Air pollution and human health

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UNIVERSITY OF UTAH
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Disclosures

- Grant funding: NHLBI, Department of Veteran's Affairs
- Consultant, Partner Therapeutics, unrelated to the content of this presentation

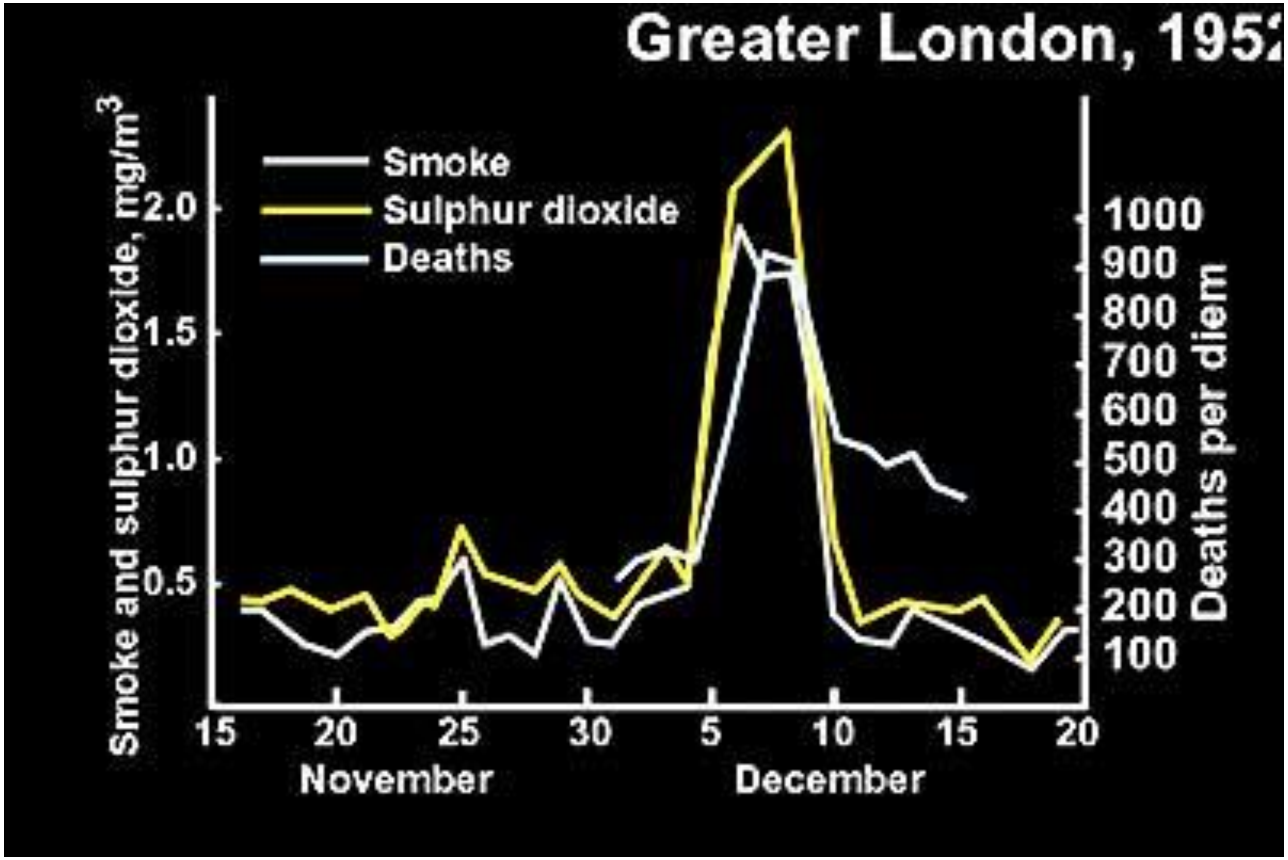
Some questions

- Why do we care about air pollution?
  - How does air pollution affect health?
  - Does changing pollution levels lead to clinically important changes in human health?
- What do we know about biological responses to pollution? What organ systems are involved?
- What kinds of air pollution are important in Utah?
  - Where does it come from?
  - What are we doing about it?
- Relevance to COVID-19?

Photo: S. Hoch (Atmos. Sci)

London, December 1952

London
December 5-9, 1952



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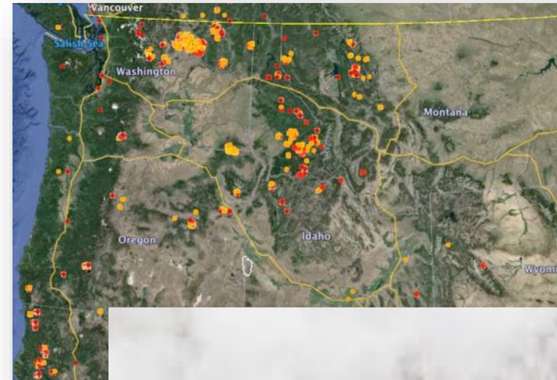
Worldwide causes of poor air quality

- Transportation
- Solid-fuel burning
- Power generation
- Municipal waste management
- Waste incineration
- Agricultural burning and wildfires
- Meteorology and topography



EPA defined “Criteria” pollutants

- Particulate matter
  - $PM_{2.5}$
- Ozone
- Lead
- Carbon monoxide
- Sulfur oxides
- Nitrogen dioxide
- Air toxics

$PM_{2.5}$ - The Key Aerodynamic Diameter to Reach the Gas Exchange Portion of The Lung

