Outdoor and Indoor Air Pollution

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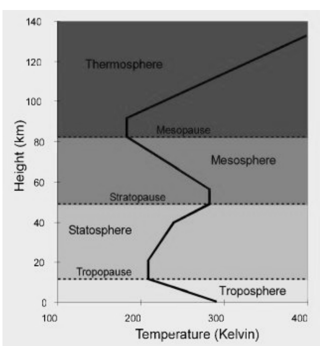
Overview

- The natural atmosphere
- Outdoor pollutants and their sources
- Indoor air pollution
- Health effects of air pollution
- Measurement of particle pollution
- Climate change

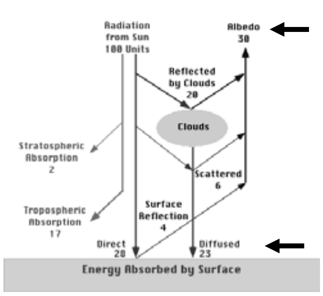
Vertical structure of the atmosphere



Troposphere

- Lowest 10 km of atmosphere
- Contains 75% of the atmospheric mass
- The layer in which most weather phenomena occur, e.g., frontal passage, storms, winds
- The layer in which most air pollution problems occur
- Energy balance is key factor

Distribution of incoming solar radiation

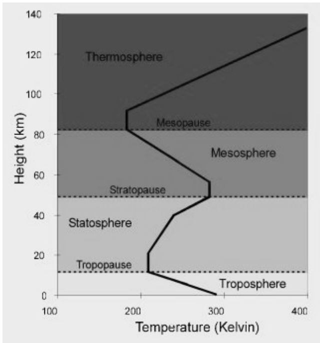


30% reflected back to space

About half absorbed by surface

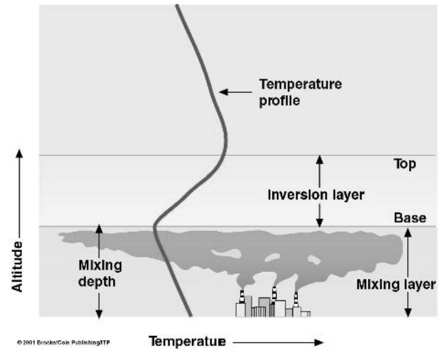
Air set in motion by:

- Absorption of energy at surface followed by transfer of heat to lowest layer of air
- Heated parcels become buoyant relative to nearby cooler parcels, thereby rising
- Rising of air parcel leaves lower pressure at surface
- Dense, cool air moves towards the area of low pressure
- Pressure gradient force drives winds



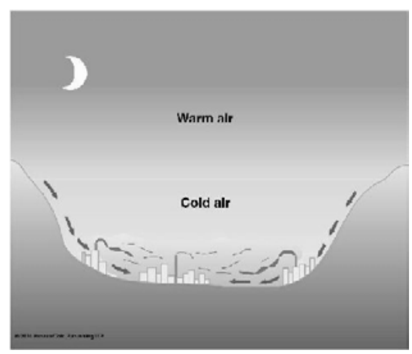
As a warm parcel rises, it expands and cools, resulting in the "normal lapse rate" (– 6.5 ºC/km) of troposphere depicted here.

When the temperature lapse rate becomes "inverted" near the surface in urban areas, high pollution levels are likely to result



A Typical Morning in Denver, Colorado

Worst Case: Inversion in a Valley



Air Pollutants of Human Health Concern

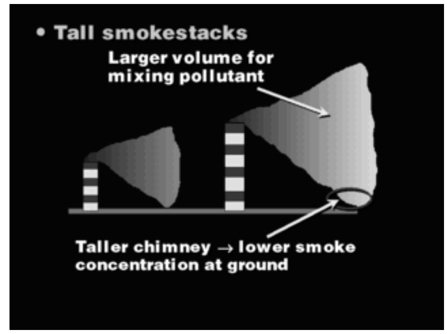
- Carbon monoxide
- Sulfur dioxide
- Nitrogen dioxide
- Volatile organics
- Ozone
- Particulate matter
  - Sulfates, nitrates, organics, elemental carbon, lead and other metals

Carbon Monoxide - CO

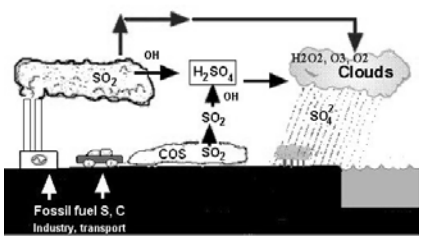
- Colorless, odorless gas
- Primary pollutant, emitted by incomplete combustion of biomass or fossil fuels
- Binds strongly with hemoglobin, displacing oxygen
- Emissions reduction by higher temperature combustion and use of catalytic converters on motor vehicles

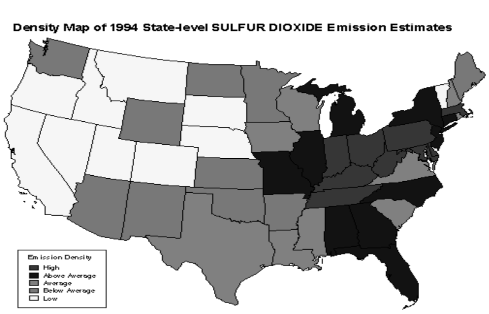
Sulfur Dioxide – SO_2

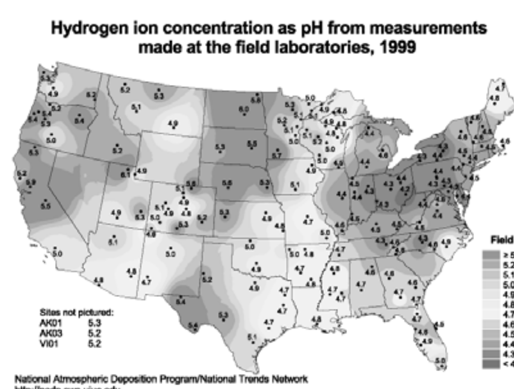
- Primary pollutant, emitted by combustion of fuels containing sulfur; also metal smelting
- Irritates upper respiratory tract
- Converted in atmosphere to acid sulfates
- Emissions reductions by building taller smoke stacks, installing scrubbers, or by reducing sulfur content of fuel being burned



