Climate Change and Health:

Air Quality and Disease

Mark L. Wilson, Sc.D.
Professor of Epidemiology and of
Ecology and Evolutionary Biology
The University of Michigan
Ann Arbor, Michigan, USA

Training on Climate Change Related Health Impacts
Republic of Mauritius
14-18 May, 2012

Overview

- Introduction to climate and air quality
- Characteristics and health effects of major anthropogenic air pollutants
- Exposure-response relationships
- Global burden of disease due to air pollution
- Has climate change affected air pollution?
  - Observed trends
  - Integrated modeling
- Co-benefits assessment

Introduction

- The mixtures of air pollutants produced by burning of fuels can:
  - Adversely affect human health
  - Promote climate change
- In addition
  - Climate change can influence air pollution, resulting in direct health effects
  - Climate change can affect other aspects of air quality, including smoke from agricultural or wildfires, and aero-allergens like pollen and mold spores

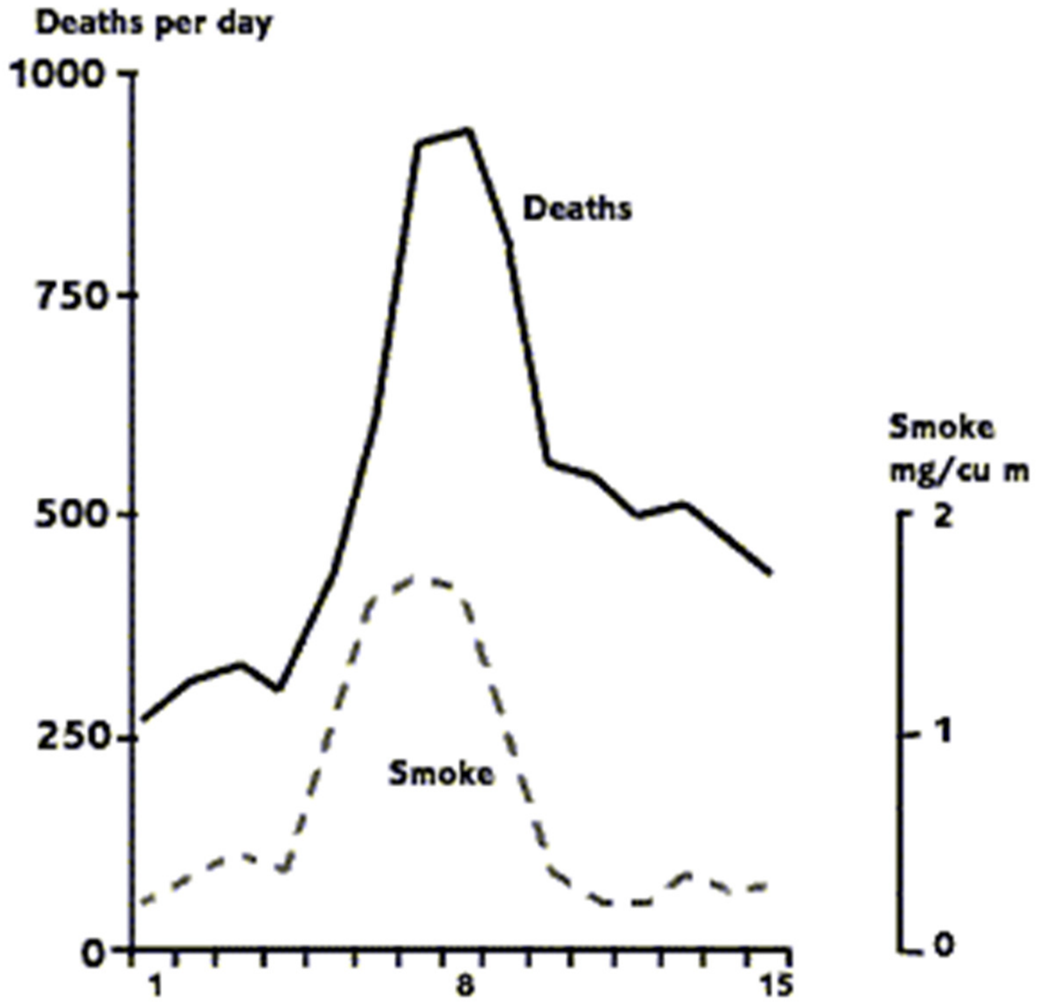
WHO 2009

London: Mid-day in December 1952

UK Met Office, 2009

WHO 2009

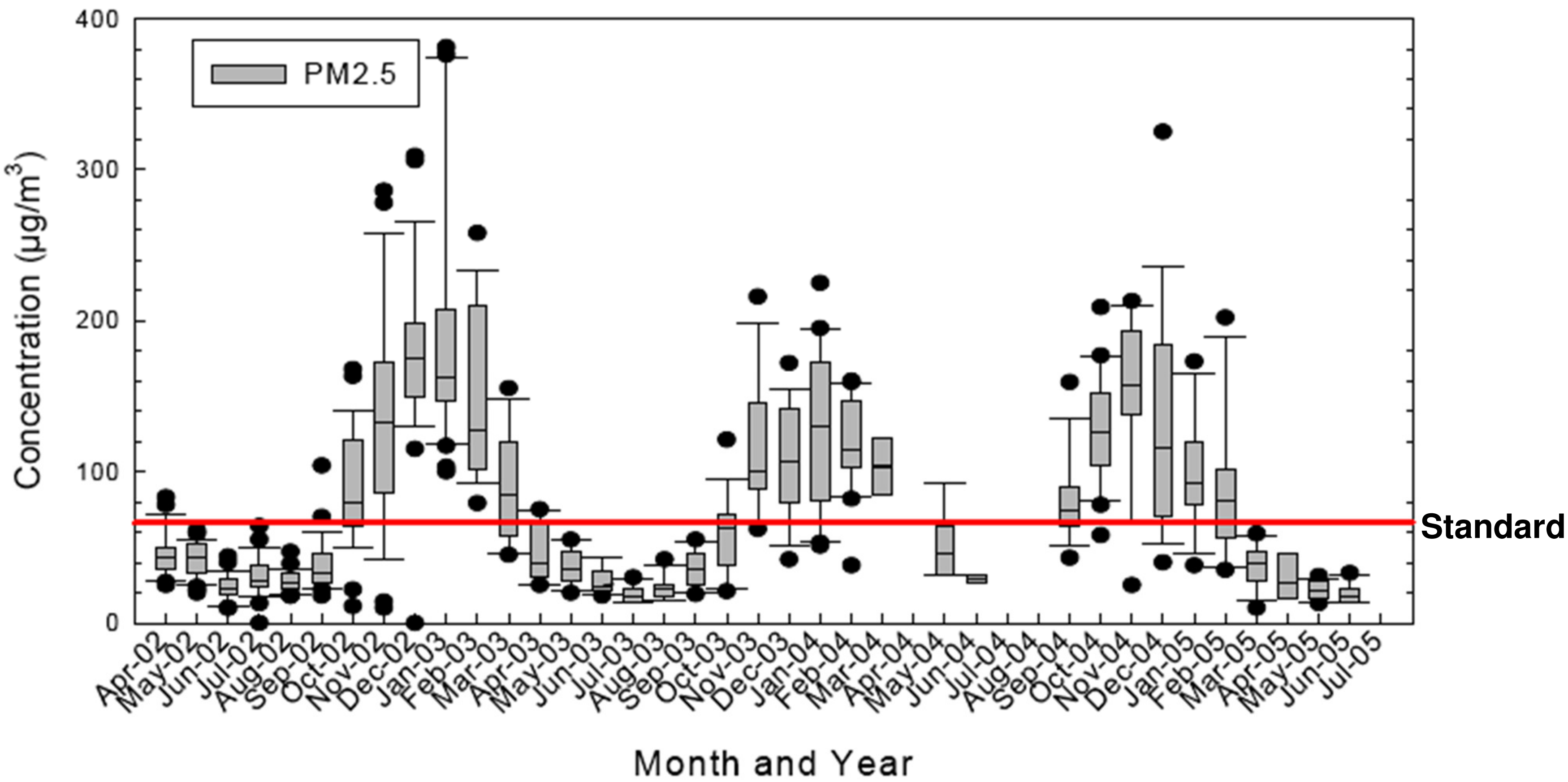
London Killer Fog, December, 1952



UK Met Office, 2009

WHO 2009

$PM_{2.5}$ Levels in Dhaka, Bangladesh



Clean Air Initiative, 2006

Common Atmospheric Pollutants of Human Health Concern

- Carbon monoxide (CO)
- Nitrogen dioxide (NO_2)
- Lead (Pb)
- Sulfur dioxide (SO_2)
- Ozone (O_3)
- Particulate matter ($PM_{2.5}$,PM_{10})

WHO 2009

Carbon Monoxide

- Produced by incomplete combustion
- Inhibits the capacity of blood to carry oxygen to organs and tissues.
- People with chronic heart disease may experience chest pain when CO levels are high
- At very high levels, CO impairs vision, manual dexterity and learning ability, and can be fatal

Nitrogen Dioxide

- Is produced from high-temperature combustion
- Affects lung function in persons with asthma
- Contributes to acid rain and secondary particle formation
- Is a precursor of ground-level ozone

Lead

- Retards intellectual development of children
- Lead in gasoline was historically the principal source
- Paint and unprotected factory work still source of exposure

Sulfur Dioxide

- Emitted from combustion of sulfur-containing coal and oil, and from metal smelting operations
- Reversible declines in lung function of people with asthma, and exacerbates respiratory symptoms in sensitive individuals
- Also contributes to acid rain and to formation of PM2.5 through atmospheric reactions
- Emissions reduced using scrubbers