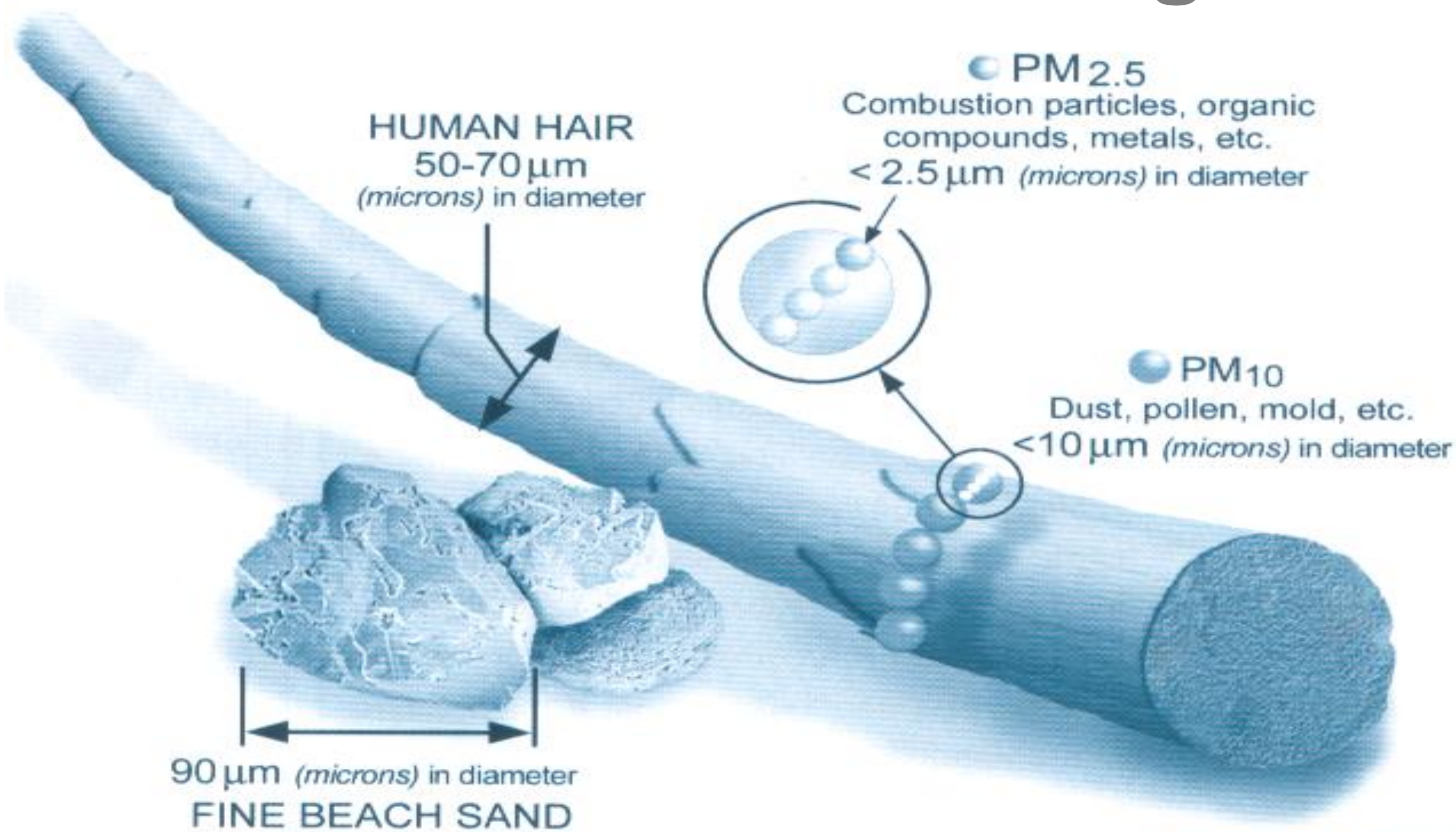
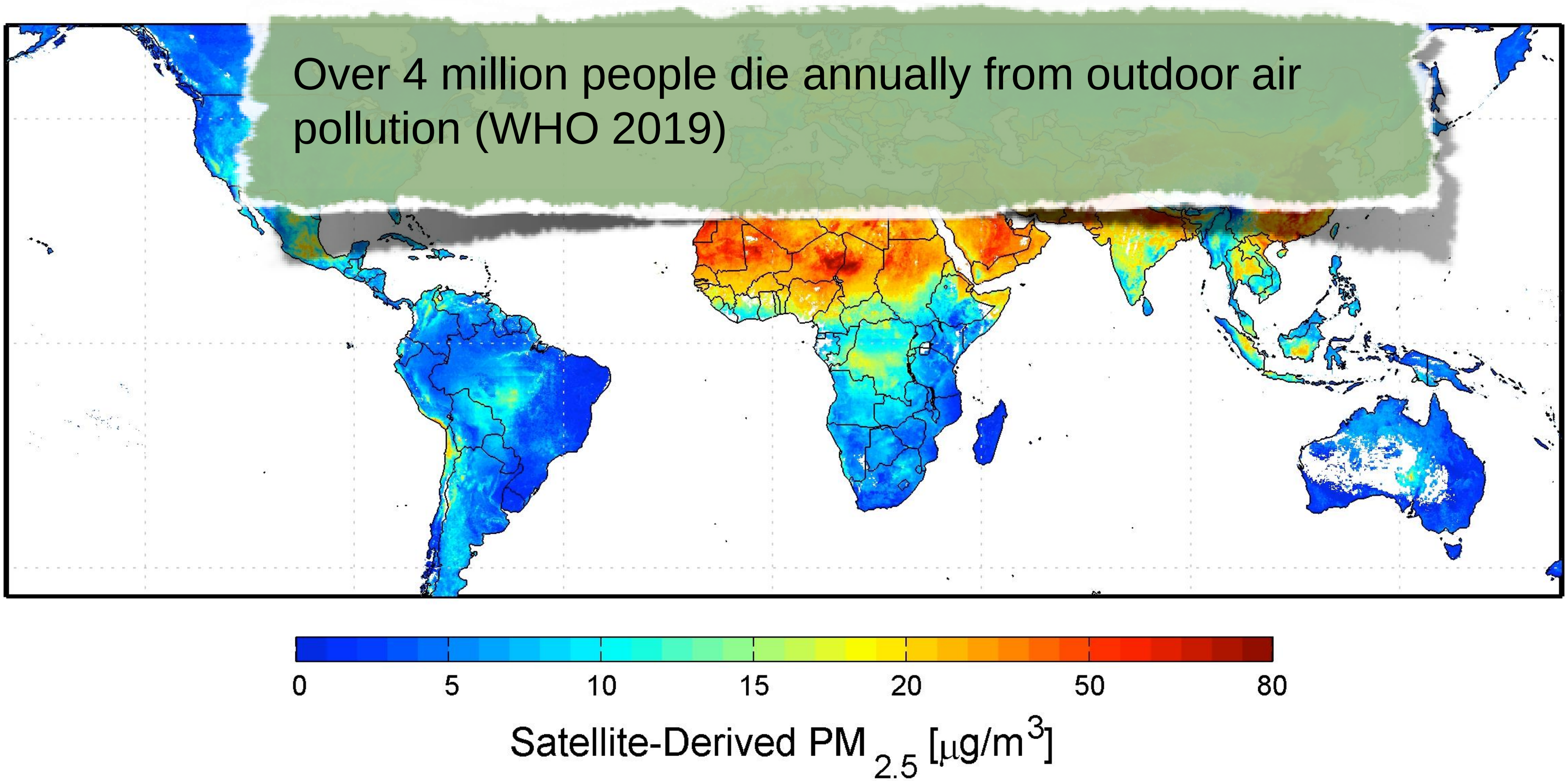


Image courtesy of the U.S. EPA

Global annual $PM_{2.5}$ levels

Over 4 million people die annually from outdoor air pollution (WHO 2019)



Nasa.gov

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Courtesy of Jonathan Samet, USC

What are our Sources of Pollution?

Mobile sources responsible for 54% of emissions and are decreasing

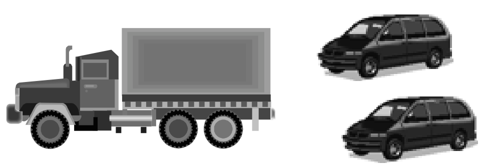
Areas sources are responsible for about 33% of emissions and are increasing

Point sources are responsible for about 12% of emissions and are increasing

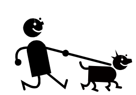
Data for Salt Lake County from DAQ SIP website, September 16, 2018