Acid Precipitation Formation







Nitrogen Dioxide – NO_2

- Formed by oxidation of NO, which is produced with high temperature combustion (NO_2 is a secondary pollutant)
- Oxidant that can irritate the lungs and hinder host defense
- A key precursor of ozone formation
- Emissions reductions by engine redesign and use of catalytic converters

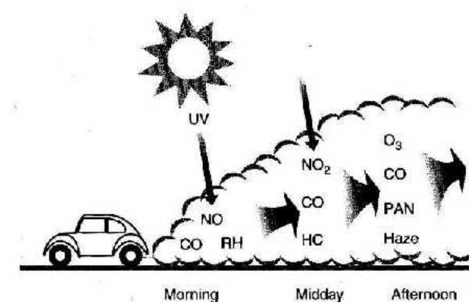
Volatile Organic Compounds VOCs

- Products of incomplete combustion, evaporation of liquid fuels, atmospheric reactions, and release from vegetation (both primary and secondary)
- Wide range of compounds with varying health effects
- Another key ozone precursor
- Emissions reductions by high temperature combustion and control of evaporation, e.g., during refueling of cars

Ozone – O_3

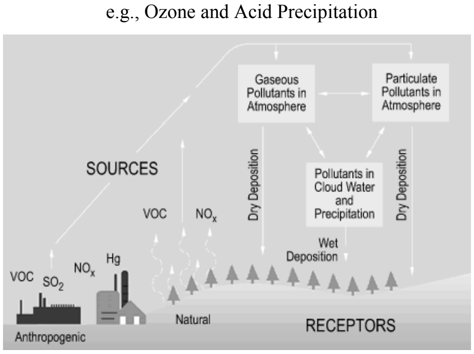
- Secondary pollutant, formed via photochemical reactions in the atmosphere from NOx and VOC in the presence of sunlight
- Strong oxidant that damages cells lining the respiratory system
- Concentrations often highest downwind of source regions
- Emissions reductions by control of NOx and VOC emissions, especially from motor vehicles

Mechanisms of Ozone Formation



Regional Air Pollution Mechanisms

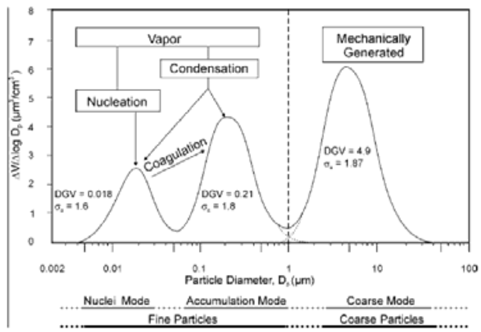
e.g., Ozone and Acid Precipitation



Particulate Matter - PM

- Products of combustion, atmospheric reactions, and mechanical processes
- Wide range of particle sizes
- Wide range of physical/chemical properties
- Wide range of health impacts, including premature death
- Control by filtration, electrostatic precipitation, and reduction of precursor gases

Distribution of particle mass at various particle diameters for a typical urban air sample



Particle size distributions differ in urban and rural areas

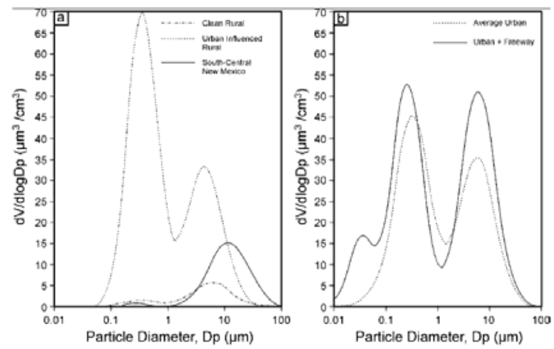


TABLE 9-2. COMPARISON OF AMBIENT PARTICLES, FINE (ultrafine plus accumulation mode) AND COARSE

	Fine		Coarse
	Ultrafine	Accumulation	
Formation Processes:	Combustion, high-temperature processes, and atmospheric reactions		Break-up of large solids/droplets
Formed by:	Nucleation Condensation Coagulation	Condensation Coagulation Reactions of gases in or on particles Reactions of gases in or on particles Evaporation of fog and cloud droplets in which gases have dissolved and reacted	Mechanical disruption (crushing, grinding, abrasion of surfaces) Evaporation of sprays Suspension of dusts Reactions of gases in or on particles
Composition:	Sulfates Elemental Carbon Metal compounds Organic compounds with very low saturation vapor pressure at ambient temperature	Sulfate, Nitrate, Ammonium, and Hydrogen ions Elemental carbon Large variety of organic compounds Metals: compounds of Pb, Cd, V, Ni, Cu, Zn, Mn, Fe, etc. Particle-bound water	Suspended soil or street dust Fly ash from uncontrolled combustion of coal, oil, and wood Nitrates/chlorides from HNO_3/HCl Oxides of crustal elements (Si, Al, Ti, Fe) $CaCO_3$, NaCl, sea salt Pollen, mold, fungal spores Plant and animal fragments Tire, brake pad, and road wear debris
Solubility:	Probably less soluble than accumulation mode	Largely soluble, hygroscopic, and deliquescent	Largely insoluble and nonhygroscopic
Atmospheric half-life:	Minutes to hours	Days to weeks	Minutes to hours
Removal Processes:	Grows into accumulation mode	Forms cloud droplets and rains out Dry deposition	Dry deposition by fallout Scavenging by falling rain drops
Travel distance:	<1 to 10s of km	100s to 1000s of km	<1 to 10s of km (100s to 1000s in dust storms)

Particle deposition in the respiratory system is a strong function of particle diameter