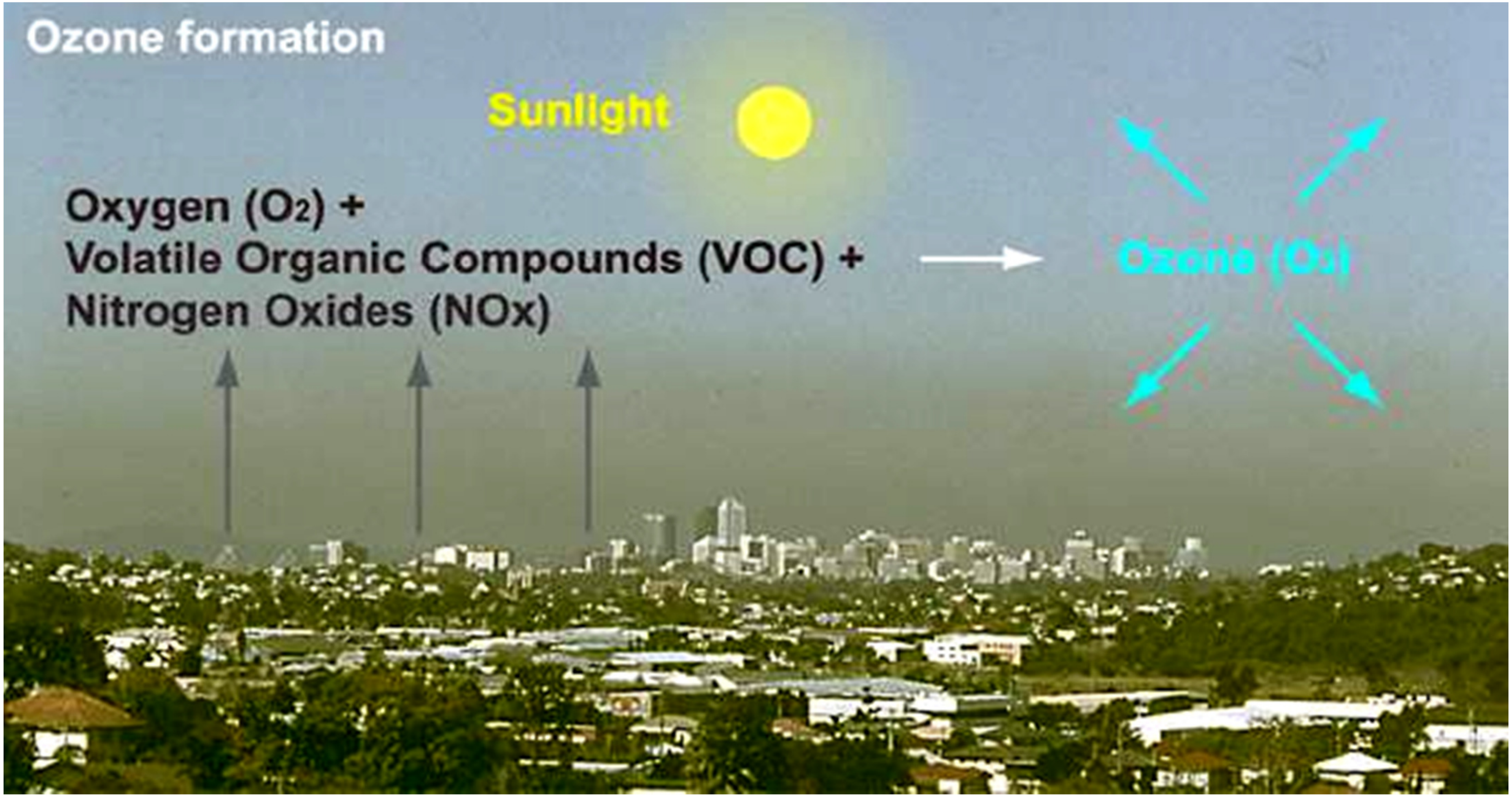
WHO 2009

Ozone

- Main pollutant responsible for photochemical smog, formed via reactions in the atmosphere from primary pollutants (NO_x and VOCs) in the presence of sunlight
- Higher temperatures favor ozone formation
- Strong oxidant that damages cells lining respiratory system, resulting in various adverse health outcomes (e.g. lung function decrease, asthma attacks, premature death)
- Ozone is also a greenhouse gas

WHO 2009

Ground-level Ozone Formation



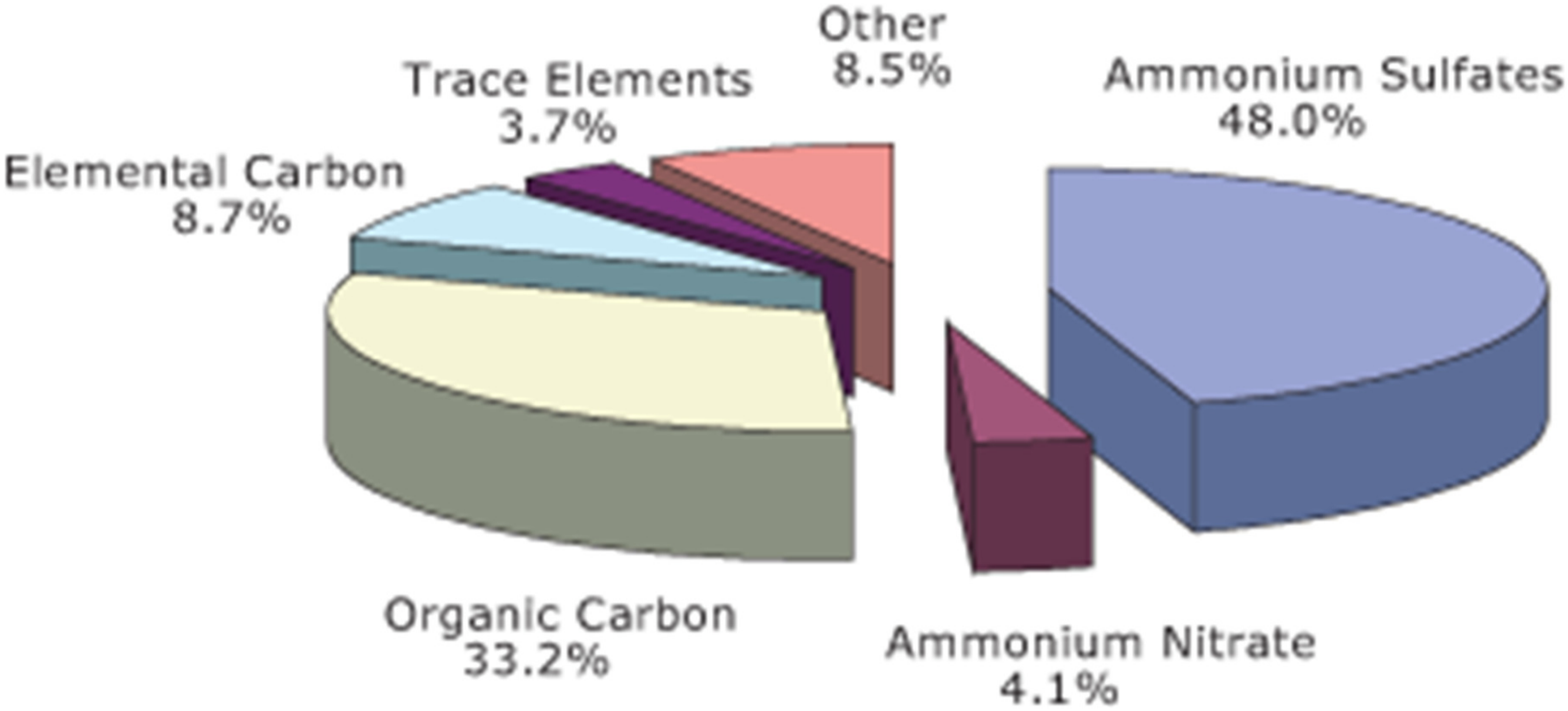
Queensland Government Environmental Protection Agency, 2006

Particulate Matter ($PM_{2.5}$, PM_{10})

- Can be either primary or secondary; produced by combustion, atmospheric reactions, and mechanical processes
- Wide range of physical/chemical properties
- Wide range of human health impacts, including premature death
- Higher temperatures may favor secondary formation
- Some particle types contribute to climate warming; others to climate cooling

WHO 2009

Fine Particle Composition



Annual average fine particle data for 2001 from the Look Rock station of the Tennessee Valley Authority

Tennessee Valley Authority, 2009

Health Effects of Air Pollution

- Historical experience provides strong evidence for causal relationship between air pollution and premature death
- Modern epidemiology studies have consistently found significant associations
- Two primary epidemiologic study designs:
  - Time series studies of acute effects
  - Cohort or cross-section studies of chronic effects
- What is the evidence for particle health effect?

WHO 2009

Air Pollution Epidemiology

- **Provides results relevant for policy makers**
- **Assesses effects of real mix of pollutants on human health**
- **Includes full range of susceptible populations**

WHO 2009

Air Pollution Epidemiology (cont.)

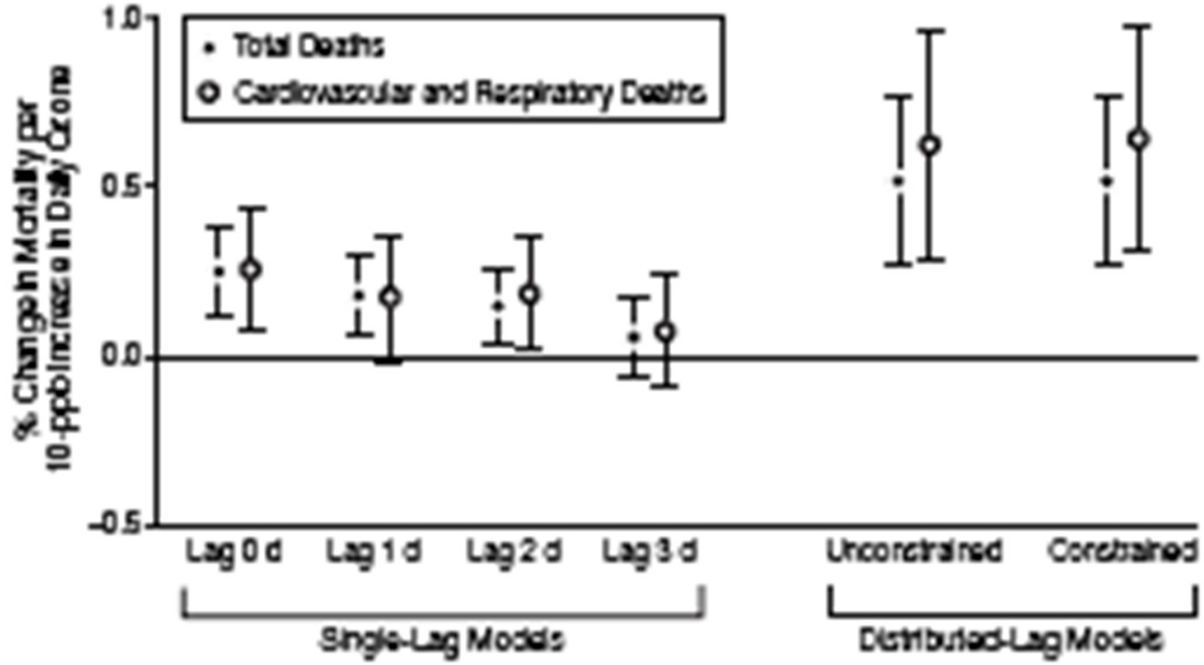
- *But…*
- **Pollutants tend to co-vary, making it hard to identify pollutant-specific effects**
- **Demonstrates association between outcome and exposure, but not cause and effect**
- **Confounding factors must be controlled**
- **Exposure assessment is “ecologic”**

Time Series Epidemiology

- Addresses short-term, acute effects of air pollution
- Involves analysis of a series of daily observations of air pollution and health data
- Widely used and economical approach, often utilizing readily-available data
- Temporal studies avoid many confounding factors that can affect spatial studies
- However, time-varying factors may confound the pollution associations …
  - Seasonal cycles, weather variables, day of week