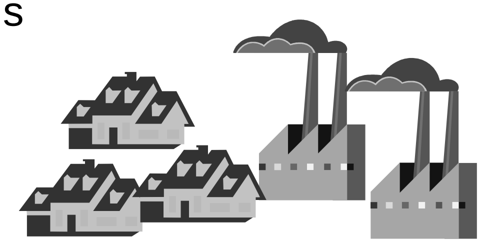
Emission Factors & Modeling

VEHICLE FLEET
FUEL
TEMPERATURE
VMT
I&M PROGRAM

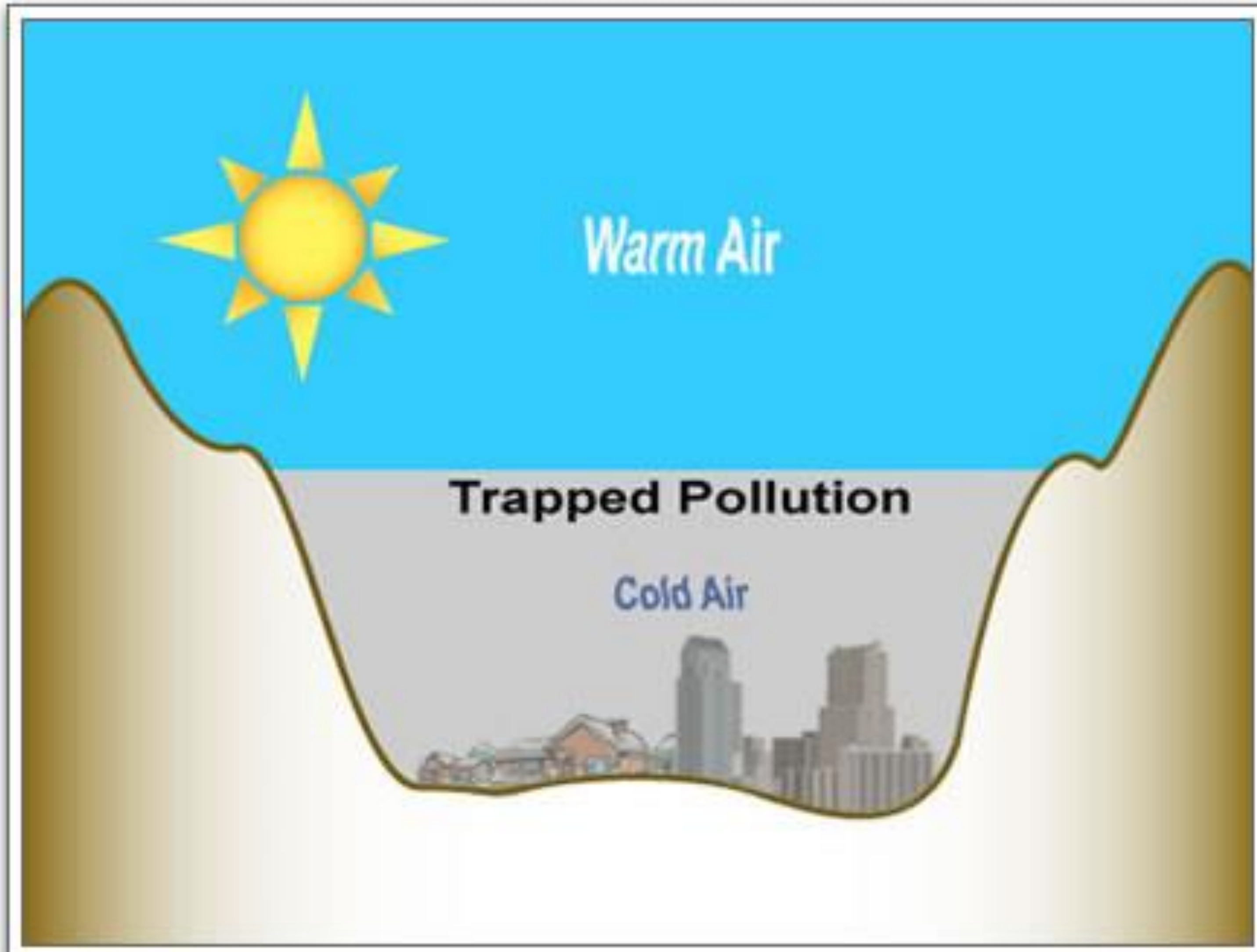


Counts

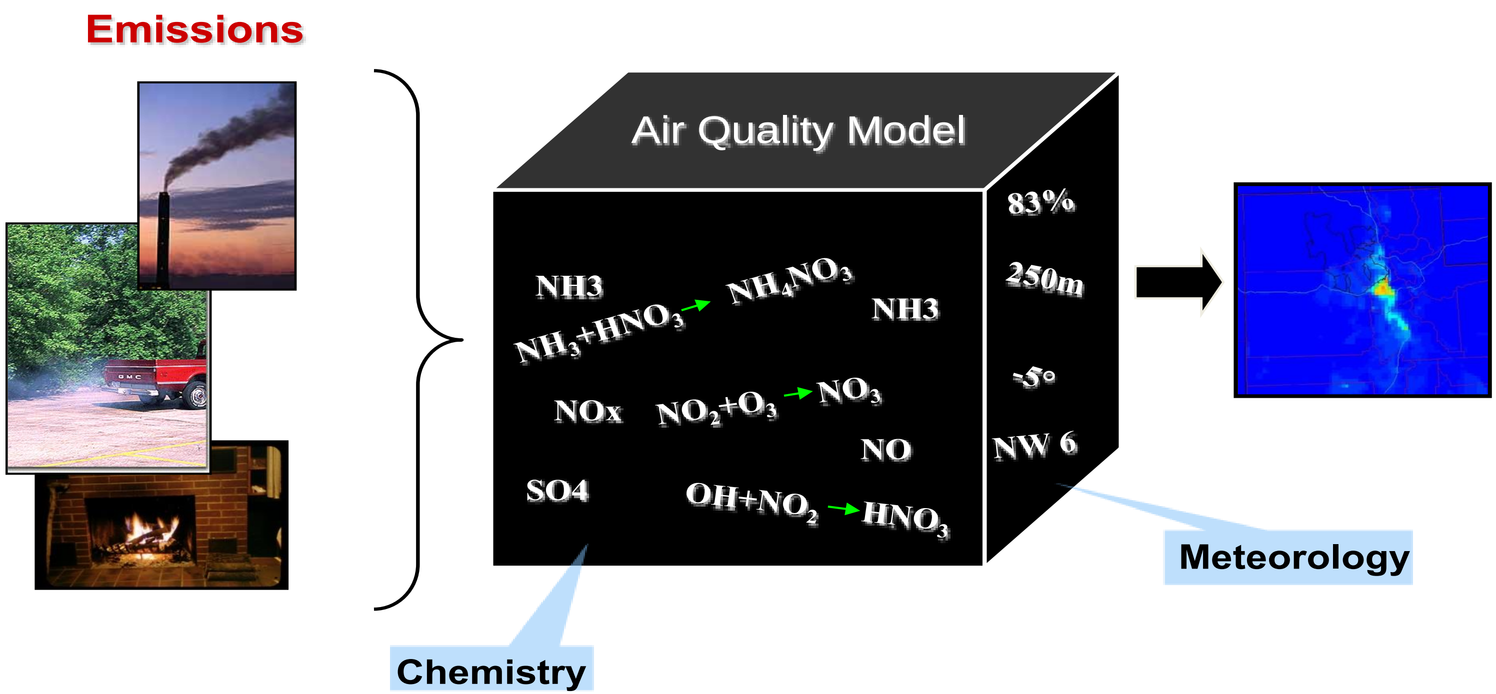




Wintertime inversions



Where does the PM come from?