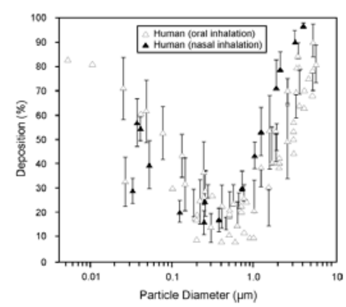
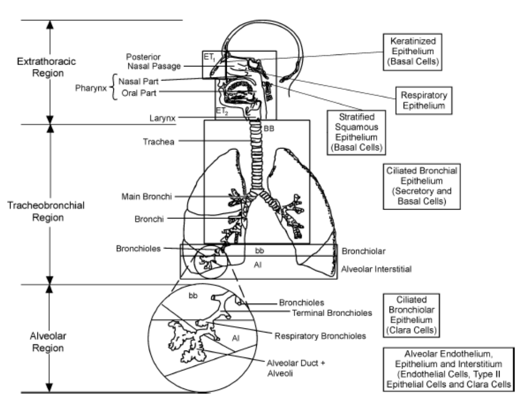


Figure 6-2. Total respiratory tract deposition (as percentage deposition of amount inhaled) in humans as a function of particle size. All values are means with standard deviations when available. Particle diameters are aerodynamic (MMAD) for those ≥ 0.5 μm.



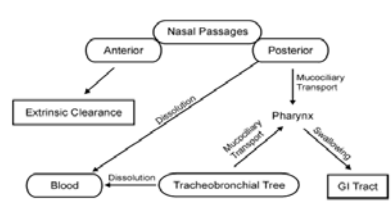


Figure 6-11. Major clearance pathways for particles deposited in the extrathoracic region and tracheobronchial tree.

Source: Adapted from Schlesinger et al. (1997).

Motor Vehicles represent a major source category for several air pollutants (CO, NO_2, VOCs, O_3, PM)

Figure 1. Trends in Vehicle Emissions and Vehicle Miles Traveled[8]

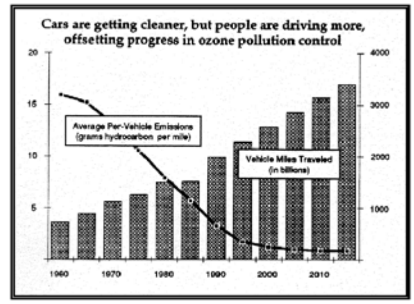


Figure 3.2 Trends in estimated U.S. Lead Emissions

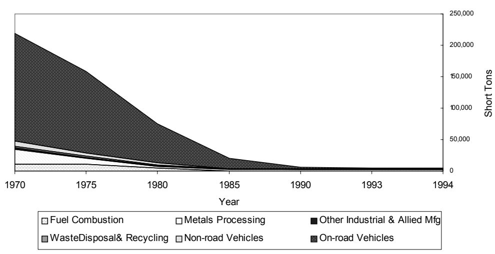
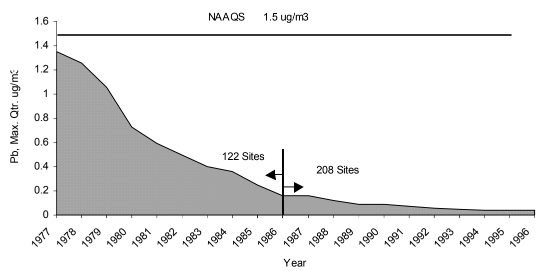


Figure 3.3 Trends in U.S. Ambient Lead Concentrations



Indoor Air Pollution

- **Combustion is principal source: cooking, smoking, heating**
- **Dilution and dispersion are limited, especially nearest the source**
- **Pollutants of greatest importance include: CO, NO2, PM, VOCs**
- **Indoor concentrations often far higher than outdoors, even in urban areas**
- **Those who spend the most time indoors near the source will be most impacted**

The most local form of air pollution: indoor combustion of biomass in India

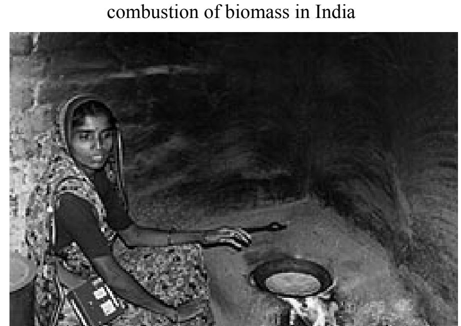
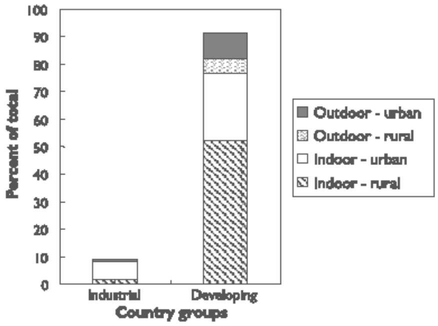


Figure 2 — Worldwide exposure to particulates: Mid-1990s



Note: Exposure = concentration x population x duration.
Source: Smith 1998a.

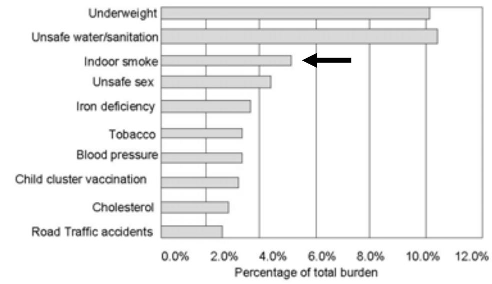


Fig. 2. Estimates of the impacts of ten largest risk factors for ill-health in poor South Asia. The impact of indoor air pollution is mainly on ALRI in children, with smaller contributions from COPD and lung cancer in adult women.
Source: World Health Organization, 2002, 2001.

