Air Quality

Professor Tim Larson
CEE 357

Fire: The Dawn of Anthropogenic Air Pollution

Early lecture on the health effects of air pollution

Bachmann, 2008

Learning Objectives

1. Describe some early air pollution episodes, their causes and their health consequences (slides 4-11)
2. List the criteria pollutants and describe their concentration trends (slides 22-29)
3. Describe the health effects associated with exposure to O_3 and $PM_{2.5}$ (slides 30-35)
4. Describe some of the health effects associated with traffic-generated air pollution (slides 40-43)

Early days: coal smoke and industrial smoke

The Smoky City – Pittsburgh

1906-1910

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A remarkable record from Central Park

Jan avg = 800 ug/m3

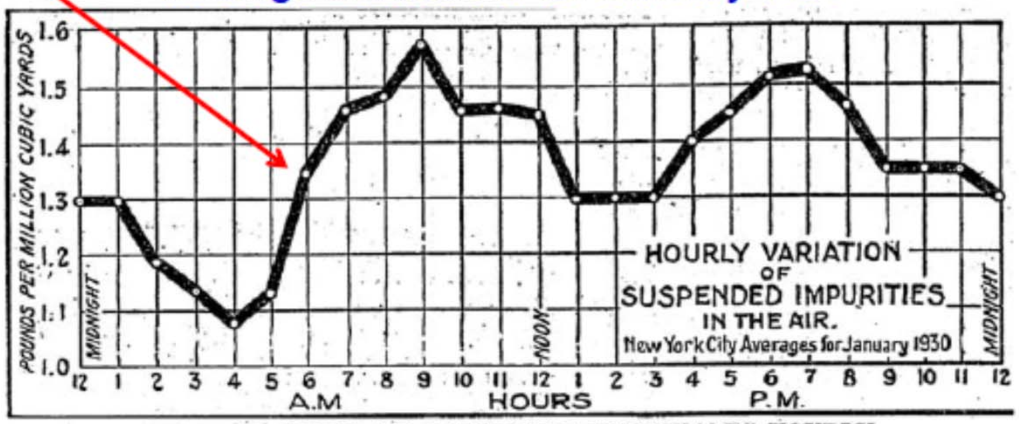
Average Diurnal PM for January 1930

FINDS CITY'S AIR PUREST AT 4 A. M.

Device That 'Breathes' in Park Records 9 A. M. as Hour of Greatest Pollution.

WORKS EACH QUARTER HOUR

61,199 Dust Particles Per Cubic Foot Is Average for January, Against 50,524 in Same Month of 1929.



HOW THE CITY'S AIR POLLUTION FLUCTUATES HOURLY.

Chart Prepared by New York Meteorological Observatory in Central Park Based on January Averages Show: the Rise in the Air's Dust Content From the Low Point at 4 A. M. to the Peak at 9 A. M.

Using a new apparatus that "breathes" the city air and registers its dust and smoke content every fifteen minutes, the New York Meteorological Observatory in Central Park has found that every million cubic yards of New York's atmosphere contained, during January, an average of 1.35 pounds of impurities. The instrument, which was installed on Jan. 1, showed the city's air to be purest at 4 A. M. and most polluted at 9 A. M., according to a report of the first month's operation made public yesterday by David R. Morris, meteorologist.

The apparatus, which is known as the Owens automatic air filter and is much used in England, keeps an automatic record throughout the day and night. It was lent by the Stevens Institute of Technology. Samples of air examined each noon by another instrument, in use at the observatory for a year, showed a higher dust content this January than last year. This year the average for the month was 61,199 particles per cubic foot, compared to 50,524 last year. January is usually the dirtiest month of the year.

The pollution of the air shown by the Owens filter varied during the month from 0.27 pound of impurities per million cubic yards, registered on Jan. 11, to 2.70 pounds on Jan. 27.

Mr. Morris has prepared a chart showing the average variation during the day, in January, of the air pollution. Starting from the low point at 4 A. M., when the air is at its purest, the curve gradually rises, as fires are made in homes and offices, until it reaches its peak at 9 A. M. It declines until after noon, and does not begin to rise again until 3 o'clock, probably because the home fires are started up again in preparation for the evening. The second peak is reached at 7 P. M., and thereafter the curve declines almost steadily, with a slight retardation between 9 and 11.

The air filter "breathes in" two liters of air every fifteen minutes. The air is sucked in through a small tube which hangs out the window. It passes through filter paper, leaving its dust and smoke in a small, round mark the size of a small pea.

Ninety-six of these marks are left around the edge of a circular filter paper. They are compared with a series of sixteen standard shades, each of which represents a certain percentage of impurity, and the amount of dust per million cubic yards is then calculated.

The New York Times
Copyright © The New York Times
Originally published February 5, 1930

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- 1930 Meuse Valley, Belgium. Air inversion results in 60 dead and thousands sick from exposure to industrial air emissions.

- 1948 Donora, Pennsylvania. Air pollution episode kills 20 people and numerous animals, and half of the town's 12,000 residents become ill due to uncontrolled emissions from industrial facilities

- 1948 - 1972 Various “killer fog” episodes beset London.

- 1952 the most famous London episode lasted about a week. Over 4000 deaths in the city were attributed to this one event. Very few deaths occurred in the surrounding countryside.

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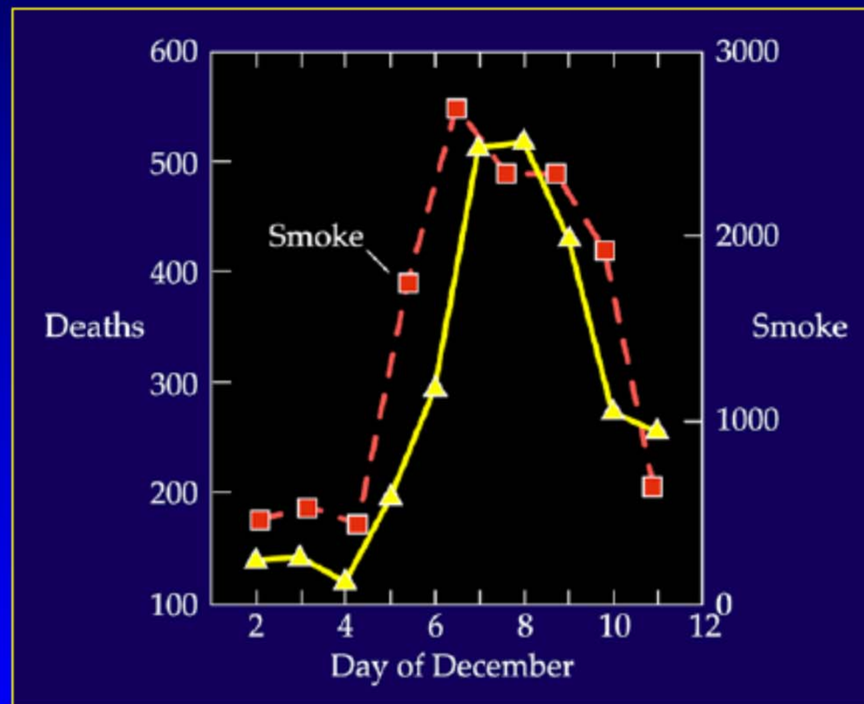
Then massive deaths – immediately and decades later



Not only did thousands succumb quickly, but survivors who got sick and recovered had shorter life spans

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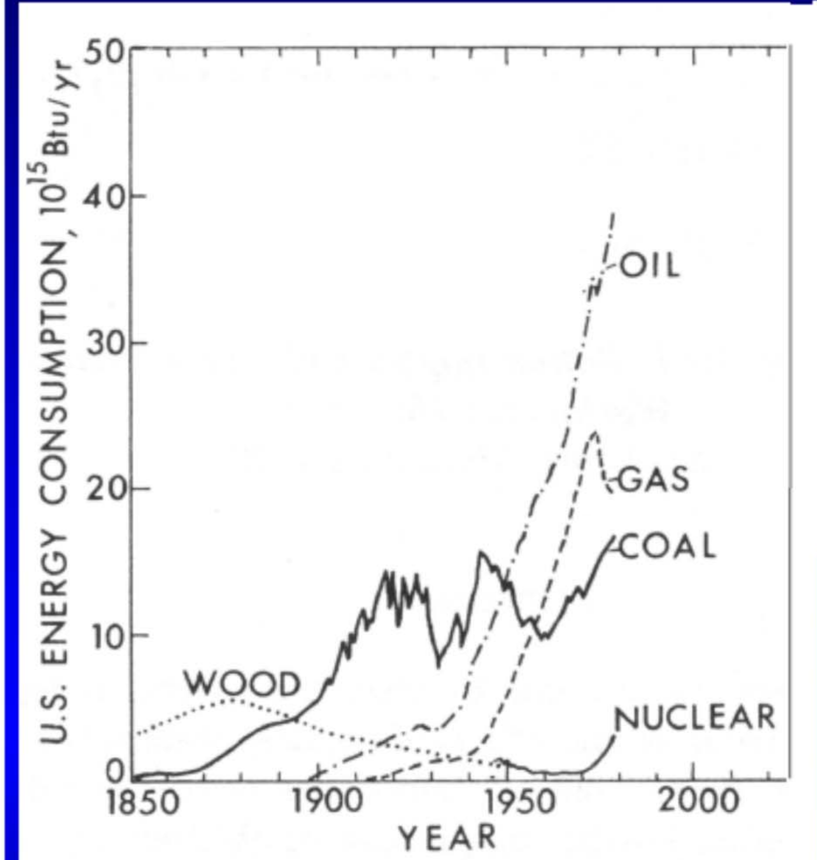
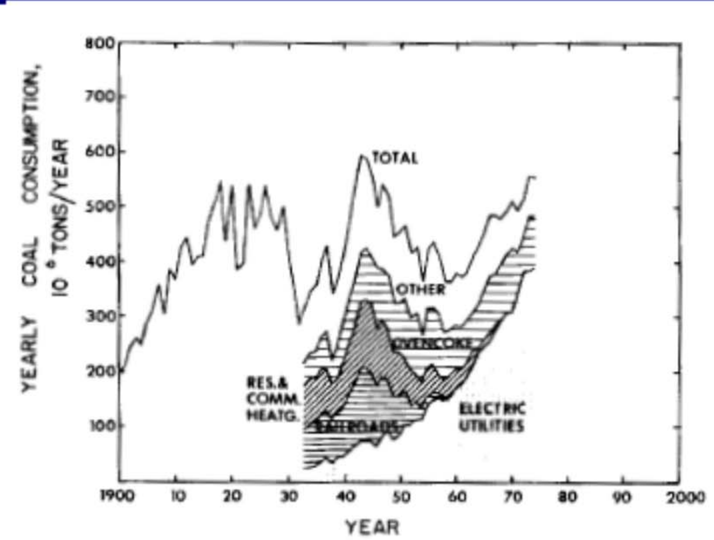
The Driver: Old King Coal





Residential & Commercial Heating with coal is phased out by the early sixties

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% Opacity

Ringelmann Chart

20% 40% 60% 80%

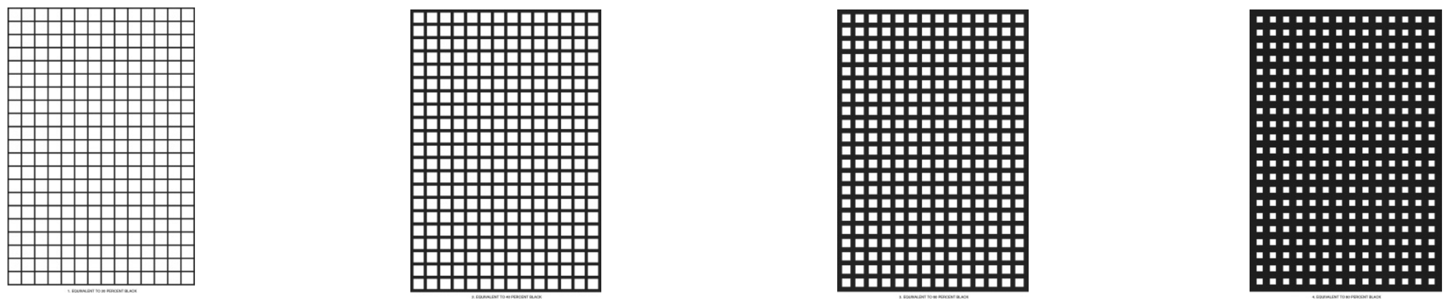
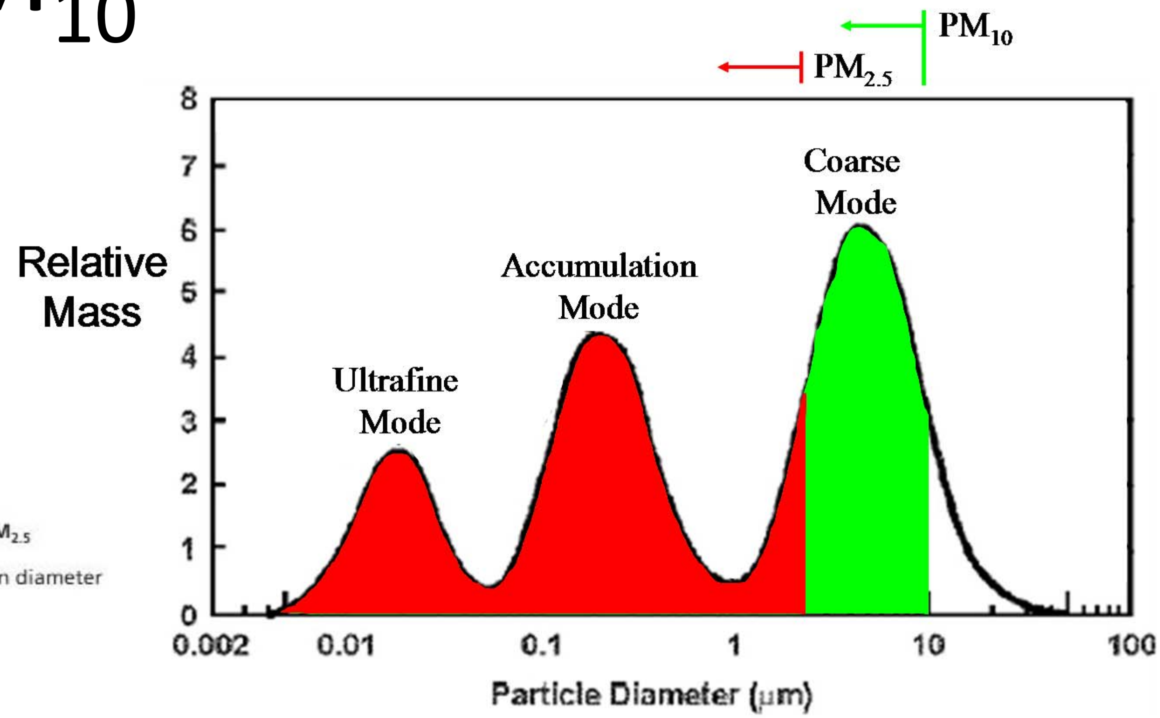


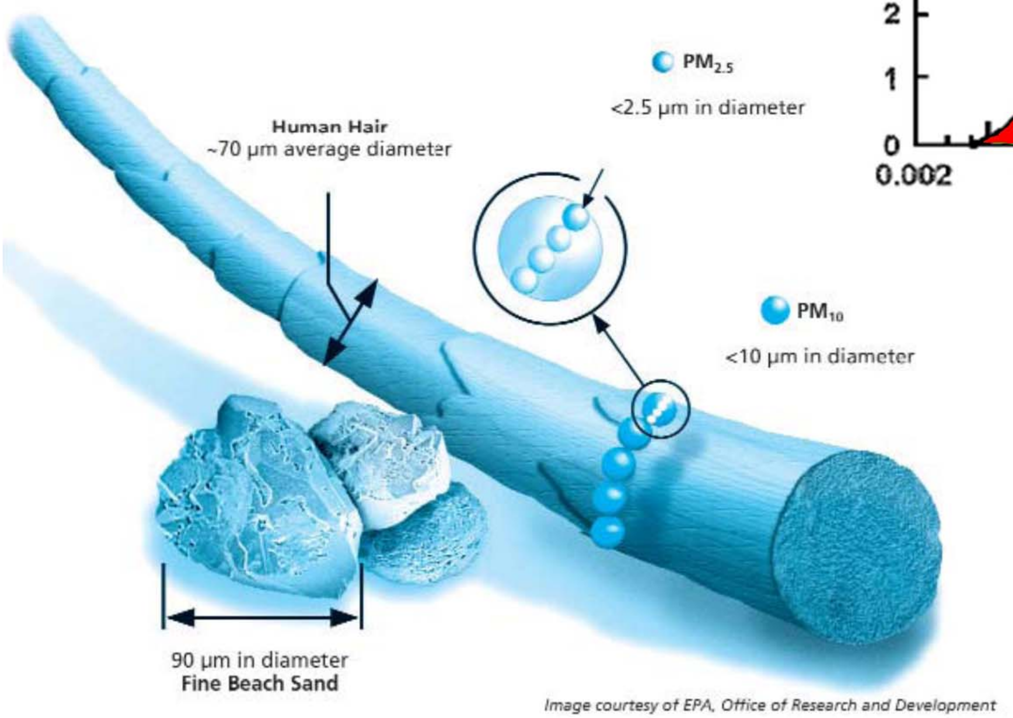
Table IV. Percent of American local regulations prohibiting visible emissions of various opacities from stationary sources.[3]

Emission greater than percent opacity prohibited	Percent of regulations prohibiting visible emissions				
	1940	1950	1960	1965	1975
60	81	69	41	32	3
40	19	31	59	66	33
20	0	0	0	2	56
0	0	0	0	0	8

Stern, 1982

$PM_{2.5}$ and PM_{10}

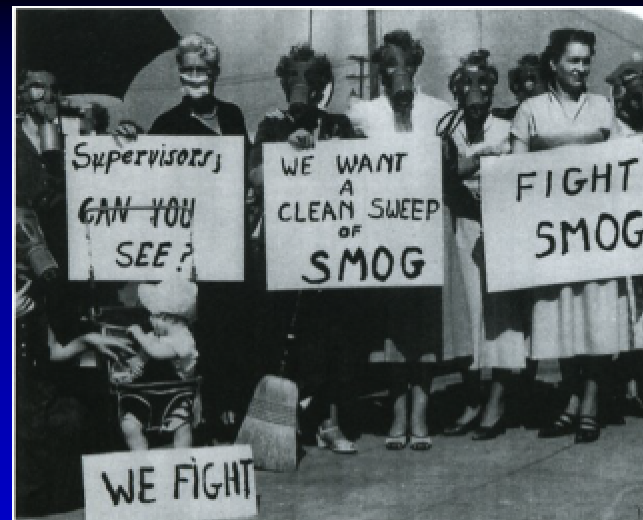




Photochemical smog

Los Angeles, 1948-55

Dense fog over the Los Angeles Civic Center, 1955. Note that the buildings project above the base of the inversion layer, while the smog remains below.



Protests at Pasadena City Hall on November 9, 1954, following fifteen days of smog in October.

