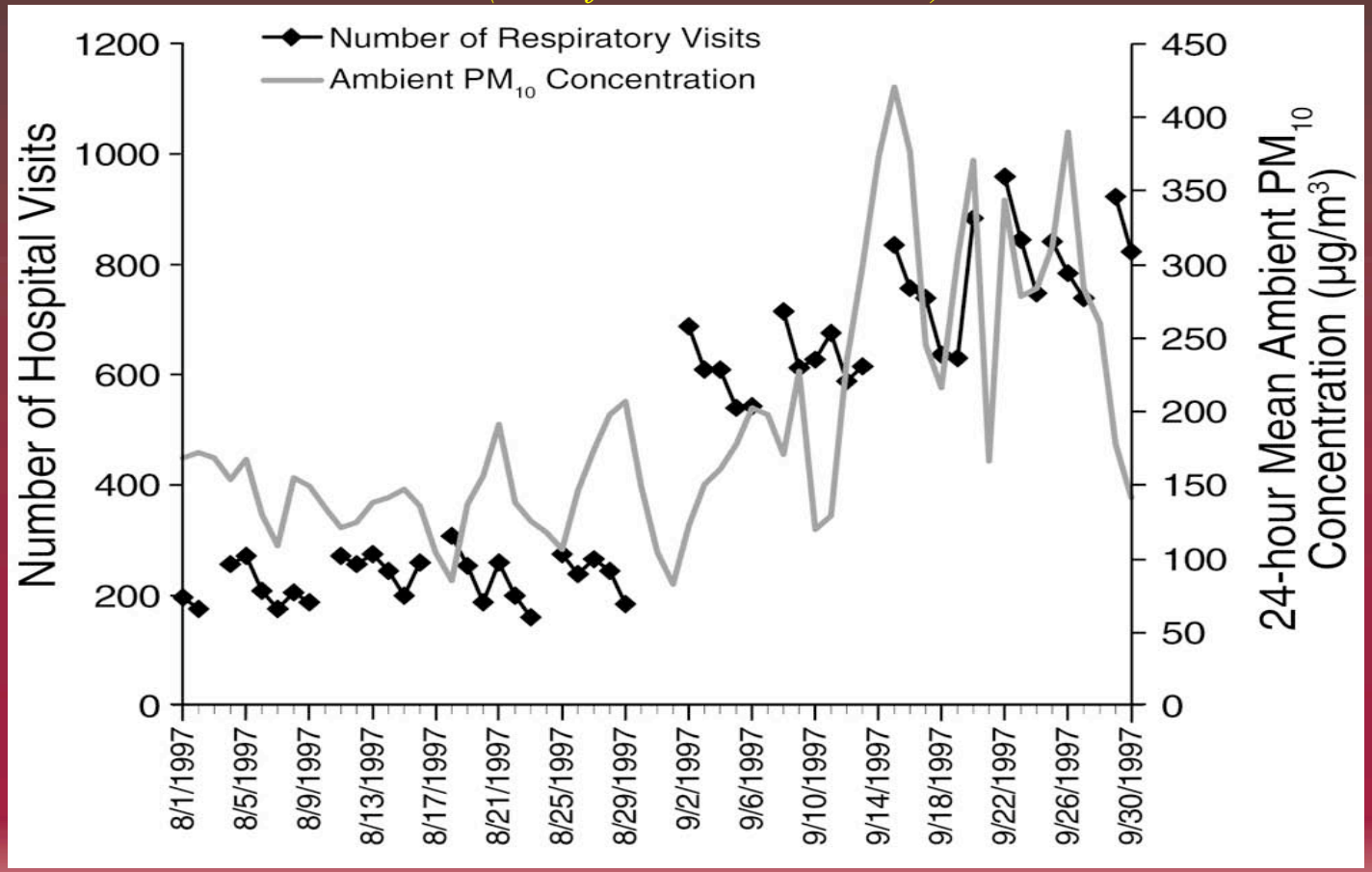


Example: Acute "Carbon" Effects

Biomass Burning and Respiratory Health

Kuala Lumpur 1997

(Data from M Brauer 1997)

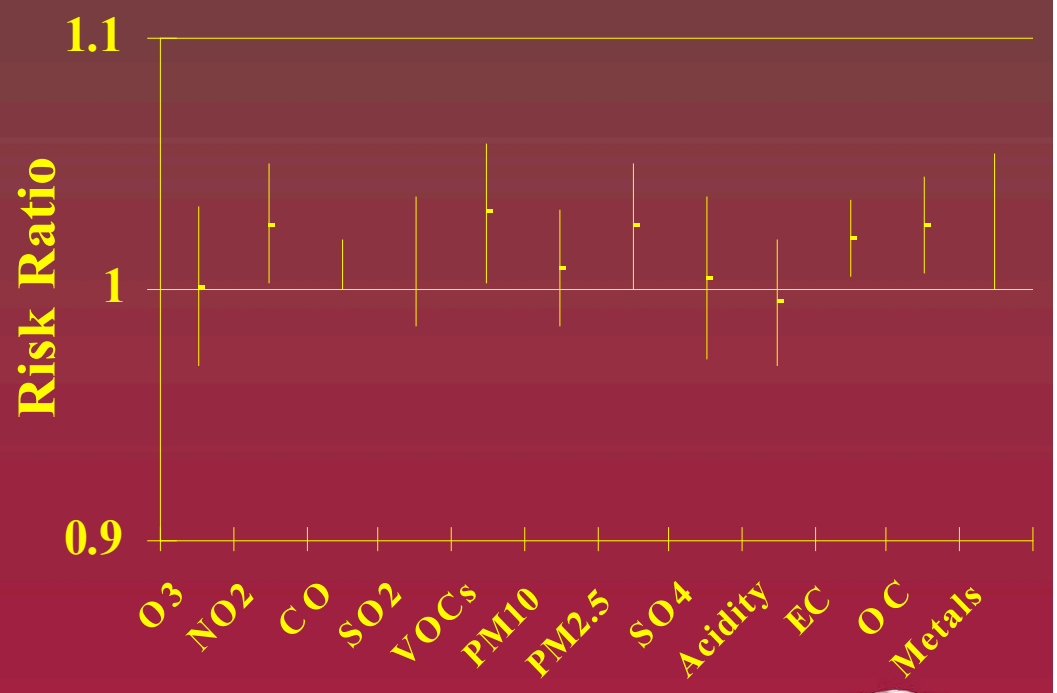


Example: Acute "Carbon" Effects

Multi-Pollutant Short Term Analyses in Atlanta

- **ARIES study in Atlanta**
- **Preliminary Results:**
  - **Carbon measures (CO, VOC, EC, OC), NO2, and PM2.5 are associated (mobile sources?)**
  - **O3, Sulfate, and Acidity are not**