Ozone and Acute Deaths

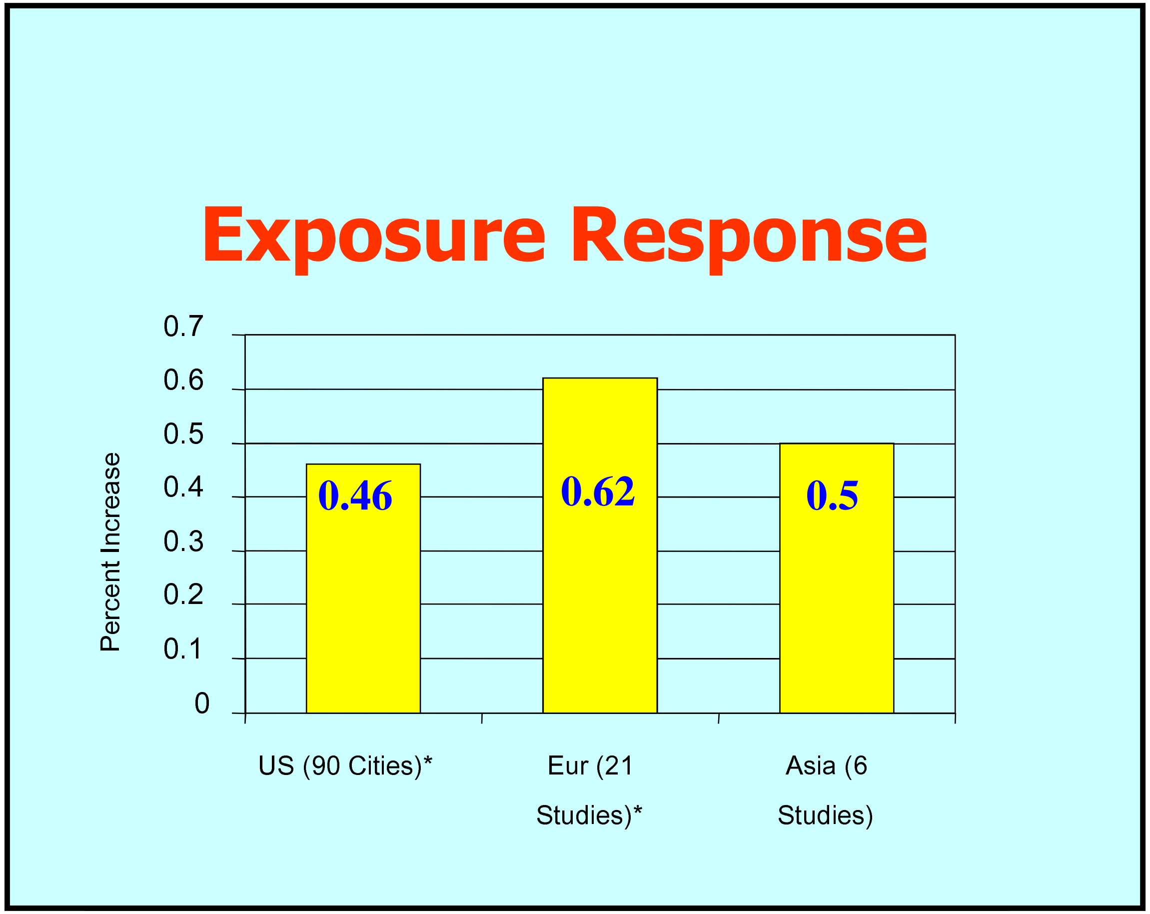
Figure 1. Percentage Change in Daily Mortality for a 10-ppb Increase in Ozone for Total and Cardiovascular Mortality, for Single-Lag and Distributed-Lag Models



The single-lag model reflects the percentage increase in mortality for a 10-ppb increase in ozone on a single day. The distributed-lag model reflects the percentage change in mortality for a 10-ppb increase in ozone during the previous week. Error bars indicate 95% posterior intervals.

Bell et al., 2004

Acute Mortality Responses to PM in US, Europe, and Asia

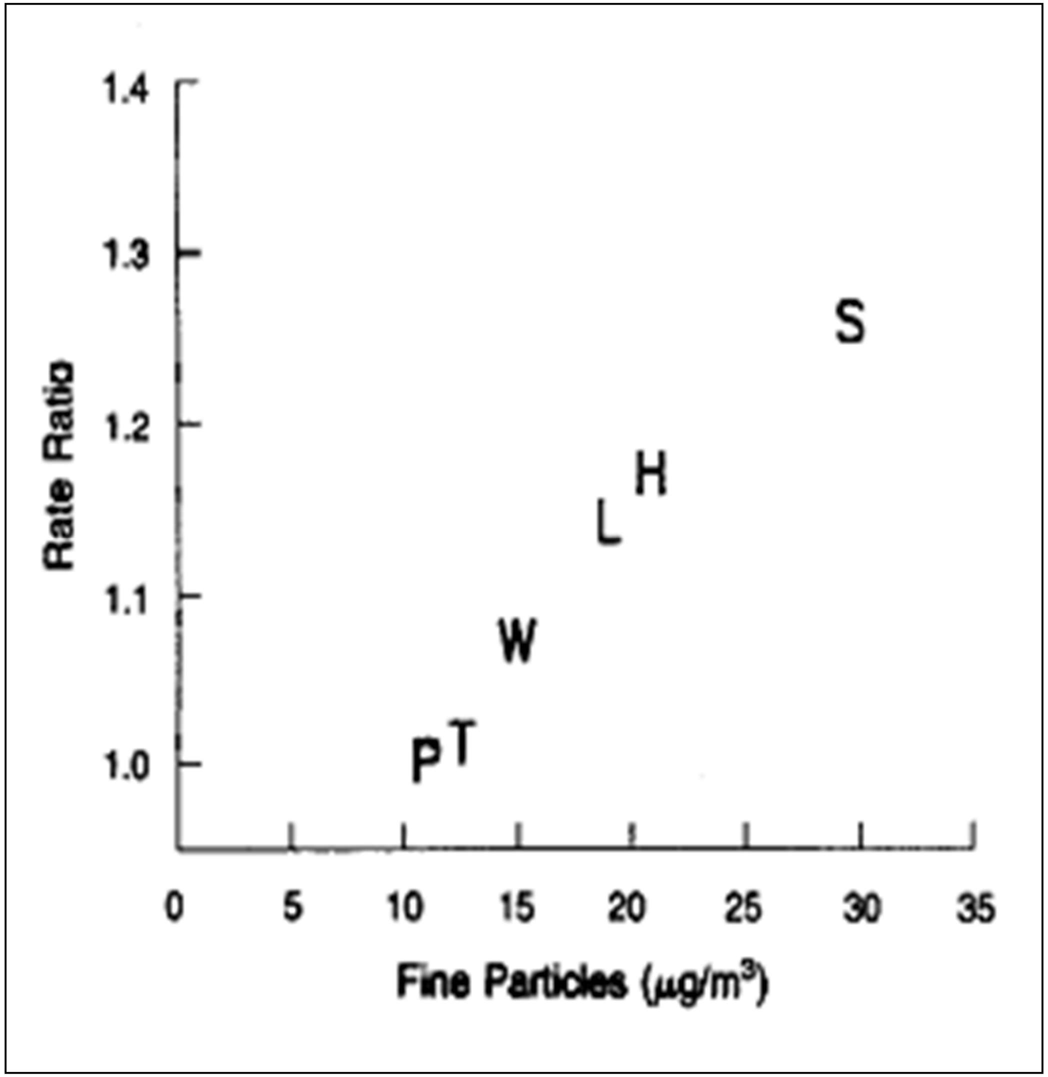


Huizenga et al., 2005

Prospective Cohort Studies

- Address long-term, chronic effects
- Large populations in multiple cities enrolled and then followed for many years to determine disease or mortality experience
- Must control for “spatial” confounders, e.g., smoking, income, race, diet, occupation
- Assessment of confounders at individual level is an advantage over cross-sectional, “ecologic” studies

Results from Harvard Six Cities Study



- <u>Long-term average concentrations</u> of fine particle air pollution were associated with mortality rates, controlling for individual-level risk factors across six US cities

Dockery et al., 1993

American Cancer Society Study

- **Objective:**
  - To assess the relationship between long-term exposure to fine particulate air pollution and all-cause, lung cancer, and cardiopulmonary mortality
- **Approach:**
  - Vital status and cause of death data were collected by the American Cancer Society through 1998 in 500,000 US adults from 50 urban areas for whom air pollution exposure data were available in 1980

Source: Pope et al., 2002

American Cancer Society Study

Results

Table 2. Adjusted Mortality Relative Risk (RR) Associated With a 10-μg/m³ Change in Fine Particles Measuring Less Than 2.5 μm in Diameter

	Adjusted RR (95% CI)*		
Cause of Mortality	**1979-1983**	**1999-2000**	**Average**
All-cause	1.04 (1.01-1.08)	1.06 (1.02-1.10)	1.06 (1.02-1.11)
Cardiopulmonary	1.06 (1.02-1.10)	1.08 (1.02-1.14)	1.09 (1.03-1.16)
Lung cancer	1.08 (1.01-1.16)	1.13 (1.04-1.22)	1.14 (1.04-1.23)
All other cause	1.01 (0.97-1.05)	1.01 (0.97-1.06)	1.01 (0.95-1.06)

*Estimated and adjusted based on the baseline random-effects Cox proportional hazards model, controlling for age, sex, race, smoking, education, marital status, body mass, alcohol consumption, occupational exposure, and diet. CI indicates confidence interval.

1136 JAMA, March 6, 2002—Vol 287, No. 9

Pope et al., 2002

American Cancer Society Study

Conclusion

- "Long-term exposure to combustion-related fine particle air pollution is an important environmental risk factor for cardiopulmonary and lung cancer mortality"

Pope et al., 2002

WHO 2005 Air Quality Guidelines: Particulate Matter

$PM_{2.5}$	PM_{10}
10 μg/m^3 annual mean 25 μg/m^3 24-hour mean	20 μg/m^3 annual mean 50 μg/m^3 24-hour mean

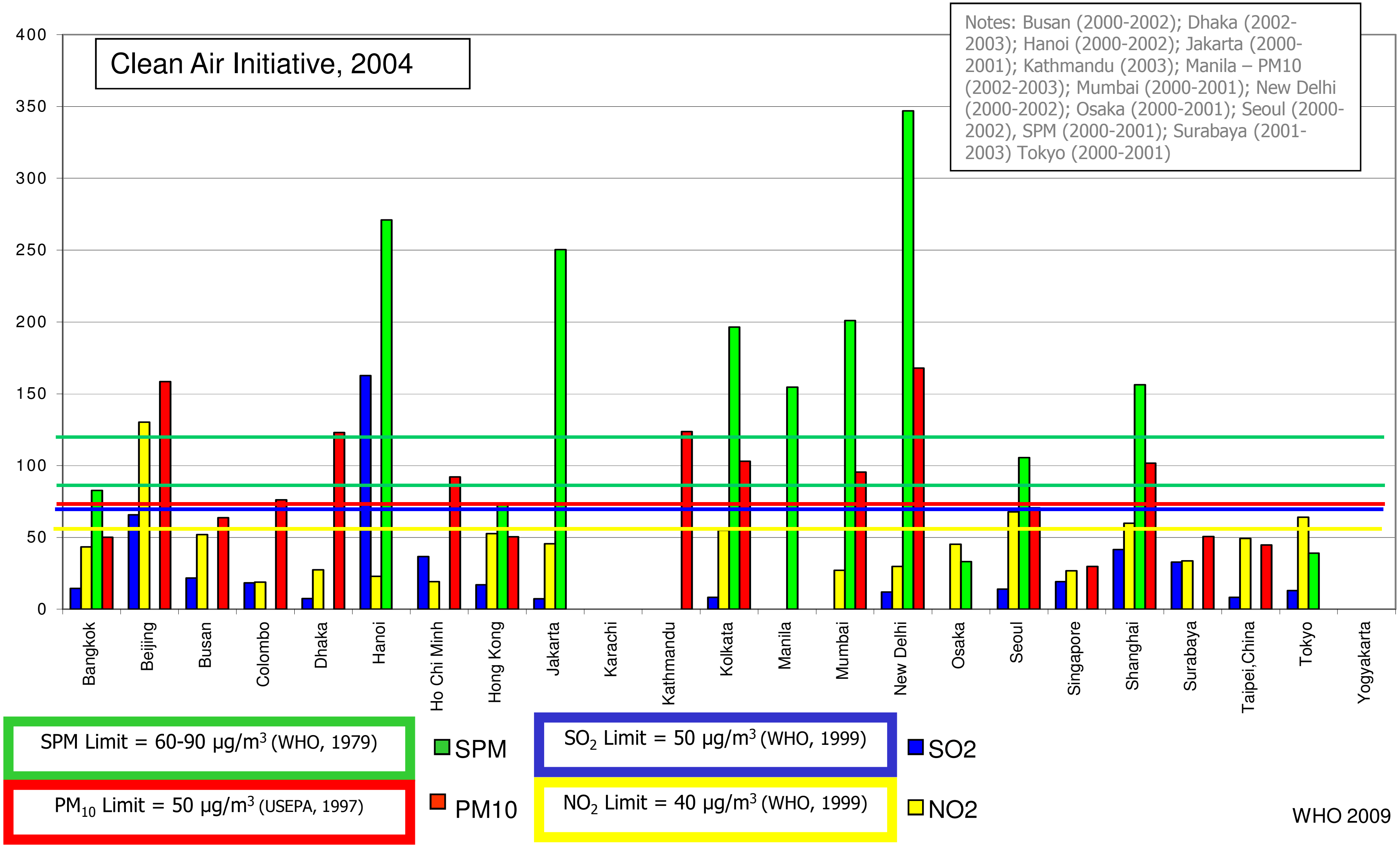
World Health Organization, 2008d

WHO 2005 Air Quality Guidelines: Ozone

Ozone (O_3)
100 μg/m^3 8-hour mean

World Health Organization, 2008d

Average Ambient Air Quality Levels (2000-2003)