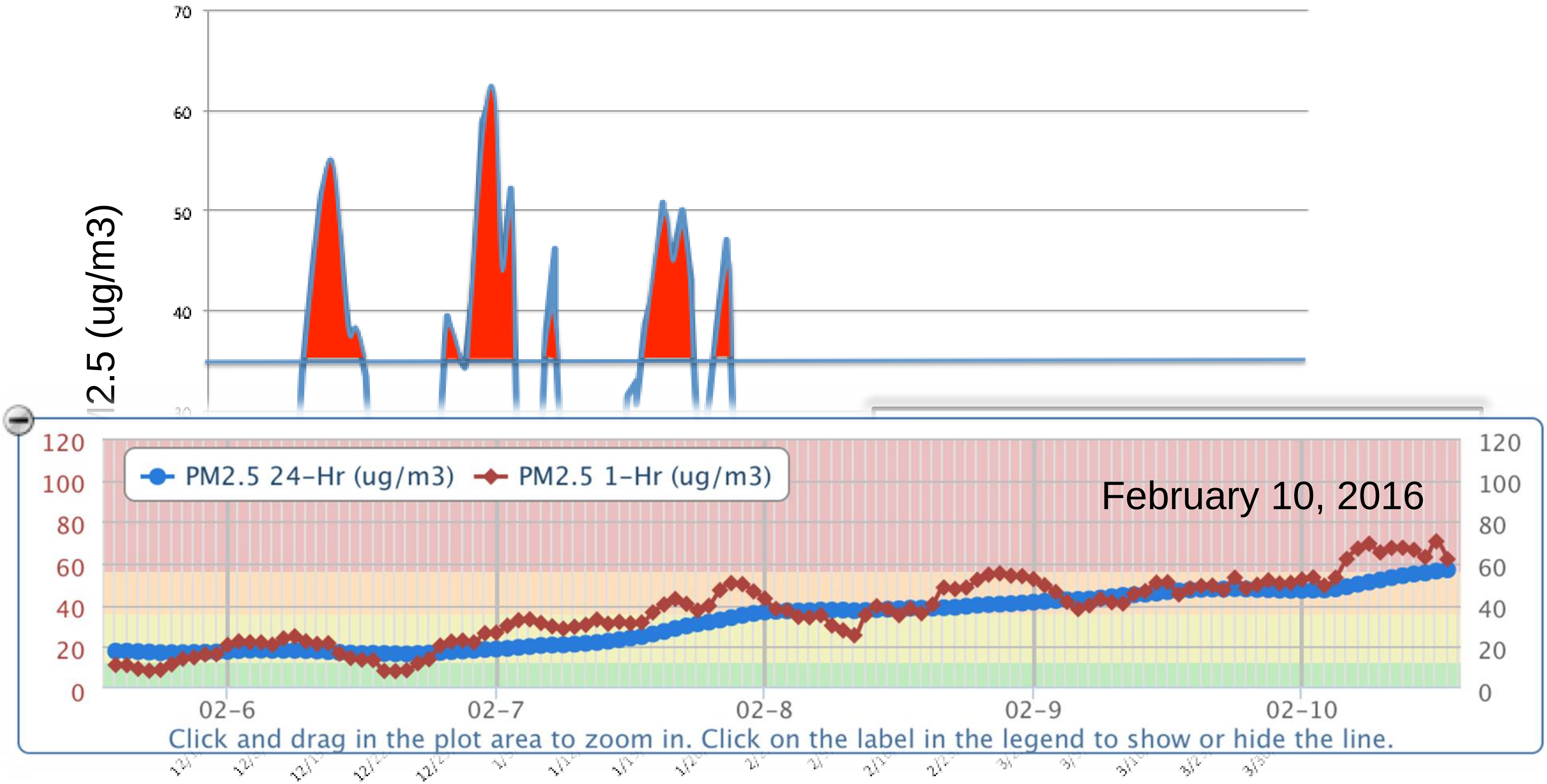


Directly emitted particles 1/3

Indirect reactions 2/3

We contribute to both direct & indirect PM

Wintertime $PM_{2.5}$ levels



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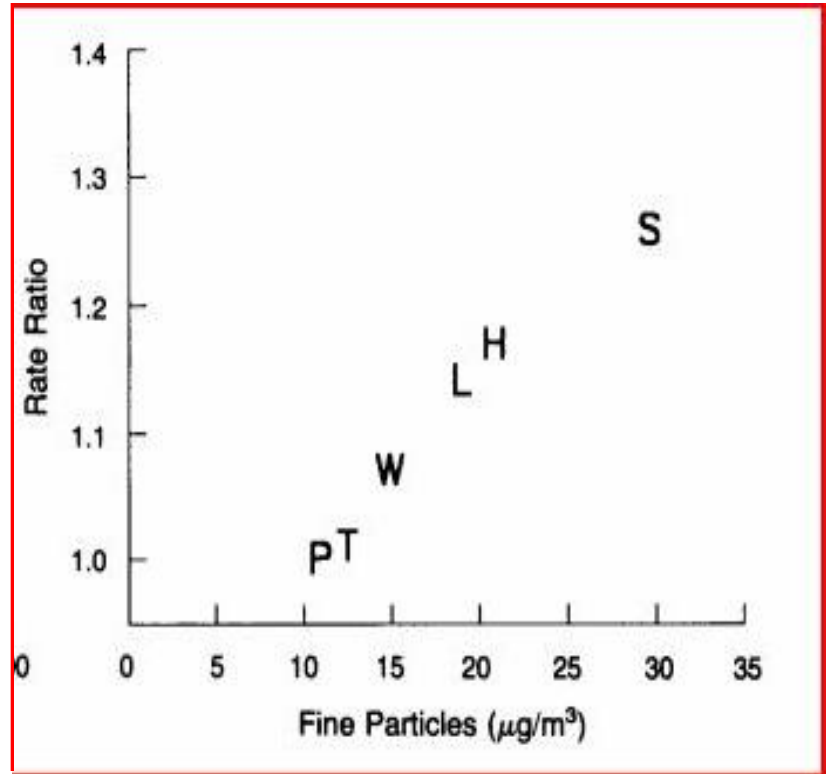
Epidemiologic data concerning the impact of air pollution

- Extensive epidemiologic evidence linking exposure to air pollution to effects on human health
  - Total mortality/life expectancy
  - The Global Burden of Disease study estimated that pollution caused 9 million deaths in 2019, of which more than 60% were due to cardiovascular disease
    - Cardiovascular events (MI and ACS, strokes, sudden death)
  - Asthma
  - Worsening of symptoms for patients with COPD
  - Cancer

Correlation of mortality with air quality - Harvard Six Cities Study

- Prospective study with enrollment in 1979 and follow-up through 1990's
- City specific mortality during early ('80's) and late ('90's) periods and over entire study
- Mortality inversely related to level of fine particulates during each period
- Similar correlations both for overall mean exposure and for exposure in the year prior to death



S- Steubenville, H- Harriman, T- Topeka, W- Watertown, L- St Louis, P- Portage

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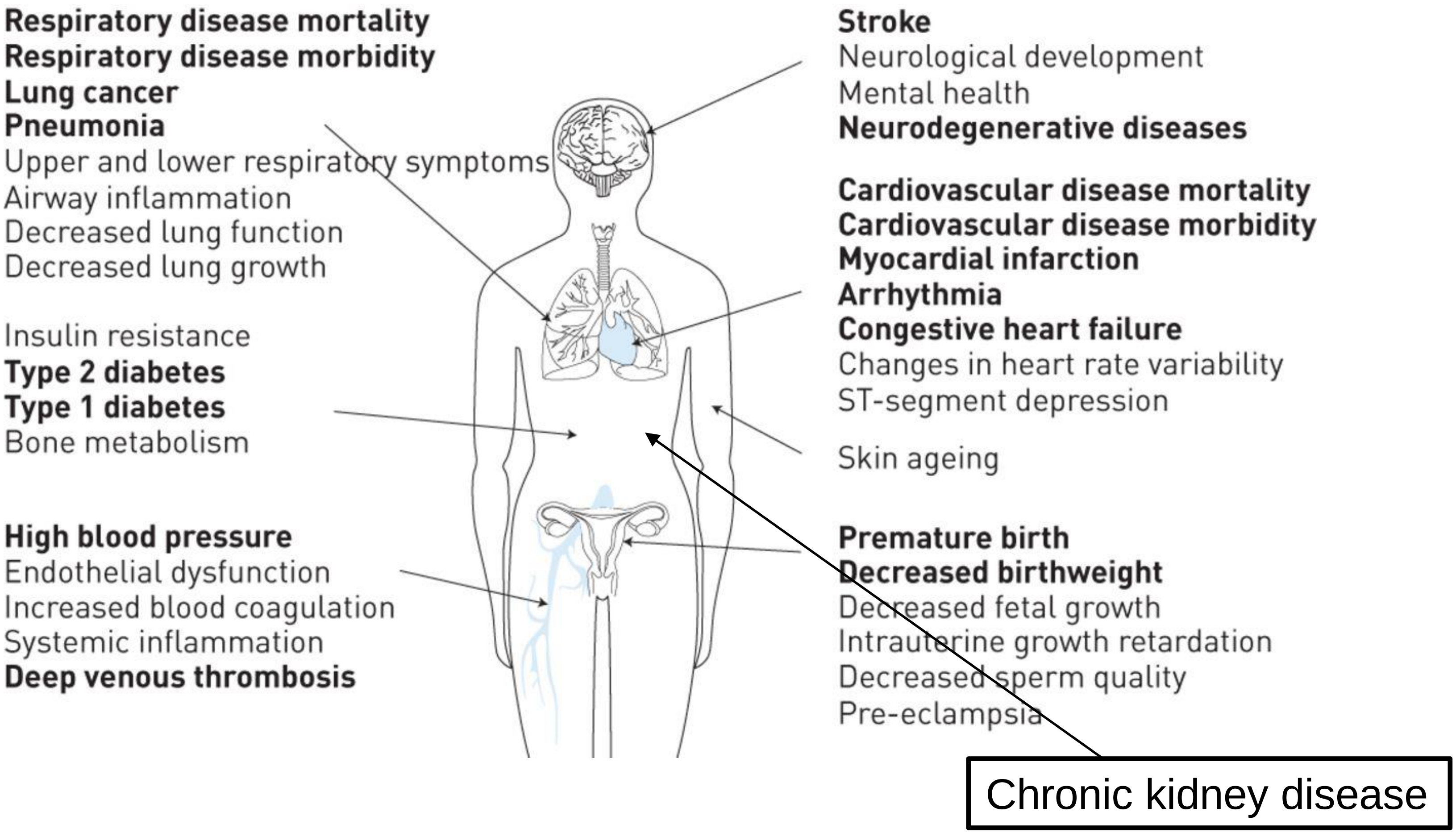
Dockery et al. NEJM 1993;329:1753-9

Air pollution impacts disease in multiple organ systems



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Thurston et al. Eur Resp J 2017

Long and short term effects on cardiovascular disease

- Long term:
  - Large national cohort studies demonstrate direct relationships being PM2.5 local exposure and both total mortality and cardiovascular mortality
    - CVD risk increases 10% for each 10 $\mu g/M^3$ increase in PM2.5
      - Thurston et al. Environmental Health Perspectives 2016
- Short term:
  - Local studies from Utah have demonstrated increased risk of heart attacks during 1-3 days after onset of increased PM2.5 pollution
    - 4% increased rate for each 10 $\mu g/M^3$ increase in PM2.5
      - Pope et al. Circulation 2006

$PM_{2.5}$ = 28.3

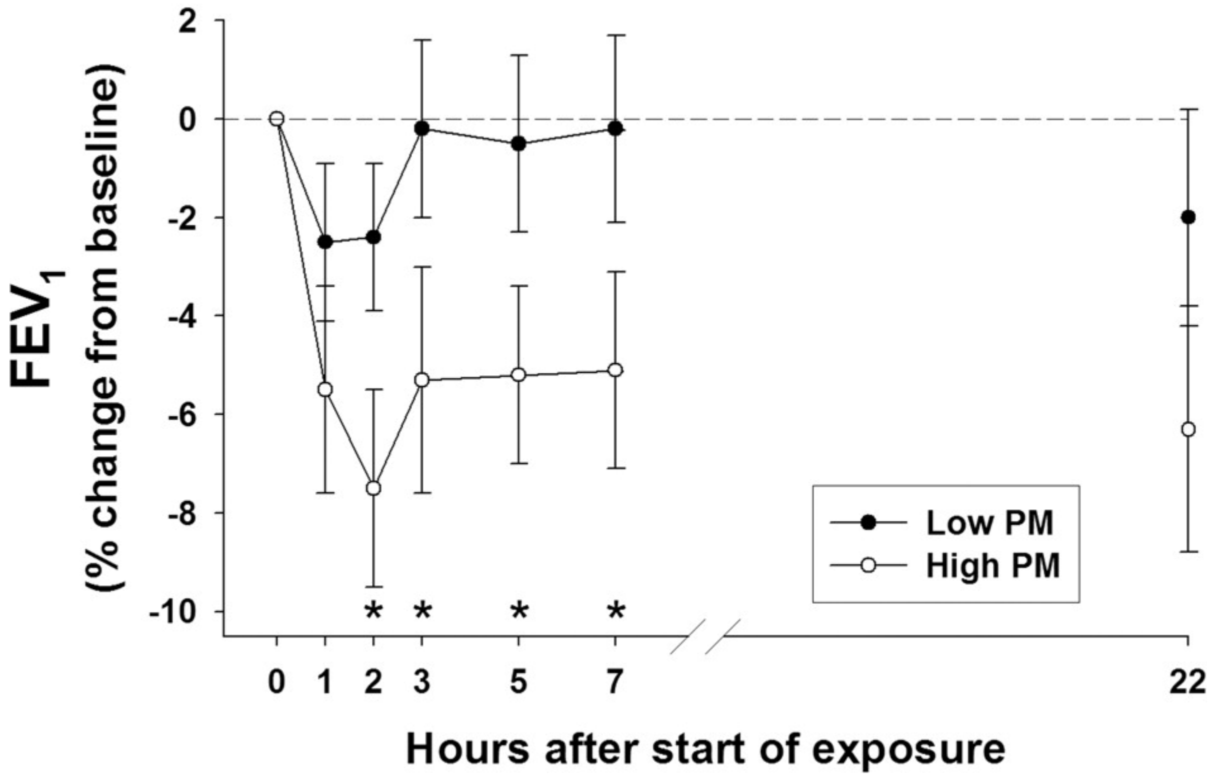
Randomized cross over trial
60 adults with mild to moderate asthma taking two leisurely 2-hr walks in London