Cardiovascular Emergency Department Visits - Atlanta



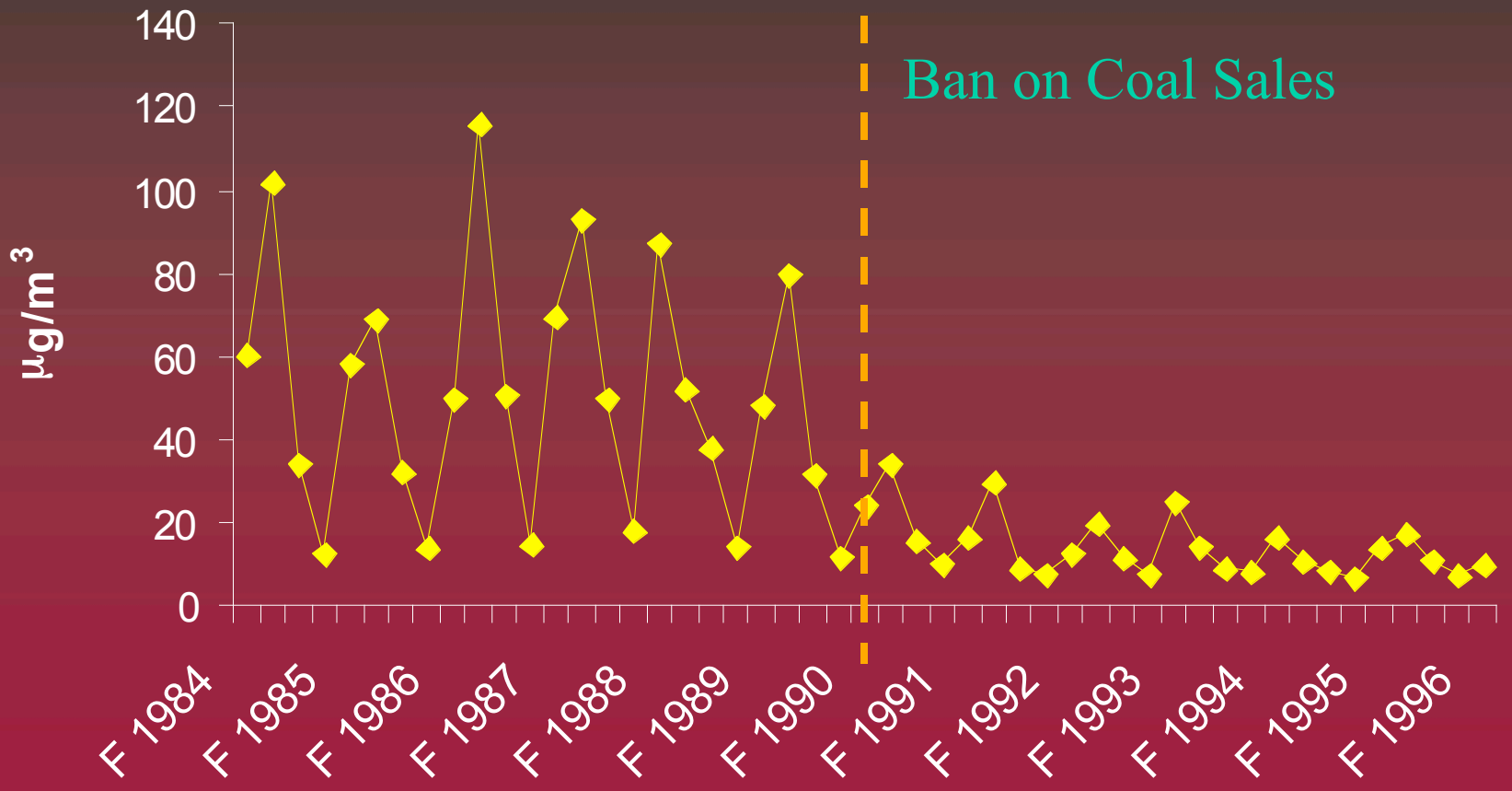
Example: Intermediate Term Effects

Intervention Study: Effect of Air Pollution Control on Death Rates in Dublin

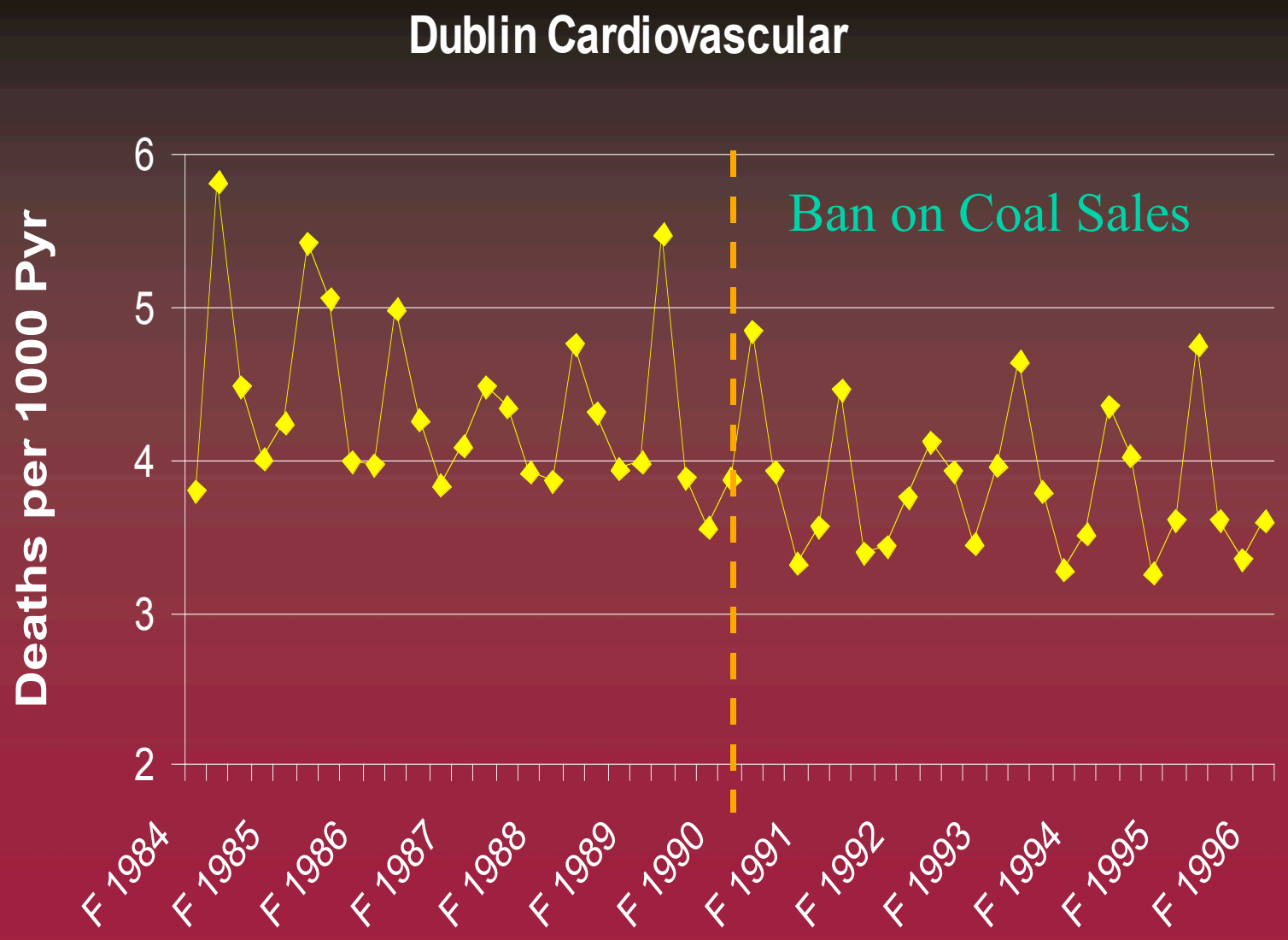
(Clancy et al 2002)

- Impacts on mortality of banning the marketing, sale and distribution of coal in Dublin
  - Ban began Sept 1, 1990 – clear effect date
- Study compared
  - levels of BS, SO2 & mortality indices
  - 72 mos. pre ban vs. 72 mos. post ban

Dublin Black Smoke



Courtesy Douglas Dockery



Courtesy Douglas Dockery

Effect of Air Pollution Control on Death Rates in Dublin

- Concentrations of BS declined 70% , (SO2 11.3%)
- Cardiovascular mortality declined 10.3%
- 12-year study duration necessitated correction for other external and risk factors:
  - Weather patterns
  - Influenza epidemics
  - Changes in Hypertension, Cigarette smoking

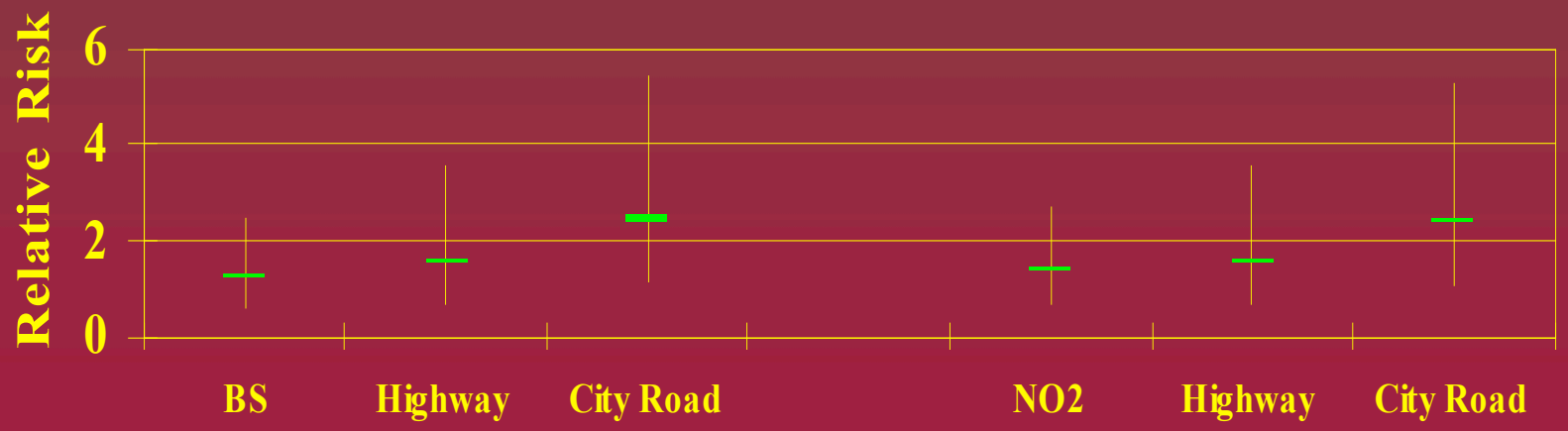
Example: Long Term "Carbon" Effects

(Brunekreef et al 2002)

Association with Cardiopulmonary Mortality in Dutch Cohort

(Pilot Study results;

Full HEI-funded study underway)