WHO 2009

Health Impact Assessment

- **Step 1. Model future environmental conditions under various emissions and/or climate scenarios**
- **Step 2. Gather existing knowledge regarding human health impacts given a change in environmental conditions (based on "exposure-response" equations)**
- **Step 3. Estimate health impacts of modeled environmental changes**

WHO 2009

Exposure-Response Calculations

- Excess deaths attributed to PM is estimated by:

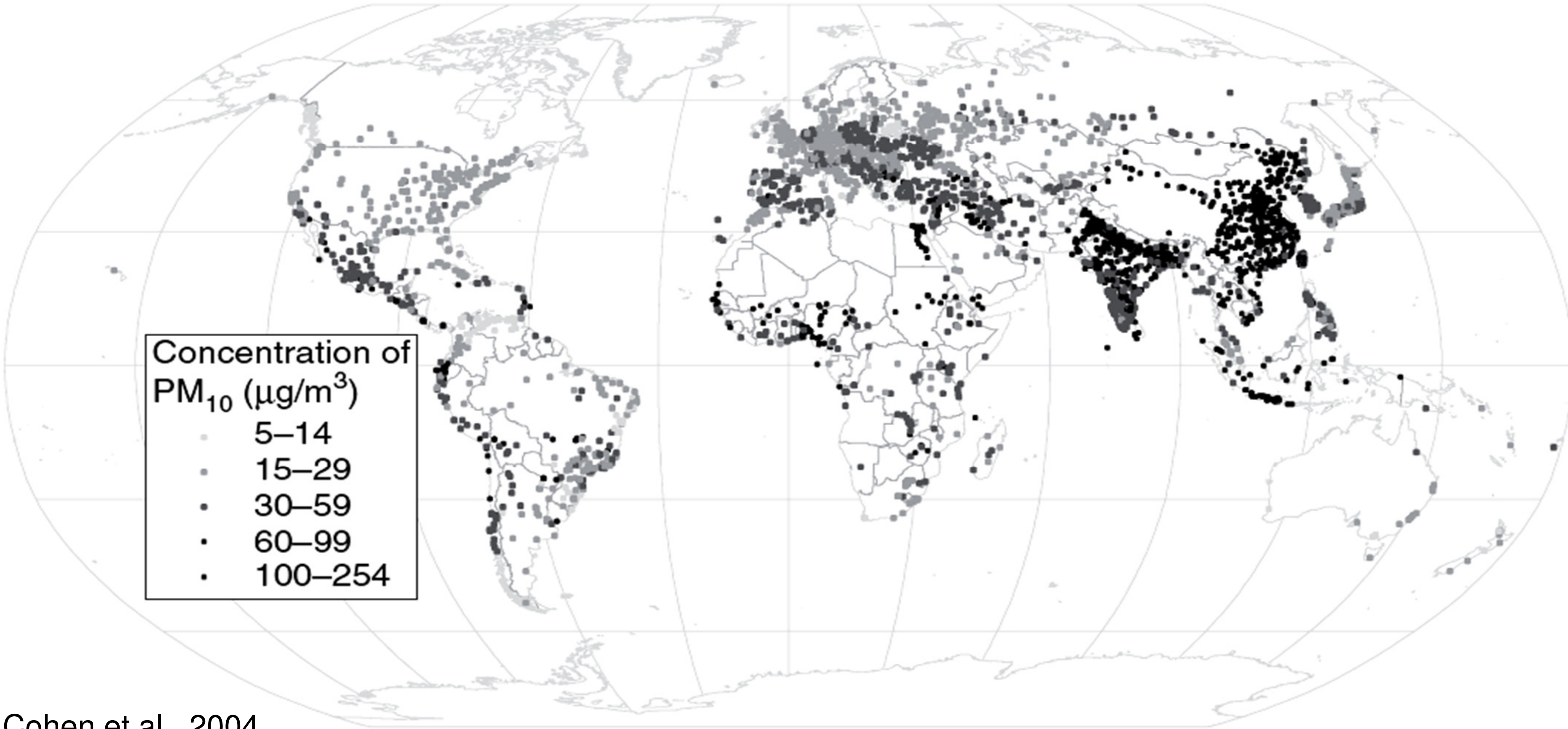
$$\Delta y = y_0 \cdot \left(e^{\beta \cdot \Delta PM} - 1\right)$$

- Where:
  - Δy is the change in mortality incidence
  - y_0 is the baseline mortality incidence, equal to the baseline incidence rate times the potentially affected population
  - β is the effect estimate
  - ΔPM is the change in $PM_{2.5}$

WHO 2009

Population Exposure to Particulate Matter

Figure 17.2 Estimated annual average concentrations of PM_{10} in cities with populations of >100 000 and in national capitals



Cohen et al., 2004

WHO 2009

Estimates of the Health Impact of Particulate Matter Exposure

Table 17.8 Attributable deaths and DALYs in 2000, by subregion (50% and 95% confidence intervals)

Subregion	*Deaths (000s)*	*50% CI*	*95% CI*	*DALYs (000s)*	*50% CI*	*95% CI*
AFR-D	22	11.1–23.7	4.3–34.5	285	155.1–361.3	28.2–557.5
AFR-E	10	7.5–14.4	3.9–22.2	147	107.7–239.9	24.7–364.7
AMR-A	28	22.1–33.7	12.7–44.0	152	158.6–239.8	94.6–314.8
AMR-B	30	23.1–37.4	12.0–50.1	232	241.8–383.6	142.9–517.7
AMR-D	5	3.2–5.3	1.6–7.6	44	34.2–62.6	14.2–87.3
EMR-B	8	4.0–8.4	2.1–13.5	77	45.6–93.4	25.0–149.2
EMR-D	51	31.2–56.2	17.0–73.0	558	384.5–737.5	163.1–970.4
EUR-A	23	19.4–29.7	9.9–42.8	117	125.7–187.4	65.8–265.4
EUR-B	38	26.7–44.4	14.8–58.5	288	241.3–386.6	138.5–507.0
EUR-C	46	28.1–53.4	10.1–83.3	320	229.6–432.1	81.9–676.0
SEAR-B	32	19.2–37.5	5.5–51.5	282	191.0–388.9	67.0–532.6
SEAR-D	132	98.3–162.1	54.1–212.3	1 312	1 185.1–1 890.5	575.2–2 409.8
WPR-A	18	13.2–21.4	6.7–28.5	84	84.3–137.0	42.9–182.0
WPR-B	355	260.8–424.8	142.8–555.1	2 504	2 447.4–3 848.7	1 431.2–5 014.1
World	799	574.8–942.5	318.2–1 196.9	6 404	5 955.6–9 288.2	3 199.9–11 472.4

Cohen et al., 2004

WHO 2009

The Challenge for Air Pollution and Climate Change

Can we assess potential future health impacts of air quality changes resulting from global climate change?

Effects of Climate Change on Tropospheric Ozone Formation

- **Formation reactions for ozone happen faster at high temperatures and with greater sunlight**
- **Biogenic VOC emissions increase at higher temperatures**

- **Regional air mass patterns over time and space may change, altering stagnation and clearance events**
- **The mixing height of the lower atmosphere may change, affecting the dilution of pollution emitted at the surface**

WHO 2009

The New York Climate and Health Project

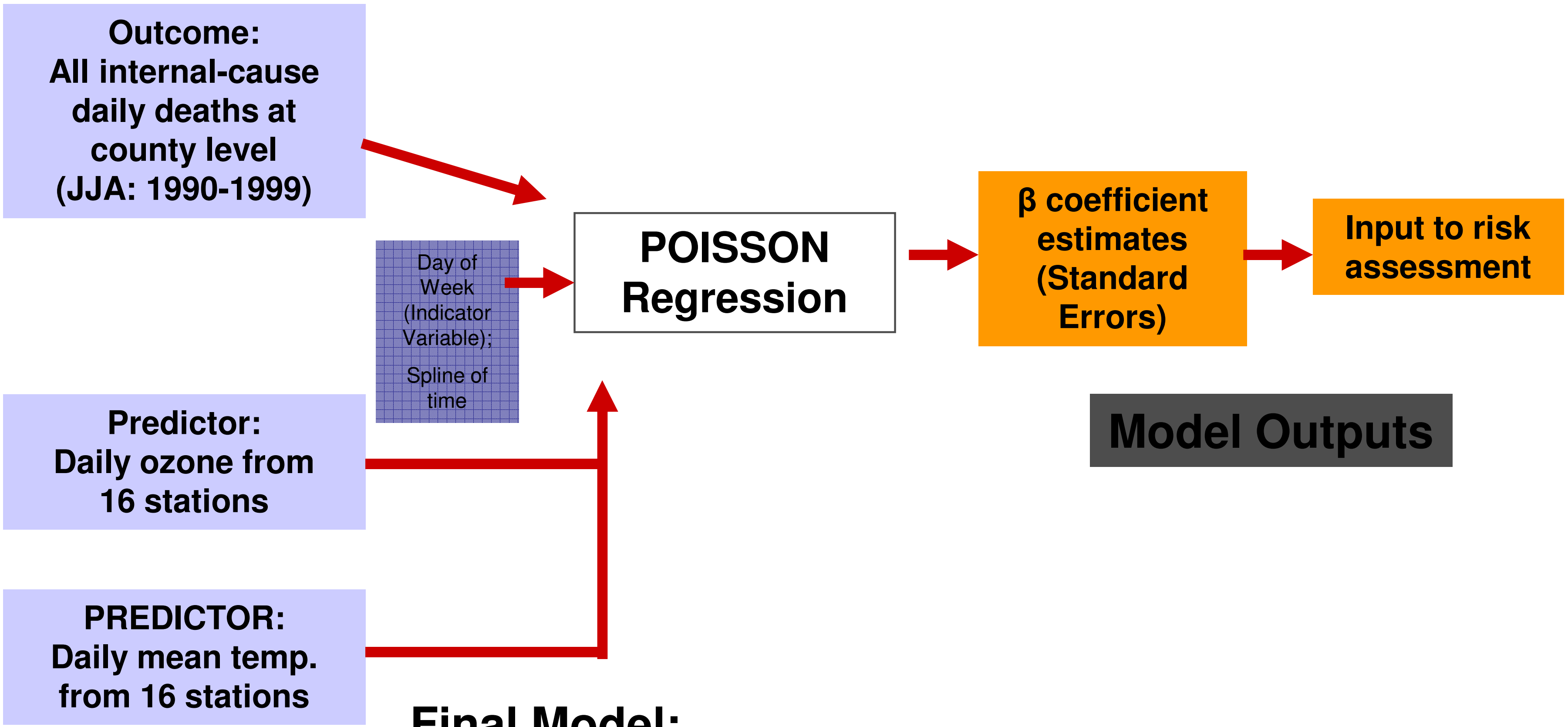
Linking models for global and regional climate, land use and cover, and air quality…