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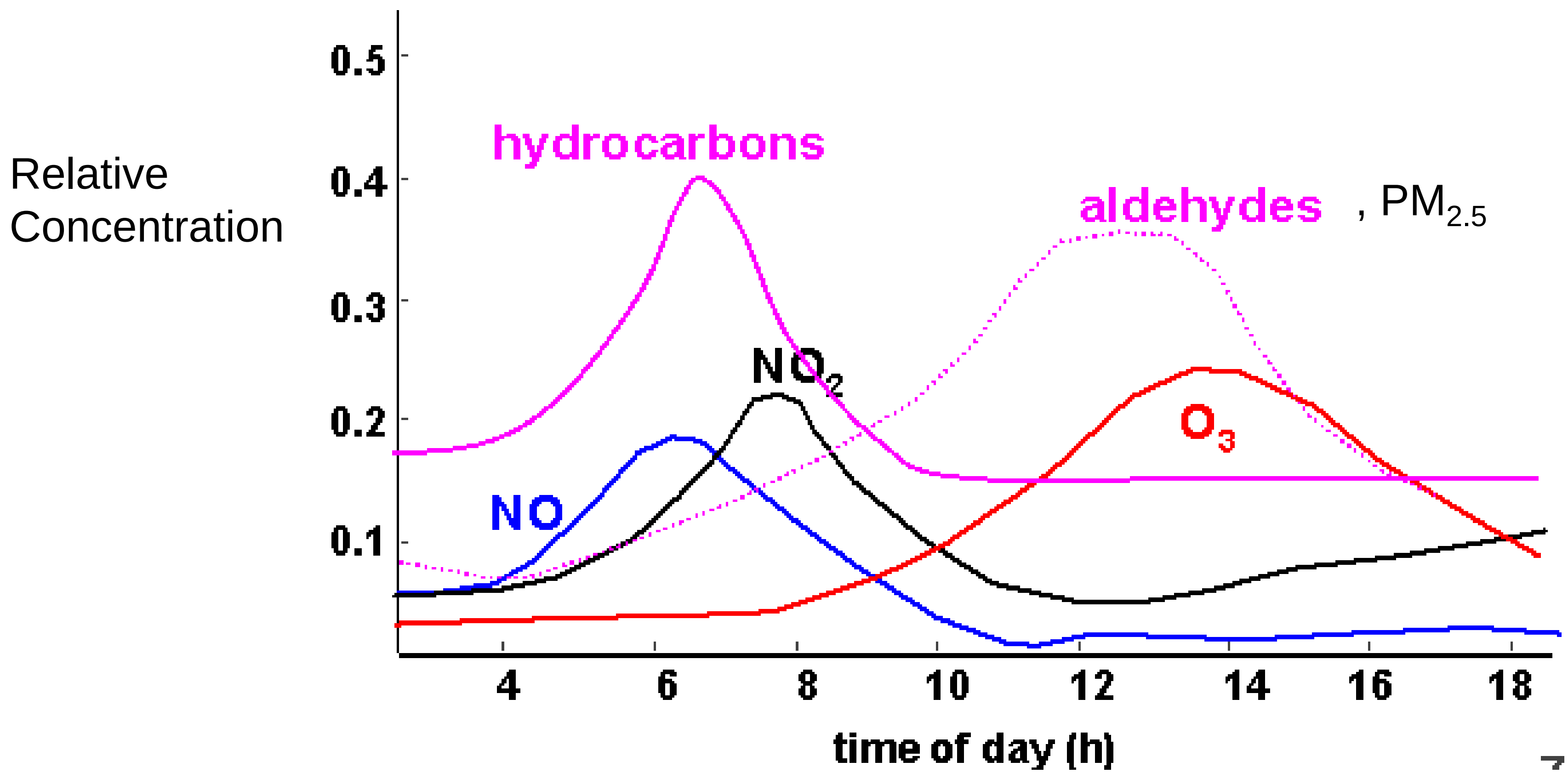
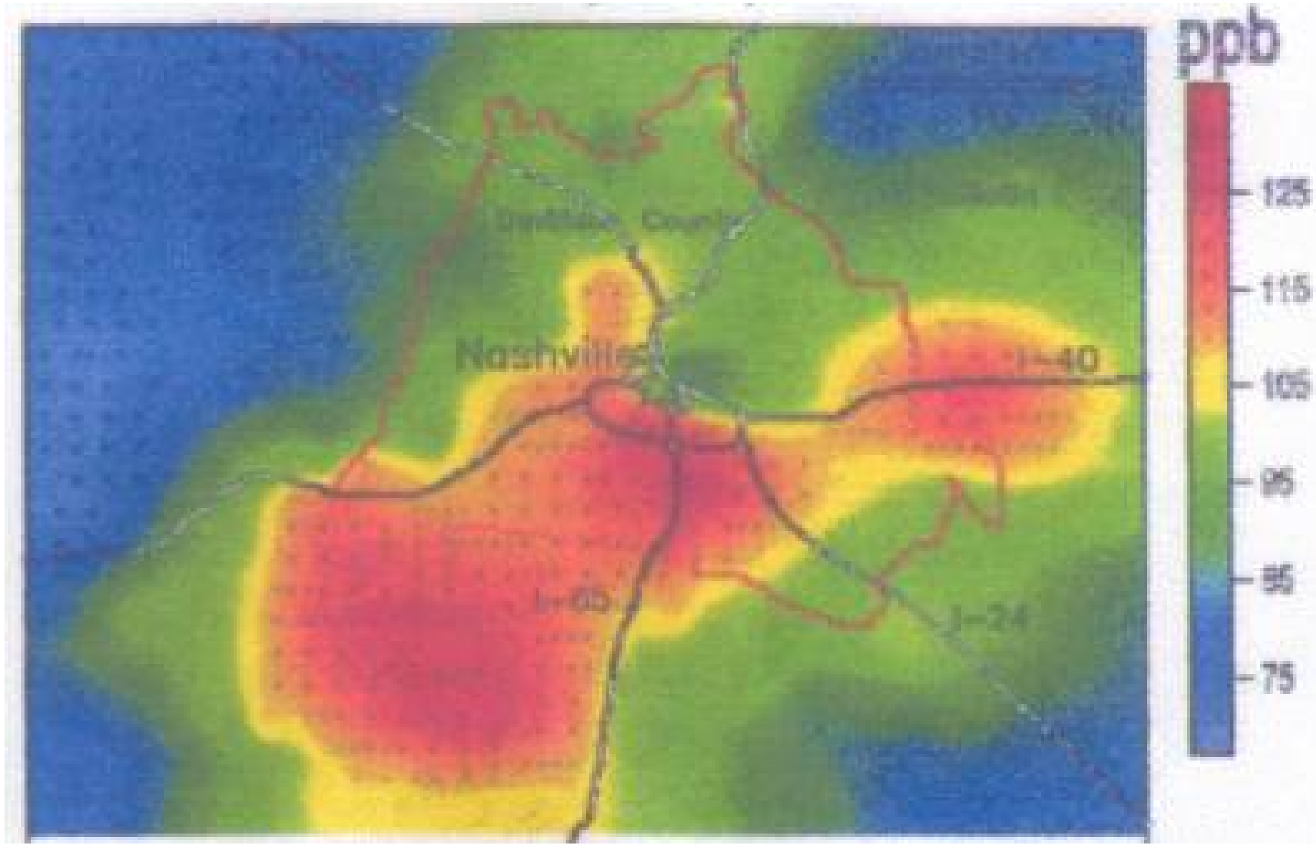
Photochemical Smog and Ozone

- early morning emissions of NO and hydrocarbons in the presence of sunlight will produce NO_2, O_3 , particulate nitrates and partially oxidized organic particles
- the O_3 and PM concentrations will peak later in the day than NO_2



Ozone formation downwind of Nashville, TN.

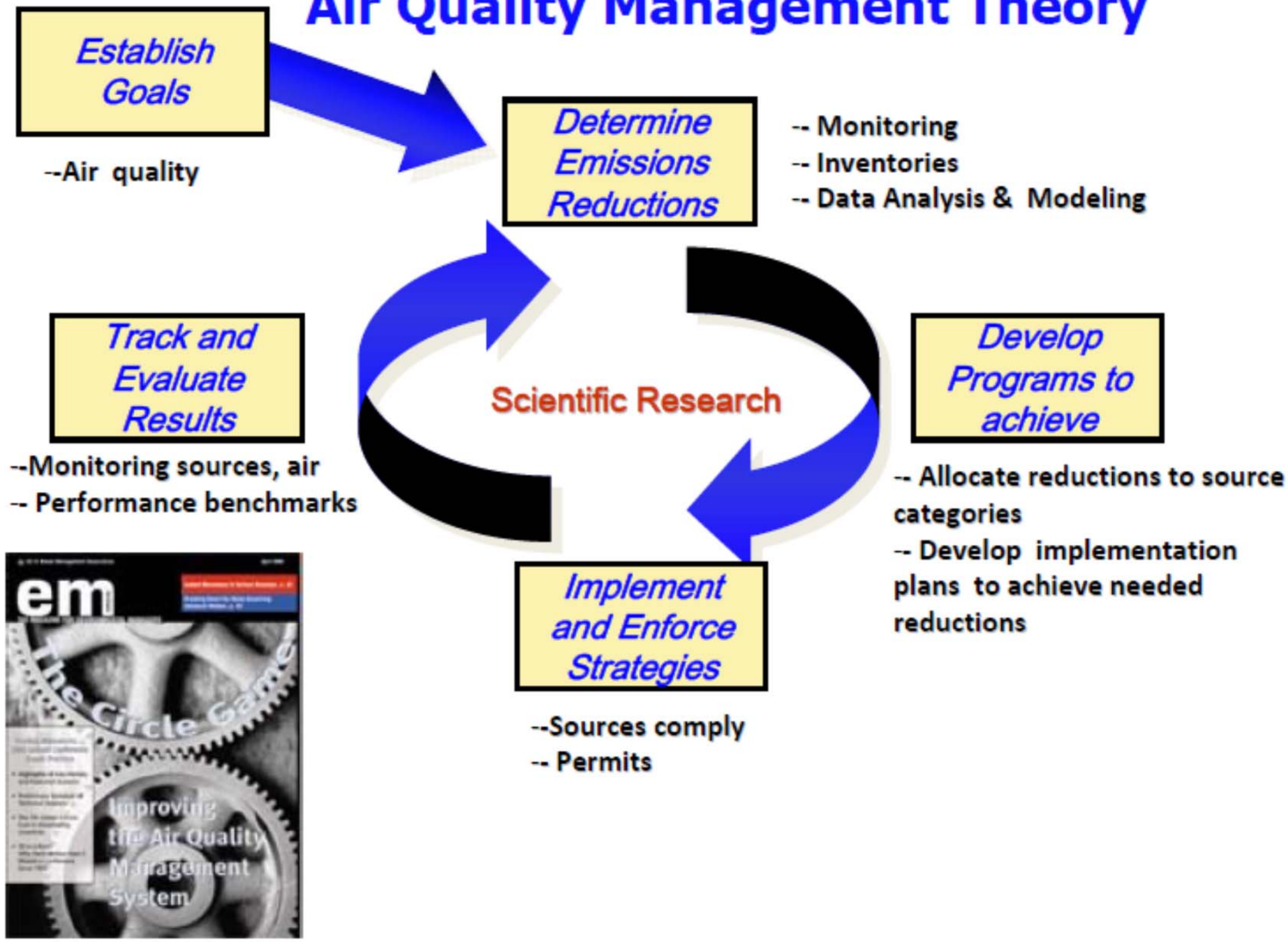


Nashville Southern Oxidants Study

Valente et al J.Geophys Res 103:22, 555-568, 1998

Air quality management: Dealing with a complex mixture of pollutants

Air Quality Management Theory



Regulated Air Pollutants in U.S.

- Criteria Pollutants
  - A group of relatively few ubiquitous pollutants
  - Regulated by EPA for 40+ years
  - “Adverse” levels are derived from non-cancer risk

- Hazardous Air Pollutants (HAPs or “Air Toxics”)
  - A much longer list of pollutants (187)
  - Regulated by EPA for 20+ years
  - “Adverse” levels are derived mainly from cancer risk

How is an air quality standard expressed?

*An average concentration over a specific time period (an hour, a day, or a year, for example).

*The averaging time is based upon the associated health and welfare impacts. (concentration x time = exposure)

*The concentration is expressed in parts per million (ppm) or micrograms of pollutant per cubic meter of air ($\mu g/m^3$).

$$0.075 \text{ ppm } SO2 = \left(\frac{75\text{x}10^{-9} m^3\ SO_2}{m^3\ \text{air}}\right)\left(\frac{64\text{x}10^{-6} \text{grams } SO_2}{10^{-6} \text{moles } SO_2}\right)\left(\frac{10^{-6} \text{moles } SO_2}{24.5\text{x}10^{-9} m^3\ SO_2}\right)^{*} = 196\ \frac{\mu g\ SO_2}{m^3 \text{air}}$$

@ 20 C, 1 atm

Definition of ppb

Molecular weight

Ideal gas law at 20c, 1 atm
(24.5 liters per mole)

Criteria Pollutants

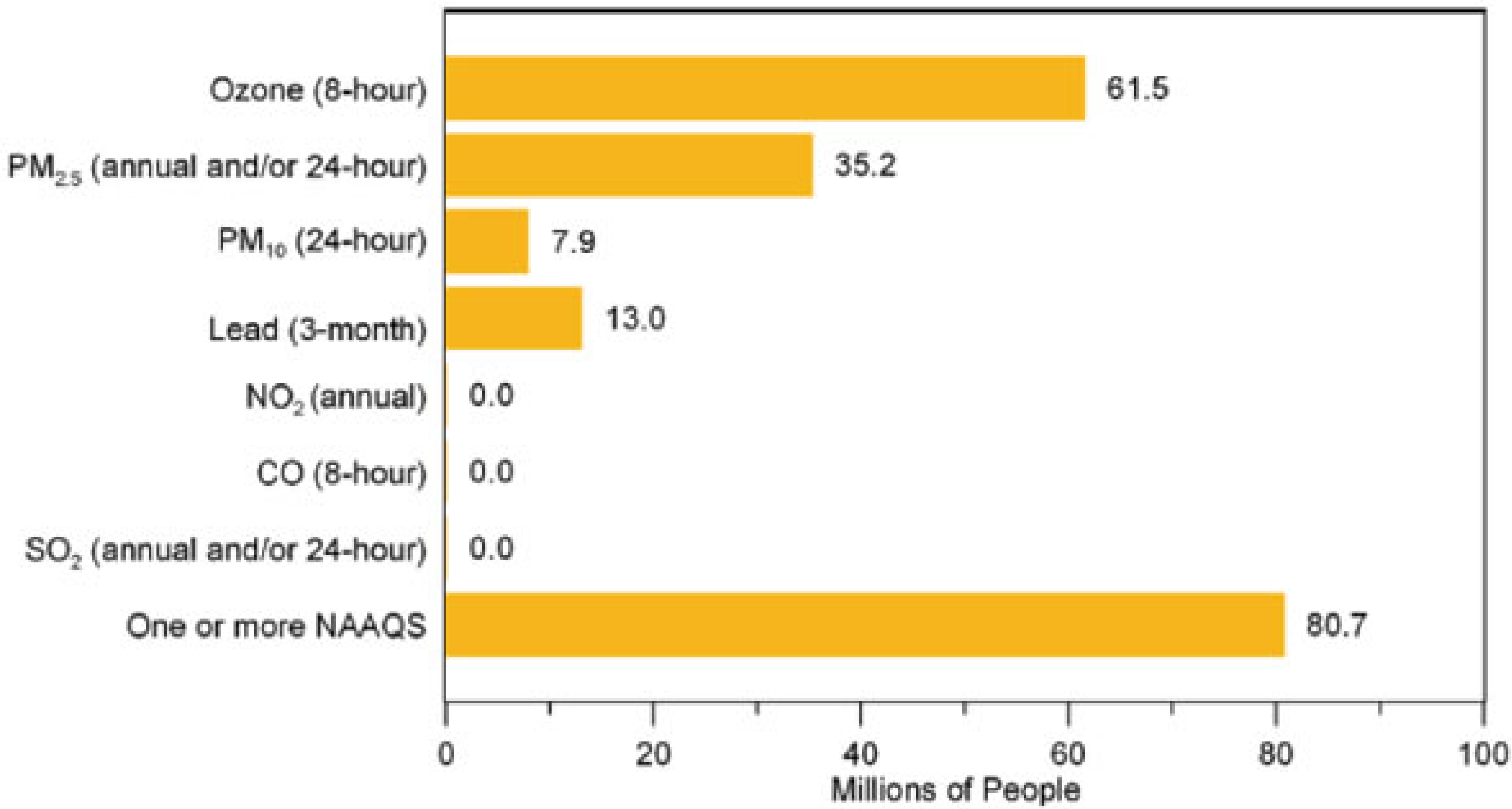
Primary = Human health-based Secondary = Non-health effects

National Ambient Air Quality Standards

	Primary Standards		Secondary Standards	
Pollutant	**Level**	**Averaging Time**	**Level**	**Averaging Time**
Carbon Monoxide	9 ppm (10 mg/m^3)	8-hour [(1)]	None	
	35 ppm (40 mg/m^3)	1-hour [(1)]		
Lead	0.15 µg/m^3 [(2)]	Rolling 3-Month Average	Same as Primary	
	1.5 µg/m^3	Quarterly Average	Same as Primary	
Nitrogen Dioxide	53 ppb [(3)]	Annual (Arithmetic Average)	Same as Primary	
	100 ppb	1-hour [(4)]	None	
Particulate Matter (PM_{10})	150 µg/m^3	24-hour [(5)]	Same as Primary	
Particulate Matter ($PM_{2.5}$)	15.0 µg/m^3	Annual [(6)] (Arithmetic Average)	Same as Primary	
	35 µg/m^3	24-hour [(7)]	Same as Primary	
Ozone	0.075 ppm (2008 std)	8-hour [(8)]	Same as Primary	
	0.08 ppm (1997 std)	8-hour [(9)]	Same as Primary	
	0.12 ppm	1-hour [(10)]	Same as Primary	
Sulfur Dioxide	0.03 ppm	Annual (Arithmetic Average)	0.5 ppm	3-hour [(1)]
	0.14 ppm	24-hour [(1)]		
	75 ppb [(11)]	1-hour	None	