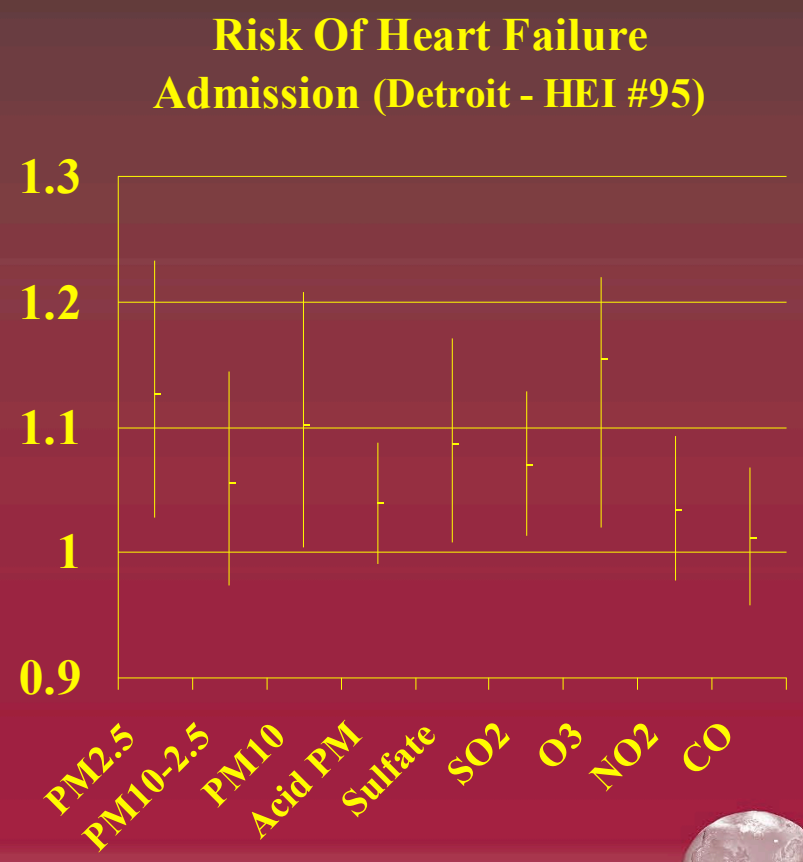
Results in Three-Exposure-Metric Models

"Sulfur" Effects

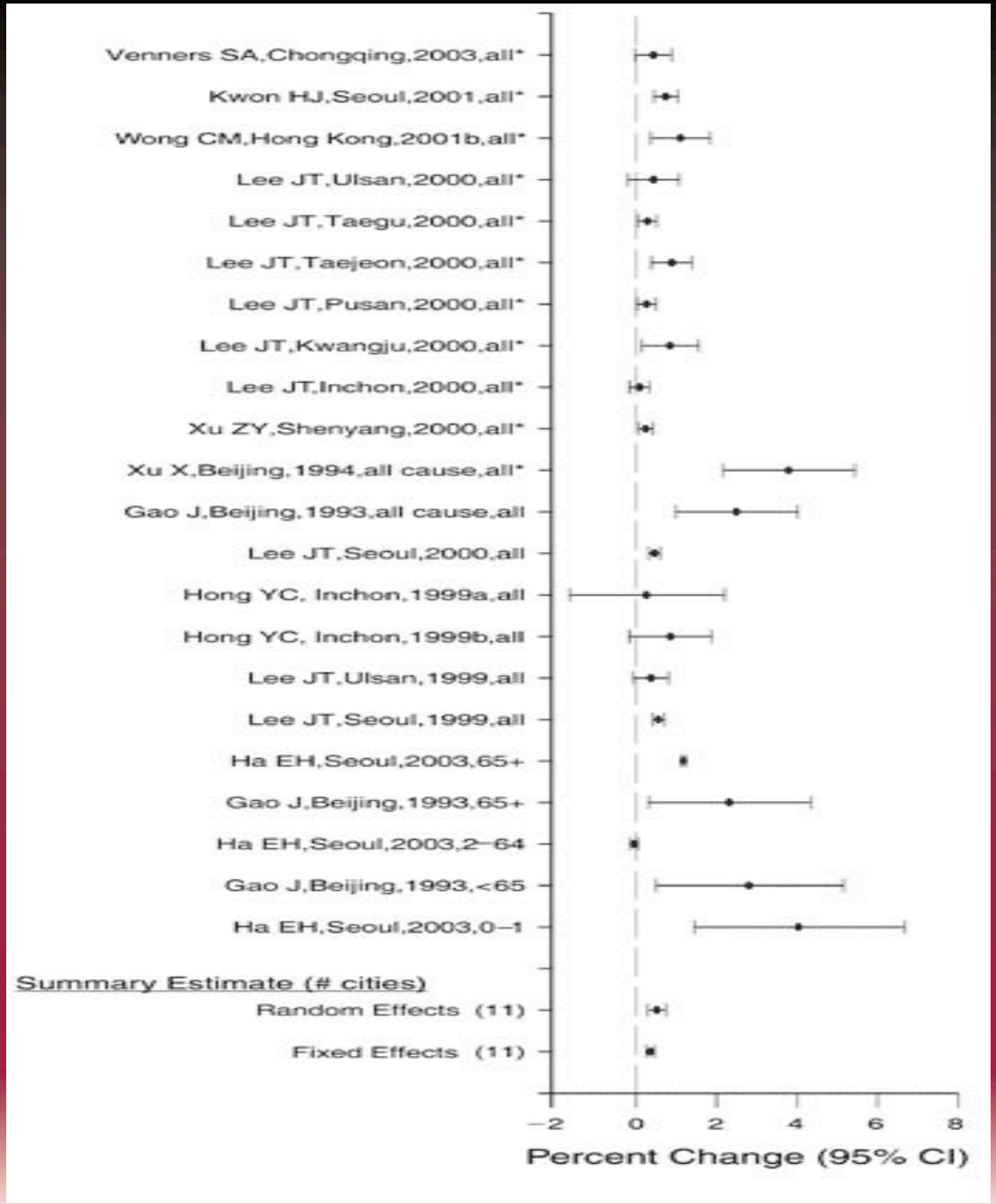
- Emitted from fossil fuel combustion
  - Sulfur Dioxide, converted to sulfates
  - Especially from coal burning facilities, high sulfur fuels
- SO2 can impair breathing in asthmatic children and adults
- However in laboratory tests sulfates alone do not show high toxicity
- Have been associated, along with PM, with
  - increased aggravation of heart and lung disease
  - premature mortality
- Recent study in Hong Kong (Lancet 2002) has found:
  - substantial reductions in SO2 emissions can result in measurable improvements in mortality and illness

Acute "Sulfur" Effects
Evidence from Multi-pollutant Study in Detroit

- **HEI Study in Detroit**
- **In this example PM2.5, Sulfate, SO2 and Ozone are associated**
- **Acid, coarse particles, NO2, and CO are not**



Acute Evidence from Asia: SO2 and All Cause Mortality



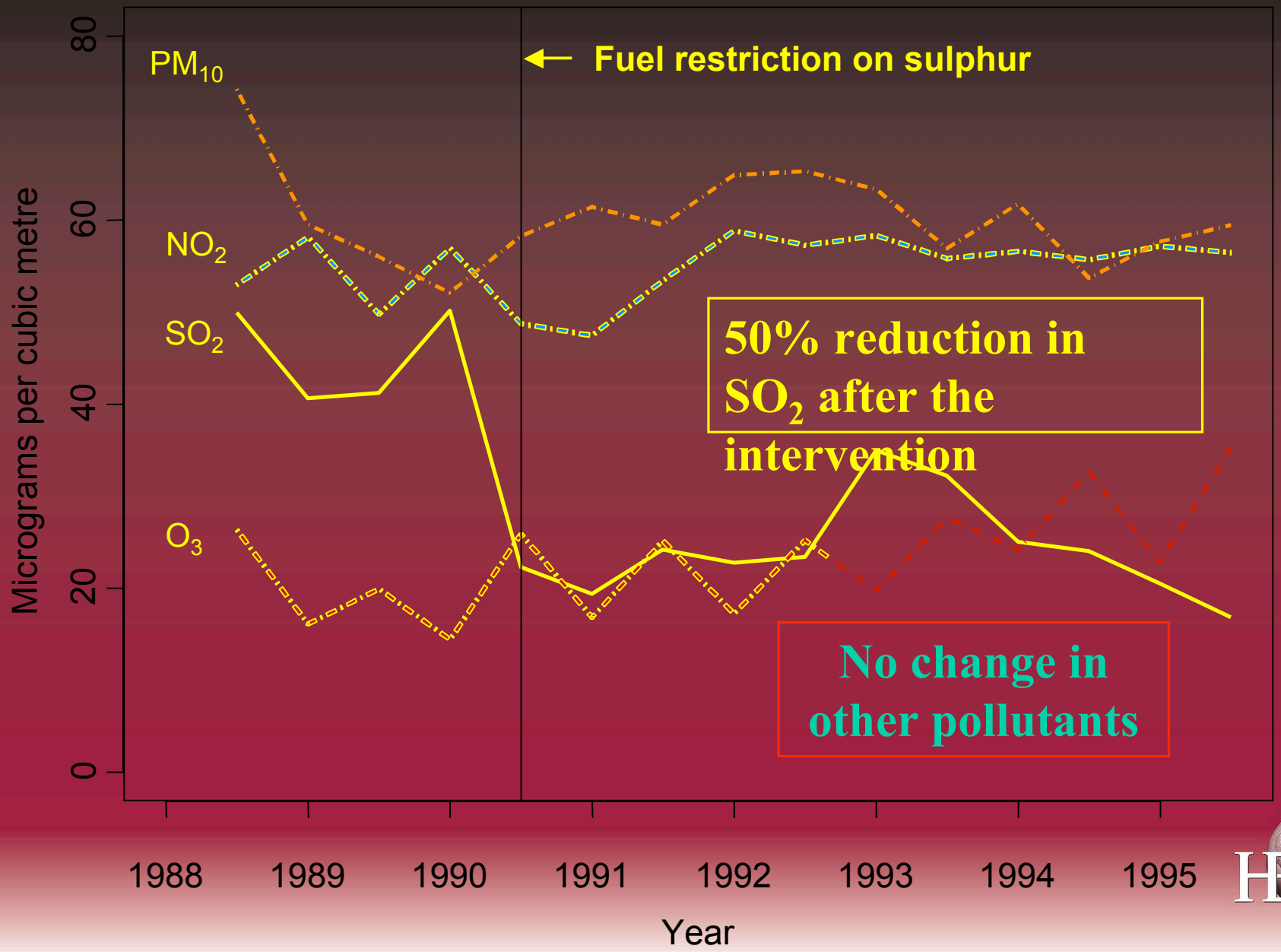
Intermediate Term "Sulfur" Effects

Hong Kong Intervention Study: Effect of Regulation to Reduce Fuel Sulfur

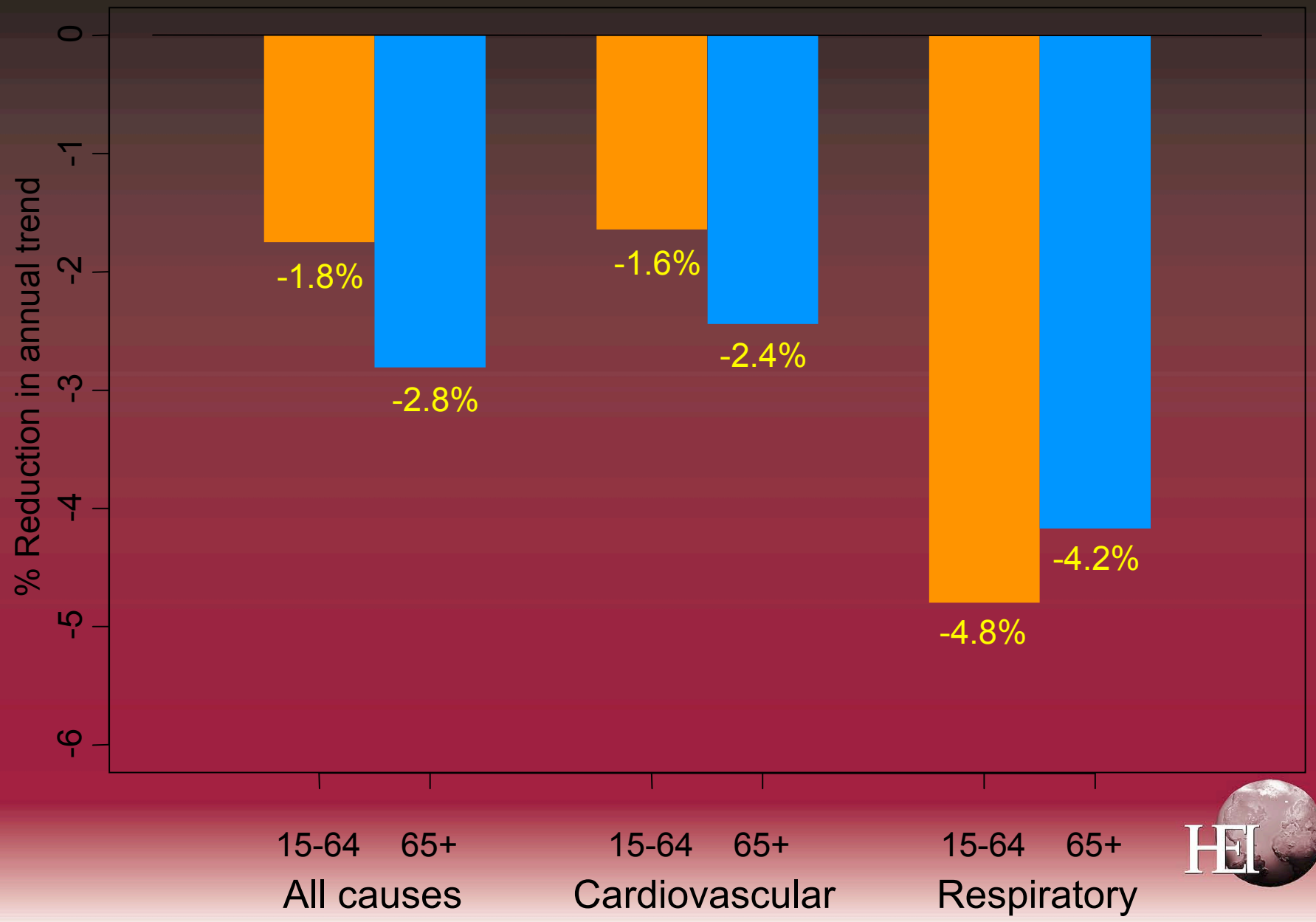
AJ Hedley et al - Lancet 8\2002

- Evaluated impact of .5% (wt) cap on fuel sulfur beginning on July 1, 1990
- Study compared SO2 levels & indices of mortality for 1988-1995 (3 pre, 5 post cap)
- Adjusted for seasonality, other factors