To examine the potential public health <u>impacts of ozone</u> under <u>alternative scenarios of climate change</u> and regional land use in the 2020s, 2050s, and 2080s in the New York City (NYC) metropolitan region

Approach

- Develop exposure-response function for ozone using historical data from the NYC metropolitan area
- Develop an integrated modeling system that includes modules for global climate, regional climate, and regional air quality
- Examine alternative greenhouse gas growth scenarios
- Combine scenarios to assess potential mortality risks in the NYC metro area in the 21st century

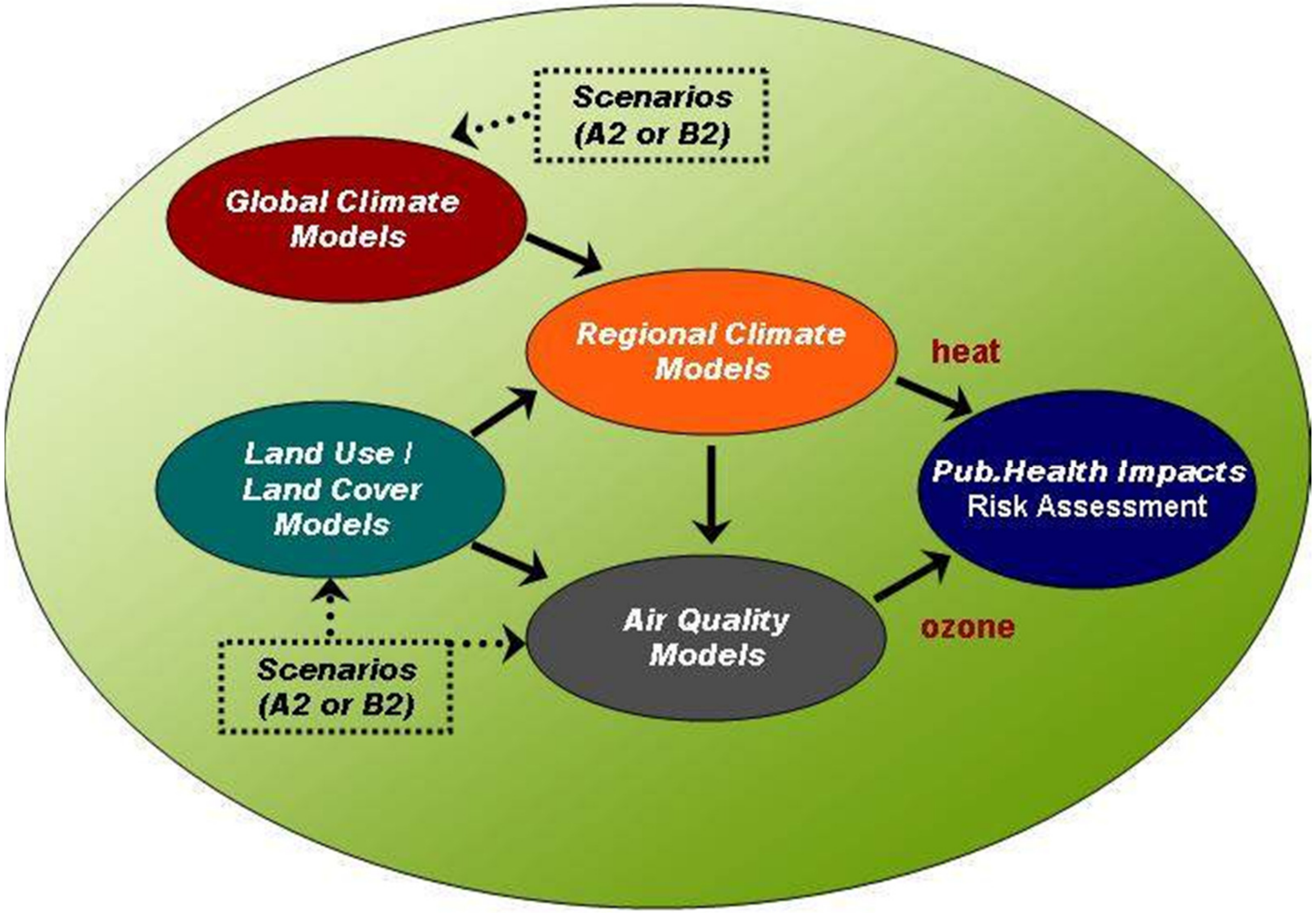
Developing NYC Exposure-Response Functions for Temperature and Ozone



Final Model:

log (daily deaths)= DOW + spline(time) + b1(mean Tlag0)1-3 + b2(max O3 lag0-1)

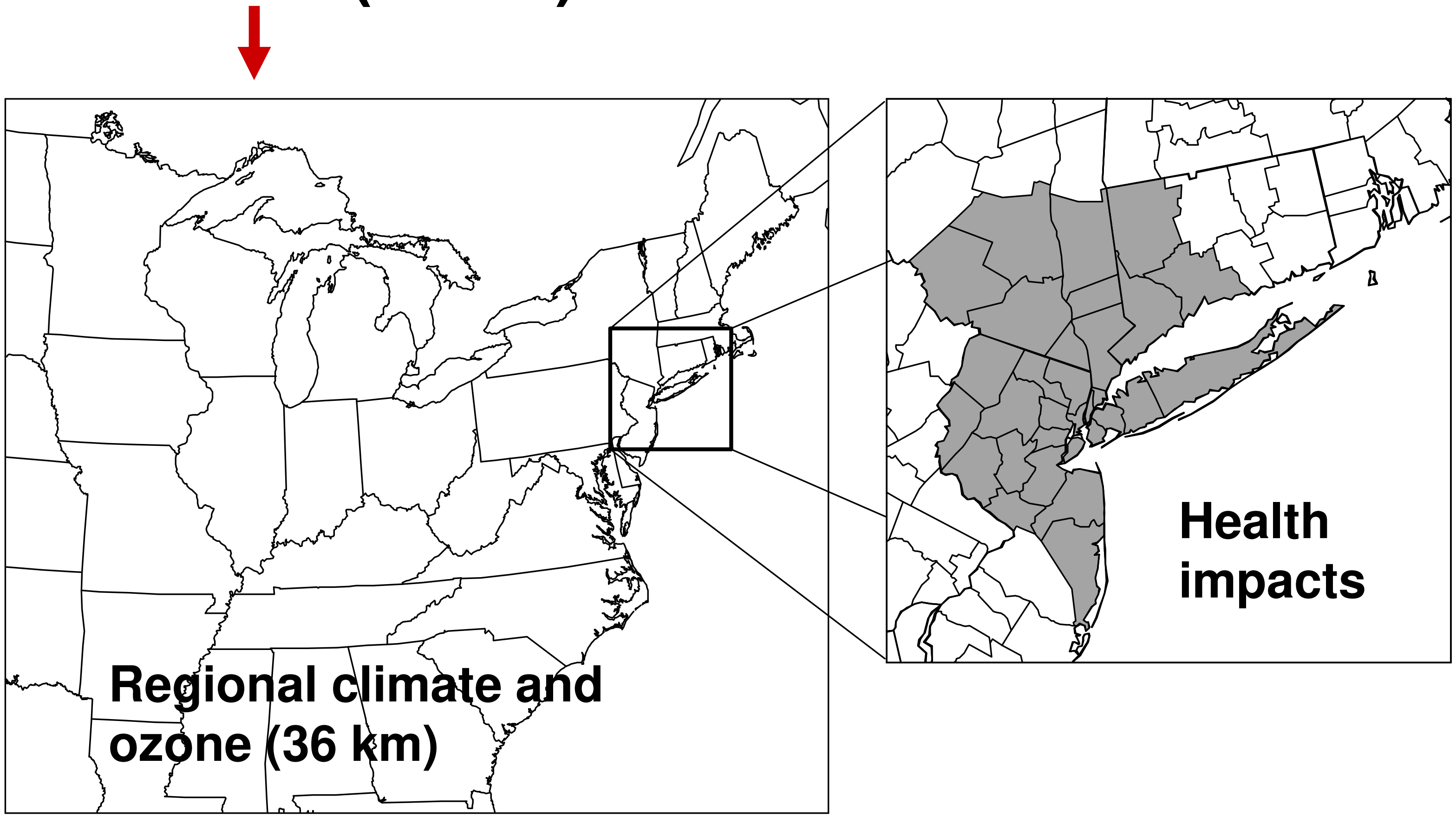
Integrated Modeling System Diagram



WHO 2009

Modeling Domains

Global climate (4 x 5°)