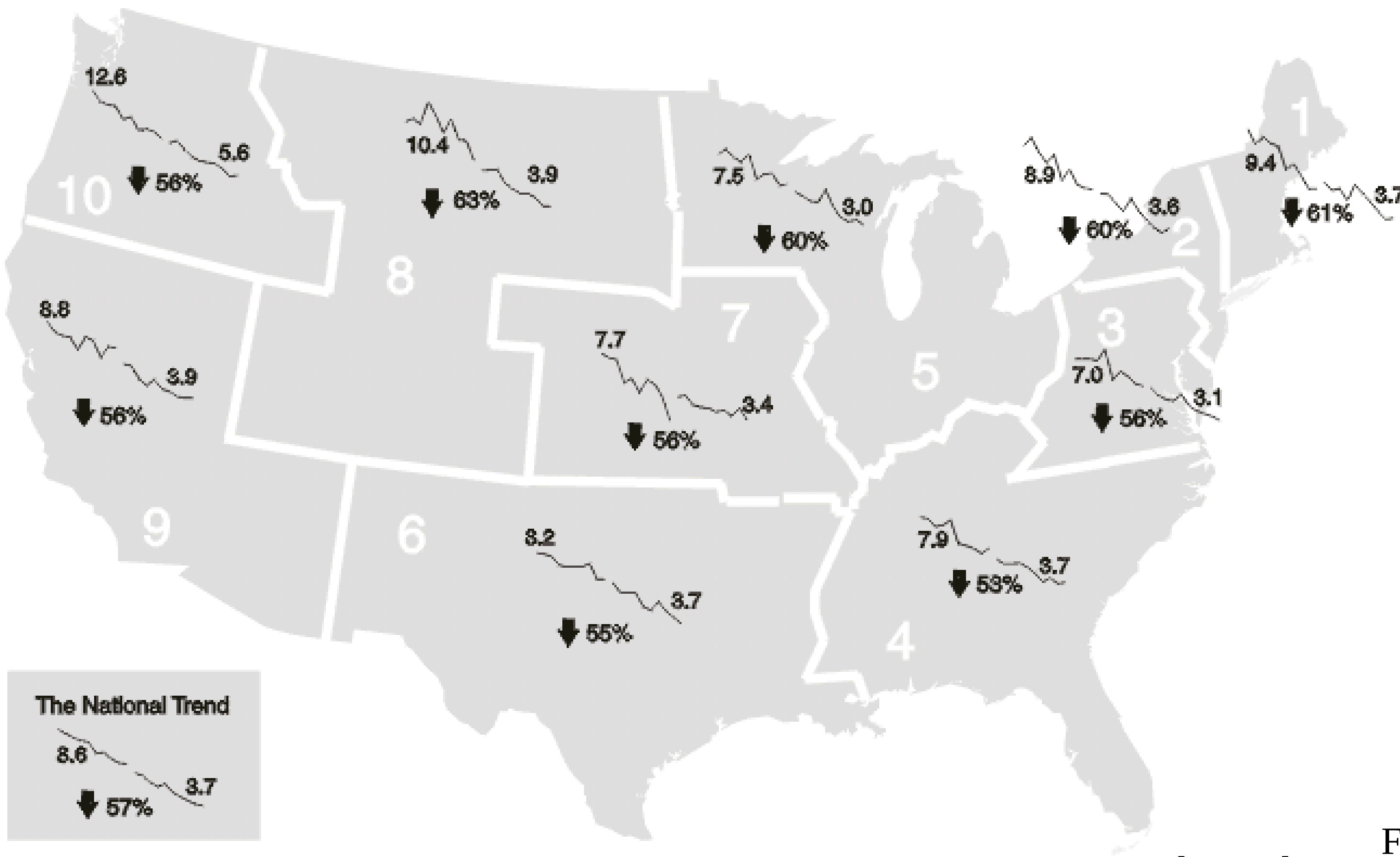
For further information see http://www.epa.gov/air/criteria.html

Number of people living in counties with EPA monitors exceeding the air quality standard

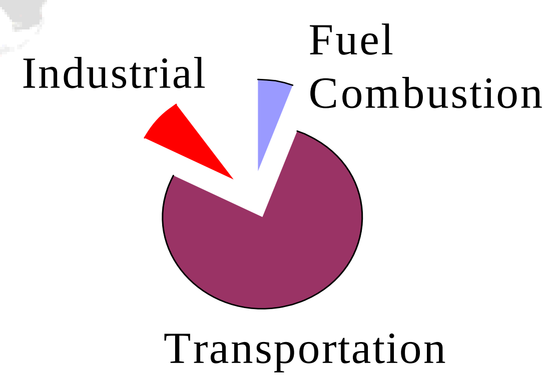


http://www.epa.gov/airtrends/aqtrends.html#airquality

CO max 8-hr average, 1980-1999

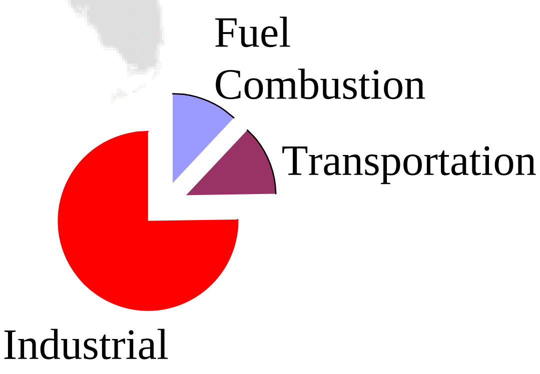


CO Emissions:



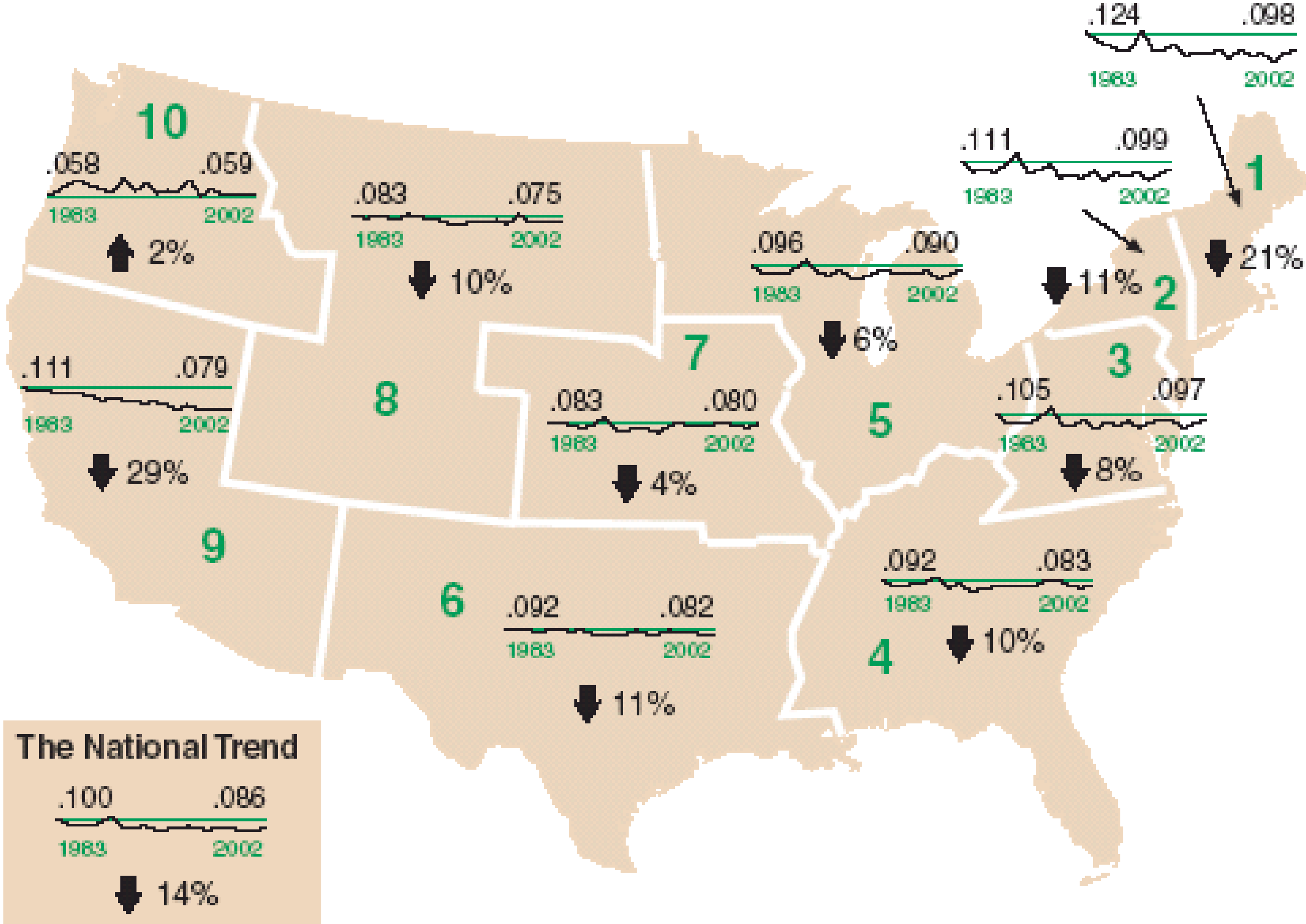
Pb max quarterly avg, 1980-1999

Pb Emissions:



Trend in 8-Hour Ozone Levels, 1983–2002, Averaged across EPA Regional Office Boundaries

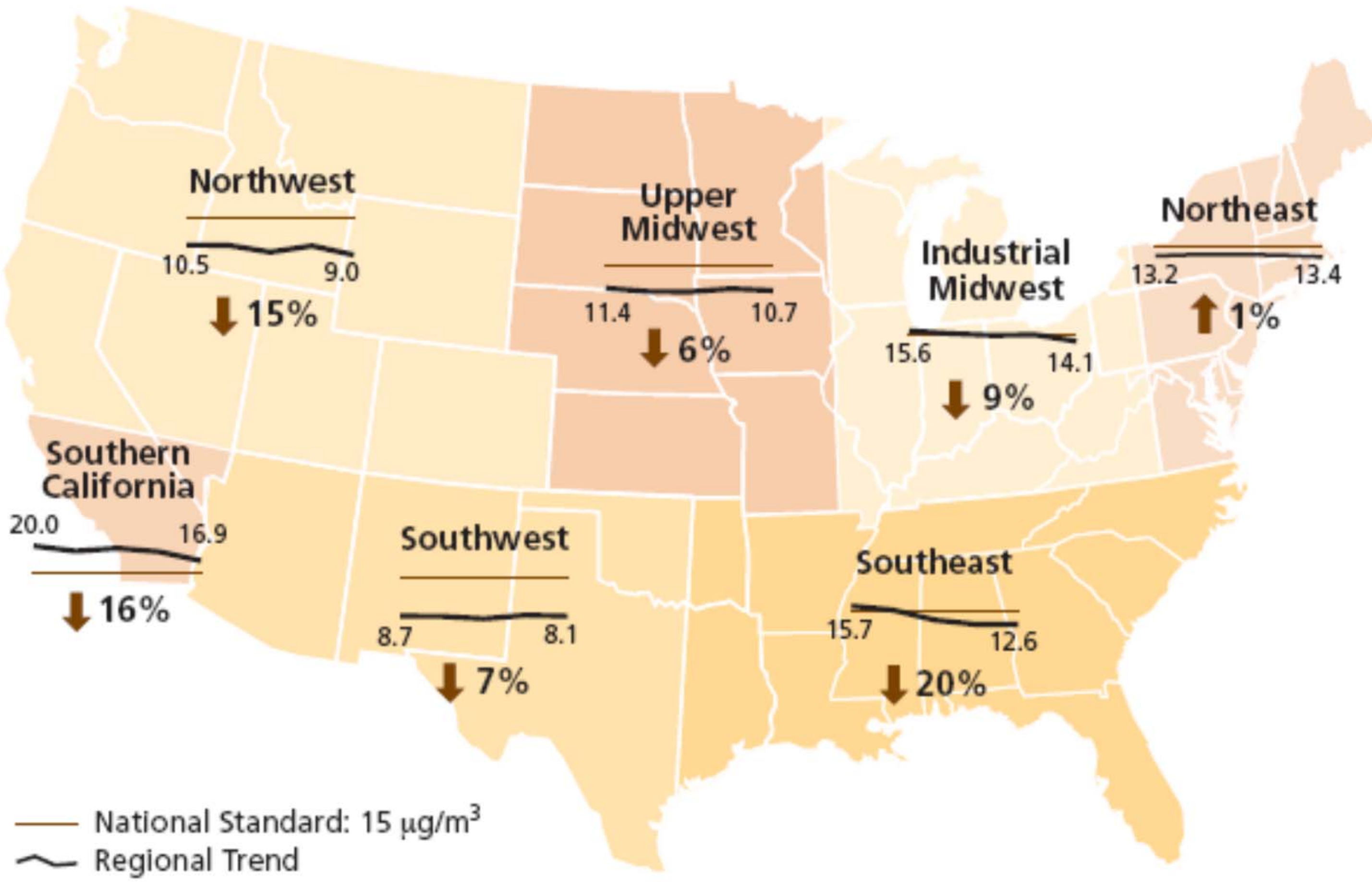
Based on Annual 4th Maximum 8-Hour Average



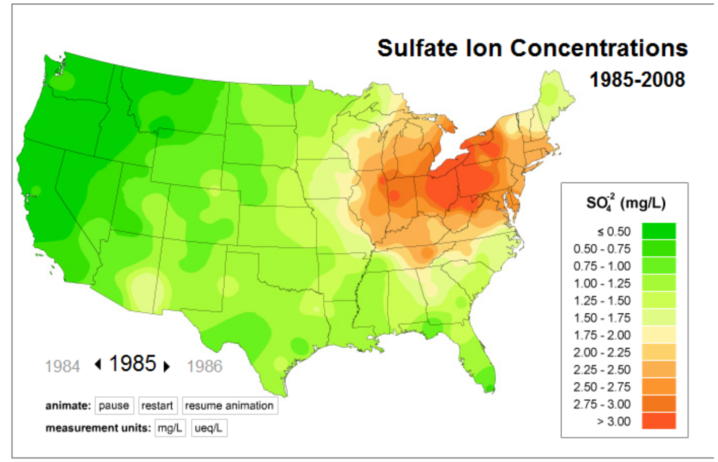
Concentrations are in parts per million (ppm).

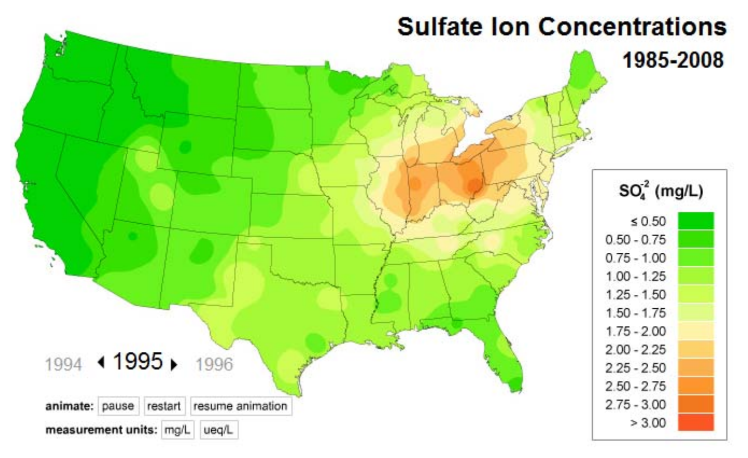
Regional and national trends in annual average $PM_{2.5}$ concentrations and emissions related to $PM_{2.5}$ formation, 1999–2003.

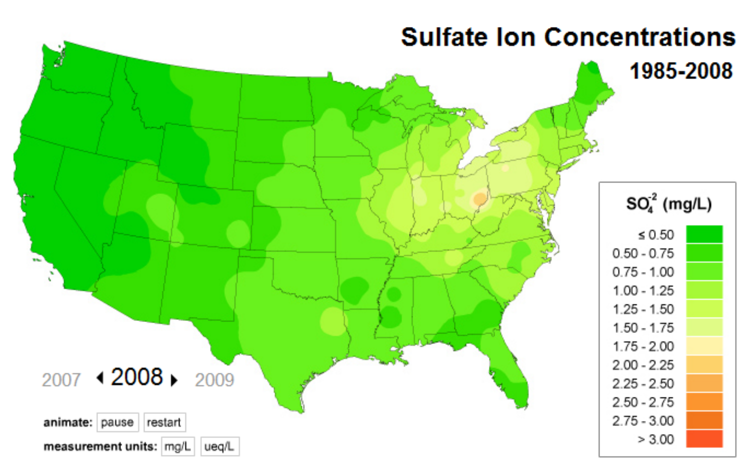
Annual Average $PM_{2.5}$ Concentrations, 1999–2003



Sulfate particles are formed downwind in the atmosphere by oxidation of SO_2 that is emitted primarily by coal power plants in the midwest.







Percent Change in Air Quality

	1980 vs 2009	1990 vs 2009
Carbon Monoxide (CO)	-80	-70
Ozone (O3) (8-hr)	-30	-21
Lead (Pb)	-93	-73
Nitrogen Dioxide (NO2)	-48	-40
PM10 (24-hr)	---	-38
PM2.5 (annual)[2]	---	-27
PM2.5 (24-hr)[2]	---	-28
Sulfur Dioxide (SO2)	-76	-65

Notes:
1. --- Trend data not available
2. PM2.5 air quality based on data since 2000
3. Negative numbers indicate improvements in air quality

http://www.epa.gov/airtrends/aqtrends.html#airquality

Health Effects

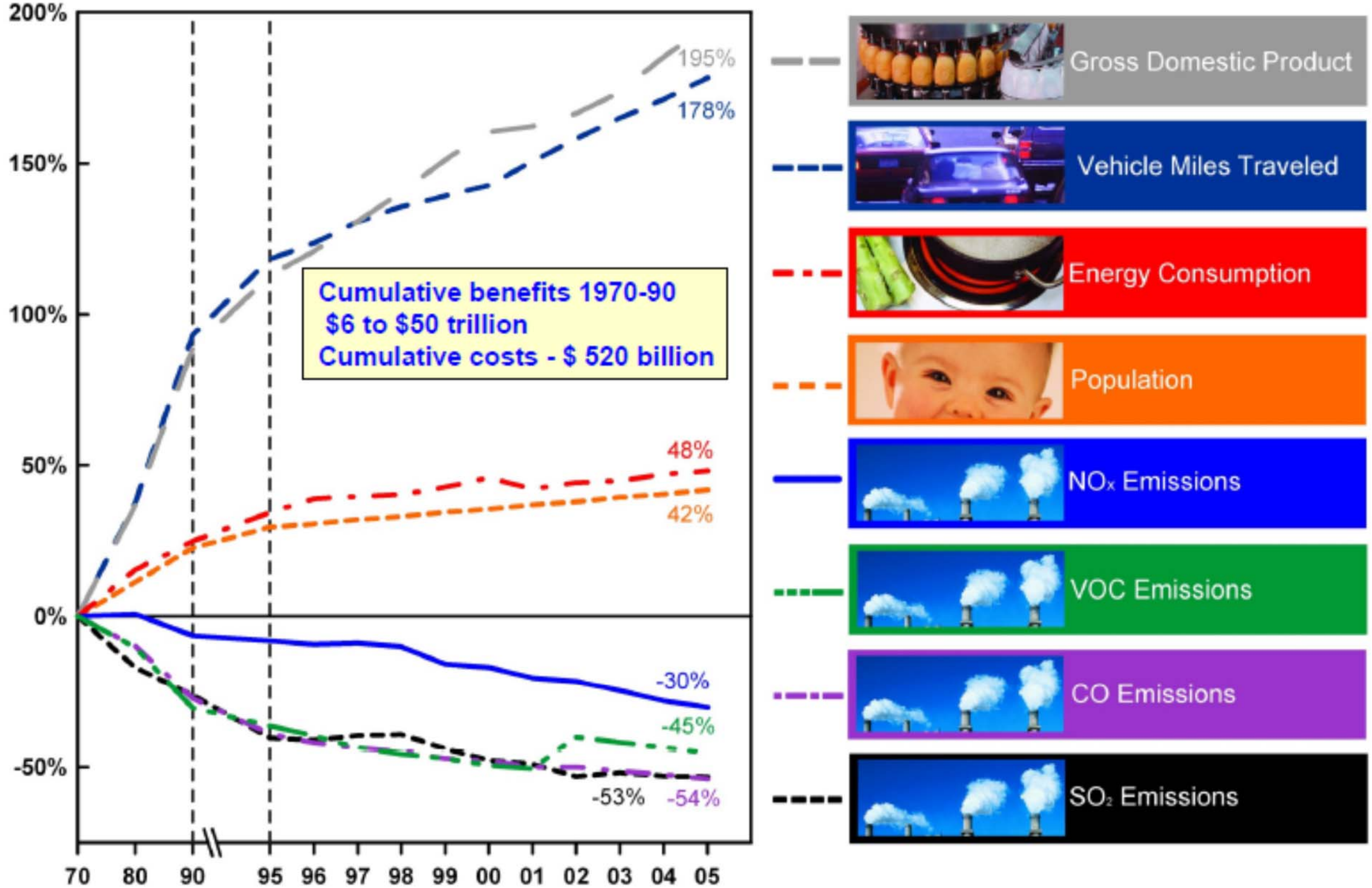
POLLUTANT	HEALTH EFFECTS	EXAMPLES OF SOURCES
Particulate Matter (PM2.5 and PM10: less than or equal to 2.5 or 10 microns, respectively)	• Hospitalizations for worsened heart diseases • Emergency room visits for asthma • Premature death	• Cars and trucks (especially diesels) • Fireplaces, woodstoves • Windblown dust from roadways, agriculture and construction
Ozone (O_3)	• Cough, chest tightness • Difficulty taking a deep breath • Worsened asthma symptoms • Lung inflammation	• Precursor sources*: motor vehicles, industrial emissions, and consumer products
Carbon Monoxide (CO)	• Chest pain in heart patients** • Headaches, nausea** • Reduced mental alertness** • Death at very high levels**	• Any source that burns fuel such as cars, trucks, construction and farming equipment, and residential heaters and stoves
Nitrogen Dioxide (NO_2)	• Increased response to allergens ▪ Worsened asthma symptoms	• See carbon monoxide sources
Sulfur Dioxide (SO_2)	▪ Bronchoconstriction ▪ Worsened asthma symptoms	▪ Coal-fired power plants ▪ Smelters ▪ High sulfur fuel combustion

*Ozone is not generated directly by these sources. Rather, chemicals emitted by these precursor sources react with sunlight to form ozone in the atmosphere.