AIR POLLUTANT CONCENTRATIONS 1988 - 95 IN HONG KONG
HALF YEARLY MEAN LEVELS



REDUCTIONS IN DEATHS AFTER SULPHUR RESTRICTION



Evidence of Long Term "Sulfur" Effects
HEI Reanalysis Results
(Krewski, et al)

- **Overall, the reanalysis**:
  - Assured the quality of the data
  - Replicated the original results,
  - Tested those results ***without substantively altering the original findings***
  - Identified robust associations with PM2.5, SO2, Sulfate
- **Recent similar results in extended ACS Cohort (Pope, et al 2002)**

Results from ACS Study Reanalysis

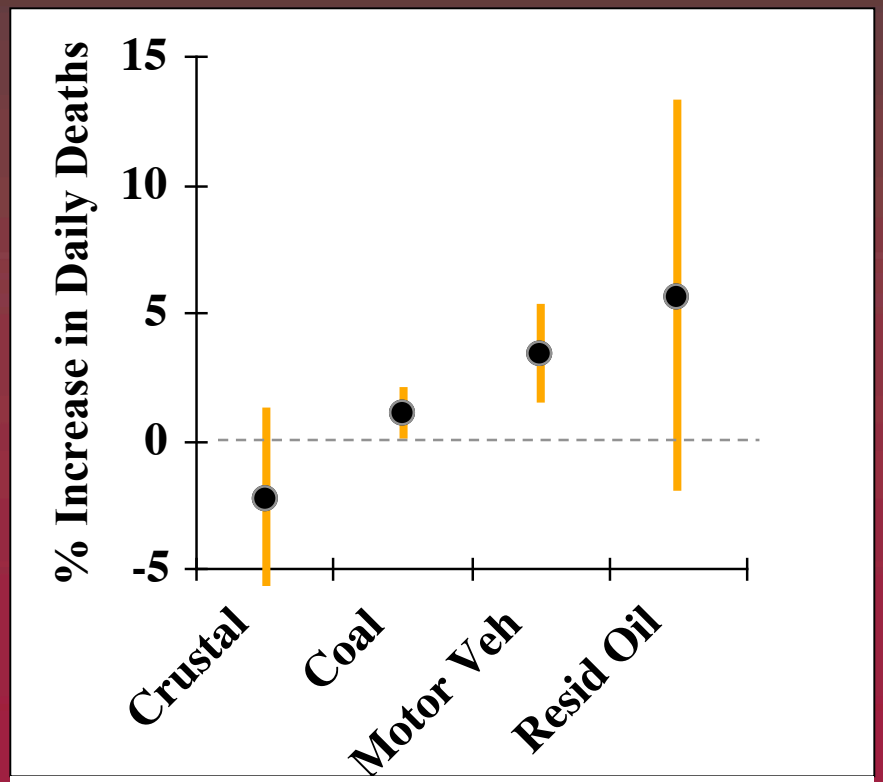
Analysis	*PM2.5*	*Sulfates*
Original	1.**17**(1.08,1.27)	1.**15**(1.08,1.22)
Full	1.**18**(1.09,1.26)	1.**15**(1.09,1.21)
Extended	1.**18**(1.09,1.26)	1.**15**(1.09,1.21)

Comparing the Effects

- There are a few studies that have tried to compare effects systematically across cities
  - Acute Effects (Laden et al)
  - Long Term Effects
    - Southern California Children's Study (Gauderman et al 2004)
    - ACS Cohort (Krewski et al 2000, Pope et al 2002)

Comparing Acute Effects of Different Sources

- $PM_{2.5}$ associated with daily mortality in six cities (1980's)
- Factor analysis of elemental composition of $PM_{2.5}$ used to estimate source-specific concentrations
- Associations estimated with 4 source classes (10 mg/m^3)
  - Crustal (Si)
  - Motor Vehicle (Pb)
  - Coal (Se)
  - Residual Oil (Vn, Mn)



Source-Specific $PM_{2.5}$ and Daily Mortality in Six US Cities *Laden, et al, EHP 2000*

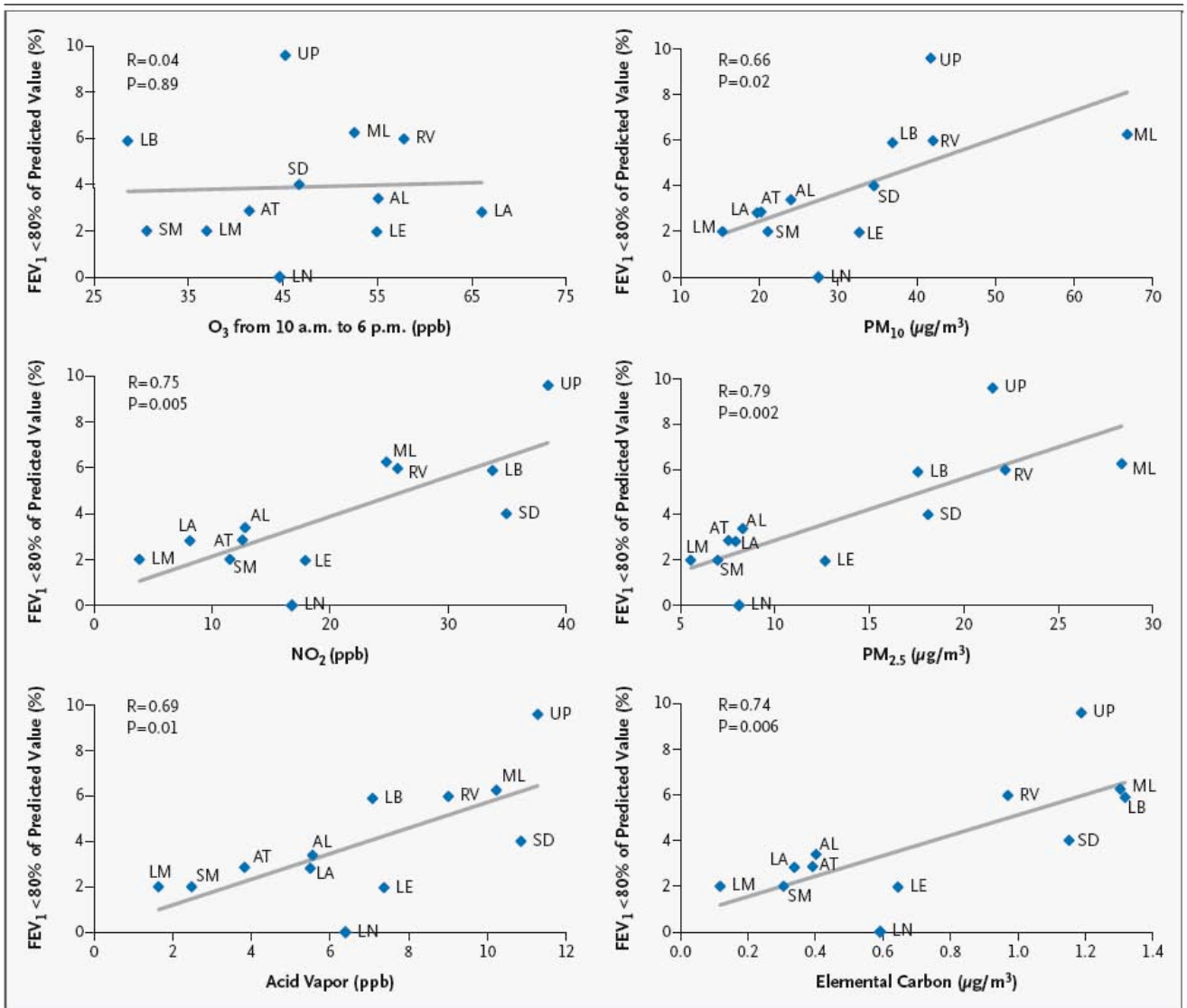


Figure 3. Community-Specific Proportion of 18-Year-Olds with a FEV_1 below 80 Percent of the Predicted Value Plotted against the Average Levels of Pollutants from 1994 through 2000.