Impact of Climate Change on Summertime Ozone Concentrations

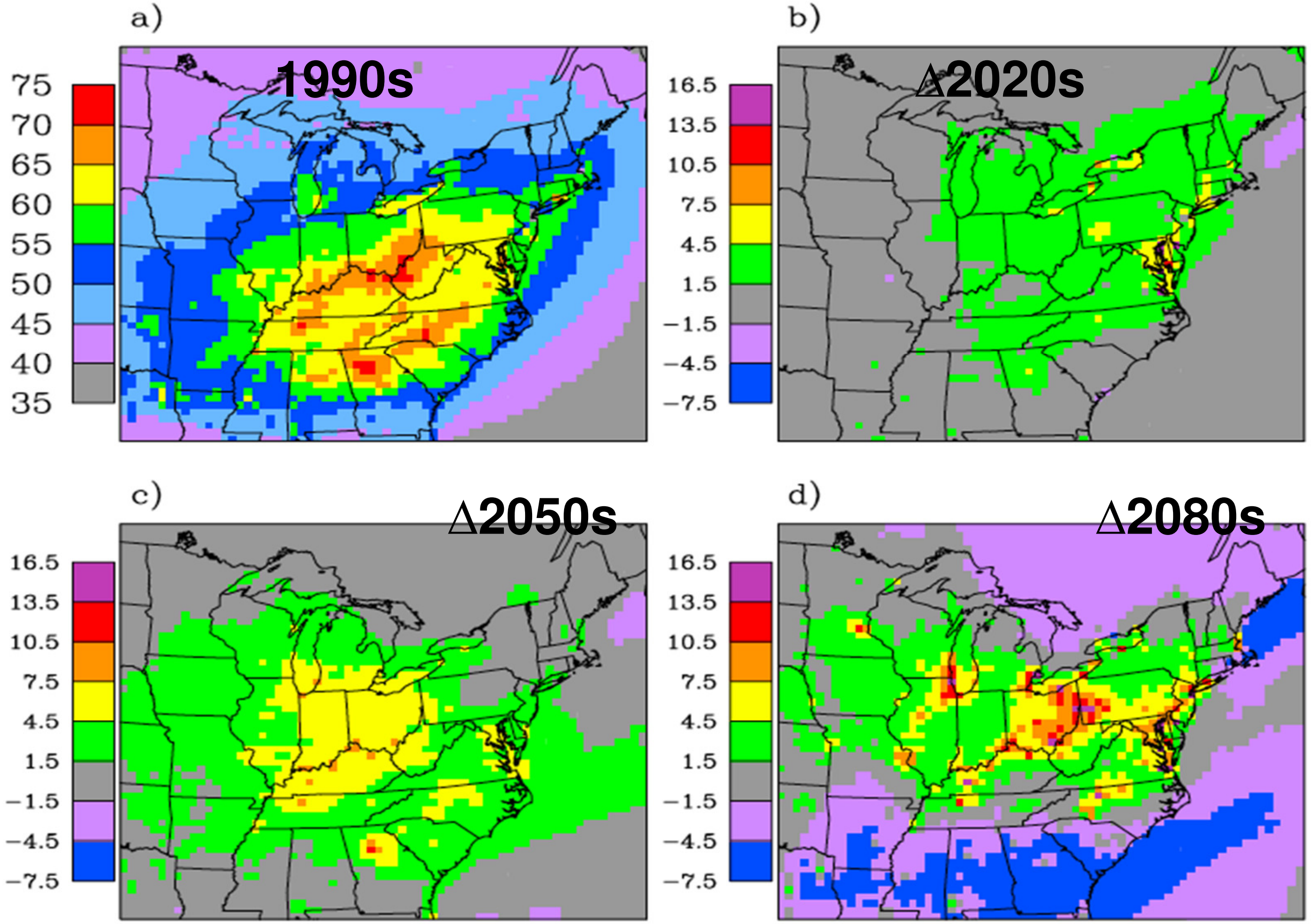
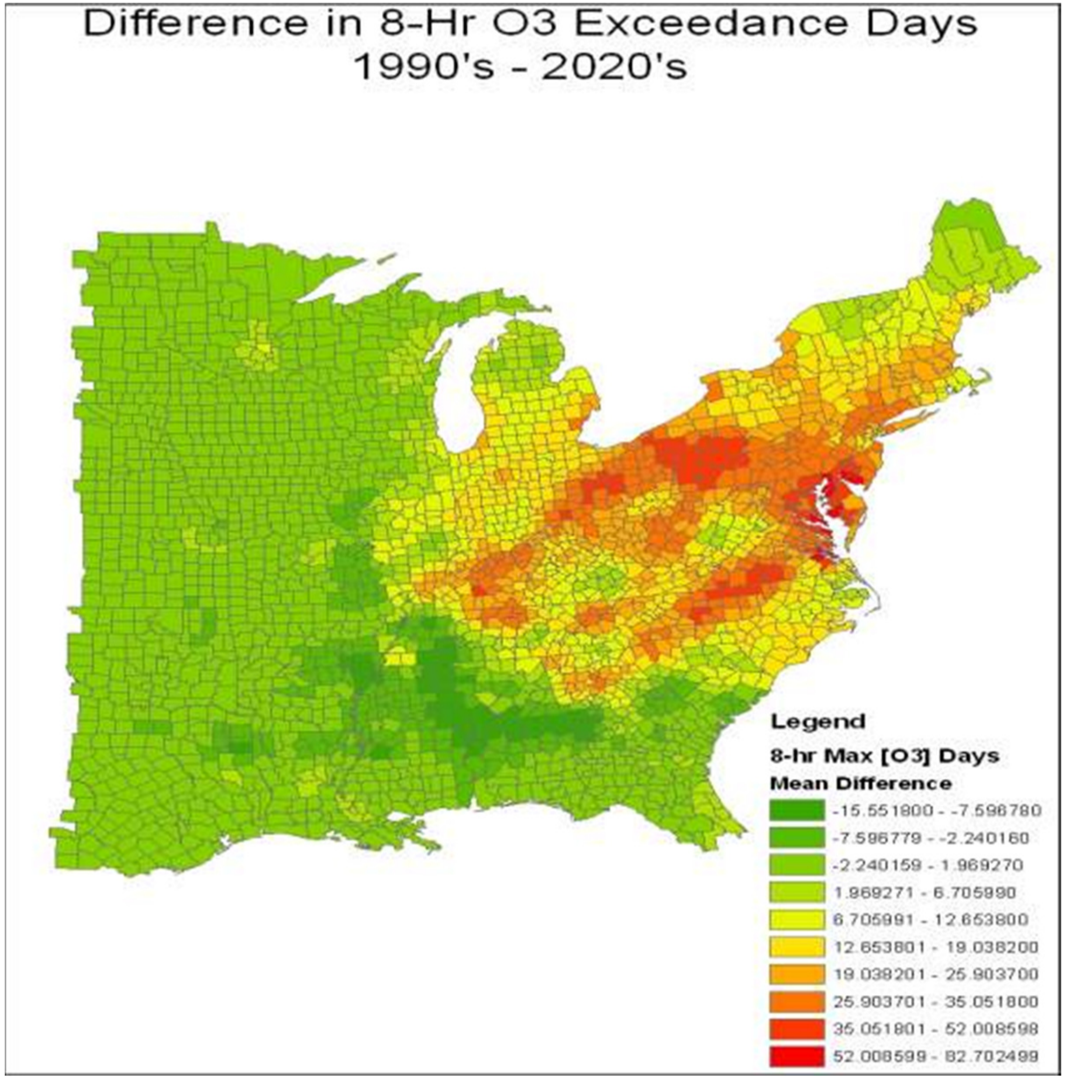


Figure 2. (a) Summertime average daily maximum 8-hour O_3 concentrations for the 1990s and changes in summertime average daily maximum 8-hour O_3 concentrations for the (b) 2020s, (c) 2050s, and (d) 2080s A2 scenario simulations relative to the 1990s, in parts per billion. Five consecutive summer seasons were simulated in each decade.

Hogrefe et al., 2004

WHO 2009

Impact of Climate Change on Compliance with Ozone Standards



Simulated changes in 8-hour standard exceedance days with climate change

1990s – 2020s

WHO 2009

Modeled Changes in:

Mean 1-hr max O3 (ppb) O3-related deaths (%)

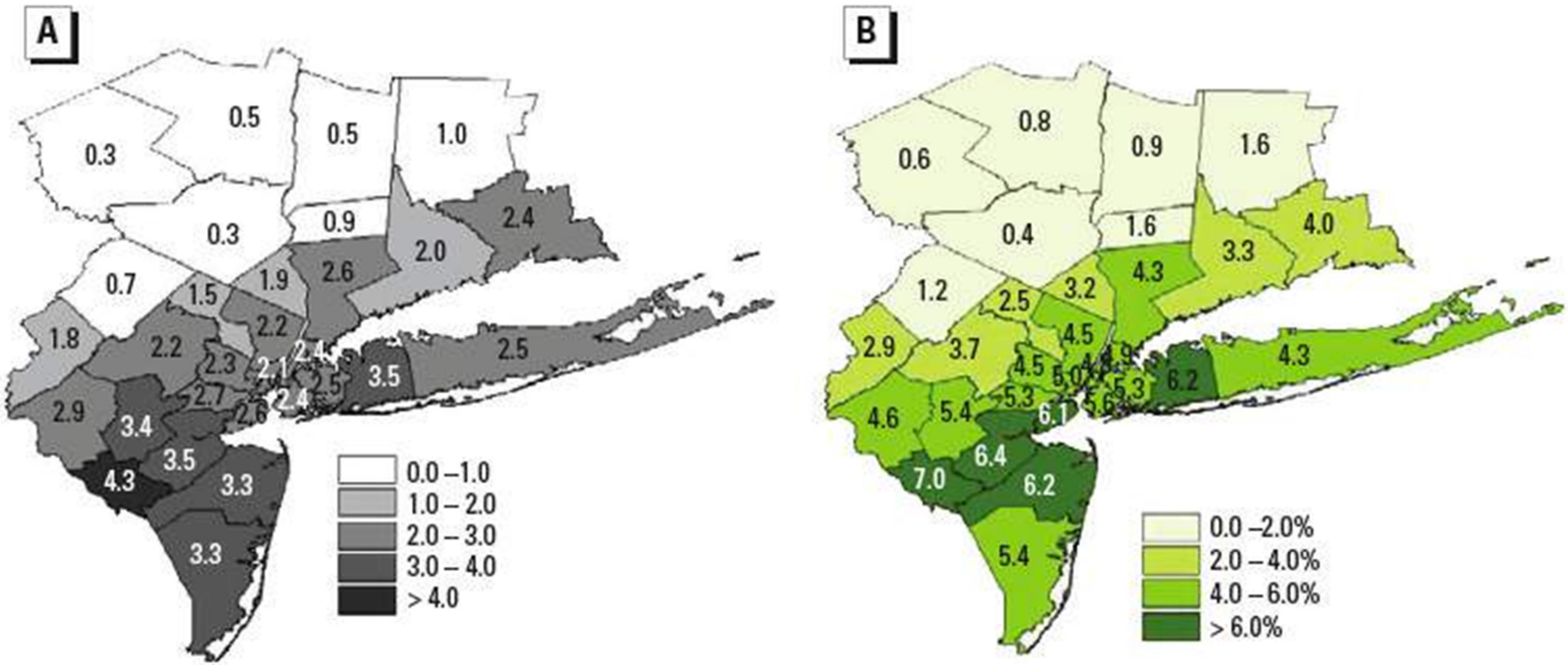


Figure 2. Estimated changes in O_3 and associated summertime mortality in the 2050s compared with those in the 1990s for M1, where climate change alone drives changes in air quality. (*A*) Changes in mean 1-hr daily maximum O_3 concentrations (ppb). (*B*) Percent changes in O_3-related mortality.

Knowlton et al., 2004

WHO 2009

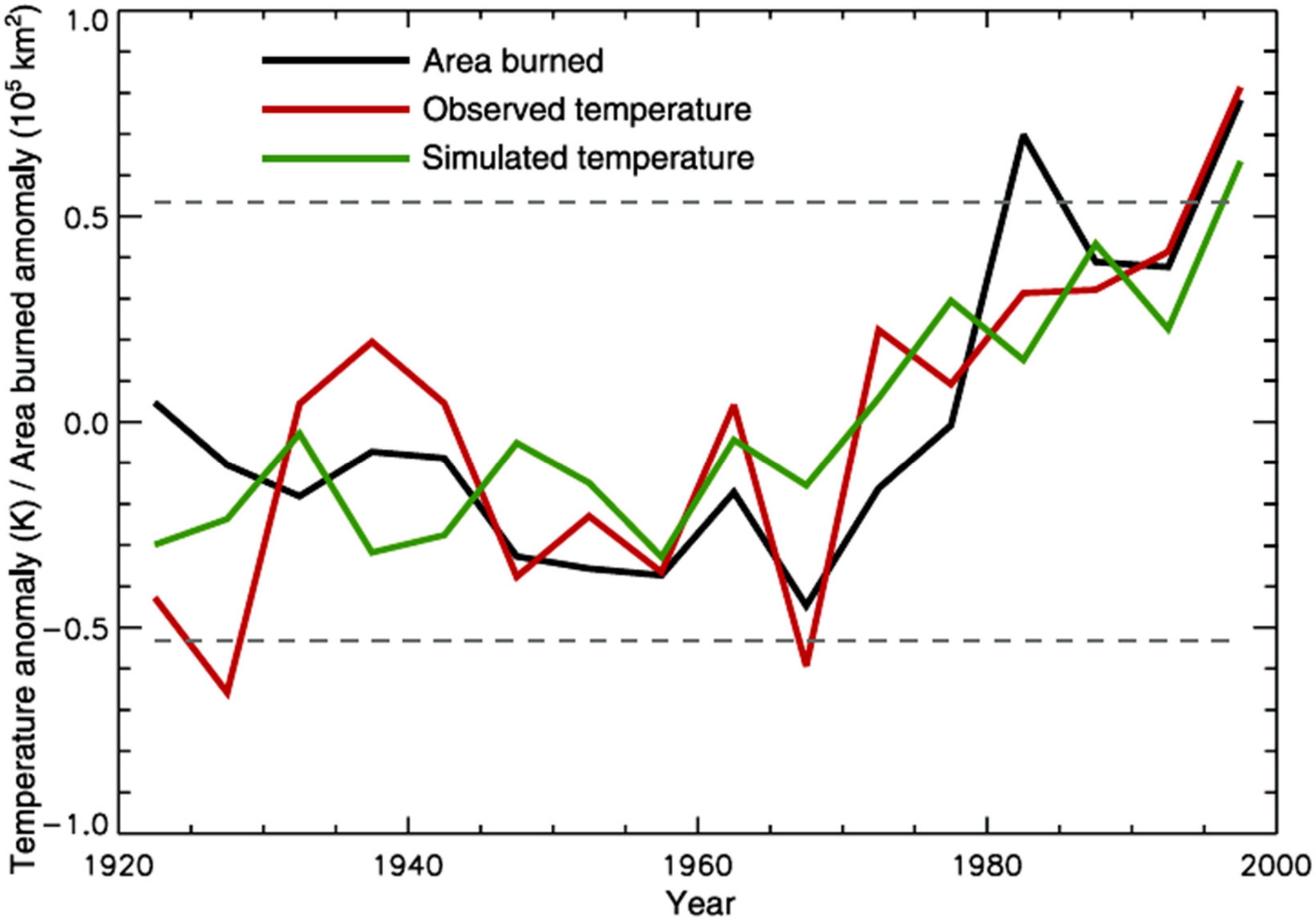
Review

- The mixtures of air pollutants produced by burning of fuels can
  - Adversely affect human health
  - Promote climate change
- In addition
  - Climate change can influence air pollution, resulting in direct health effects
  - Climate change can affect other aspects of air quality, including smoke from agricultural or wild fires, and aero-allergens like pollen and mold spores