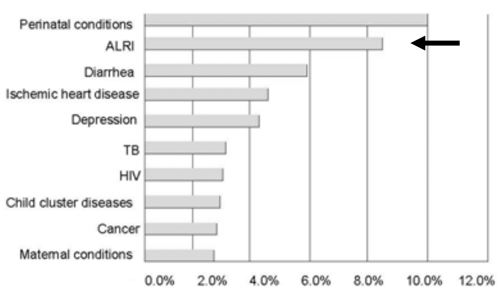


Fig. 1. Top ten diseases in poor South Asia measured as lost healthy life-years (DALYs). Includes India, Bangladesh, Myanmar and Nepal.
Source: World Health report, 2002, 2001.

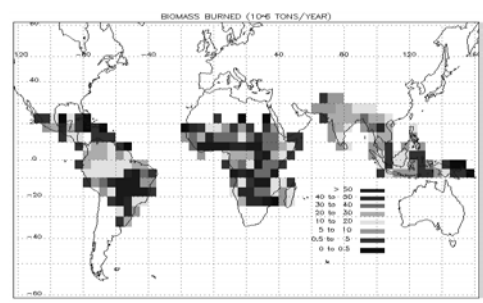
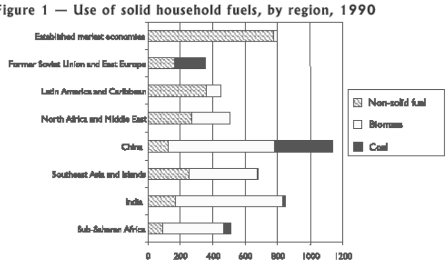


Figure 1 — Use of solid household fuels, by region, 1990



Source: Reddy, Williams, and Johansson 1997.

- About half the world 's households use unprocessed solid fuels for cooking,ranging roughly from near zero in developed countries to more than 80%in China,India,and Sub-Saharan Africa (Holdren et al.,2000).
- In simple small-scale devices,such as household cookstoves, solid fuels have rather large emission rates of a number of important health-damaging airborne pollutants including respirable particulates,CO,dozens of PAHs and toxic hydrocarbons,and, depending on combustion and fuel characteristics, nitrogen and sulfur oxides.
- A large,although uncertain,fraction of such stoves are not vented,i.e.do not have flues or hoods to take the pollutants out of the living area.
- Even when vented to the outdoors,unprocessed solid fuels produce enough pollution to significantly affect local pollution levels with implications for total exposures (Smith et al.,1994).As cookstoves are essentially used everyday at times when people are present,their exposure effectiveness (or intake fraction)is high,i.e.the percentage of their emissions that reach people 's breathing zones, is much higher than for outdoor sources(Smith, 2002; Bennett et al.,2002).
- The individual peak and mean exposures experienced in such settings are large by comparison with WHO guidelines and national standards.

From: Kirk Smith, Indoor Air 2002;12:198 .207

Table 1. Evidence from indoor area monitoring for particulates in biomass-burning households in developing countries

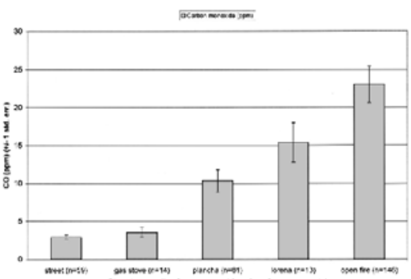
Region (number of studies)	Number of households	Duration of study	Particulate level (micrograms per cubic meter)[a]
Pacific (2)	15	12 hr	1,300–5,200
South Asia (7)	504	Cooking	4,000–21,000
	135	Cooking	850–4,400 (I)
	100	Noncooking	630–820
	68	Noncooking	880 (I)
	61	24 hr	2,000–2,800 (I)
China (8)	73	Various	2,600–2,900
	35	Various	1,100–11,000 (I)
Africa (5)	28	Cooking/heating	800–1,700
	40	Cooking/heating	1,300 (I)
	100	24 hr	1,300–2,100 (I)
Latin America and the Caribbean (5)	42	Cooking/heating	440–1,100 (I) 340 (R)
	53	24 h	720–1,200 (I) 520–870 (R)

Note: Total number of studies, 27; total number of households, about 600.
a. I, inhalable; R, respirable)

For comparison: US annual $PM_{2.5}$ standard is 15 ug/m³

Country	Year of publication	Description of sample	Concentration [μg/m³]
India	1983	n=65, 4 villages	6800
	1987	n=165, 8 villages	3700
	1987	n=44, 2 villages	3600
	1988	n=129, 5 villages	4700
	1991	n=95, winter/summer/monsoon	6800/5400/4800
	1996	n=40, two urban slums, infants, 24 h	400/520 (I)
Nepal	1986	n=49, 2 villages	2000
	1990	n=40, trad/impr	8200/3000
Zambia	1992	n=184, 4 h, urban, wood/charcoal	470/210 (R)
Ghana	1993	n=143, 3 h, urban, wood/charcoal	590/340 (R)
South Africa	1993	n=15, 12 h, children, winter/summer	2370/290

Table 4.3. Indoor particle air pollution from biomass combustion in developing countries: partial list of studies of individual breathing area concentrations (women during cooking, unless otherwise stated) (Smith 1996).



Indoor and outdoor $PM_{2.5}$ and CO in high- and low-density Guatemalan villages[1]

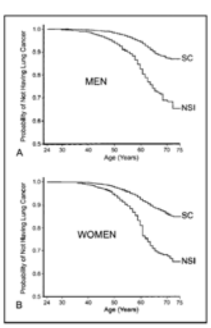
L.P. NAEHER,[a] K.R. SMITH,[b] B.P. LEADERER,[a] D. MAGE[c] AND R. GRAJEDA[d]

TABLE 2. Twenty-four hour $PM_{2.5}$ (μg/m³) Concentrations for the Open Fire, *Plancha*, and Gas/Open Fire Combination

stove type	N[a]	mean ± SD	geometric mean (95% CI)	median	range
open fire	58	1930 ± 1280	1560 (1310, 1850)	1630	300−6750
plancha	59	330 ± 220	280 (240, 320)	270	50−1130
LPG/open fire	60	1200 ± 1080	850 (680, 1050)	780	125−5510

[a] N refers to the total number of observations for the 10 households in each cookstove condition.