$PM_{2.5}$ = 11.9

Assessed pollutant exposure, changes in pulmonary function; airway inflammation

McCreanor et al. NEJM 2007; 357:2348

Changes in pulmonary function during and after Exposure on Oxford Street and in Hyde Park



- Key correlations were with $PM_{2.5}$, ultrafine particles, elemental carbon and nitrogen dioxide
- Significant increases in markers of airway inflammation

McCreanor et al.
NEJM 2007; 357:2348

The NEW ENGLAND JOURNAL of MEDICINE

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Impact of air pollution on cognitive function

- Nurses' Health Study
  - 19,000 women aged 70-81
  - Followed over time with estimates of PM2.5 and course particle exposure
  - Decline in cognitive function on sophisticated testing associated with increased pollution
  - An increment of 10 $\mu g/m^3$ long term PM exposure was cognitively equivalent to aging by approximately 2 years

Arch Intern Med 2012; 172:219

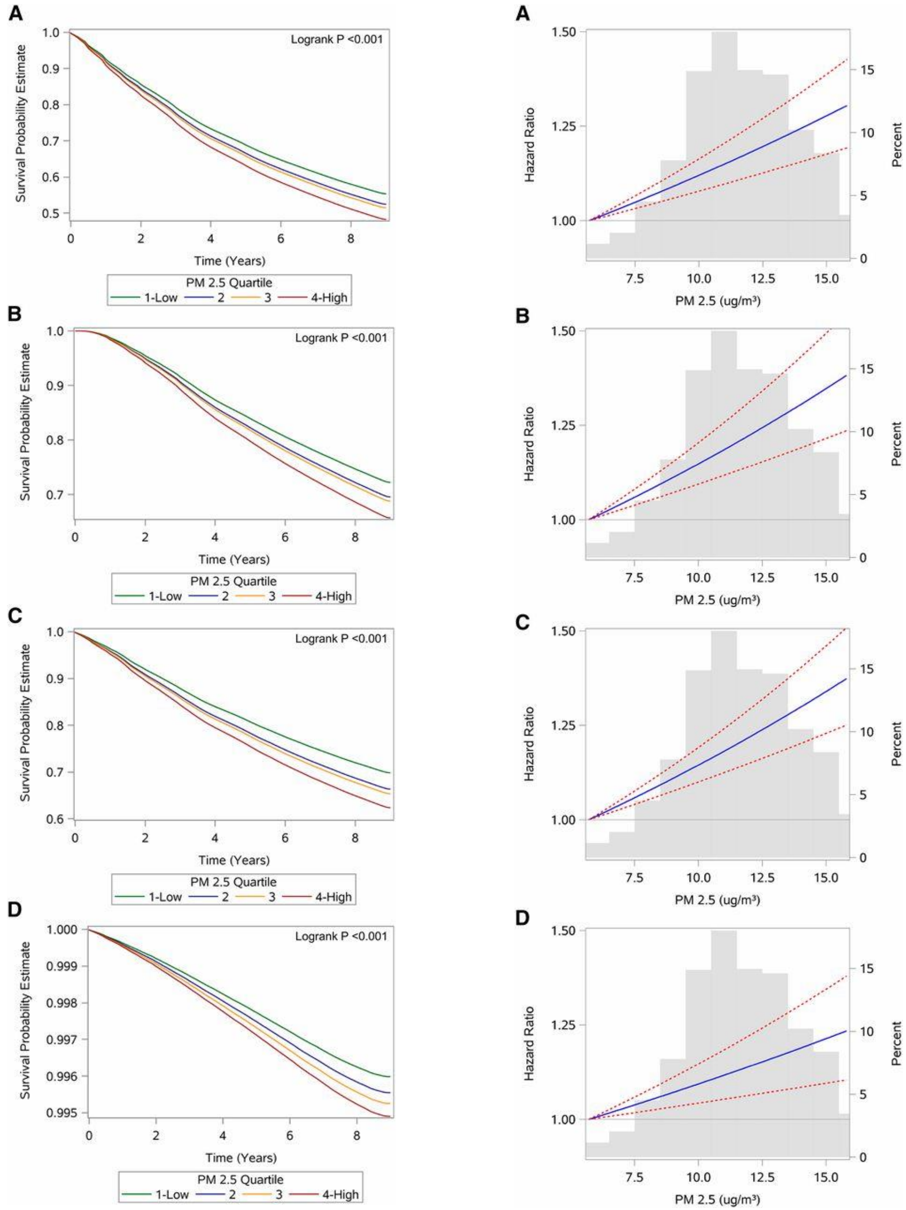
Effects of Air Pollution on Children

- Incidence of asthma
- Acute asthma exacerbations
- Lung growth
- Lost IQ points

Is there a risk of CKD associated with increased exposure to PM2.5?

- PM2.5 exposure is associated with
  - Hypertension
  - Endothelial cell dysfunction
  - Oxidative stress
- Bowe et al. JASN 2018
  - Observational cohort of 2482737 Veterans followed 8.52 years
  - Ground level PM2.5 monitoring and NASA satellite data

Analyses of risk of renal outcomes by PM2.5 concentrations (PM2.5 of 5.7 μg/m3 served as a reference) with PM2.5 probability distribution in the background.



Risks:

eGFR<60ml/min/1.73 M2

Incident CKD

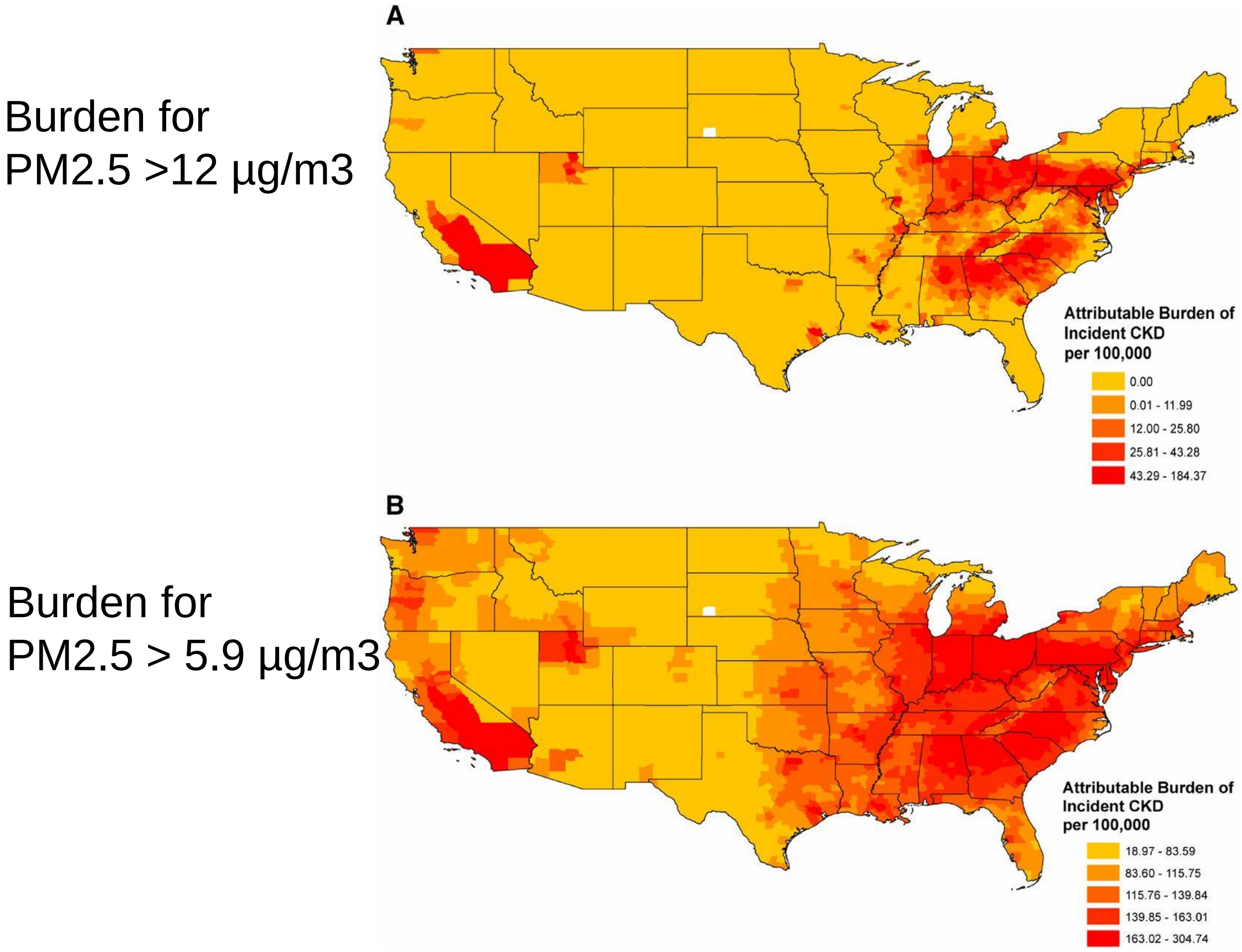
eGFR decline >30%

ESRD

Benjamin Bowe et al.
JASN 2018;29:218-230

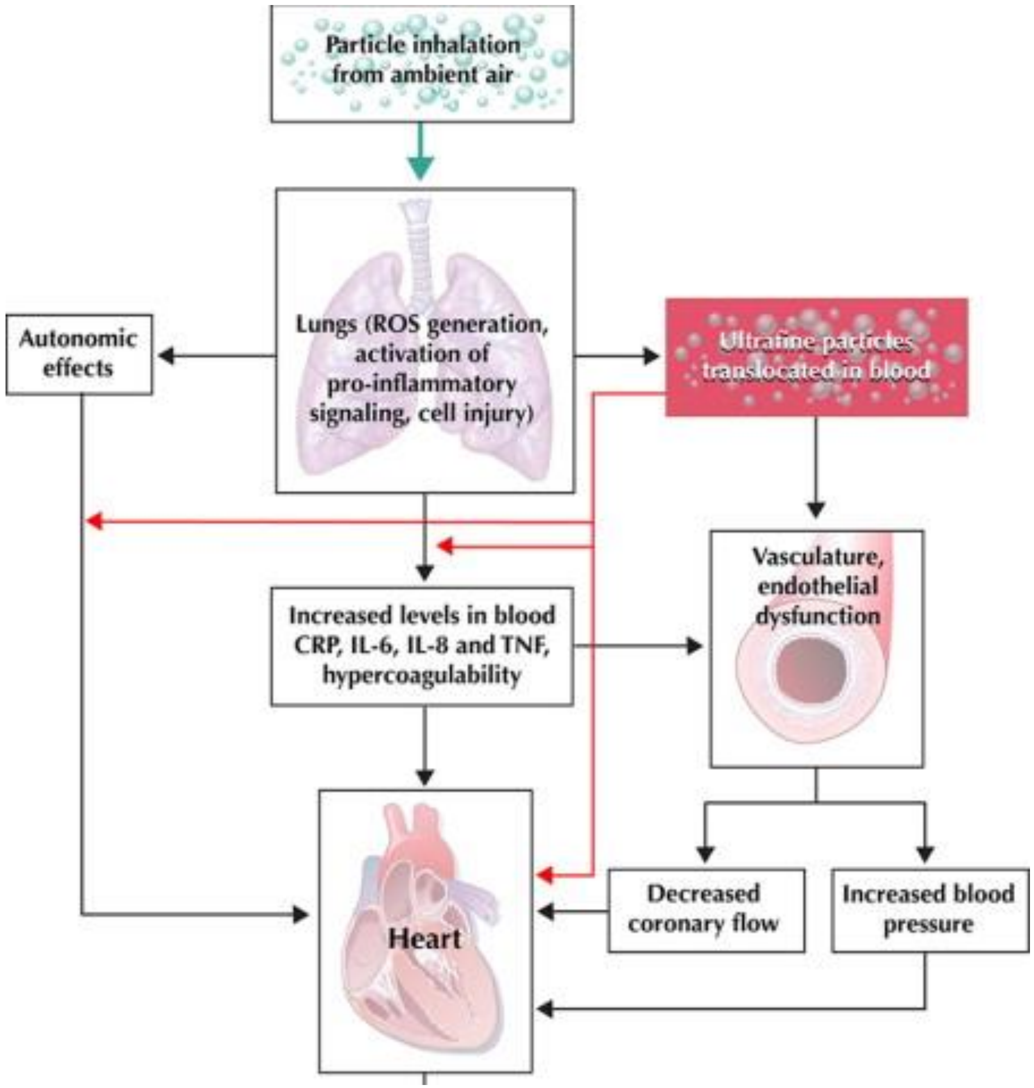
JASN
JOURNAL OF THE AMERICAN SOCIETY OF NEPHROLOGY

Geographic distribution of the national burden of incident CKD attributable to air pollution in the United States.



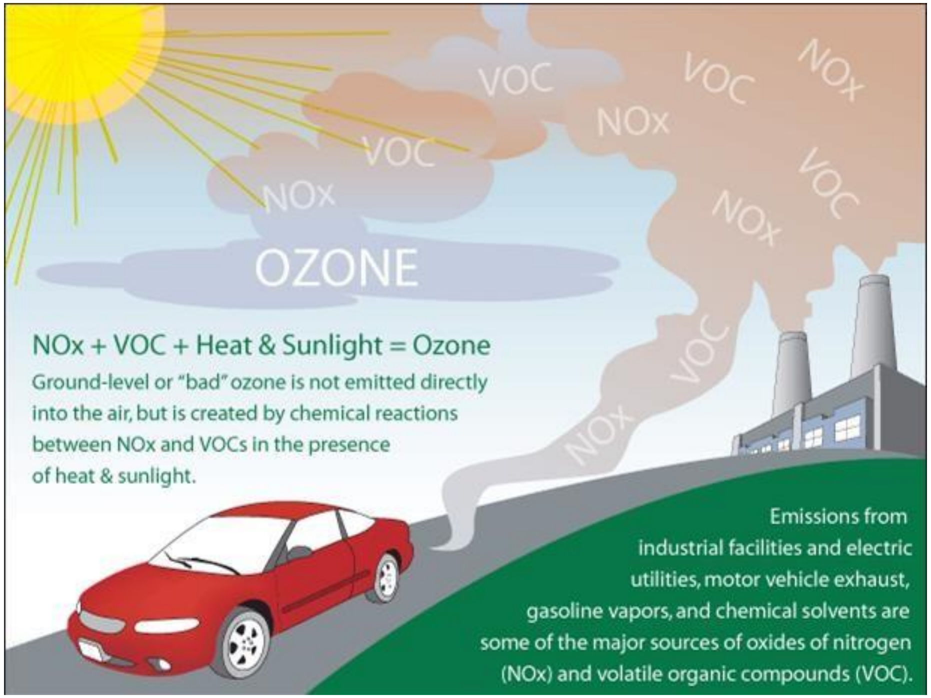
Benjamin Bowe et al. JASN 2018;29:218-230