**Health effects from CO exposures occur at levels considerably higher than ambient.

http://www.arb.ca.gov/research/health/health.htm

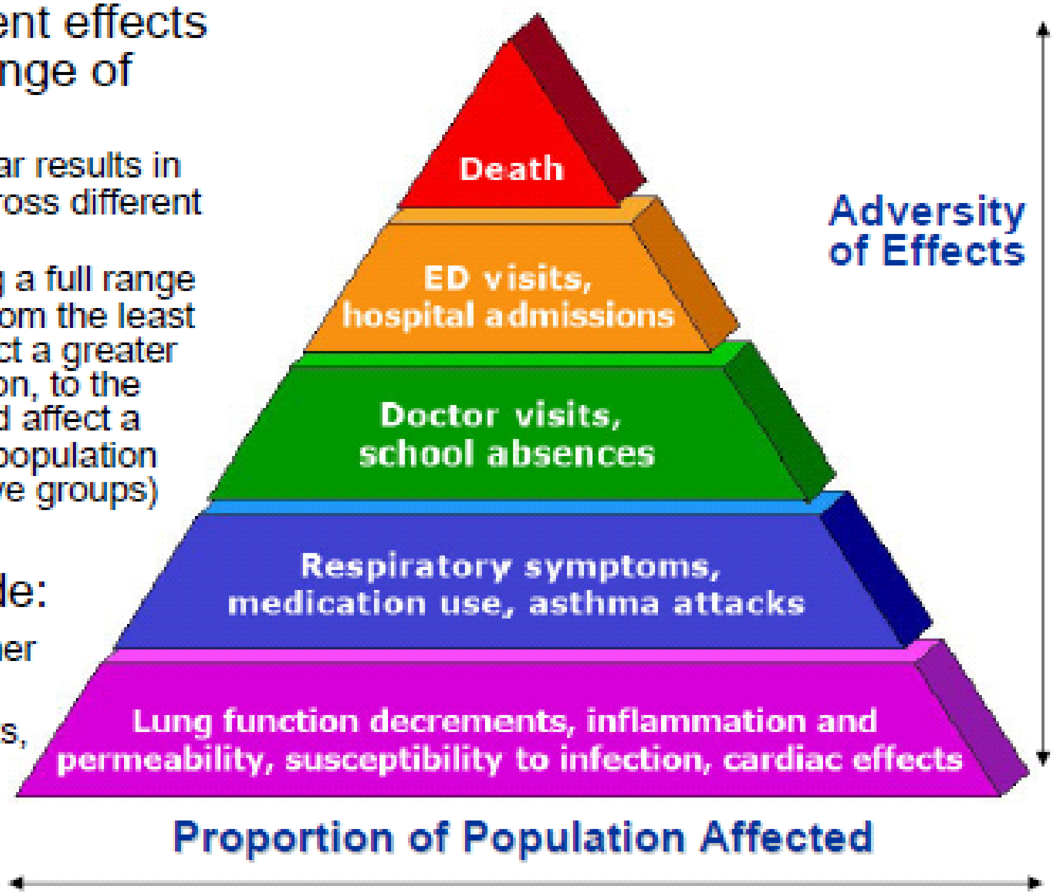
The Clean Air Act Success Story



Bachmann, 2008

Ozone Health Effects Overview: “Pyramid of Effects”

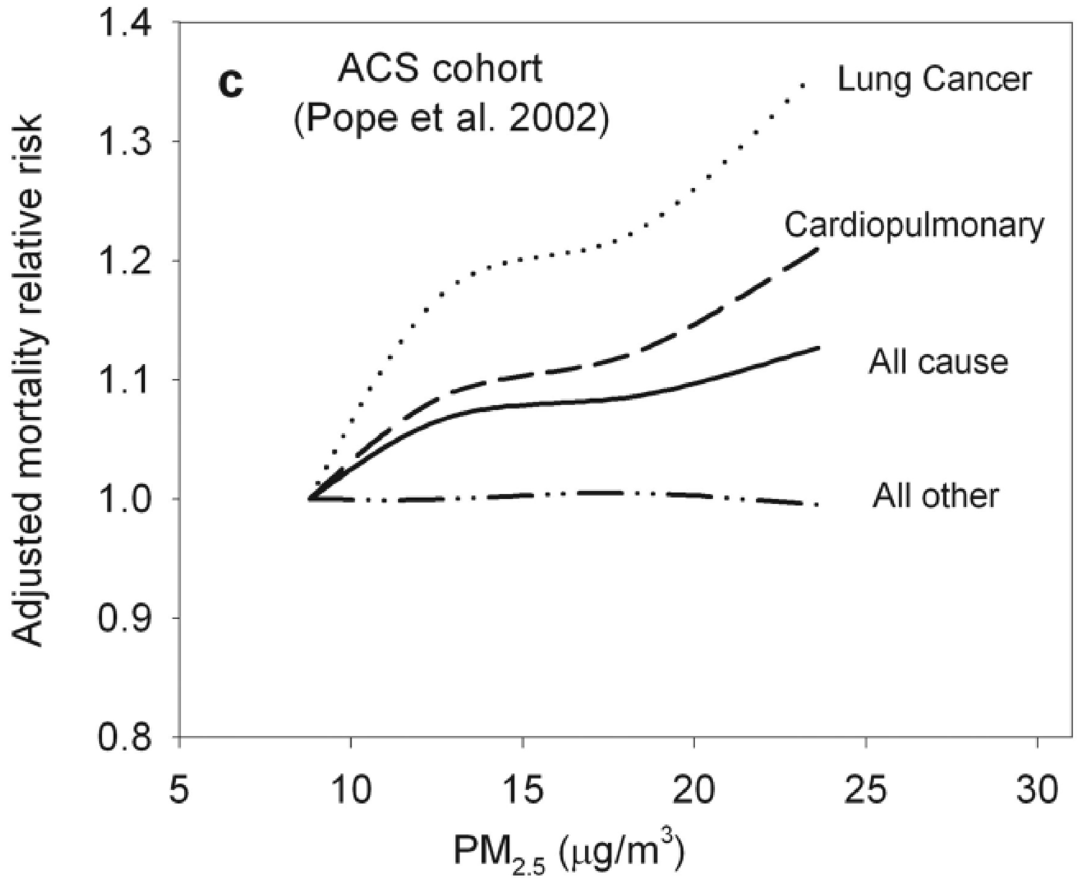
- Consistent and coherent effects seen across a wide range of health outcomes
  - Consistent effects -- similar results in different locations and across different types of studies
  - Coherent effects -- finding a full range of related health effects from the least serious, which would affect a greater proportion of the population, to the most serious, which would affect a smaller proportion of the population (primarily those in sensitive groups)
- Sensitive groups include:
  - Asthmatic children and other people with lung disease
  - All children and older adults, especially people active outdoors
  - Outdoor workers



EPA, 2007

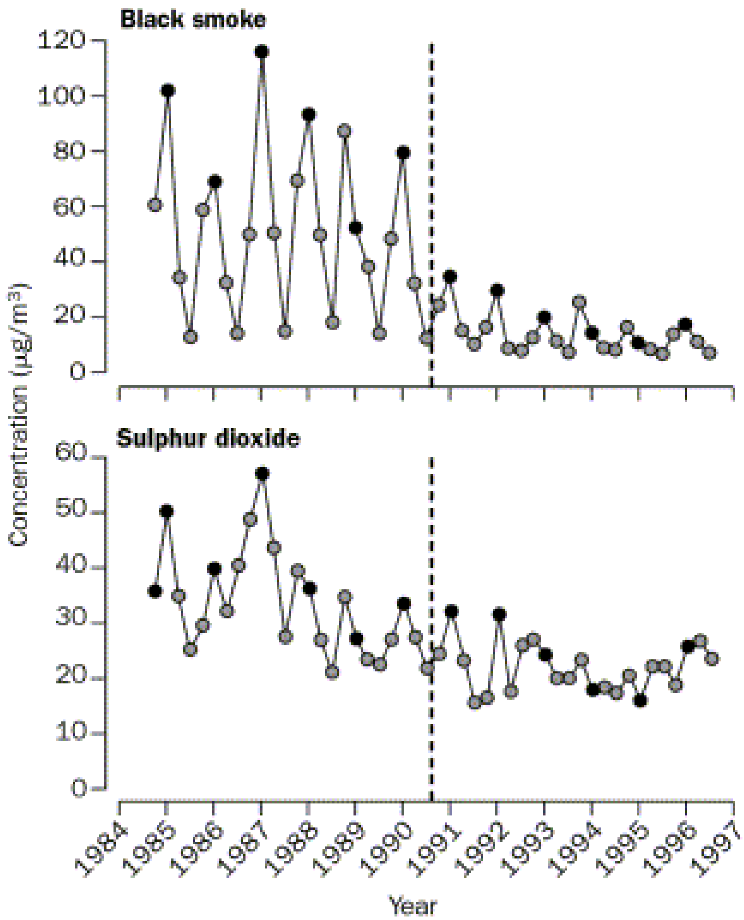
Chronic Effects of $PM_{2.5}$ Exposure

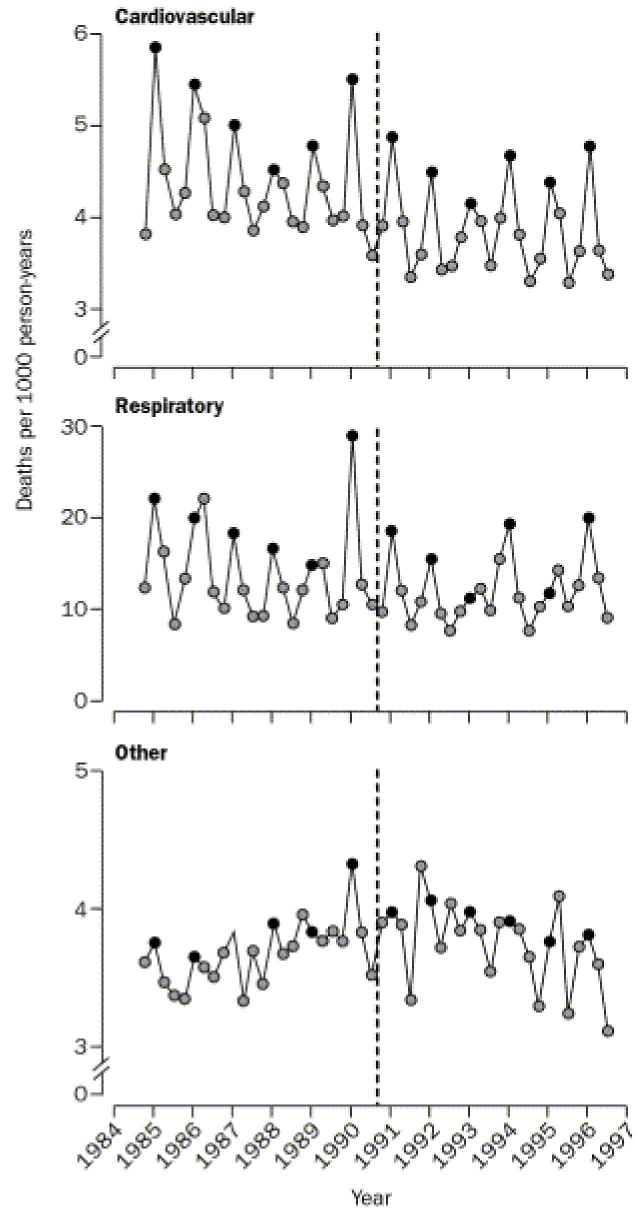
Long term exposure to $PM_{2.5}$ is associated with about a 20% higher risk of cardiopulmonary mortality for those living in a dirty city (annual avg. = 25μg/m^3) compared with those living in a 'clean' city (annual avg. = 10 μg/m^3)



Pope & Dockery JAWMA, 2006

Long-term exposures in Dublin, Ireland

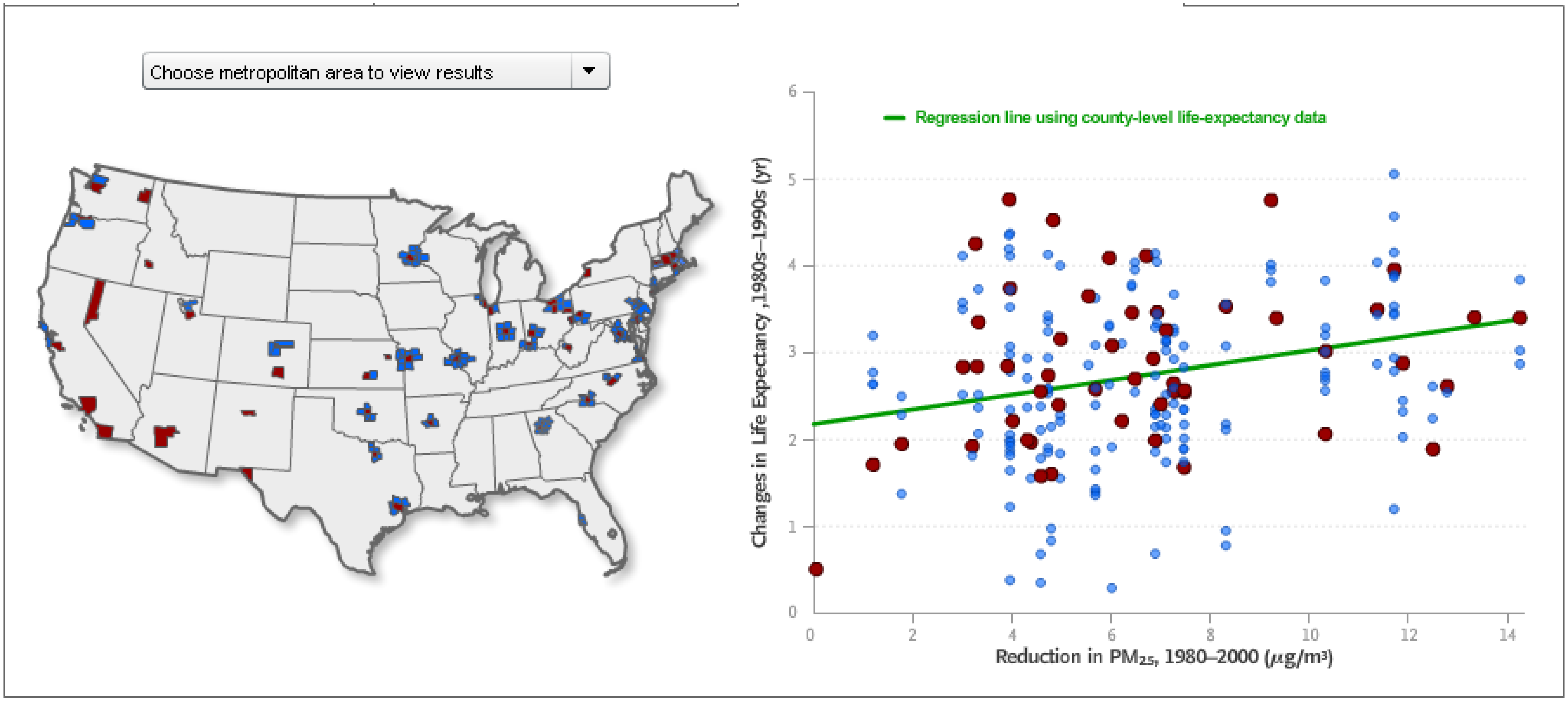




Clancy et al, 2002 The Lancet 360 (9341), 1210-1214

Health Benefits of reducing PM

Long-term decreases in $PM_{2.5}$ are associated with increased life expectancy



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Reducing greenhouse gas emissions from electricity generation also reduces health impacts from traditional air pollution

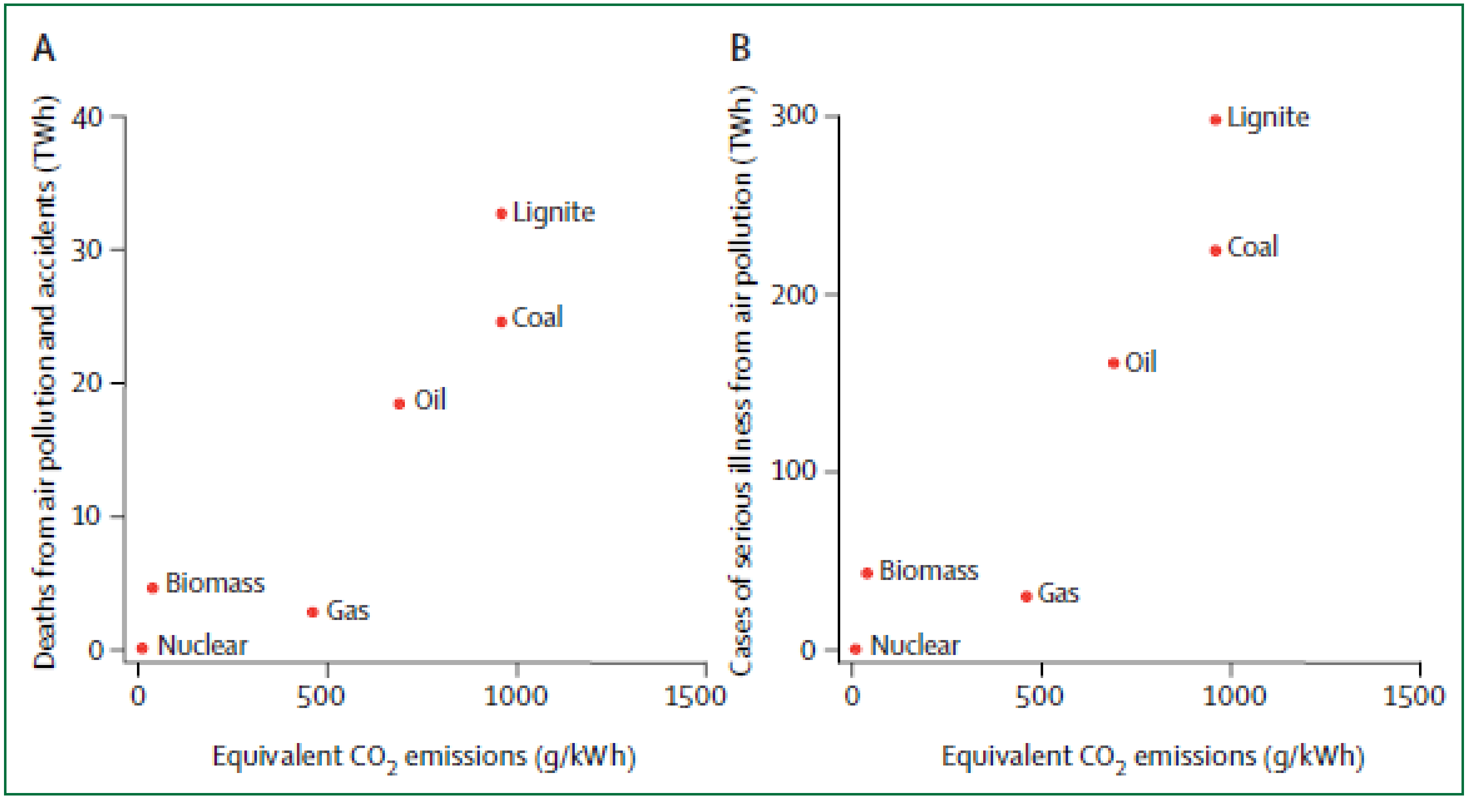


Figure 3 : Health effects of electricity generation per TWh
(A) deaths from air pollution and accidents involving workers or the public; (B) cases of serious illness attributed to air pollution. Data for CO_2 equivalent emissions from IAEA, 2001.[40]