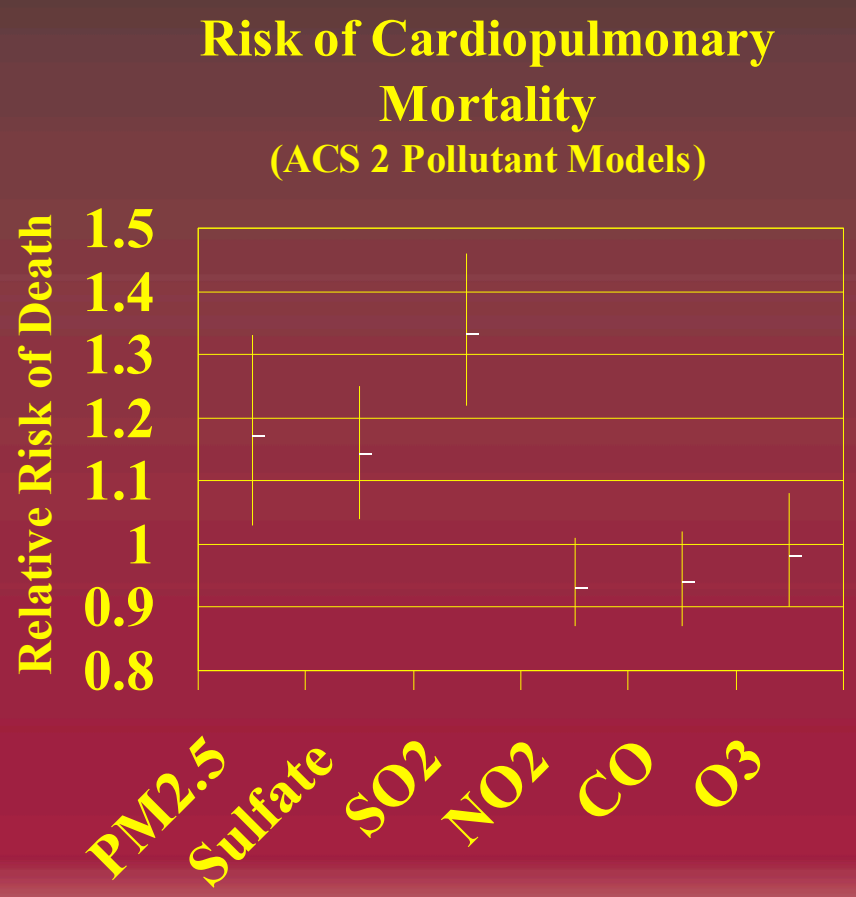
The correlation coefficient (R) and P value are shown for each comparison. AL denotes Alpine, AT Atascadero, LE Lake Elsinore, LA Lake Arrowhead, LN Lancaster, LM Lompoc, LB Long Beach, ML Mira Loma, RV Riverside, SD San Dimas, SM Santa Maria, and UP Upland. O_3 denotes ozone, NO_2 nitrogen dioxide, and PM_{10} and $PM_{2.5}$ particulate matter with an aerodynamic diameter of less than 10 μm and less than 2.5 μm, respectively.

Comparison of long-term effects from pollutants on children's lung function development

(Southern California Children's Study, Gauderman et al 2004)

American Cancer Society Results

Effect of Different Pollutants (Krewski et al)



- Reanalysis tested multiple pollutants
- $PM_{2.5}$, sulfate, and SO_2 had positive association
- O3, NO2, and CO did not
- Similar Results reported in Extended ACS follow-up (Pope, et al 2002)

Summary:
What does this tell us about health effects from different components, pollutants?

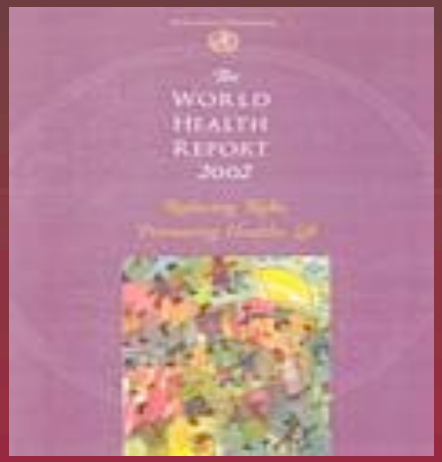
- Strong body of evidence on effects of a wide variety of pollutants
  - PM, Ozone, Carbon and Sulfur components
- To date, no evidence that there is a "threshold" below which effects do not occur
  - This is important for benefits estimation
- Some clear differences among pollutants
  - e.g. PM and ozone long term vs. short term effects
- But difficult to distinguish PM effects among carbon and sulfur components
- Continuing challenge of the air pollution metrics we have available
  - Highly correlated
  - Many components not measured regularly (e.g. metals)

Quantifying Population Impacts and Benefits

- Health studies – and concentration-response curves (CR) - provide basis for:
  - Estimating population impact of current levels
  - Estimating benefits to be derived from planned control measures
- Examples:
  - Population Impact – WHO Global Burden of Disease
  - Benefits Estimation – US EPA and Health Canada
  - Many others using similar techniques (e.g. EC, CARB)

How large is the burden of disease due to outdoor air pollution?

- WHO Global Burden of Disease
- Systematic analysis and comparison of wide range of environmental and other risk factors
  - Outdoor and Indoor air pollution
  - Tobacco
  - Waterborne disease
  - Malnutrition and obesity
- Published in World Health Report 2002