JASN
JOURNAL OF THE AMERICAN SOCIETY OF NEPHROLOGY



Simkhovich et al. J Am Coll Cardiol 2008

Ground level ozone



EPA 8 hr standard < 70 ppb

Summertime ozone is a challenge along the Wasatch Front

Wintertime ozone is a challenge in the Uinta Basin

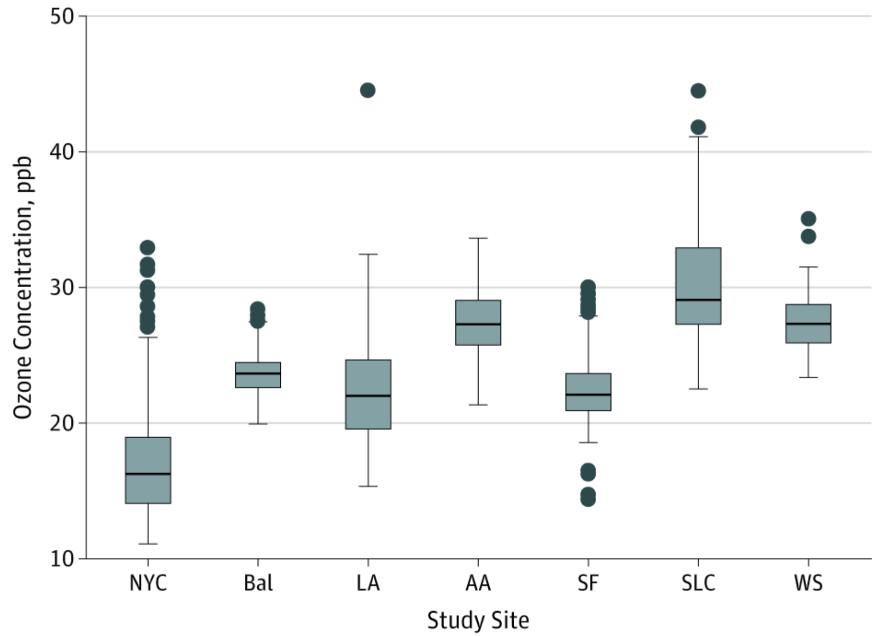
Short-term ozone exposure

- EPA threshold of 8-hr level of 70 ppb
- Association with
  - Acute exacerbations of asthma
  - Acute exacerbations of COPD
- Less information about longer term effects of ozone
  - No annual threshold designated by EPA

JAMA Network

From: **Association of Long-term Ambient Ozone Exposure With Respiratory Morbidity in Smokers**

JAMA Intern Med. 2020;180(1):106-115. doi:10.1001/jamainternmed.2019.5498

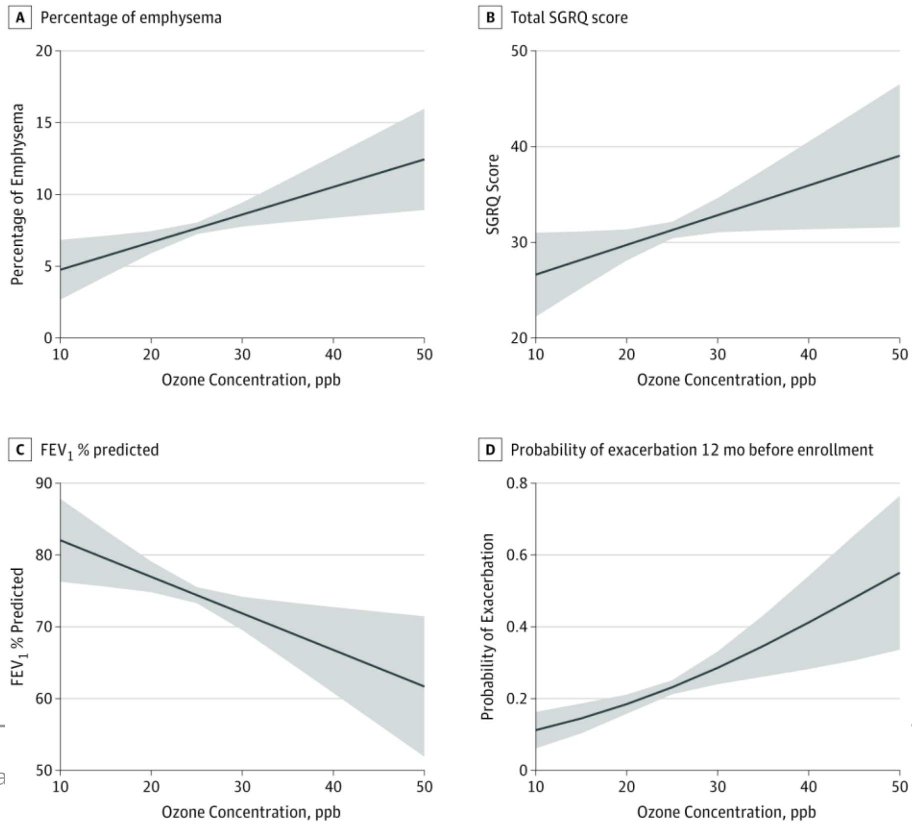


Distribution of 10-Year Historical Ozone Concentration by Study Site

JAMA Network

From: **Association of Long-term Ambient Ozone Exposure With Respiratory Morbidity in Smokers**

JAMA Intern Med. 2020;180(1):106-115. doi:10.1001/jamainternmed.2019.5498



Adjusted Associations of 10-Year Historical Ozone Concentration With Selected Outcomes of Interest: FEV_1 indicates forced expiratory volume in the first second of expiration; ppb, parts per billion; SGRQ, St. George Respiratory Questionnaire. Shaded areas represent 95% CIs.

Da

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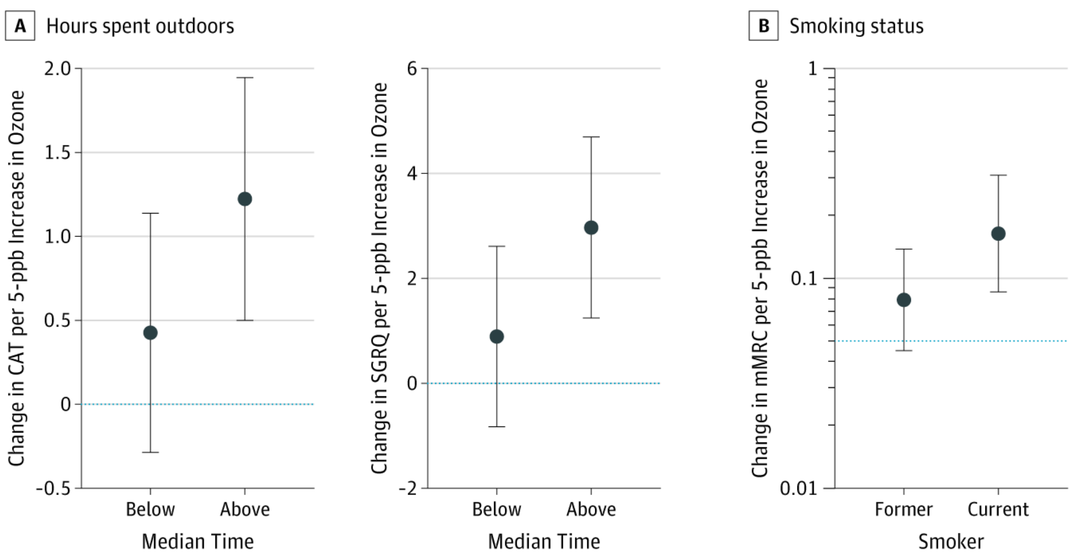

Effect Estimate of Ozone on Outcomes by Time Spent Outdoors and Smoking StatusCAT indicates COPD (chronic obstructive pulmonary disease) Assessment Test; mMRC, modified Medical Research Council Dyspnea Scale; ppb, parts per billion; SGRQ, St. George Respiratory Questionnaire. Error bars represent 95% CIs. P for interaction <.05 for analyses.

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Air Pollution and COVID-19

- The lockdown in response to the pandemic has lead to improved air quality, best seen in China and Europe
- Air pollution exposure is associated with increased risk of, and poor outcomes from, pneumonia
  - Dysregulated inflammation
  - Oxidative stress
- Prior to COVID, air pollution exposure is associated with increased risk of acute respiratory distress syndrome from viral infections, trauma