Markandya and Wilkinson, Lancet, 2007

Monetized Damages from Air Pollution: Coal-Fired Plants

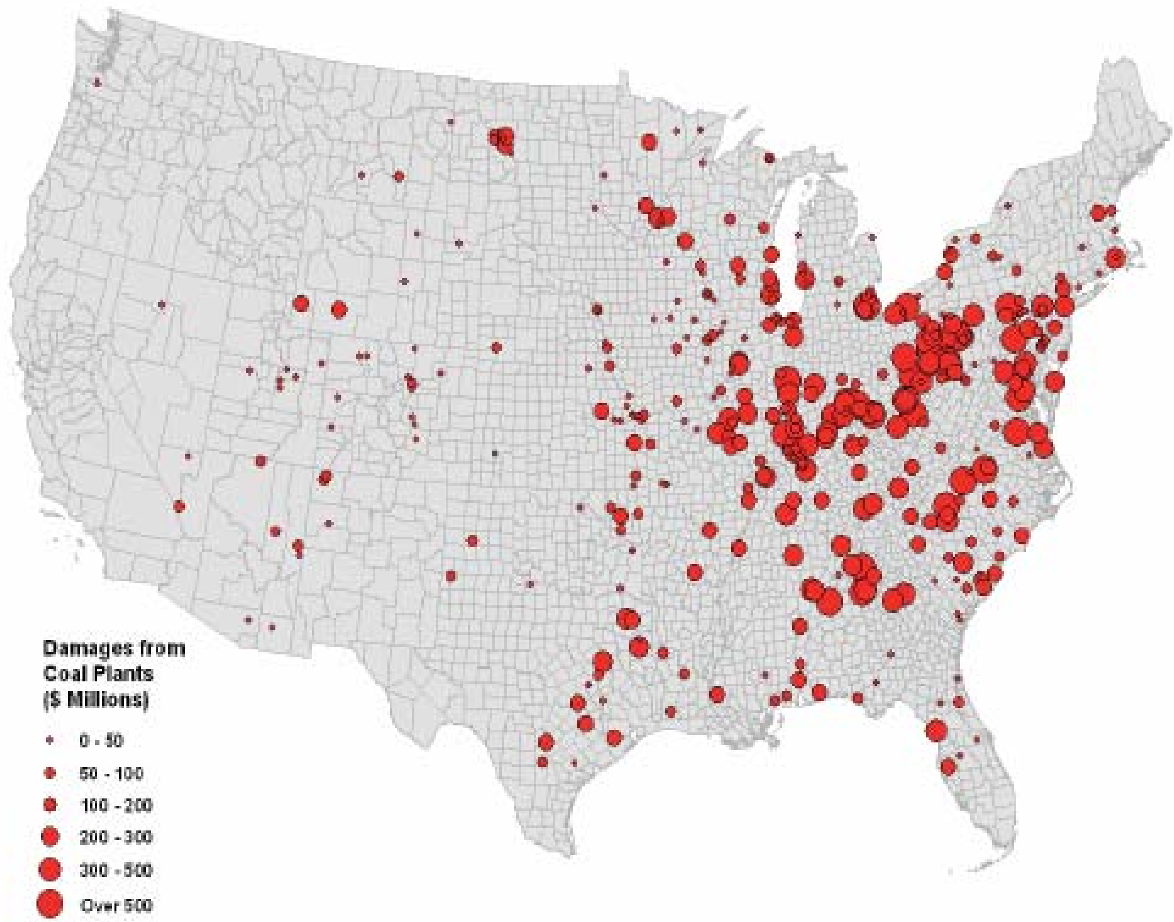


FIGURE 2-6 Air-pollution damages from coal generation for 406 plants, 2005 (U.S. dollars, 2007). Damages related to climate-change effects are not included.

Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption, National Research Council. "1 Introduction." *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. Washington, DC: The National Academies Press, 2010.

Monetized Damages from Air Pollution: Coal-Fired Plants

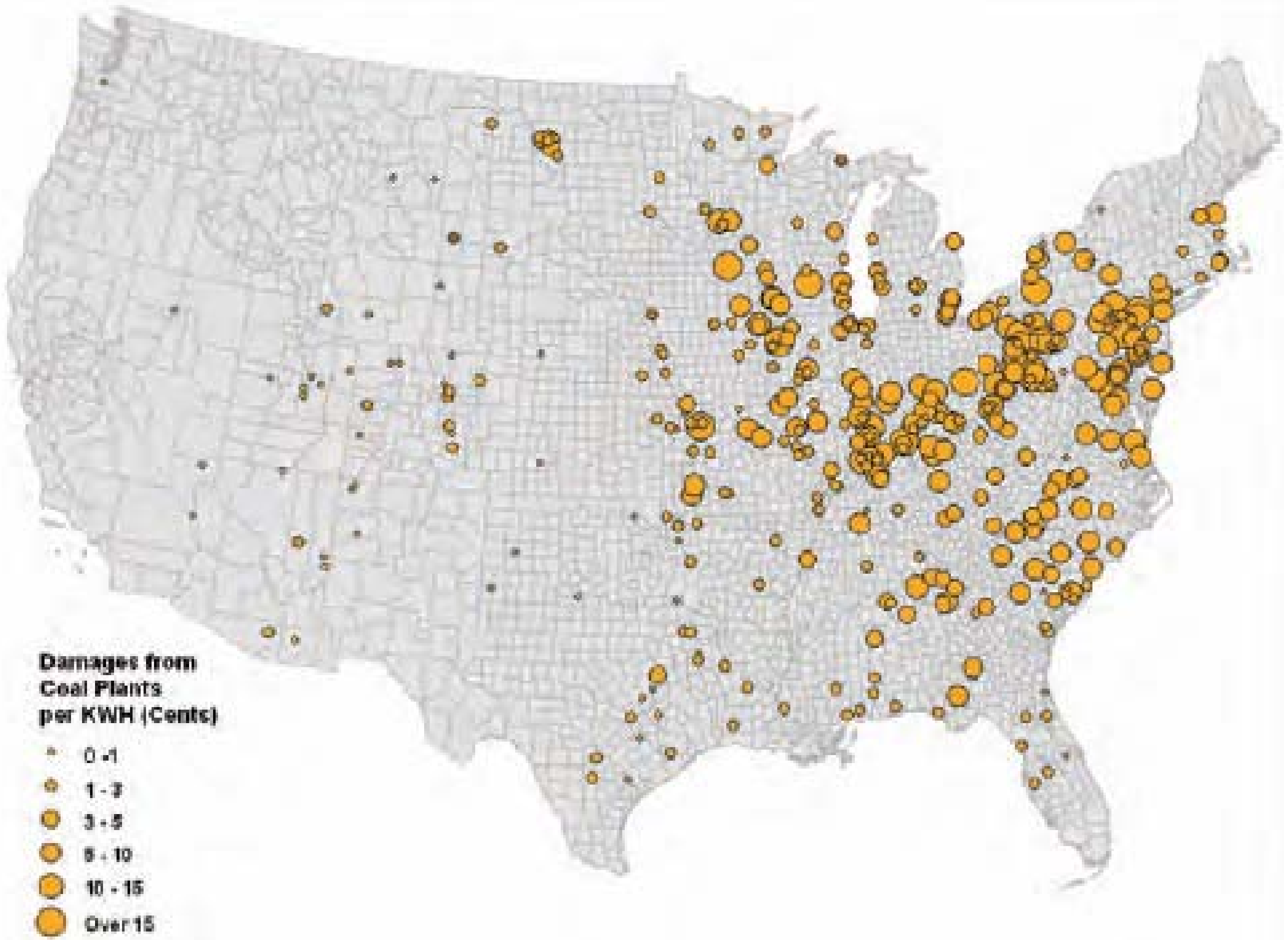


FIGURE 2-8 Regional distribution of air-pollution damages from coal generation per kWh in 2005 (U.S. dollars, 2007). Damages related to climate change are not included.

Monetized Damages from Air Pollution: Gas-Fired Plants

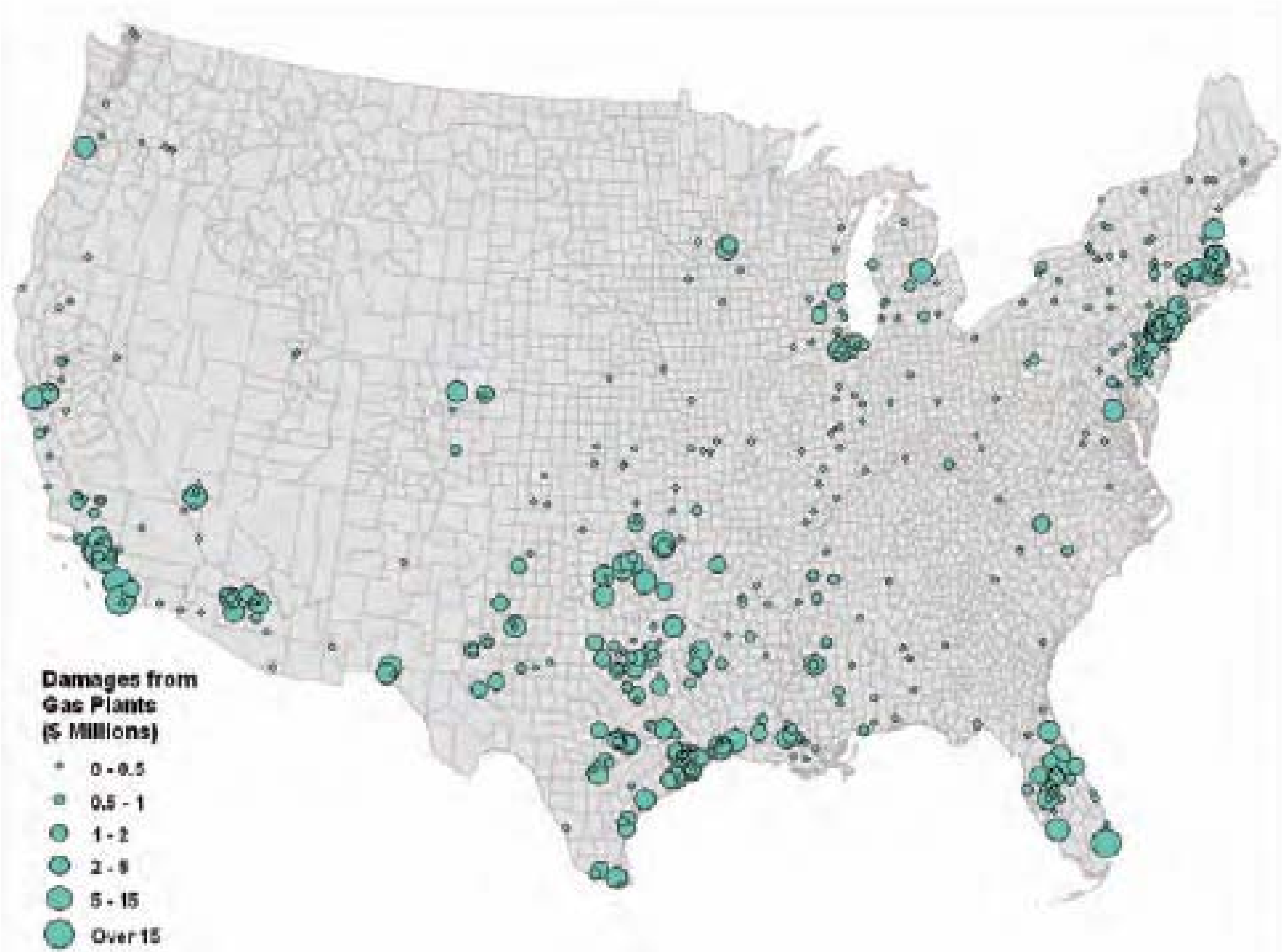


FIGURE 2-15 Criteria-air-pollutant damages from gas generation for 498 plants, 2005 (U.S. dollars, 2007). Damages related to climate change are not included.

Monetized Damages from Air Pollution: Gas-Fired Plants

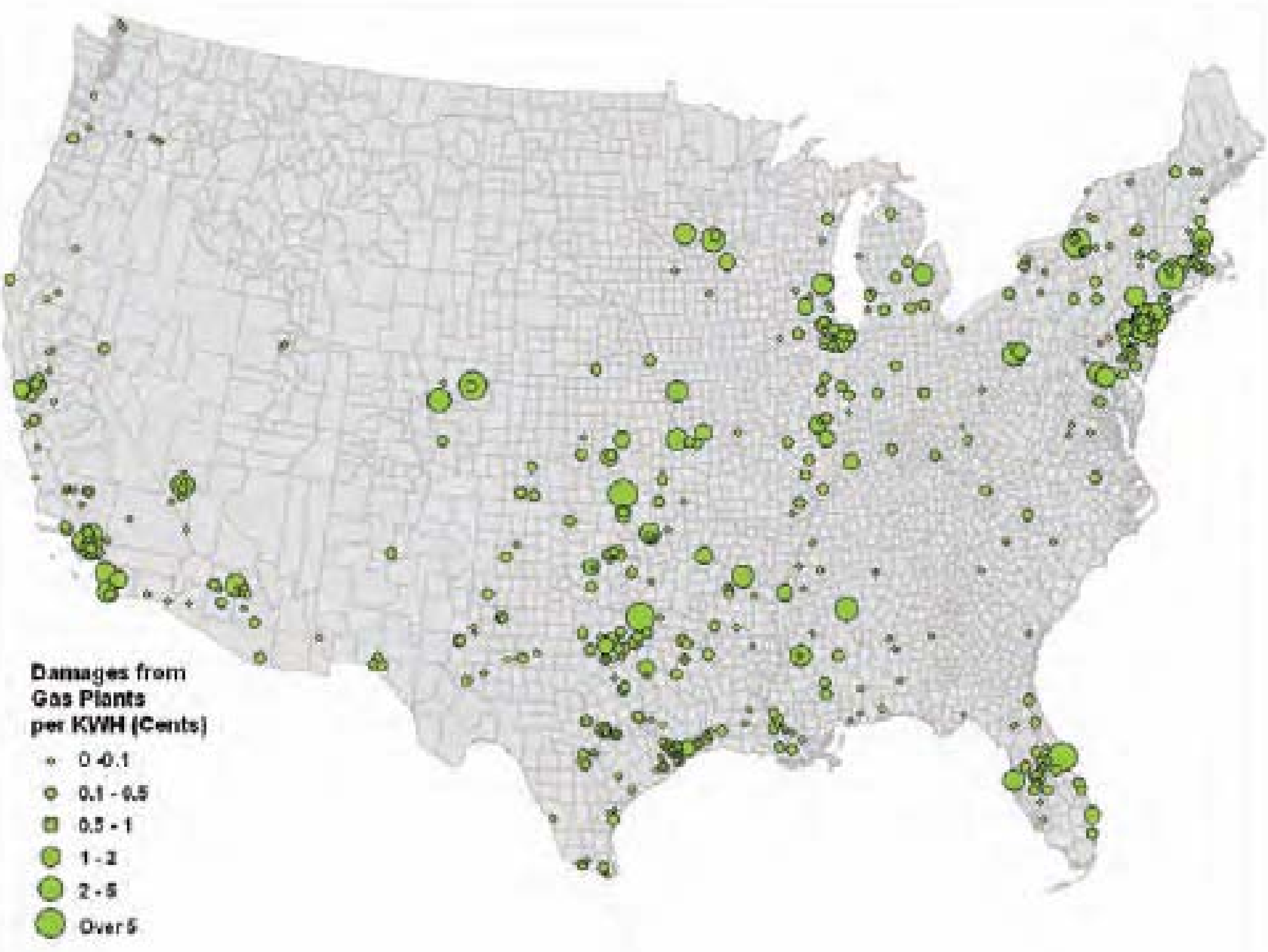
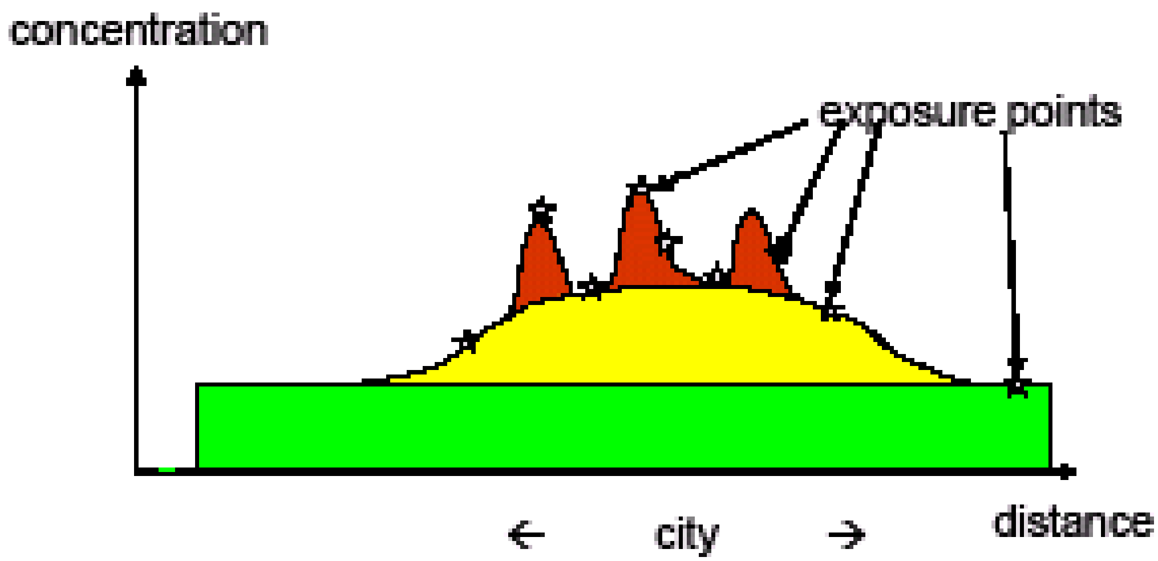


FIGURE 2-17 Regional distribution of criteria-air-pollutant damages from gas generation per kWh (U.S. dollars, 2007). Damages related to climate change are not included.