Estimation of burden

Current exposure minus counterfactual exposure

X

CONCENTRATION - RESPONSE FUNCTION RELATING OUTCOME TO UNIT OF POLLUTION

RELATIVE RISK

ATTRIBUTABLE FRACTION
X
OUTCOMEBASELINE

ATTRIBUTABLE BURDEN

Current exposure minus specified predicted exposure

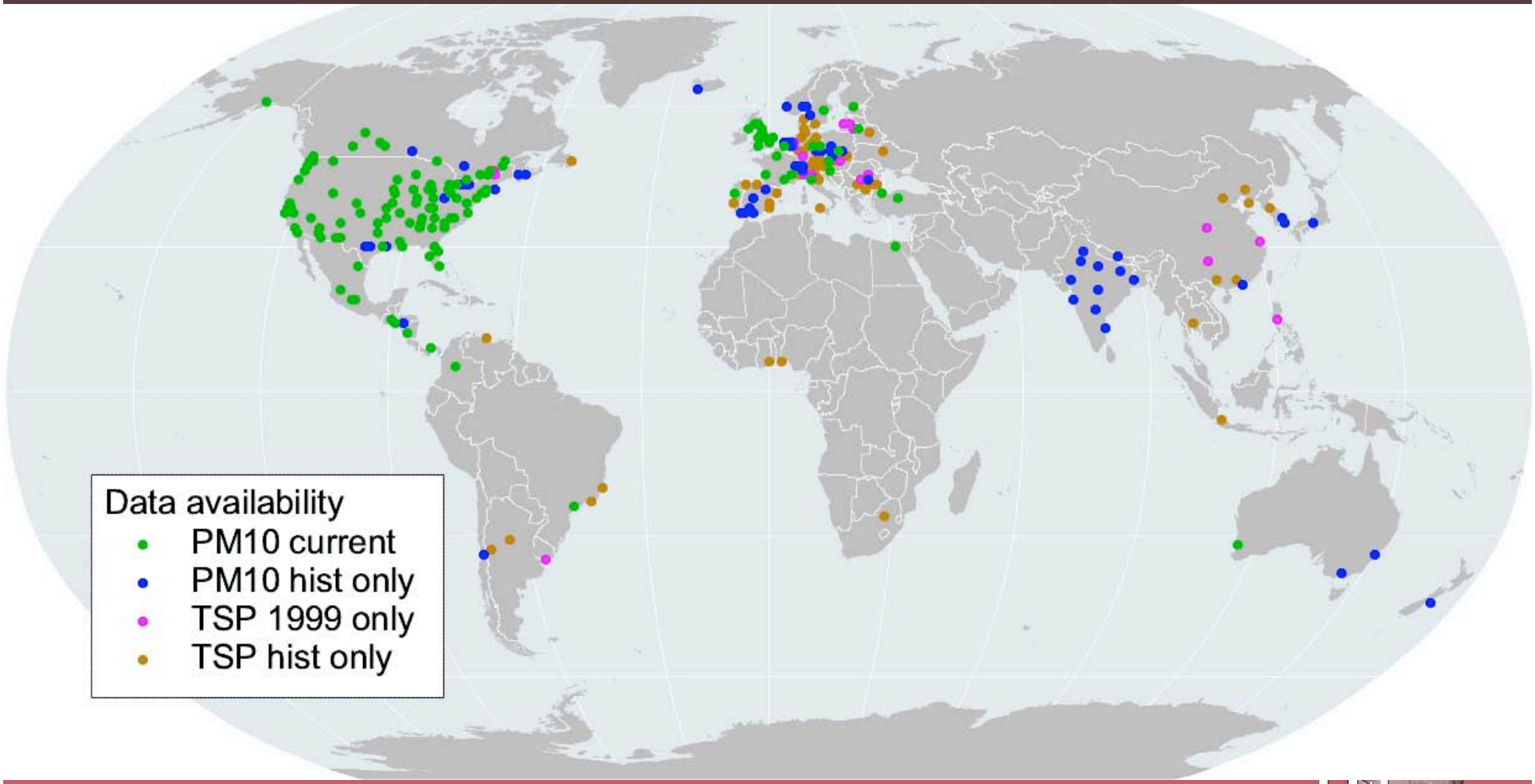
X

RELATIVE RISK

ATTRIBUTABLE FRACTION
X
OUTCOMEBASELINE

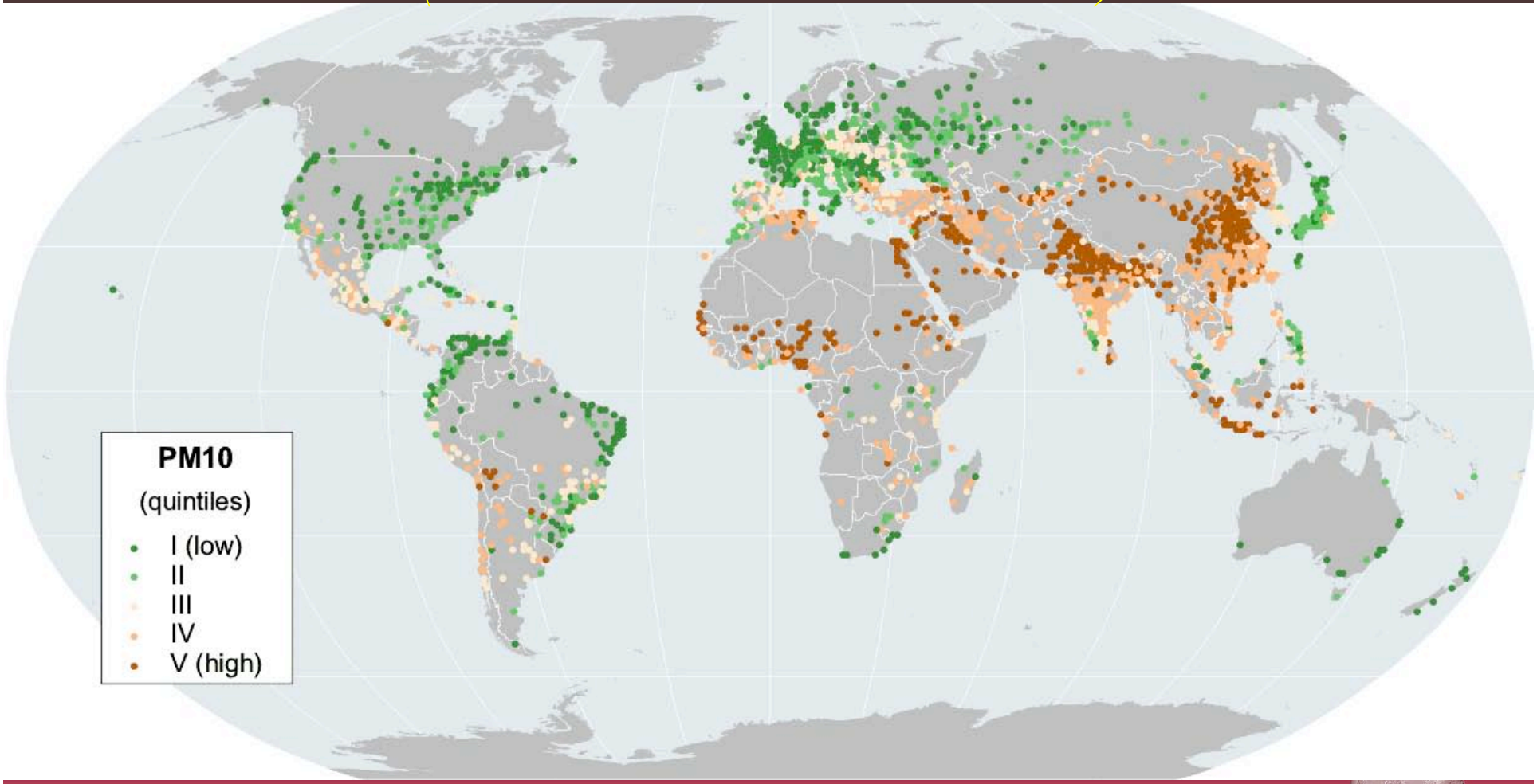
AVOIDABLE BURDEN

AVAILABILITY OF EXPOSURE DATA AT FIXED MONITORING SITES IN RESIDENTIAL AREAS

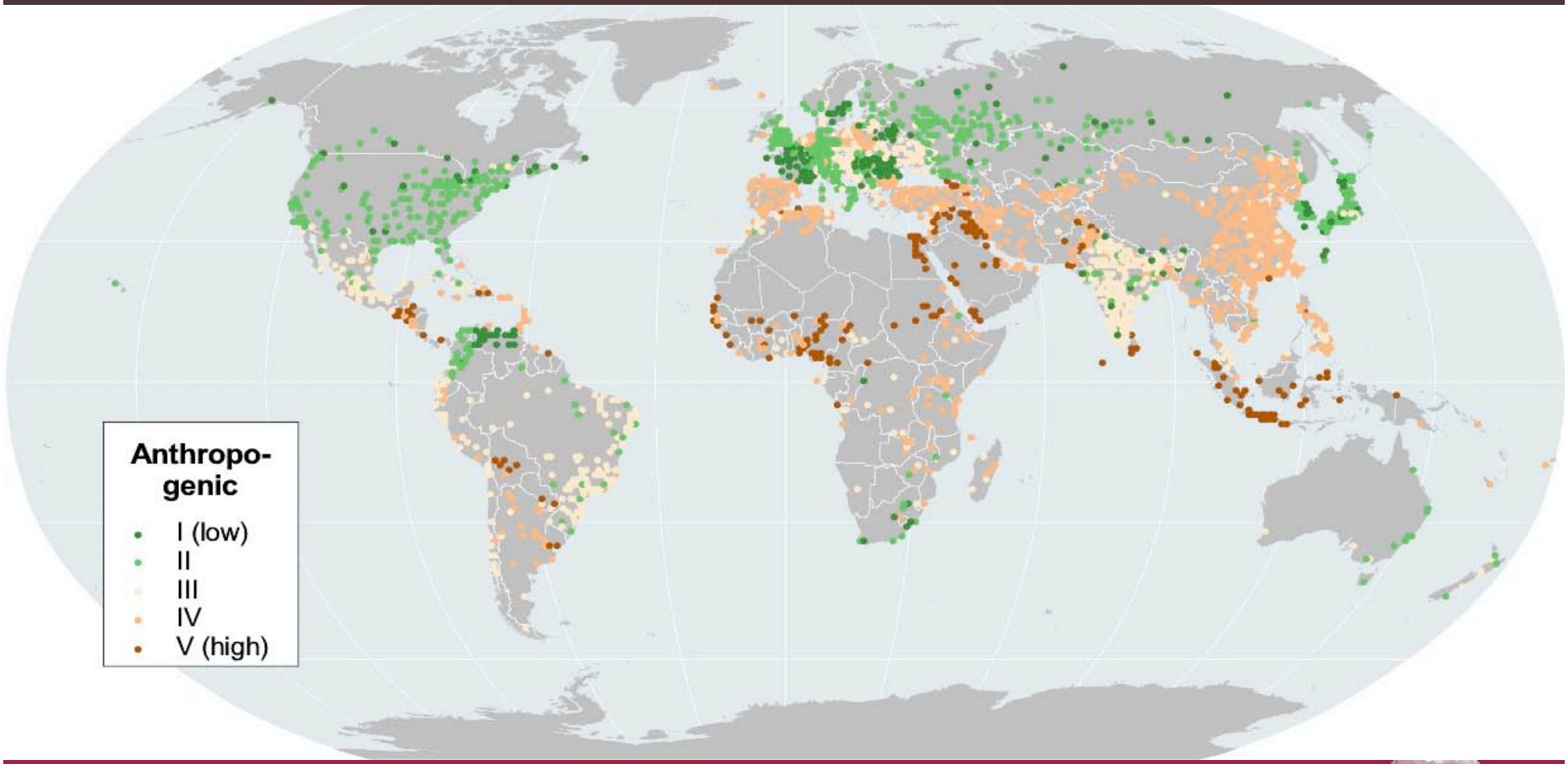


Estimated PM10 Concentration in World Cities (pop=100,000+)

(World Bank Econometric Model)



Anthropogenic Contribution to PM10



Concentration response
ACS cohort (Pope et al JAMA 2002)

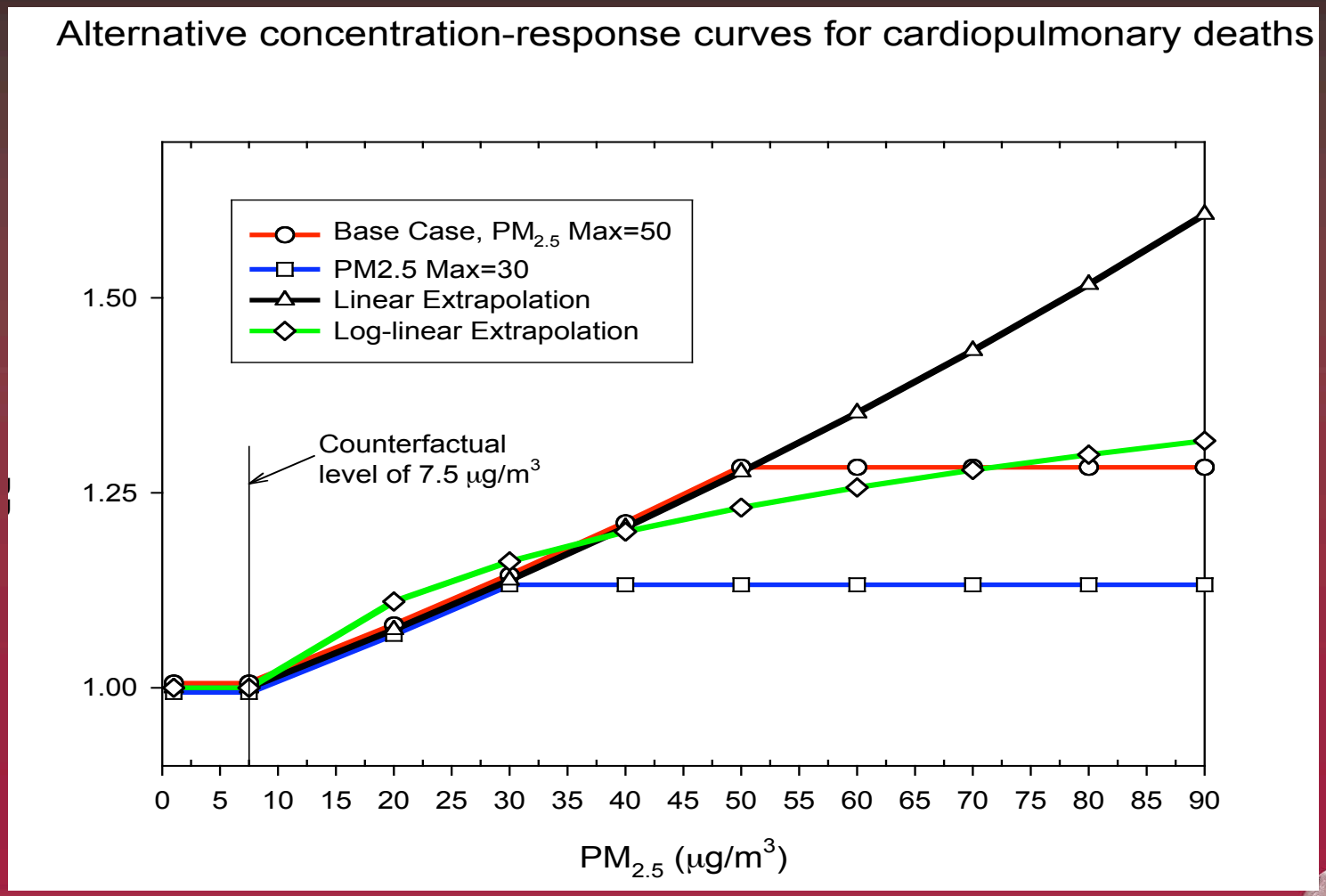
500 000 adults followed 1982 - 1998

RR (adj) per 10μg/m^3 $PM_{2.5}$ 1979-83		
	RR	95% CI
Cardiopulmonary	1.06	1.02-1.10
Lung Cancer	1.08	1.01-1.16