Albalak R. et al., Environ. Sci. Technol. **200**1, 35, 2650-2655



Household Stove Improvement and Risk of Lung Cancer in Xuanwei, China

Qing Lan, Robert S. Chapman, Dina M. Schreinemachers, Linwei Tian, Xingzhou He

[J Natl Cancer Inst 2002;94:826–35]

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**
- **Let's look at the evidence for particle health effects…**

London Killer Fog, December, 1952

London

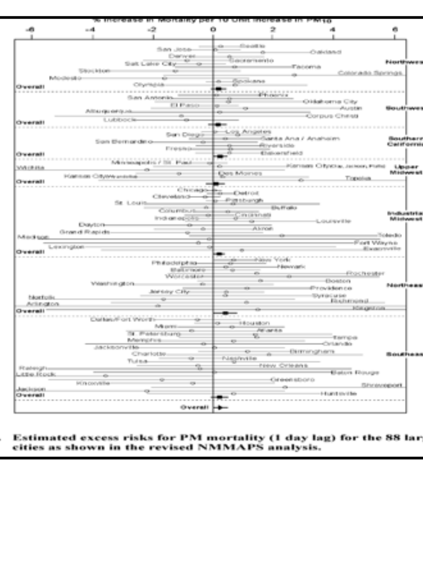
Mid-day in December 1952

Air Pollution Epidemiology

- **Provides most directly relevant results for policy makers**
- **Assesses effects of real mix of pollutants on human populations**
- **Pollutants tend to co vary, making it hard to distinguish effects**
- **Can demonstrate associations between outcome and exposure, but not cause and effect**
- **Must control for confounding factors**
- **Exposure assessment is "ecologic"**

Time Series Epidemiology

- **Addresses effects in narrow time window**
- **Involves multiple regression analysis of long series of daily observations**
- **Large number of studies have reported significant associations between daily deaths and/or hospital visit counts and daily average air pollution.**
- **Time series design avoids spatial confounding; however, temporal confounding due to seasons and weather must be addressed.**
- **Particles often appear most important, but CO, SO_2, NO_2, and/or ozone may also play roles.**
- **For example, NMMAPS Study**



Estimated excess risks for PM mortality (1 day lag) for the 88 largest U.S. cities as shown in the revised NMMAPS analysis.

Cohort Epidemiology

- Address long-term exposure-response window
- Large populations in multiple cities enrolled and then followed for many years to determine mortality experience
- Cox proportional hazards modeling to determine associations with pollution exposure
- 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

Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution

Pope, C.A. et al., Journal of the American Medical Association: 287, 1132-1141, 2002

Context Associations have been found between day-to-day particulate air pollution and increased risk of various adverse health outcomes, including cardiopulmonary mortality. However, studies of health effects of long-term particulate air pollution have been less conclusive.

Objective To assess the relationship between long-term exposure to fine particulate air pollution and all-cause, lung cancer, and cardiopulmonary mortality.

Design, Setting, and Participants Vital status and cause of death data were collected by the American Cancer Society as part of the Cancer Prevention II study, an ongoing prospective mortality study, which enrolled approximately 1.2 million adults in 1982. Participants completed a questionnaire detailing individual risk factor data (age, sex, race, weight, height, smoking history, education, marital status, diet, alcohol consumption, and occupational exposures). The risk factor data for approximately 500000 adults were linked with air pollution data for metropolitan areas throughout the United States and combined with vital status and cause of death data through December 31, 1998.

Main Outcome Measure All-cause, lung cancer, and cardiopulmonary mortality.

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, C.A., et al.,

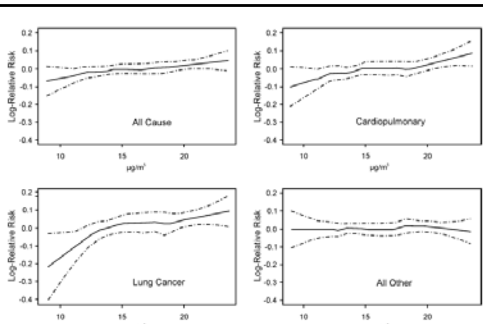
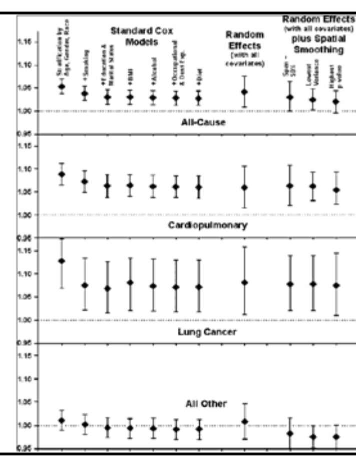


Figure 8-9. Natural logarithm of relative risk for total and cause-specific mortality per 10 μg/m³ $PM_{2.5}$ (approximately the excess relative risk as a fraction), with smoothed concentration-response functions. Based on Pope et al. (2002) mean curve (solid line) with pointwise 95% confidence intervals (dashed lines).



Conclusion

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

Human Health Effects of Airborne Particulate Matter

- Daily time-series studies have demonstrated small but consistent associations of PM with mortality and hospital admissions, reflecting acute effects.
- Acute effects on lung function, asthma exacerbations, and other outcomes
- Multi-city prospective cohort studies have shown increased mortality risk for cities with higher long-term PM concentrations, reflecting chronic effects.

Implications

- Acute effects are well documented but of uncertain significance
- Chronic effects imply very large impacts on public health.
- A new US national ambient air quality standard for $PM_{2.5}$ was established in 1997, largely based on the cohort epidemiology evidence
- Mechanistic explanation for chronic effects remains unclear
- Weaknesses in exposure assessment limits interpretation

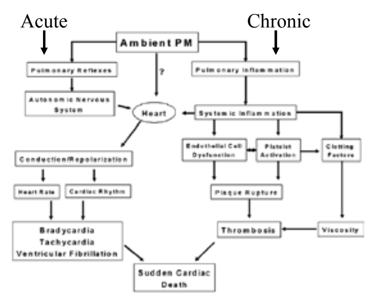


Figure 9-15. Schematic representation of potential pathophysiological pathways and mechanisms by which ambient PM may increase risk of cardiovascular morbidity and/or mortality.