A recent regulatory focus on traffic-related pollutants

Most regulatory monitors in the U.S. capture urban scale pollution gradients, but not local gradients near roadways

$$C_{total} = C_{region} + C_{urban} + C_{local}$$



What pollutants are elevated near roadways?

Black Carbon (BC), CO, NOx, coarse and ultrafine particle concentrations are increased within 100 m downwind of major roadways relative to upwind values. In contrast, $PM_{2.5}$ is not very different.

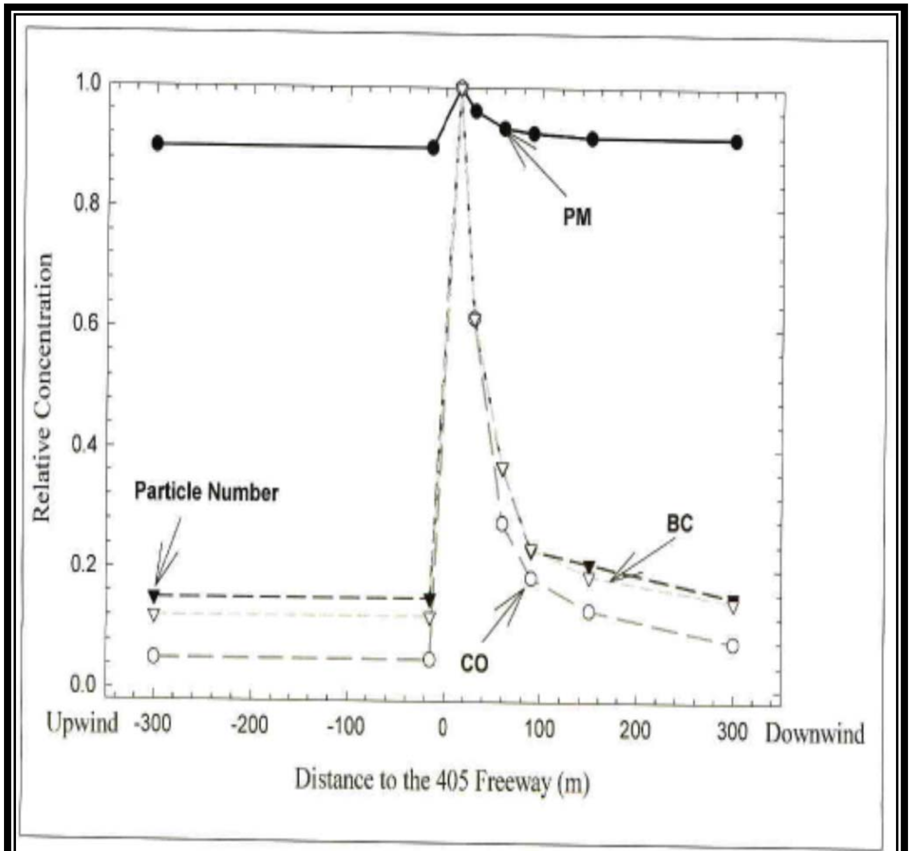
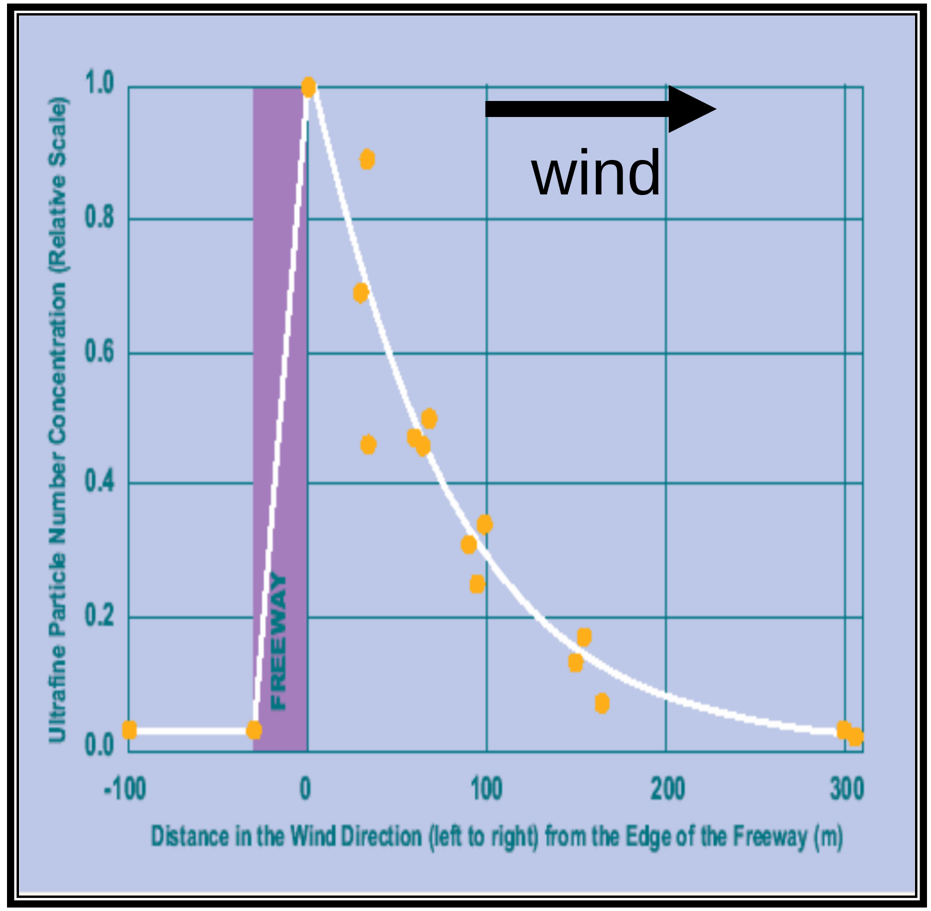


Figure 8. Relative mass, number, BC, and CO concentrations vs. downwind distance.



Zhu et al, 2002

Truck traffic vs. Lung Function

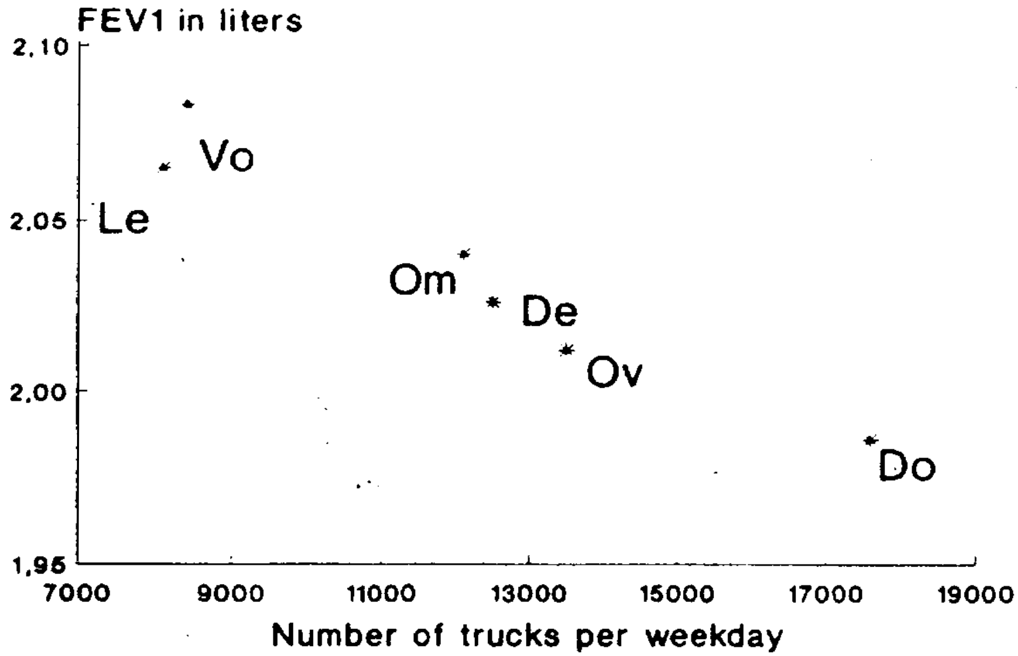


FIGURE 1. Association between truck traffic density and forced expiratory volume in 1 second (FEV_1) in children living <300 m from a motorway, adjusted for age, gender, smoking in the home, presence of pets, damp or mold stains in the home, ethnicity, number of persons in the household, gas cooking, gas-fired, unvented water heaters, and parental education. *Le* = Leiderdorp; *Vo* = Voorburg; *Om* = Ommoord; *De* = Delft; *Ov* = Overschie; *Do* = Dordrecht.

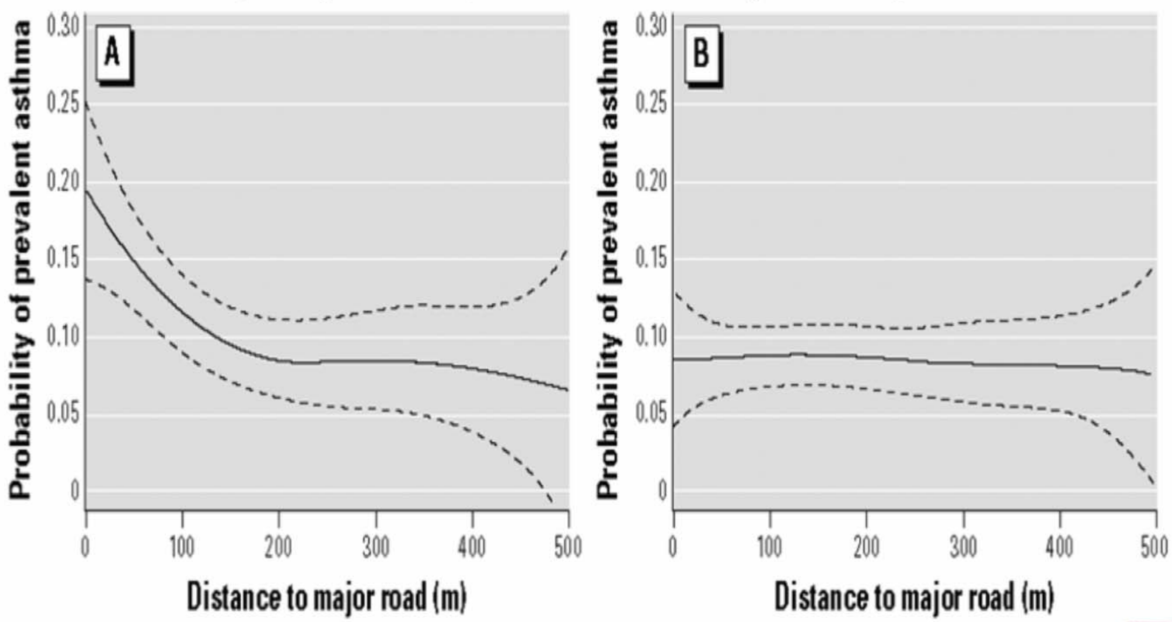
- SES gradient
- Truck vs. car
- Loop detectors

Brunekreff et al, 1997

Why are we concerned about these near-roadway exposures?

Prevalence of Asthma by Distance to a Major Road

Children (5-7 year old) with no family history of asthma



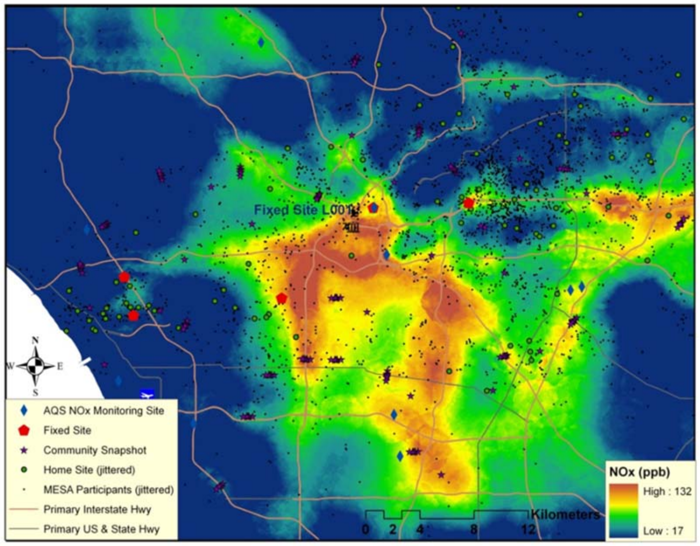
A. Long-term residents

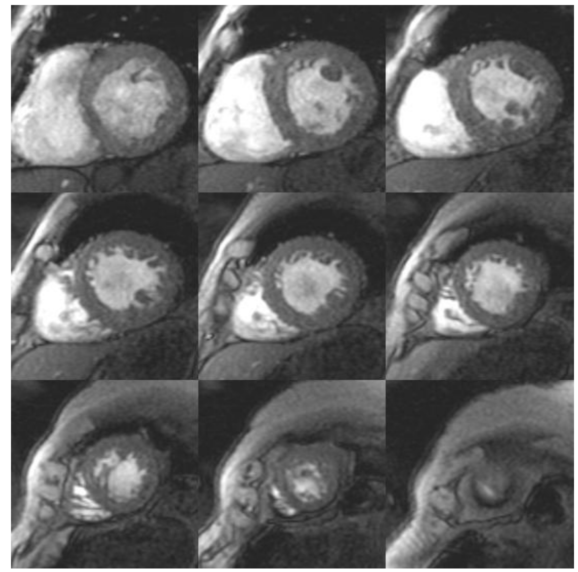
B. Short-term residents

McConnell et al, 2006

Children's Health Study

Association Between LVMI and NO_x Exposure

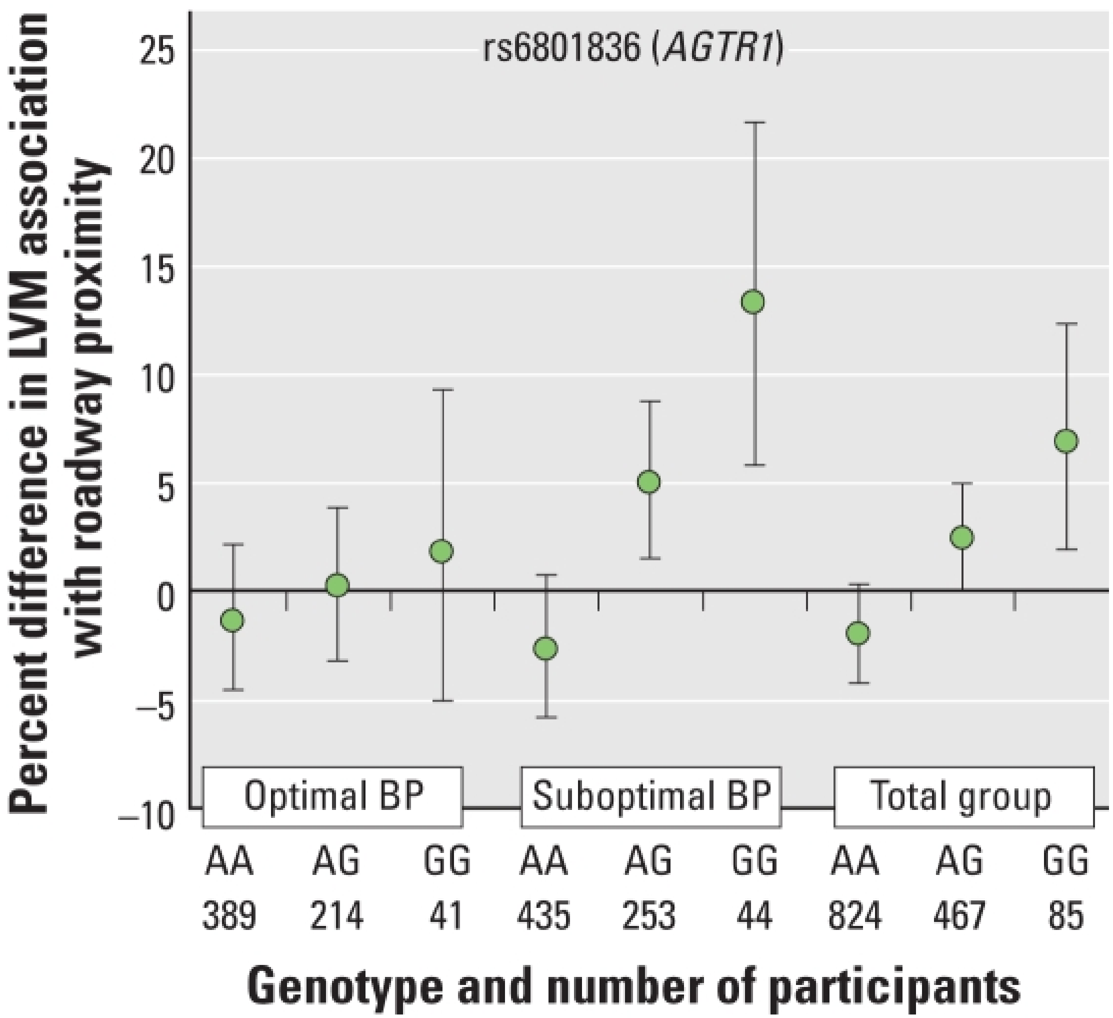




- Left ventricular mass index (LVMI) is a marker of subclinical cardiovascular disease, measured by cardiac MRI in MESA cohort
- Increased LVMI associated with hypertension, atherosclerosis, failure

VanHee et al., 2011

Near-road effects modulated by genes associated with blood pressure regulation



VanHee et al., EHP 2010

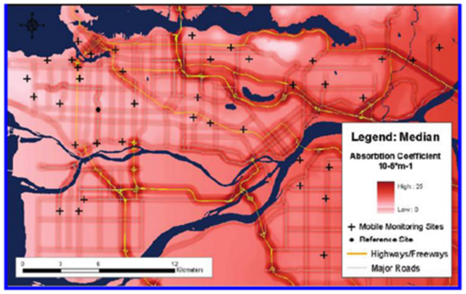
UW & UBC Studies

Long-term exposure to traffic soot is correlated with CHD mortality

Spatial distribution of soot

Vancouver, BC

(late summer)