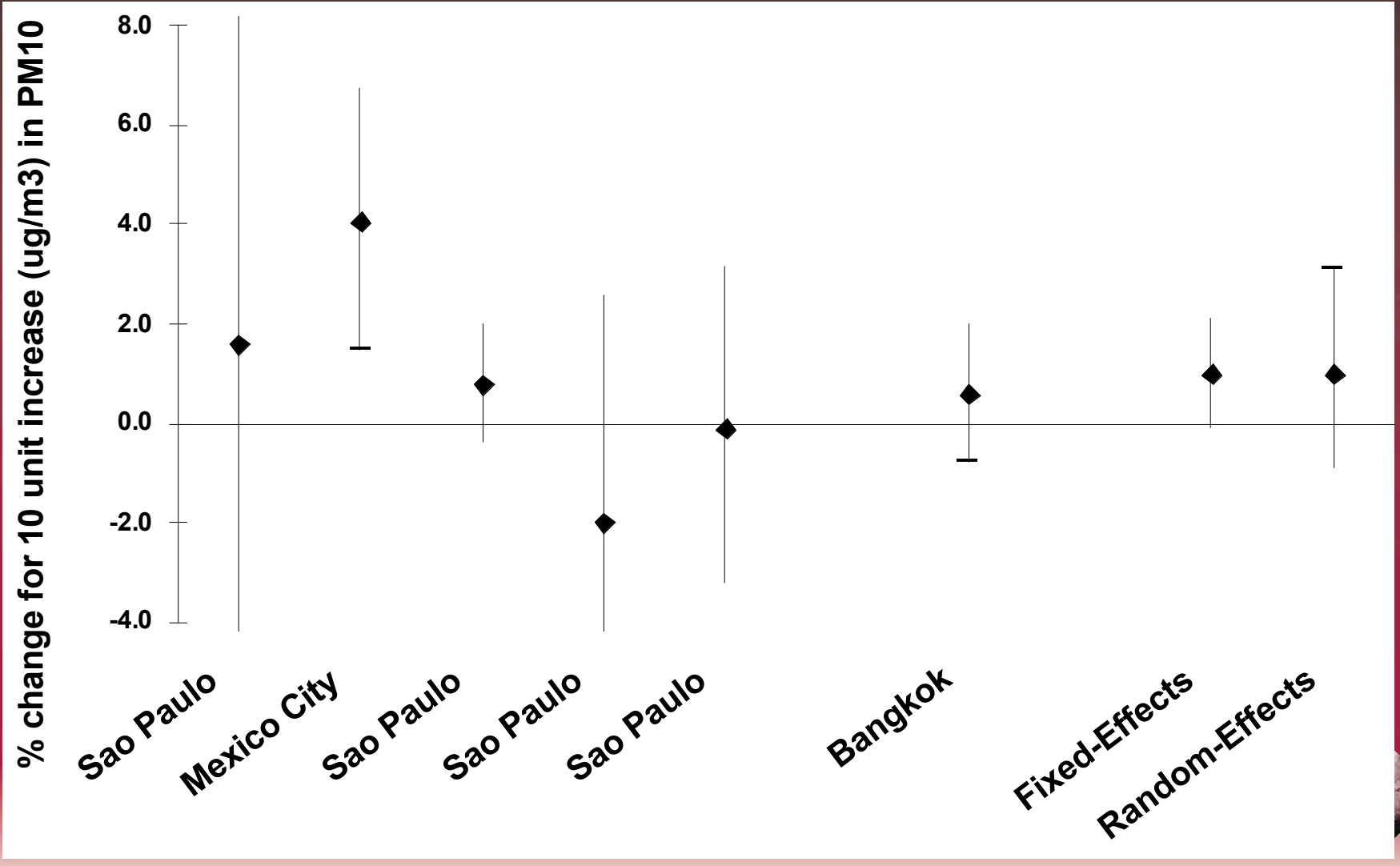
Random effects Cox proportional hazards model controlling for age, sex, race, smoking, education, marital status, body mass, alcohol, occupational exposure and diet.

How to extrapolate the ACS concentration-response function?

(Figure from Cohen AJ, Anderson HR, Ostro B et al. 2004 In Press)



%change in mean daily number of child and infant deaths associated with 10 units of particles. (Scaling PM2.5 = 0.6*PM10, BS = 0.5*PM10 & TSP = 2*PM10)



Estimated Burden of Urban Air Pollution Worldwide
(95% confidence intervals)

Global distribution of mortality attributable to 20 leading selected risk factors

Deaths Attributable to Outdoor Air Pollution by Region

DALYs (YLL) Attributable to Outdoor Air Pollution by Region

Quantifying Benefits from Control Measures

- Approaches now in use by many agencies
  - EPA, EC, Canada
- Build on health estimation approach
  - e.g. Global Burden of Disease
- Add two key components:
  - Modeled estimates of reductions expected from measures
  - Economic valuation
- Examples
  - US Utility, Diesel Rules
  - Canadian Fuel Sulfur Rule

Key Steps in the EPA Approach

(courtesy of Bryan Hubbell, EPA)

Establish Baseline Conditions (Emissions, Air Quality, Health)

↓

Estimate Expected Reductions in Precursor Pollutant Emissions

↓

Model Changes in Ambient Concentrations of Ozone and PM

↓

Estimate Expected Changes in Human Health Outcomes

↓

Estimate Monetary Value of Changes in Human Health Outcomes

What health effects does EPA quantify?

	PM	Ozone
Current		
Mortality	⎫	
Chronic bronchitis	⎫	
Hospital Admissions	⎫	⎫
Asthma ER visits	⎫	⎫
Acute respiratory symptoms	⎫	⎫
Asthma attacks	⎫	⎫
Work loss days	⎫	
Worker productivity		⎫
Planned		
Myocardial infarctions	⎫	
School absence rates		⎫
Cardiovascular ER visits	⎫	

Emerging Public Health Impacts

- Infant mortality/low birth weight
- Decreased lung development
- Cancer
- Doctor visits
- New incidence of asthma
- Ozone mortality

- Not yet quantified due to
  - Lack of appropriate baseline incidence rates
  - Not enough weight of evidence
  - Not easily monetized or characterized in terms of public health significance

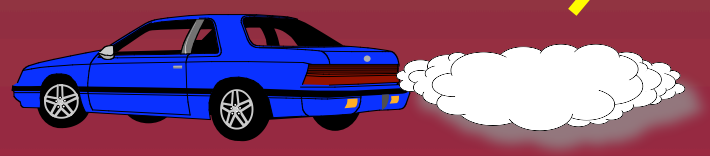
The Canadian Approach:

How to Evaluate a Emissions Control Strategy?

Select Pollution Reduction Strategy

Model Changes in ambient air concentrations of pollutants

Model Changes in Health Effects



Model Changes in Emissions

Model Changes in human exposure

Model Value of Health Benefits

So what are the key pieces?

- Incidence rates
- Affected populations (prevalence)
- Estimated pollutant effect C-R coefficients
  - Prime driver – PM mortality from Pope ACS study
- Modeled changes in ambient air pollution

Key Sources of Uncertainty

- Projection of inputs and impacts across time and space
- Uncertainty regarding interpretation of observed data, i.e. potential thresholds in concentration-response functions
- Use of modeled changes in ambient concentrations of PM and ozone
- Use of valuation estimates based on similar but not identical health risks

How do we value improvements in public health?

- Cost of illness
  - Hospital admissions
  - Work loss days
- Willingness to Pay
  - Premature death
  - Chronic bronchitis
  - Respiratory symptoms
- Life Years Lost?, e.g.
  - Quality Adjusted (QALYs)
  - Disability Adjusted (DALYs)

Current EPA values for health effects

• Premature death:	$6.1 million
• Chronic bronchitis:	$330,000
• Hospital admissions:	$6,000 - $18,000
• ER visits:	$300
• Respiratory symptoms	$15 - $60
• Asthma attacks	$40
• Work loss days	$100

Results of recent EPA analyses

Proposed National Electric Utility SOx and NOx reductions

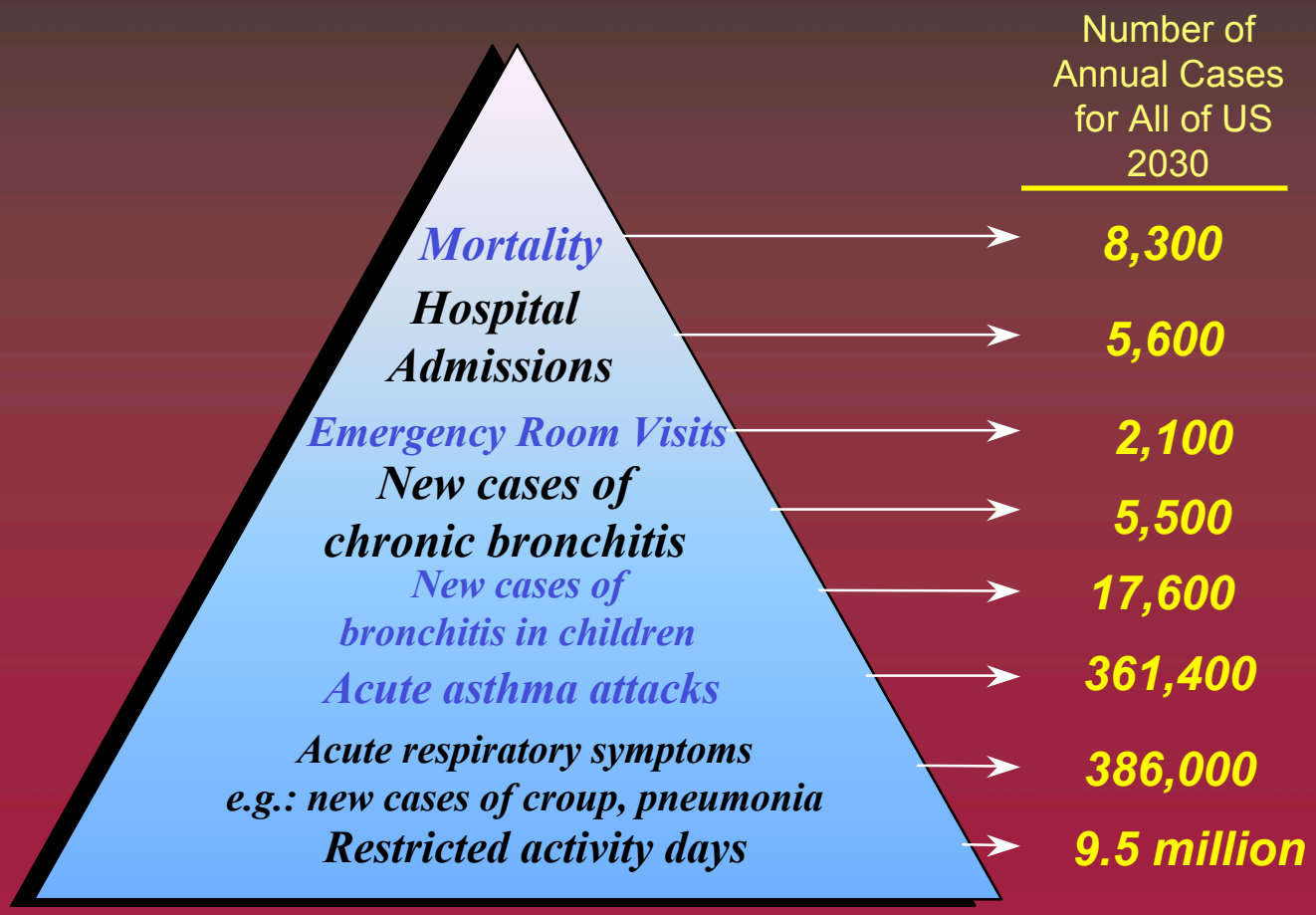
- Utility NOx and SO2 caps of 1.7 million and 3 million tons respectively
- 14,100 premature mortalities avoided
- 8,800 cases of chronic bronchitis avoided
- 30,000 hospital admissions avoided
- Millions of respiratory symptoms days avoided
- Millions of work loss days avoided
- Valued at $113 billion (relative to $6.3 billion in costs)