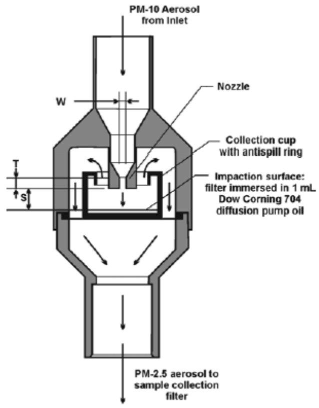
It is also unclear…

- Whether a threshold exists
- Who is at risk due to
  - Higher exposures
  - Greater susceptibility
- What particle components are most toxic
- Which sources should be controlled

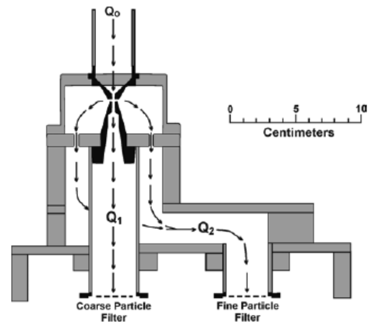
Measurement of Airborne Particulate Matter

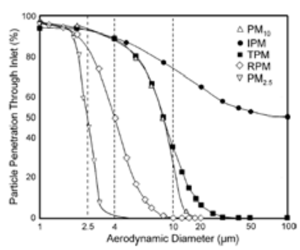
- **Getting the size right**
- **A look at some field studies**

A typical impactor design for size selective particle sampling onto a filter

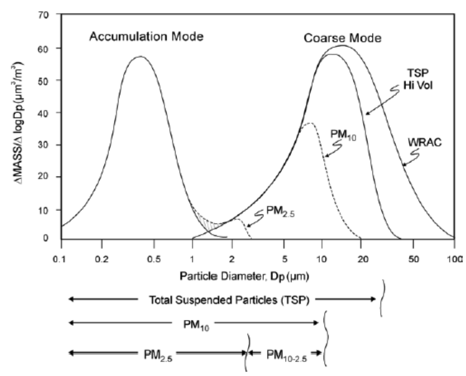


Variation on a theme – the Virtual Impactor





Specified particle penetration (size-cut curves) through an ideal (no-particle-loss) inlet for five different size-selective sampling criteria. Regulatory size cuts are defined in the Code of Federal Regulations; $PM_{2.5}$ (2001c), PM_{10} (2001a). $PM_{2.5}$ is also defined in the Federal Register (1997). Size-cut curves for inhalable particulate matter (IPM), thoracic particulate matter (TPM) and respirable particulate matter (RPM) size cuts are computed from definitions given by American Conference of Governmental and Industrial Hygienists (1994).



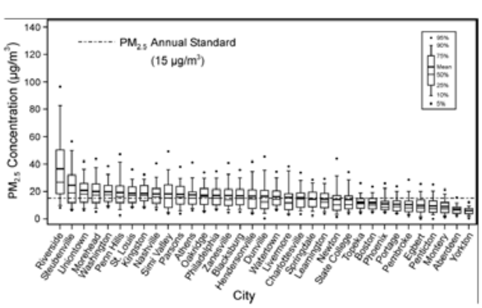
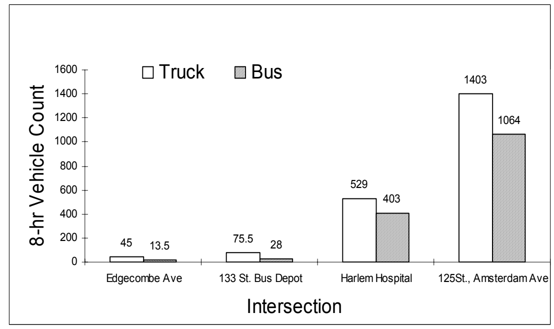


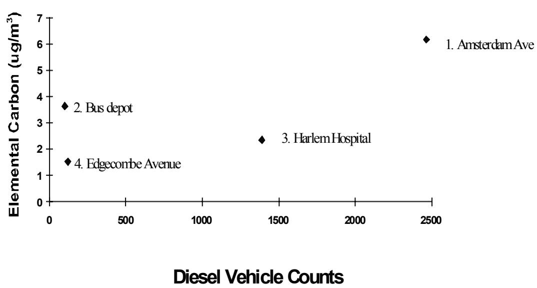
Figure 3-5. Collection of annual distribution of 24-h average $PM_{2.5}$ concentrations observed in U.S. and Canadian health studies conducted during the 1980's and early 1990's.

Diesel Traffic and Air Pollution Study

Truck and Bus Counts at Four Harlem Intersections
(Kinney et al., Environ. Health Perspec., 2000)



Mean Elemental Carbon Concentrations at Four Harlem Intersections



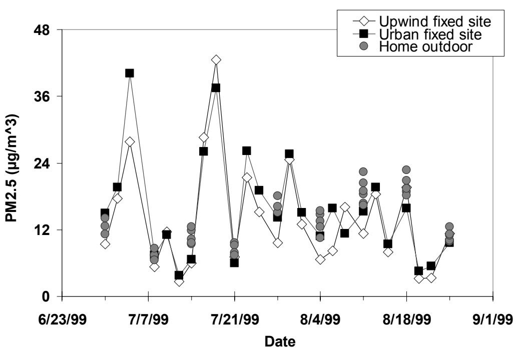
Air Toxic Exposures of High School Students, the TEACH Study

Close up of personal sampling backpack

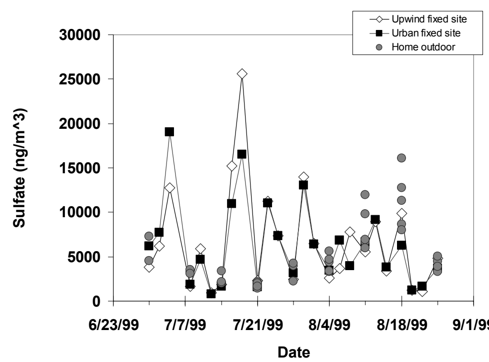
Analysis of Particle Samples

- Mass determined by weighing Teflon filter before and after sampling under controlled conditions
- Elemental carbon estimated by light absorption
- Analysis of trace elements by ICP-mass spectrometry