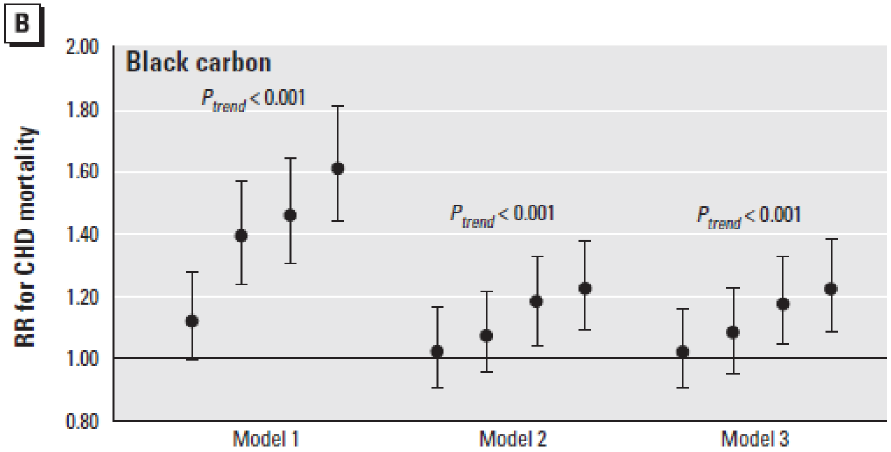


c.v. $R^2 \sim 0.7$

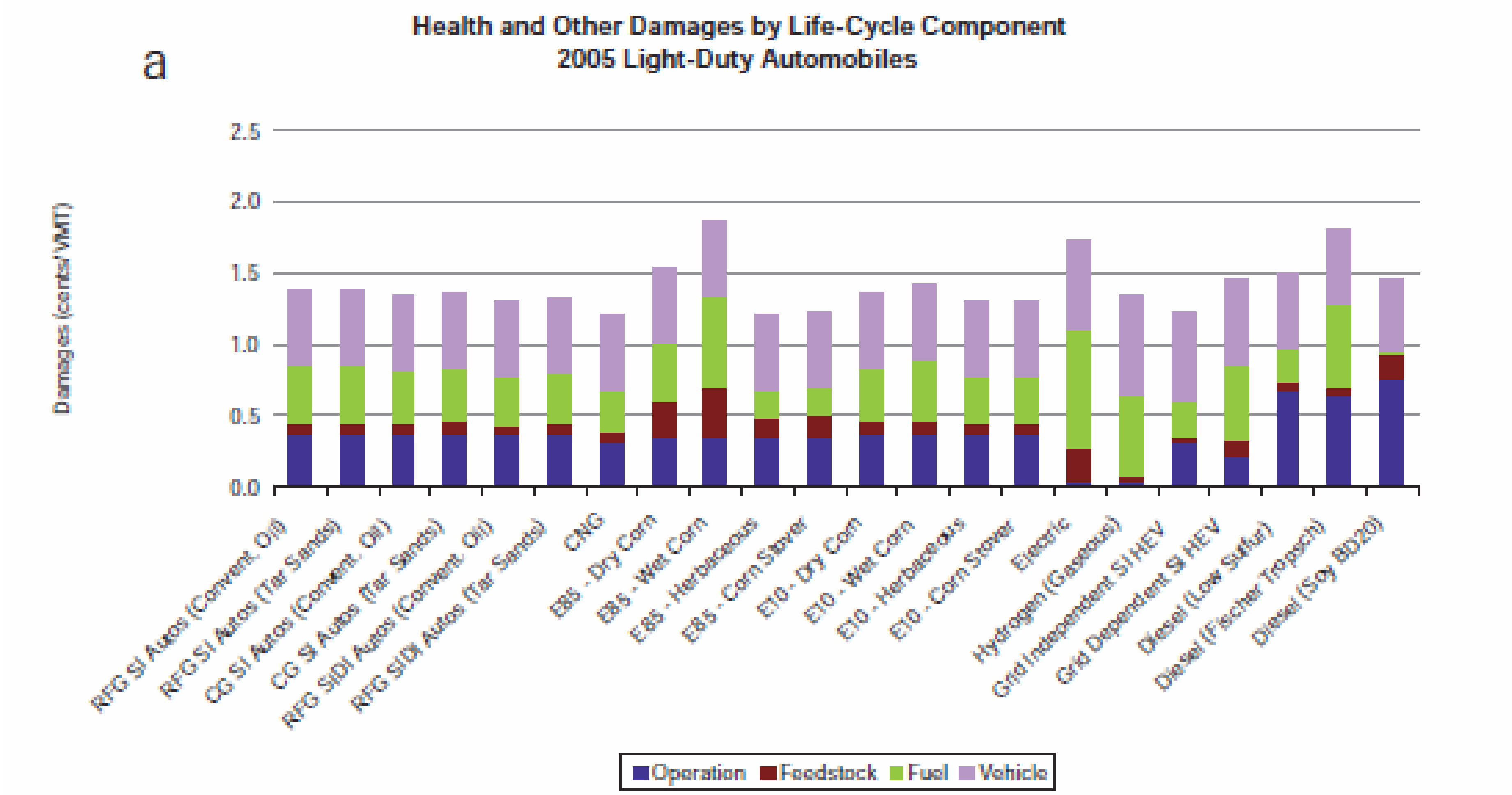
Larson et al (2009) *Environmental Science and Technology* 43(13), 4672-4678.

Coronary Heart Disease Mortality

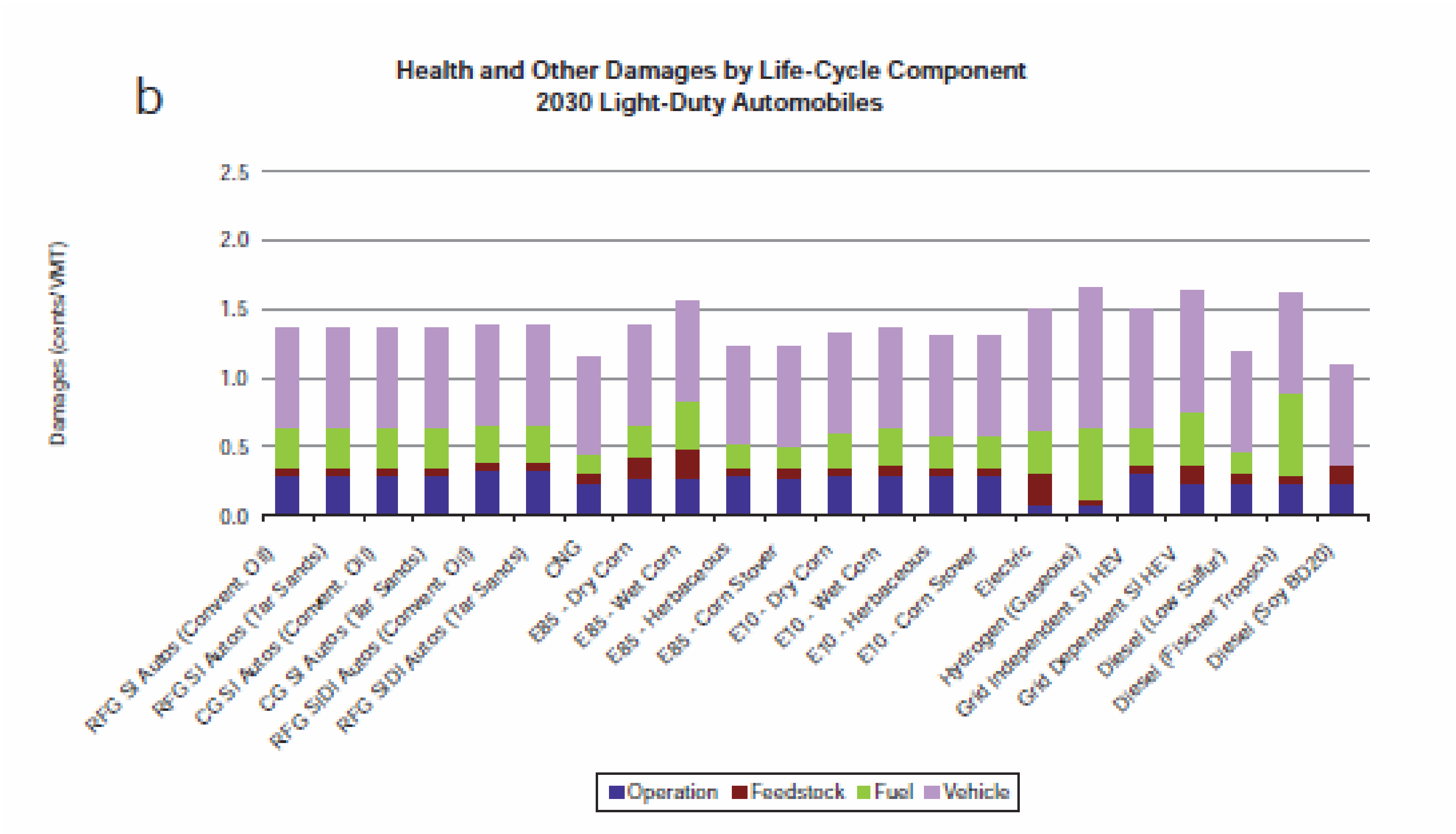
(452,725 participants)



Gan et al, Environ Health Perspect 119:501–507 (2011).



Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption, National Research Council. "1 Introduction." *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. Washington, DC: The National Academies Press, 2010.

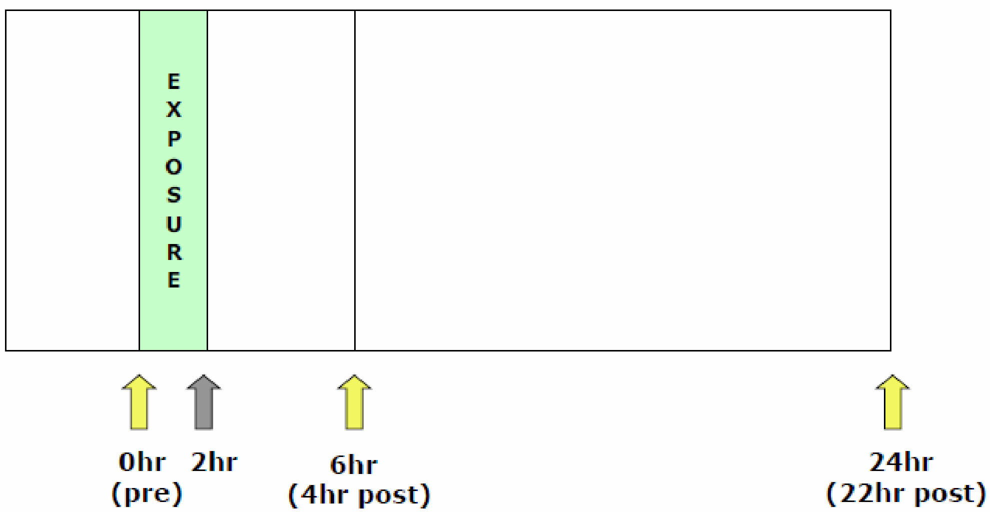


Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption, National Research Council. "1 Introduction." *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. Washington, DC: The National Academies Press, 2010.

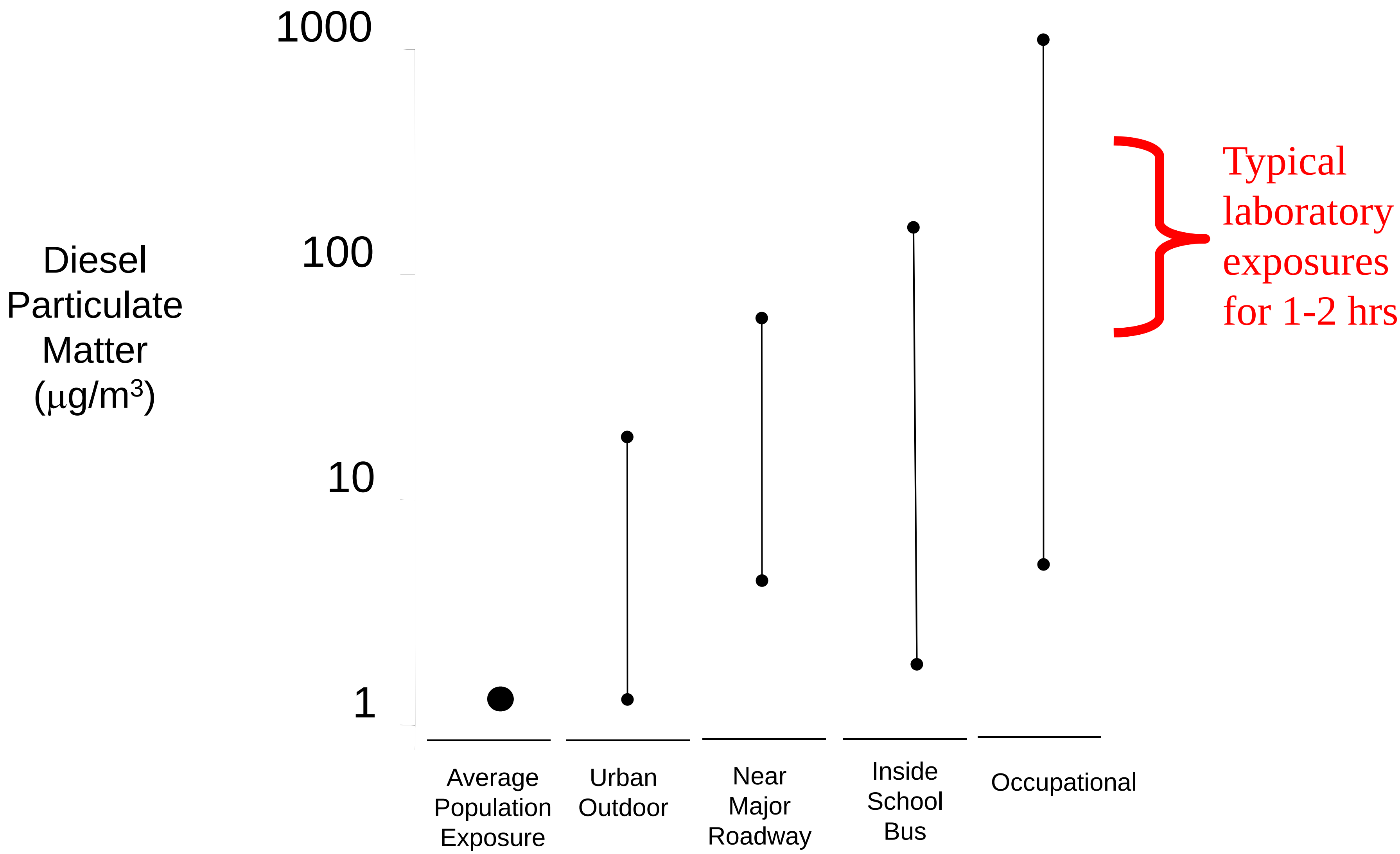
Laboratory Health Effects Studies

Human Controlled Exposure Study

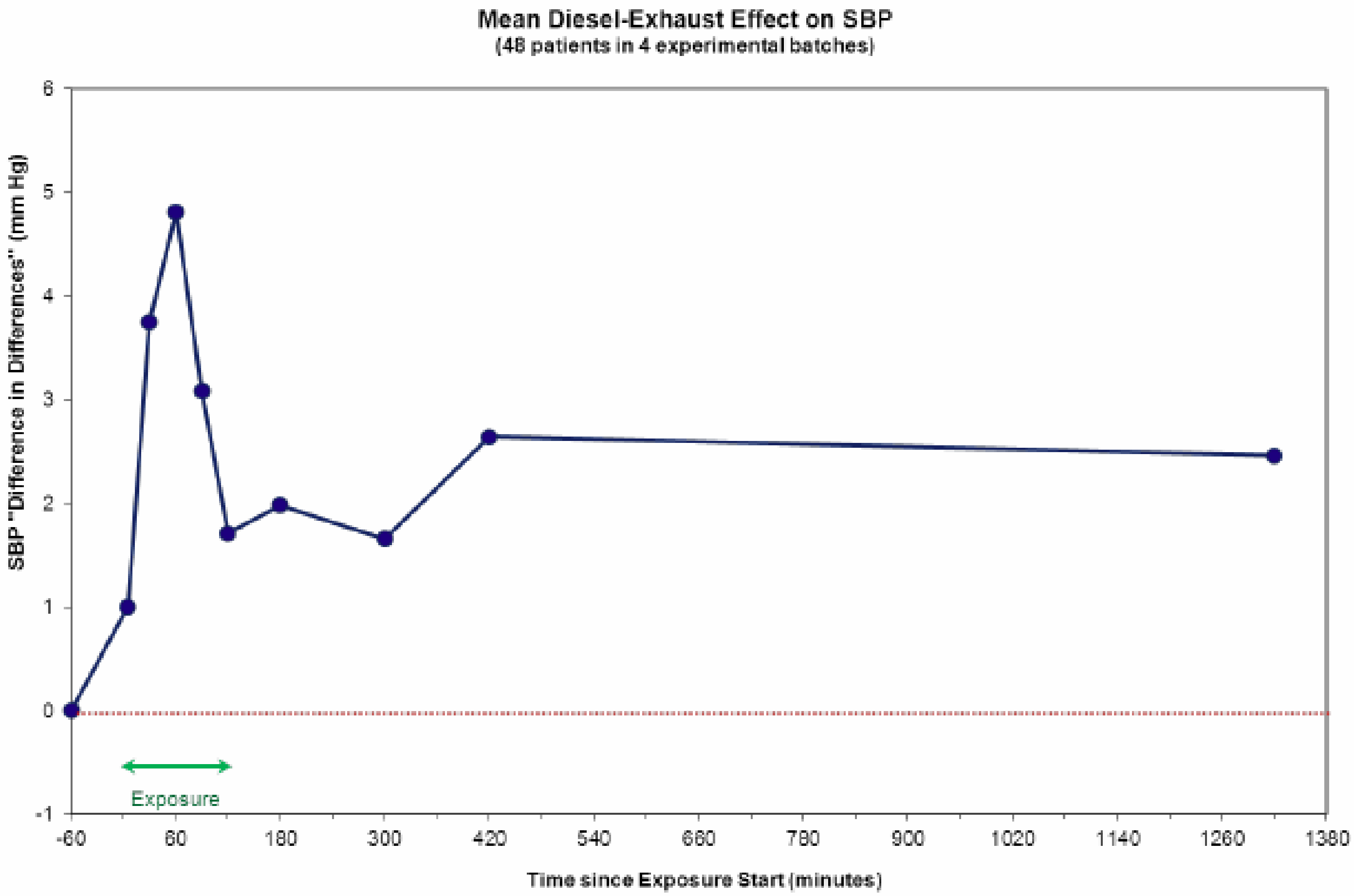
- 2 hrs at specified concentrations of pollutants or FA
- Monitor BP
- Serial blood draws
- Serial brachial artery dimensions and FMD