Results of recent EPA analyses (cont)

- Tier 2 and Heavy Duty Engine regulations
  - Reduces PM and NOx emissions by over 5 million tons by 2030 (particle traps, catalysts)
  - 13,000 premature mortalities avoided
  - 7,800 cases of chronic bronchitis avoided
  - Millions of acute respiratory symptoms and work loss days avoided
  - Valued at over $100 billion

Estimates of Heavy Duty Vehicle Rule benefits

(Source: US EPA RIA, 2000)



Results of recent EPA analyses (cont)

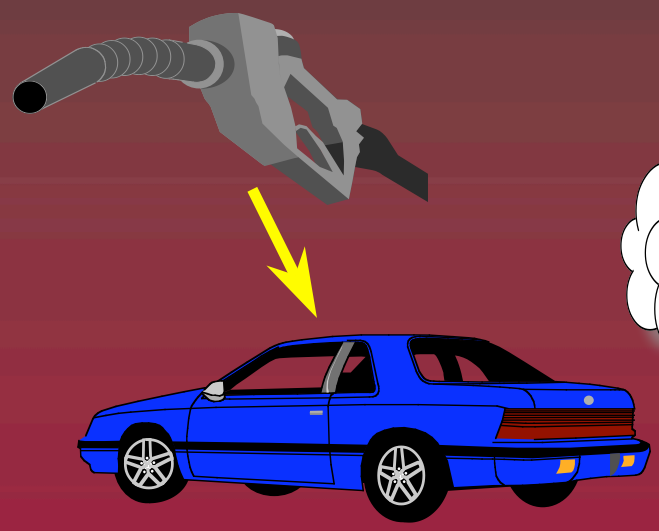
- Nonroad Diesel Engines
  - By 2030, reduces NOx emissions by over 800,000 tons and diesel PM by over 126,000 tons
  - 12,000 premature mortalities avoided
  - 5,600 cases of chronic bronchitis avoided
  - 15,000 nonfatal heart attacks avoided
  - Millions of acute respiratory symptoms and work loss days avoided
  - Valued at over $80 billion

Experience from Canada: Assessing the Health Benefits of Gasoline Sulfur Rules

- Canada implemented a substantial reduction in sulfur in gasoline
  - From 360 ppm to 30 ppm
- Designed to
  - reduce direct emissions, and
  - improve effectiveness of catalytic converters
- Independent analysis of health benefits conducted by Health Canada

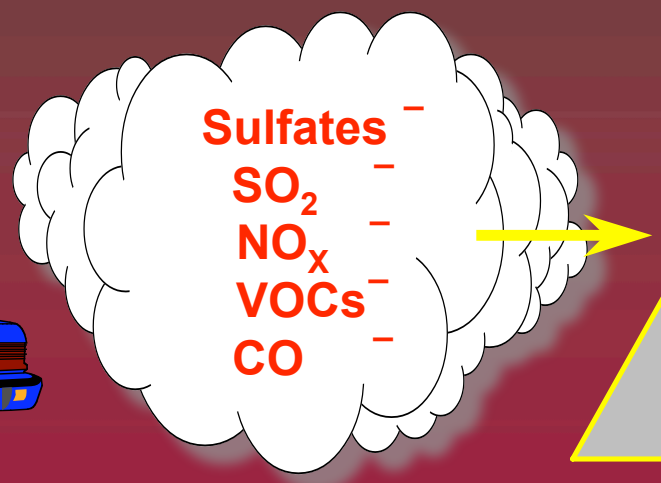
Effects of Sulfur in Gasoline on Health

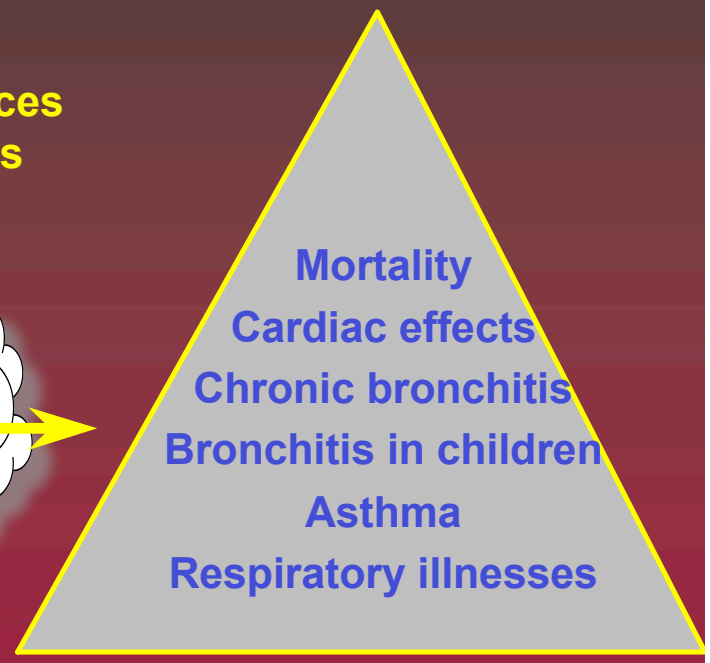
Canadian average sulfur level is 360 ppm



Sulfur reduces efficiency of catalytic converters

Low sulfur gasoline reduces emissions from vehicles





Reduced emissions result in better air quality, and this in turn leads to improved health for Canadians

Effects of Sulfate on Premature Mortality

Source: HEI Reanalysis of the American Cancer Society Study (Krewski 2000)

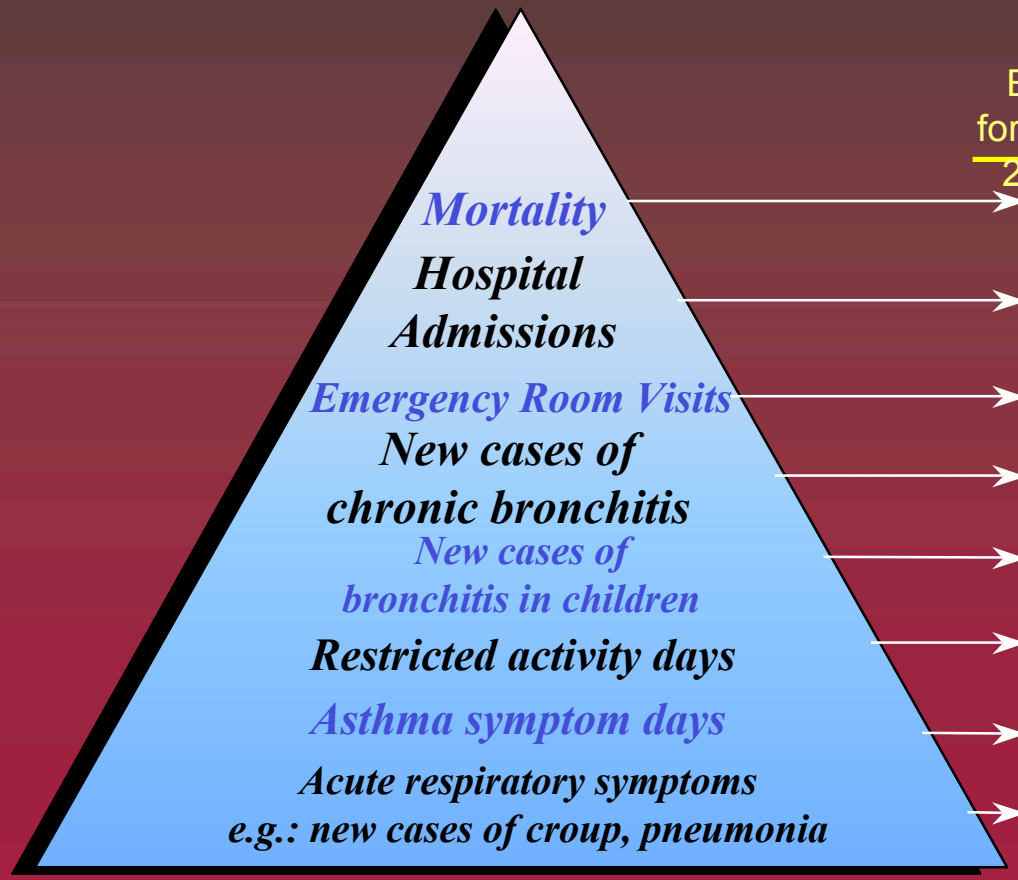
Relative risk of mortality (residuals)

Sulfate($\mu g/m^3$)

Health Effects Consensus Findings
(Independent Canadian Expert Panel)

Reducing sulphur to 30 ppm improves the health of Canadians

Health Effects of Pollution Mixture May Be Much Greater than Particles Alone



	Number of Cases Extrapolated for All of Canada 2001 to 2020
Mortality	2,100
Hospital Admissions	2,400
Emergency Room Visits	6,800
New cases of chronic bronchitis	7,600
New cases of bronchitis in children	93,000
Restricted activity days	1.6 million
Asthma symptom days	3.3 million
Acute respiratory symptoms e.g.: new cases of croup, pneumonia	11 million

Summary and Conclusions

- **Substantial health effects and C-R evidence for a variety of pollutants**
- **Techniques in place, and in use**
  - **To estimate population impact**
  - **To estimate benefits of control measures**
- **Opportunities and challenges**
  - **Growing knowledge (e.g. for estimates of ozone acute mortality)**
  - **Current knowledge does not easily separate effects/benefits of different components of the PM aerosol**

Thank You!

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