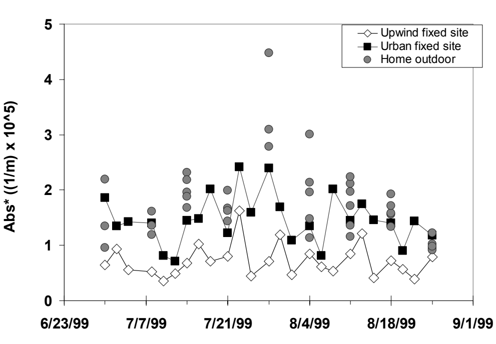
NY Summer PM2.5



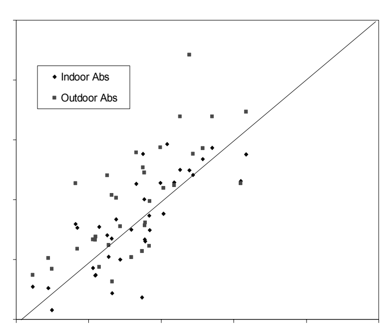
NY Summer Sulfate

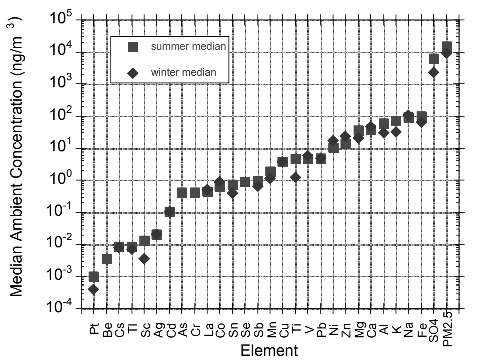


NY Summer Absorbance (Black Carbon)

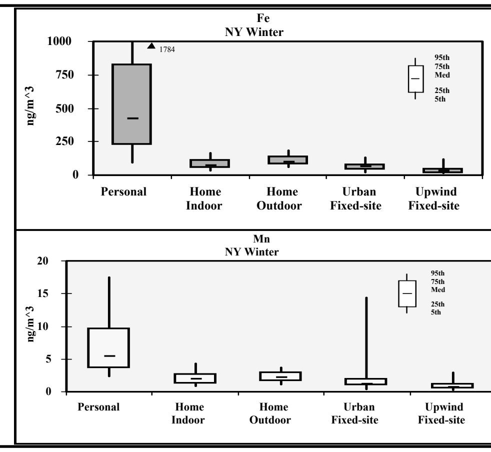


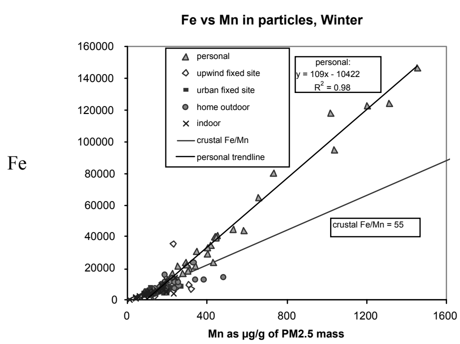
Winter NYC Individual Data:
Indoor and Outdoor vs. Personal Absorbance



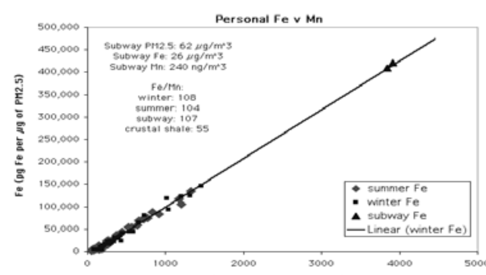


Median concentrations at urban fixed site, NYC winter and summer





Elevated personal samples are consistent with steel dust in subway air!



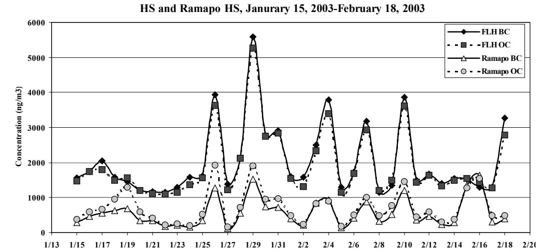
Preliminary Conclusions

- We see strong urban influences on air toxic exposures for some particle components.
- Personal exposures are closely associated with outdoor concentrations of black carbon, an indicator of diesel exhaust particles.
- Diesel particle exposures are associated with lung cancer and have been suggested to play a role in asthma.
- New studies underway to examine the diesel/asthma link.

Traffic-related Particle Exposures among NYC Children

P. Kinney, PI

Figure 1. Daily Black Carbon (BC) and Organic Carbon (OC) concentrations for FLH HS and Ramapo HS, Janurary 15, 2003-February 18, 2003

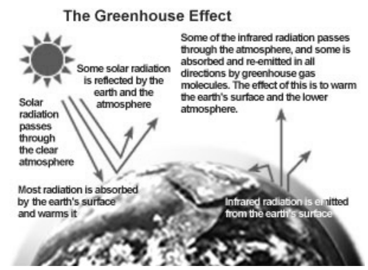


Urban Diesel Exposure and Inner City Asthma

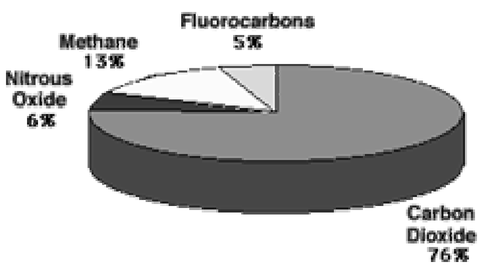
R. Miller, PI

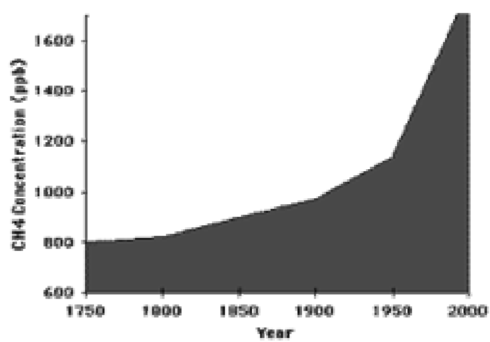
Objective:

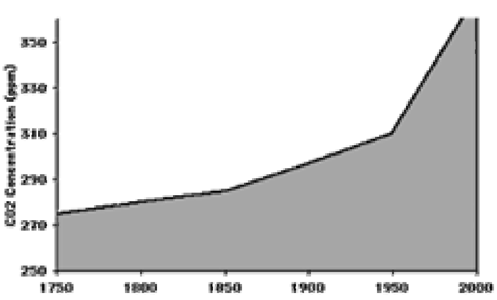
To assess geographic associations between diesel exposure and asthma development in a NYC birth cohort

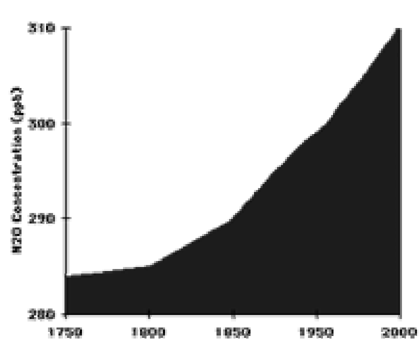


The Greenhouse Gases

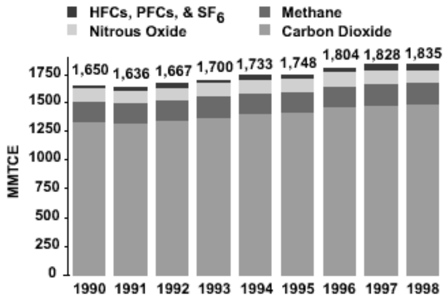


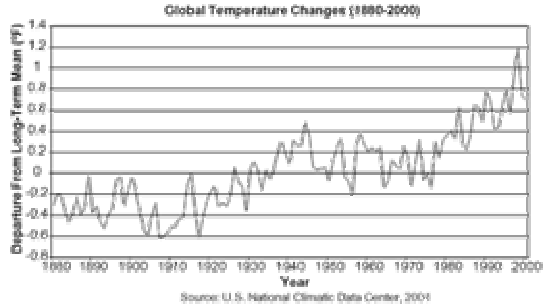




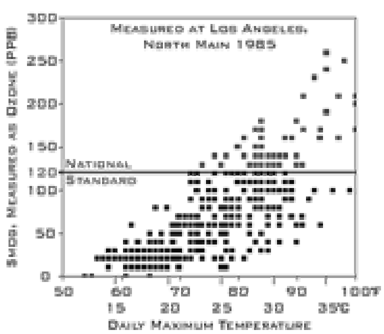


US greenhouse gas emission trends





Air pollution and heat: the Ozone example



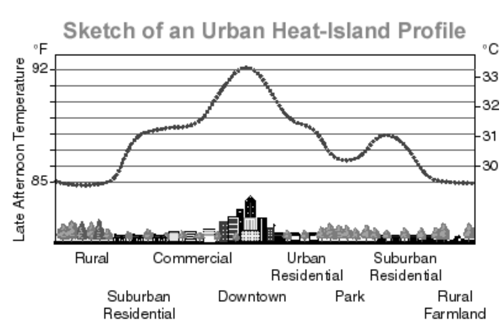
Impacts of Climate Change

- General warming; greater at poles; greater in winter
- Sea level rise
- Changing rainfall patterns
- Greater variability and intensity of weather extremes
  - – Longer and deeper droughts
  - – More frequent and extreme storms

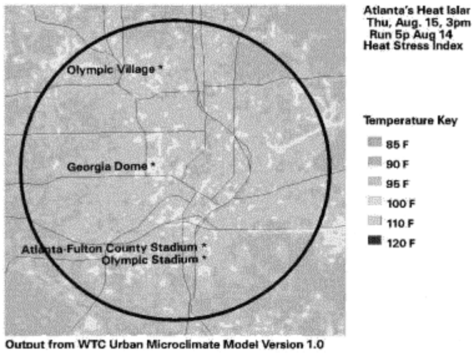
Climate Change and Public Health

- Changing patterns of rainfall will have profound effects on local agriculture, water supply, and well-being
- Heat-related mortality and morbidity
- Death and injury due to extreme storms
- Changing patterns of vector-borne diseases
- Air pollution
- Ability to adapt will vary with income level

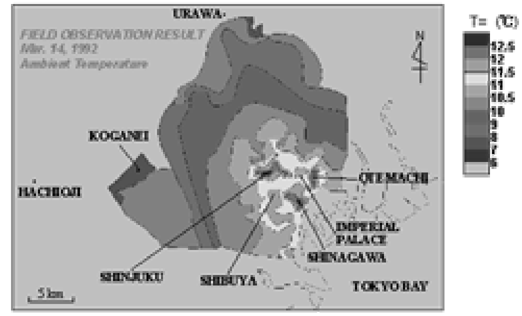
Another aspect of energy balance: the Urban Heat Island



Urban Heat Island in Atlanta Metro Area



Urban Heat Island over Tokyo



New York Climate and Health Project

- **How might health in the NY metropolitan region be affected by climate and land use change?**

Mailman School of Public Health:
Patrick Kinney (PI) – Public health impact analysis

Goddard Institute for Space Studies:
Cynthia Rosenzweig – Global and regional climate modeling

LDEO: Chris Small – Remote sensing

Hunter College: Bill Solecki – Regional land-use/land-cover modeling

SUNY Albany: Christian Hogrefe – Regional air quality modeling

Duke University: Roni Avissar – Regional climate modeling