Exposures to Diesel Exhaust



DE Impact on Blood Pressure



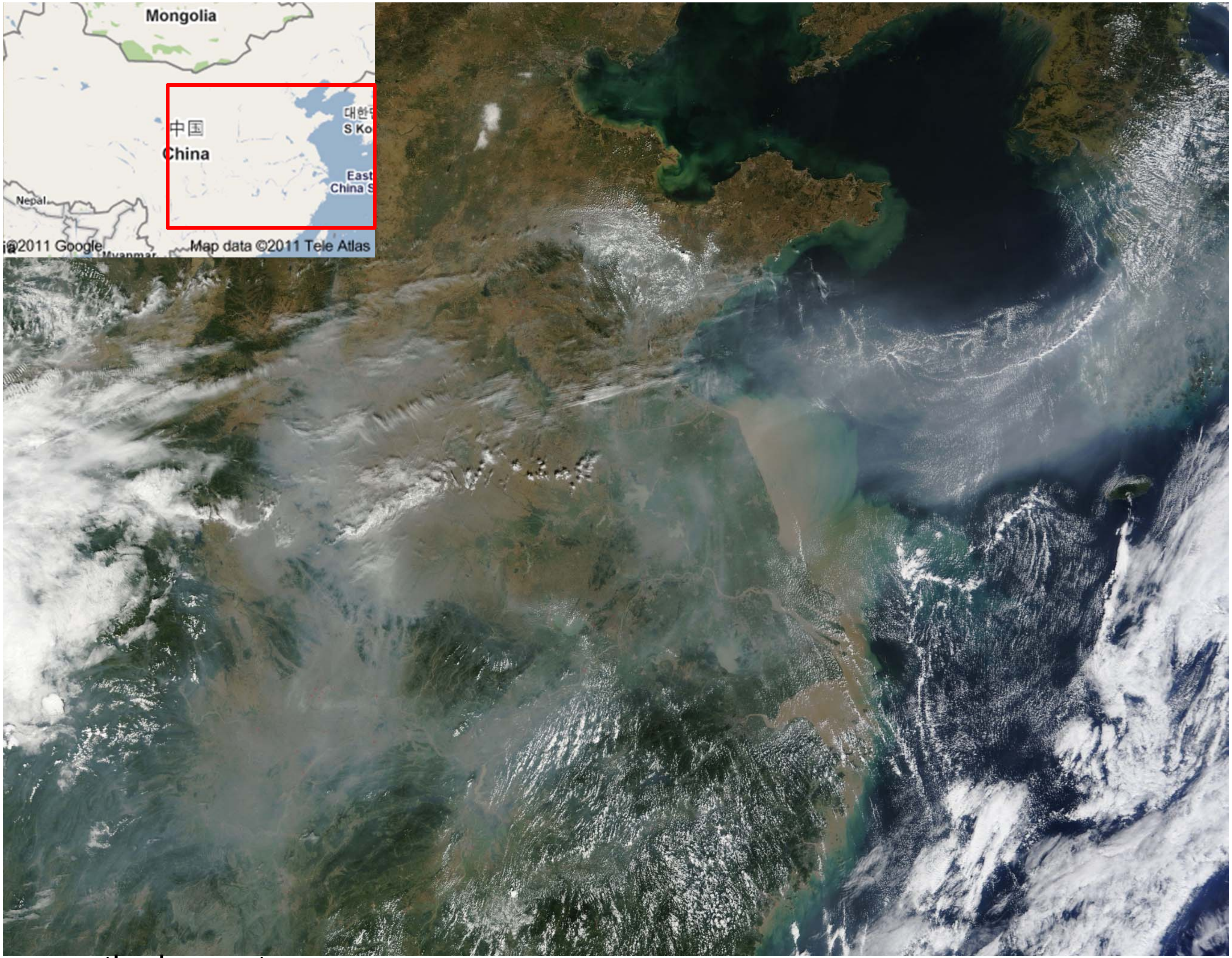
Cosselman et al, 2011

International Air Quality

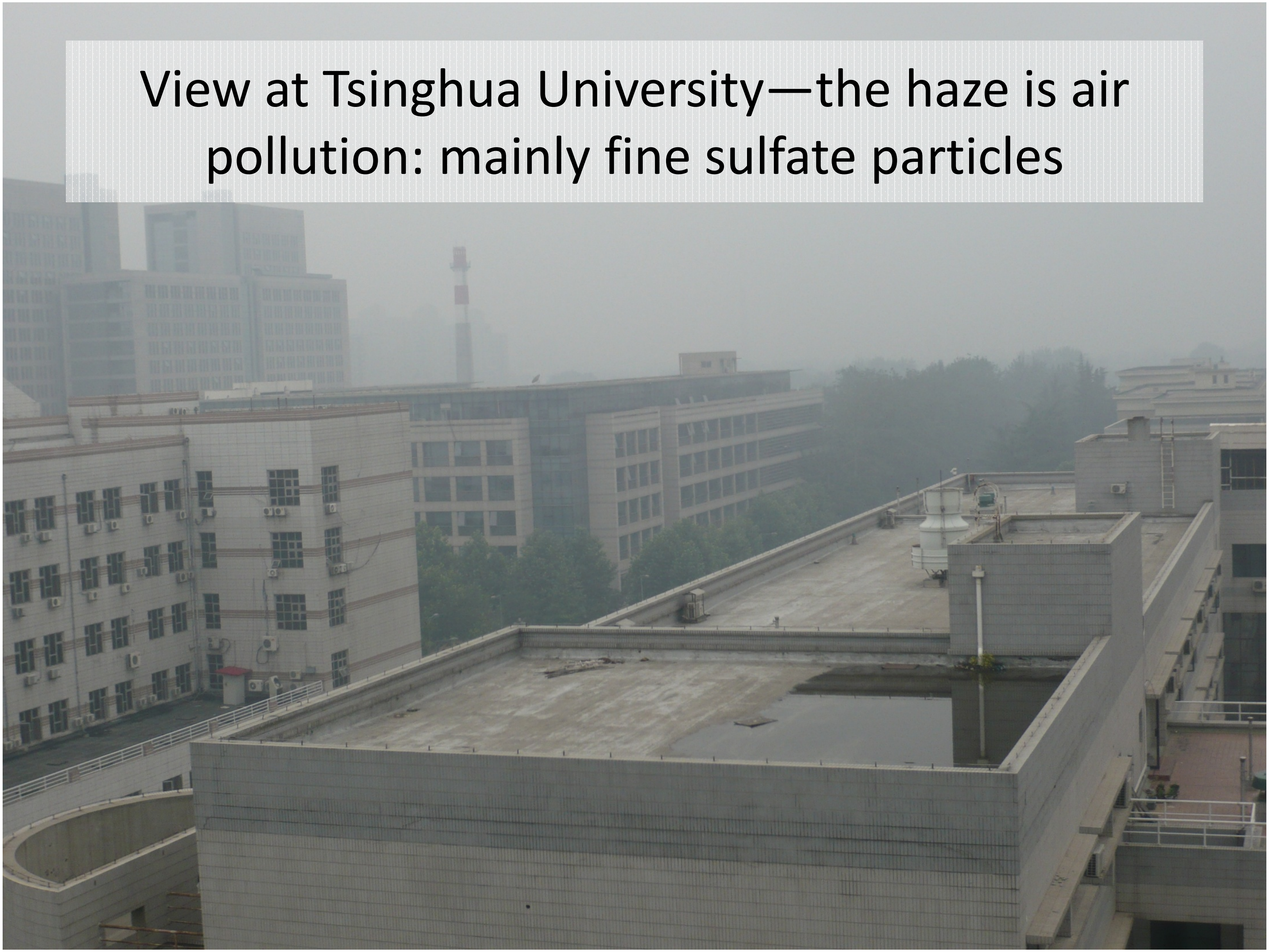
	PM$_{10}$ (µg/m^3)		PM$_{2.5}$ (µg/m^3)		Ozone (µg/m^3)	
	1 year	24 hours	1 year	24 hours	8 hours	1 hour
WHO *(2)*	20	50 [a]	10	25 [a]	100	
European Union *(3)*	40	50 [b]			120	
United States *(4)*		150	15	**35**	**147**	
California *(5)*	20	50	12		137	180 [c]
Japan *(6)*		100				118 [c]
Brazil *(7)*	50	150				160
Mexico *(8)*	50	120	15	65	157 [c]	216
South Africa *(9)*	60	180				235
India *(10)* (sensitive populations/	50/60/120					
China *(11)* (Classes I/II/III) [d]	40/100/150	50/150/250				120/160/200

[a] Not to be exceeded more than 3 days per year.
[b] Not to be exceeded more than 35 days per year.
[c] Photochemical oxidants.
[d] Class I: tourist, historical and conservation areas; Class II: residential urban and rural areas; Class III: industrial and heavy traffic areas.

WHO, 2005



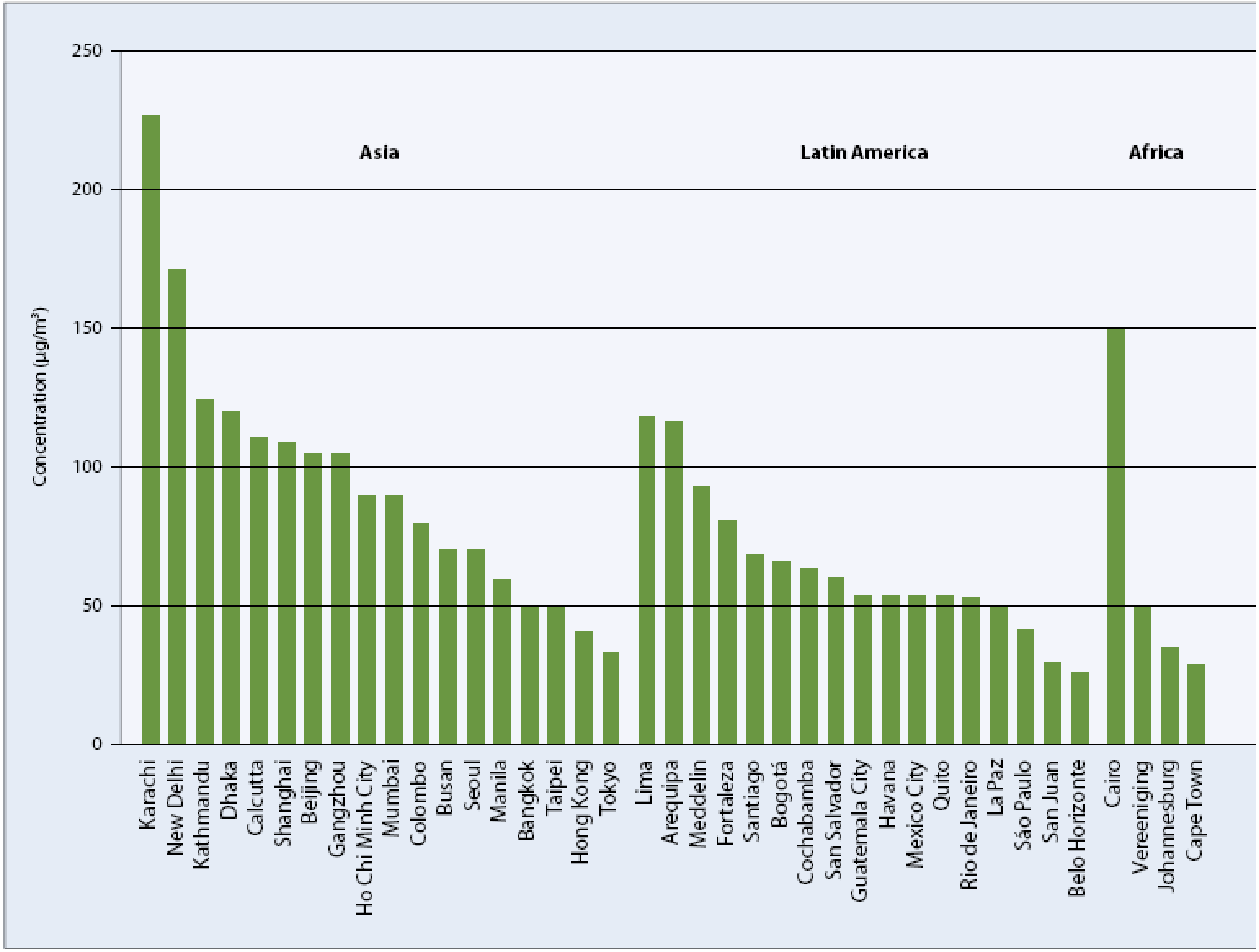
Nasa earth observatory


View at Tsinghua University—the haze is air pollution: mainly fine sulfate particles

Hotel next to National Stadium

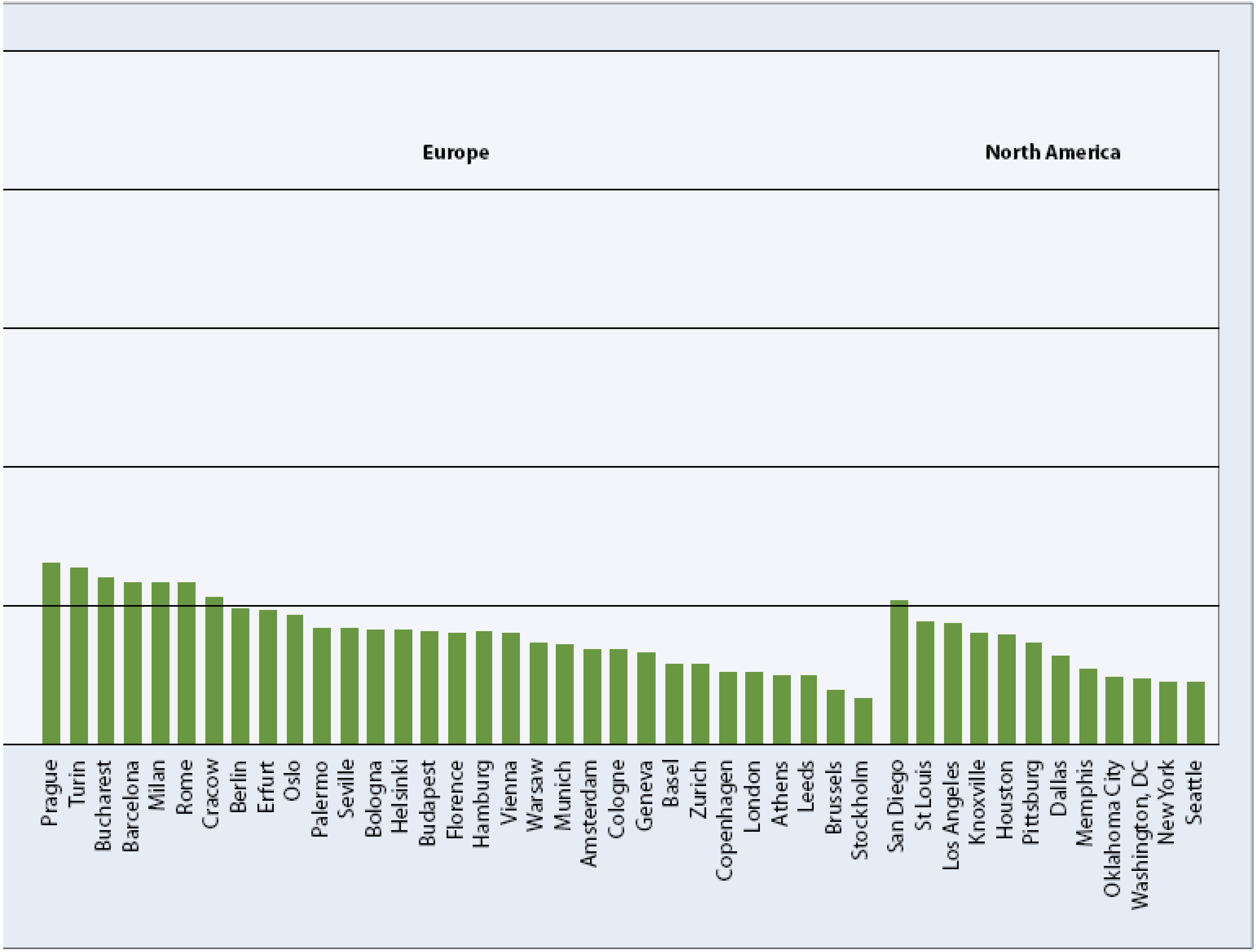
…and no there is nothing wrong with the camera…

Fig. 4. Annual average PM_{10} concentrations observed in selected cities worldwide



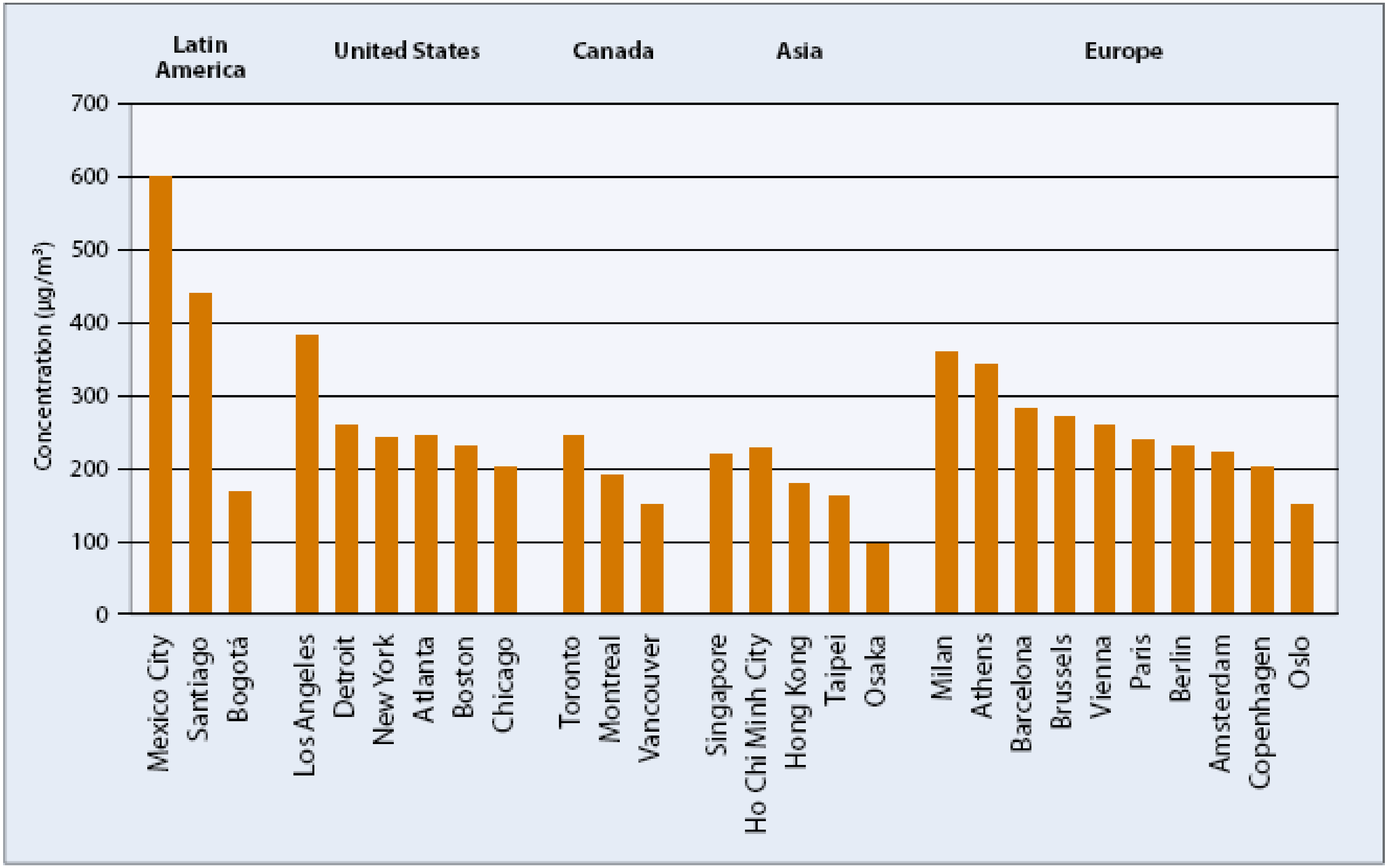
Sources: Bourotte et al. *(7)*; US Environmental Protection Agency *(8)*; Sivertsen & El Seoud *(9)*; Sivertsen et al. *(10)*; State Environmental Protection Agency *(11)*; CAFE *(12)*; Department of Environment and Heritage *(13)*; Department of Environmental Affairs and Tourism *(14)*; US Environmental Protection Agency *(15)*.

WHO, 2005



Europe
North America
Prague
Turin
Bucharest
Barcelona
Milan
Rome
Cracow
Berlin
Erfurt
Oslo
Palermo
Seville
Bologna
Helsinki
Budapest
Florence
Hamburg
Vienna
Warsaw
Munich
Amsterdam
Cologne
Geneva
Basel
Zurich
Copenhagen
London
Athens
Leeds
Brussels
Stockholm
San Diego
St Louis
Los Angeles
Knoxville
Houston
Pittsburg
Dallas
Memphis
Oklahoma City
Washington, DC
New York
Seattle

Fig. 6. Highest (1-hour average) ground-level ozone concentrations measured in selected cities



WHO, 2005

Fig. 8. Annual average sulfur dioxide concentrations in 2000–2005 reported from selected cities worldwide