Furthermore

- **Other "air pollutants" besides those from tail pipes and smoke stacks have important impacts on human health, and for which climate change is causing changes…**

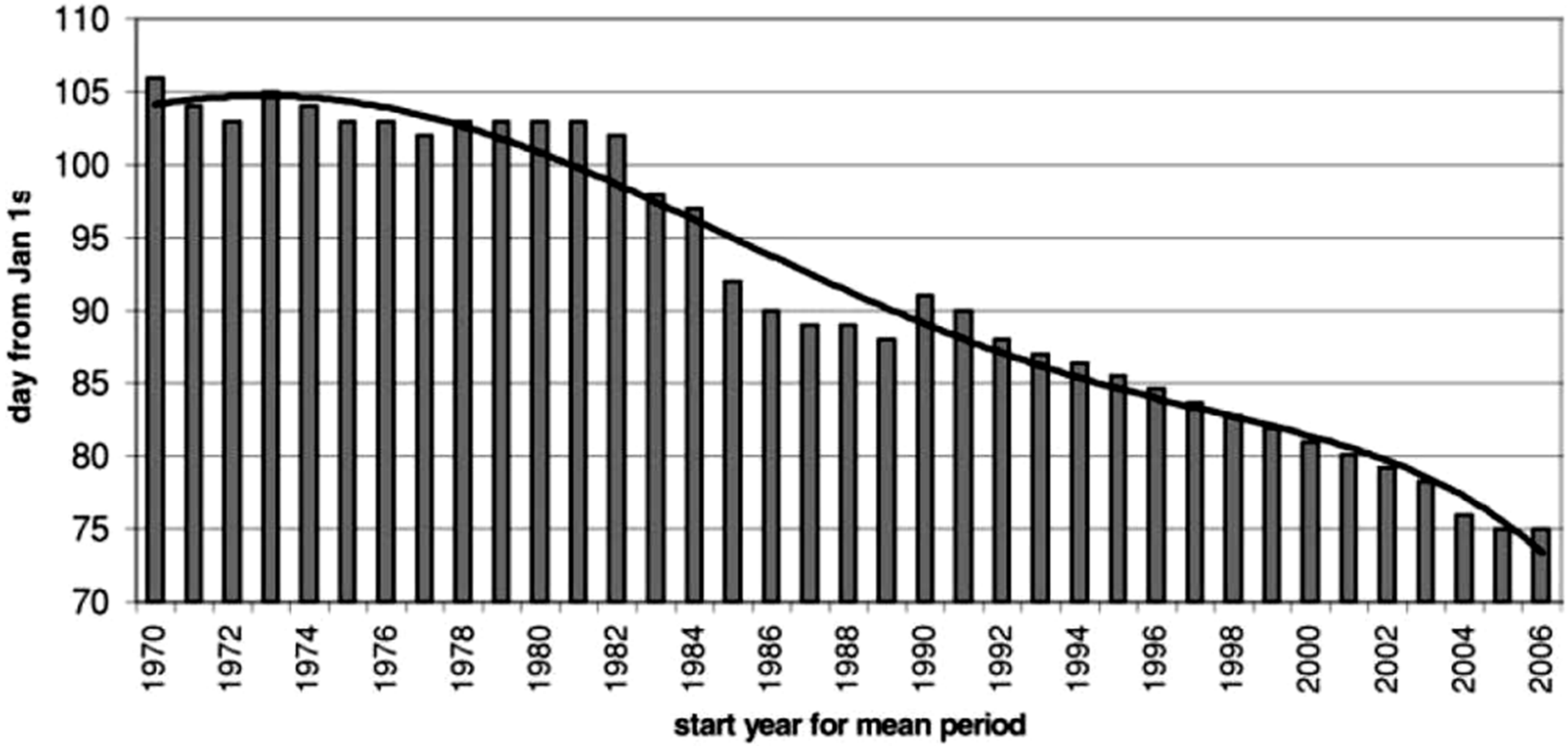
Forest Area Burned and Temperature Trends Canada 1920-1999: 5-year Means



Gillett et al., 2004

Start Date of Birch Pollen Season in Brussels

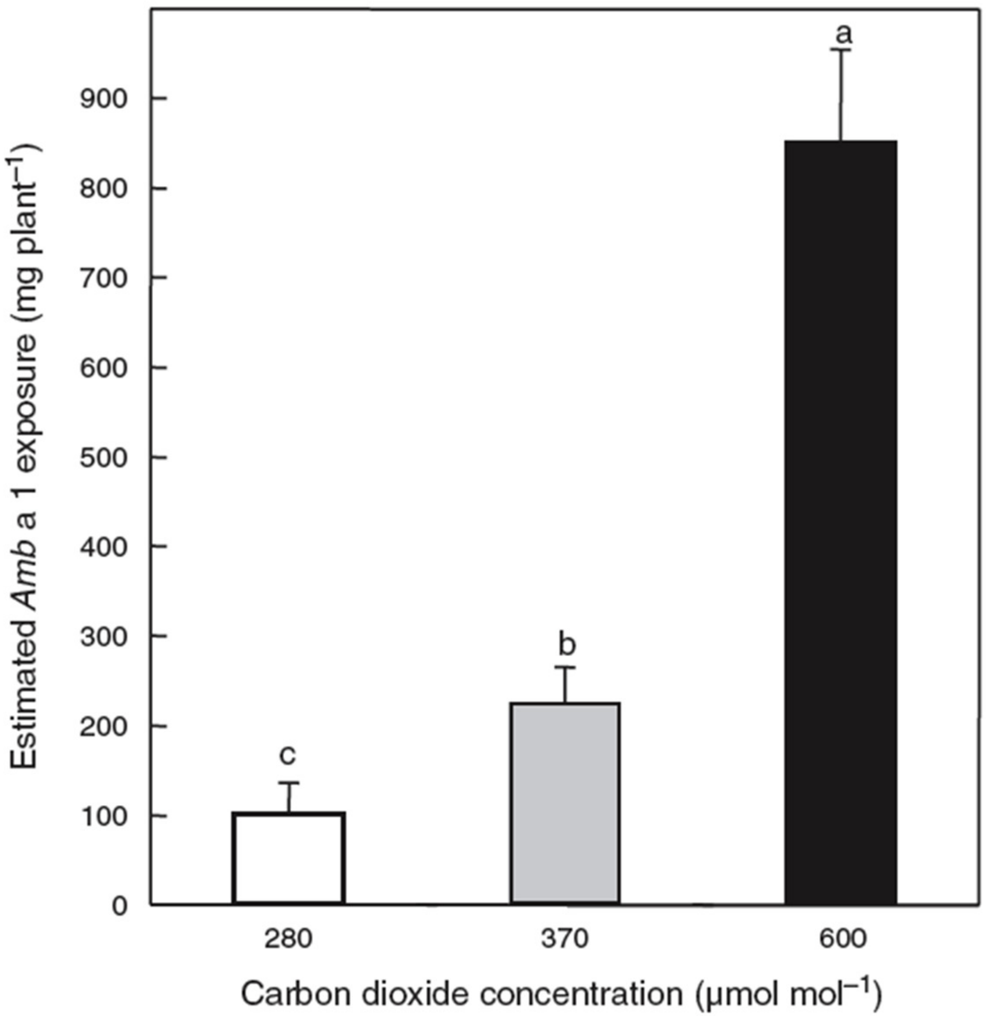
1970-2006 Days after Jan 1 (5-year running means)



Emberlin et al., 2002

Impact of Increasing CO_2 Concentrations on Ragweed Allergen Production

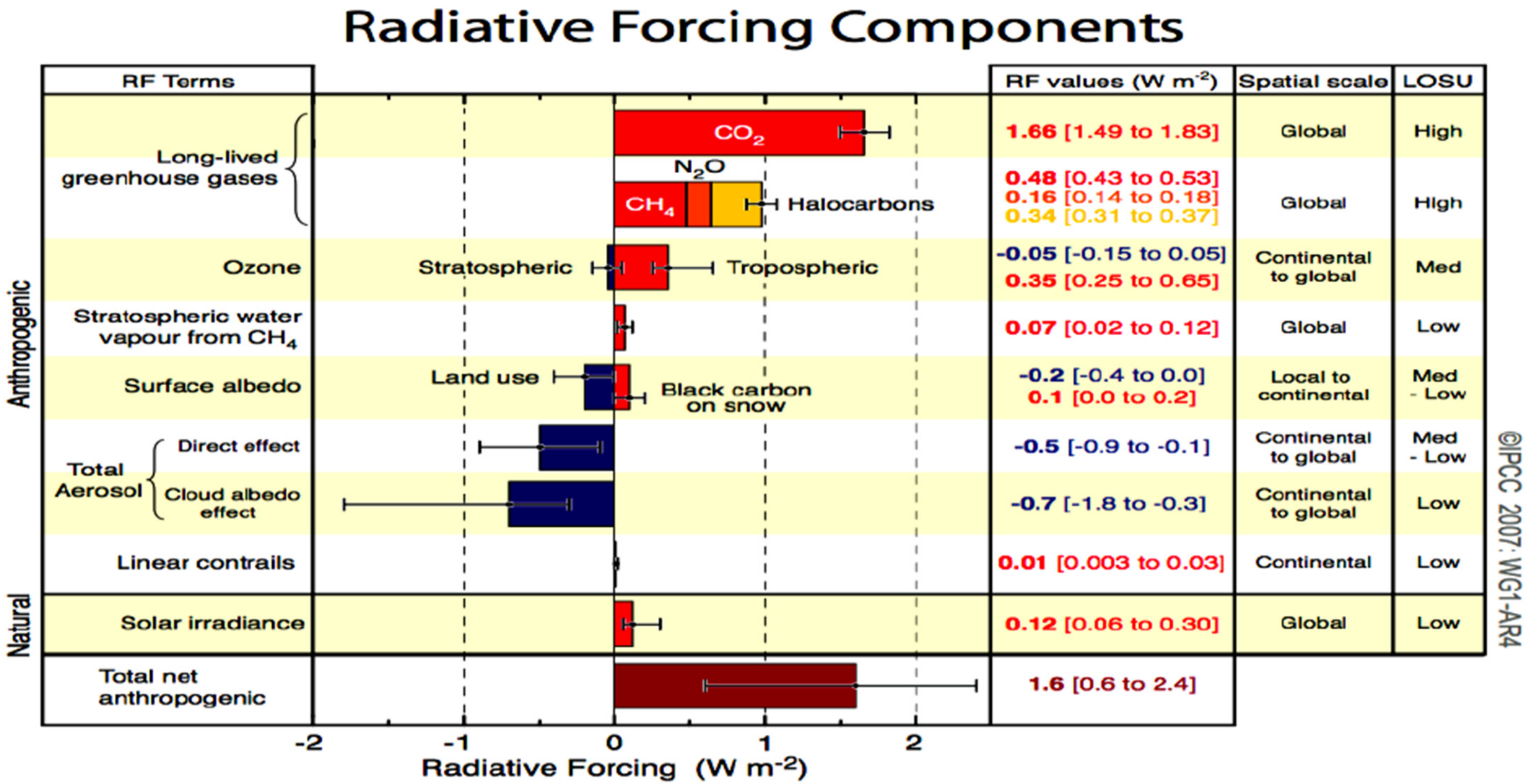
Ragweed allergen production increases as a function of CO_2 concentration



Singer et al., 2005

WHO 2009

Components of Radiative Forcing and Their Relative Impact



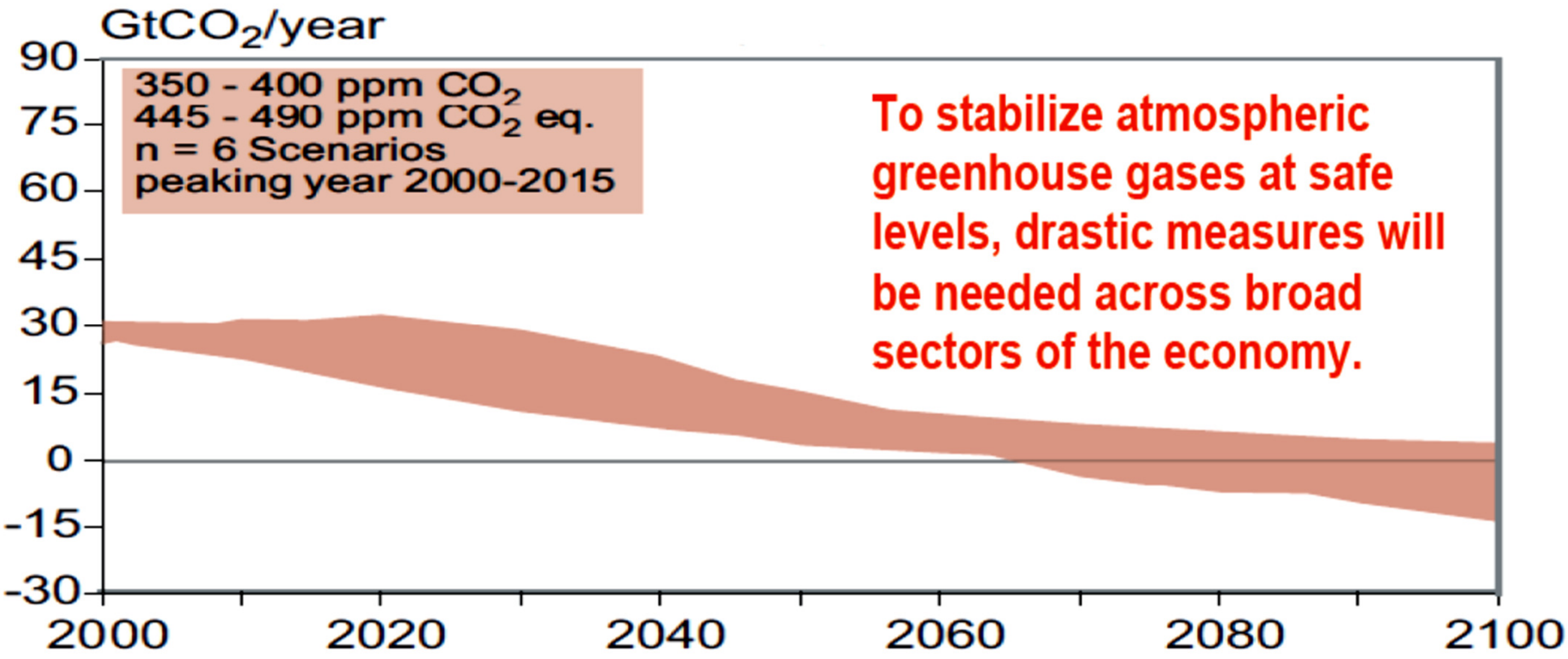
IPCC, 2007b

Actions to Reduce Emissions from Fuel Combustion Will…

- Improve public health via reductions in local and regional concentrations of PM, ozone, and other toxic air pollutants
- Reduce human influence on global climate by reducing CO_2 emissions
- To the extent possible, these two "environmental health" goals should be addressed in an integrated, systematic way

WHO 2009

Conclusions: CO_2 Stabilization Will Require Significant Changes



WHO 2009

Conclusions: CO_2 Stabilization Could Generate Health Co-benefits

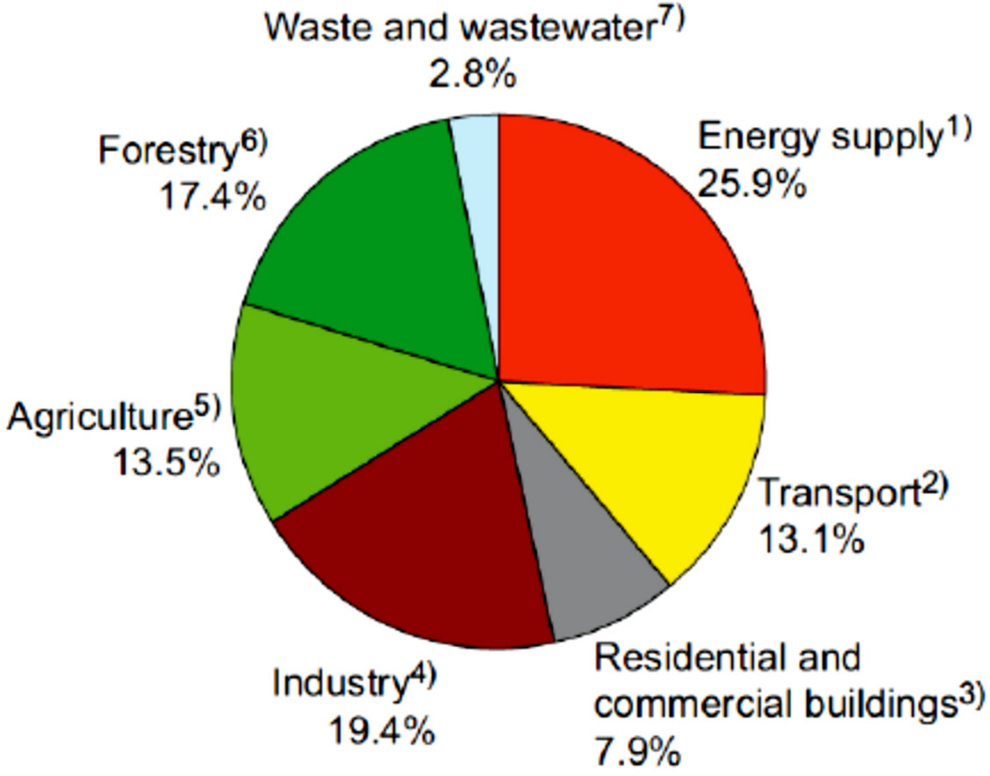
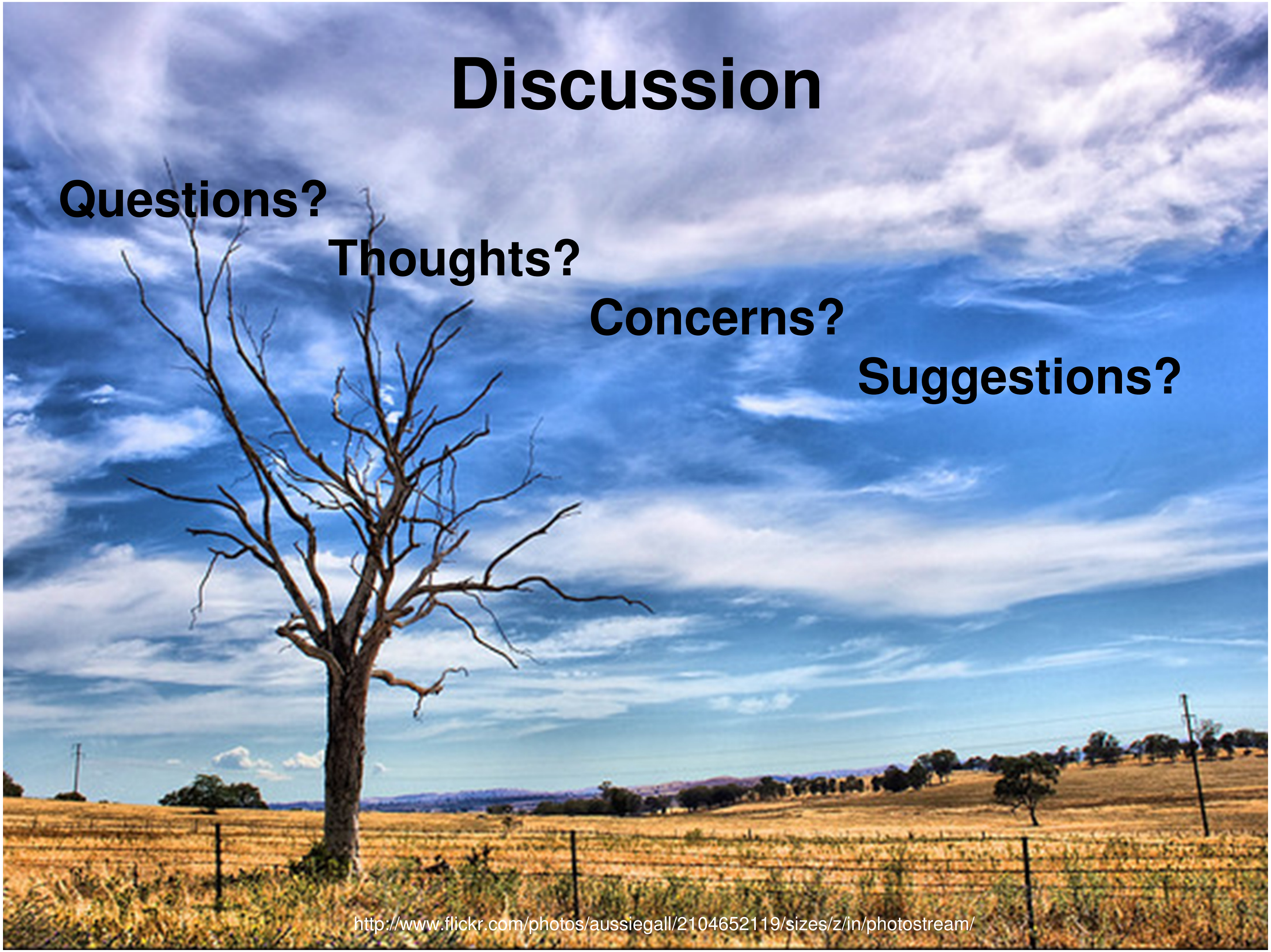


Figure TS.2b: *GHG emissions by sector in 2004 [Figure 1.3b].*

Public Health practitioners will be called upon to assess the health co- benefits of mitigation activities, including equity aspects.

IPCC, 2007c

WHO 2009


Discussion
Questions?
Thoughts?
Concerns?
Suggestions?
http://www.flickr.com/photos/aussiegall/2104652119/sizes/z/in/photostream/

Acknowledgements

- **Based in part on lectures developed by the author for courses taught at the University of Michigan, Ann Arbor, MI, USA.**

- **Some material was modified from the WHO "Training course for public health professionals on protecting our health from climate change (2009)."**

- **Supported by the Mauritius Ministry of Environment & Sustainable Development (No: MoESD/AAP/02/11)**