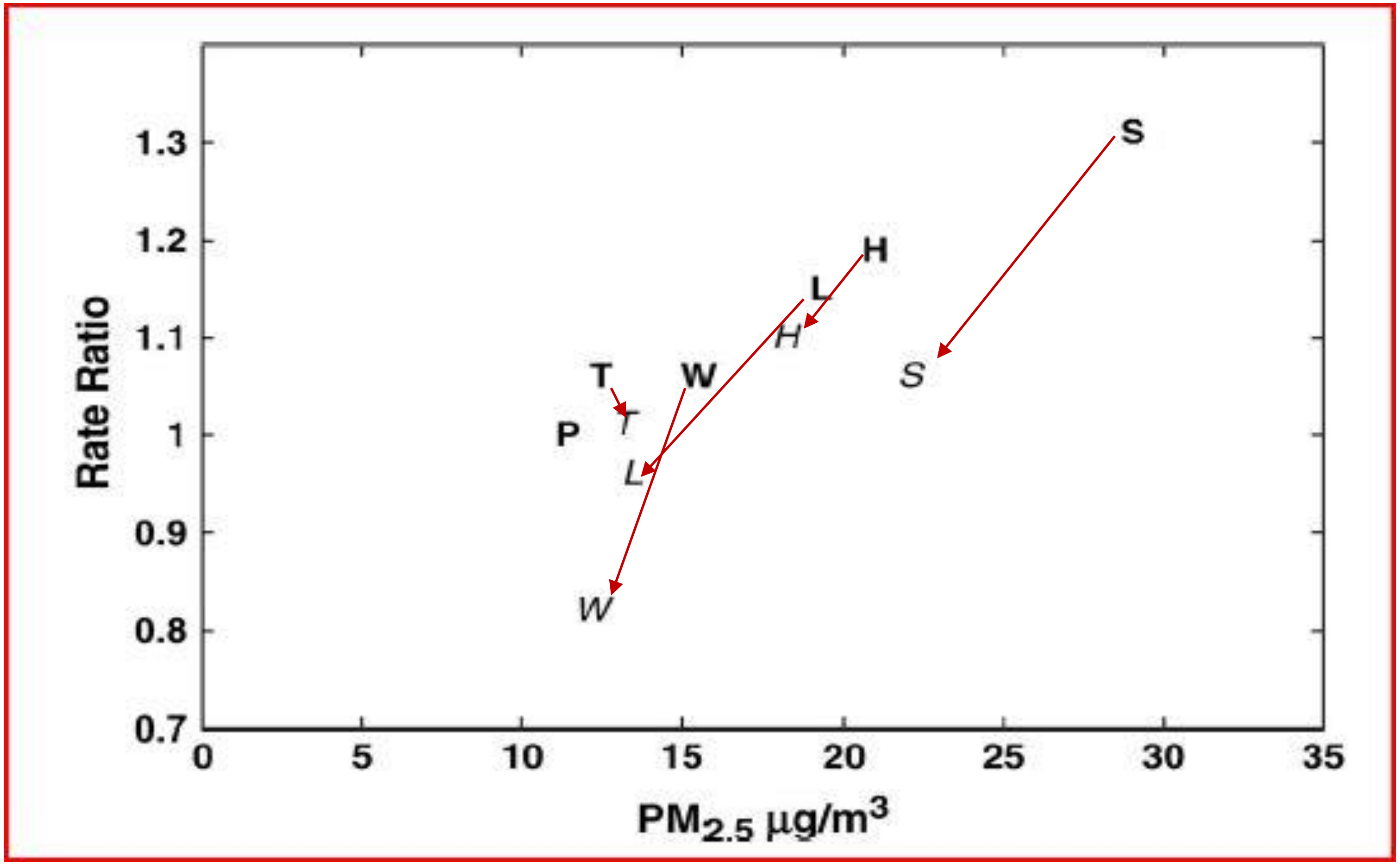
Table 1. Studies evaluating long-term air pollution exposure and COVID-19 incidence or mortality

Study	Country	Exposure	COVID-19 Outcome	Principal Findings
Wu *et al.* (April 2020)	United States	$PM_{2.5}$ Average between 2000 and 2016	Mortality rate	Increase of 1 µg/m^3 in $PM_{2.5}$ associated with an 8% increase in mortality rate
Cole *et al.* (June 2020)	The Netherlands	$PM_{2.5}$, NO_2, and SO_2 Average between 2015 and 2019	Cases Hospital admissions Deaths	1 µg/m^3 increase in $PM_{2.5}$ associated with 9.4 more cases, 3.0 more hospital admissions, and 2.3 more deaths NO_2 (but not SO_2) associated with cases and deaths
Hendryx *et al.* (June 2020)	United States	$PM_{2.5}$*, diesel PM† and O_3*	Cases Deaths	$PM_{2.5}$ and diesel PM associated with higher prevalence and mortality Diesel PM appeared to be the primary driver for associations with $PM_{2.5}$
Travaglio *et al.* (June 2020)	England	$PM_{2.5}$, PM_{10}, SO_2, NO_2, NO, and O_3 Average between 2018 and 2019	Cases Deaths Infectivity rate	NO and NO_2 significant predictors of cases independent of population density 1 µg/m^3 increase in SO_2 and NO associated with 17% and 2% higher mortality, respectively O_3 negatively associated with cases and deaths $PM_{2.5}$, PM_{10}, and SO_2 associated with SARS-CoV-2 infectivity (OR, 1.12, 1.07, and 1.32, respectively) but not cases or deaths
Konstantinoudis *et al.* (August 2020)	England	$PM_{2.5}$ and NO_2 Average between 2014 and 2018	Mortality rate	1 µ/m^3 increase in $PM_{2.5}$ and NO_2 associated with 1.4% and 0.5% higher mortality rate, respectively
Liang *et al.* (October 2020)	United States	$PM_{2.5}$, NO_2, and O_3 Annual mean between 2010 and 2016	CFR Mortality rate	NO_2 associated with 11.3% and 16.2% higher CFR and mortality rate, respectively, per IQR $PM_{2.5}$ associated with 14.9% higher mortality rate per IQR, but not with CFR No association between O_3 and CFR or mortality rate

Mein et al. AnnalsATS 2021, 18:1450

Do efforts to improve air quality make a difference for health?

Reduction in Fine Particulate Air Pollution and Mortality: Extended Follow-up of the Harvard Six Cities Study



Am J Respir Crit Care Med Vol 173. pp 667–672, 2006

Fine particulate air pollution and life expectancy in the US

- Detailed monitoring information at the county level
- Looking at late 1970's and early 1980's and at late 1990's and early 2000's
- Cross-sectional comparisons within each period
- Proxies for smoking, access to health care, etc.
- Temporal comparisons between periods each county as its own control

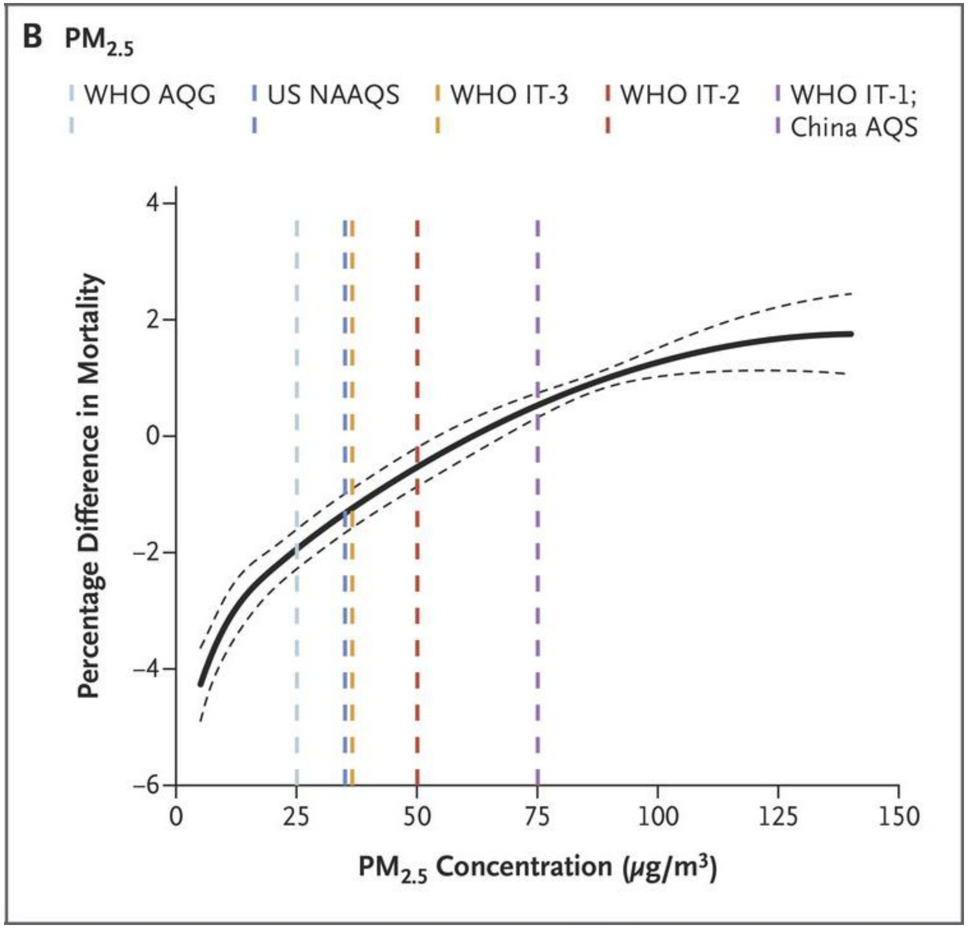
Pope et al. NEJM 2009; 360: 376

Pope et al. 2009: Results

- Air quality improved over time across the country
- Life expectancy increased (2.72 years)
- During each period, cross-sectional data showed negative association between life expectancy and pollution levels
- Reduction of 10 µm/m^3 resulted in increase of 0.61 ± 0.2 years life
- Benefit regardless of baseline level; in fact greater increase for those areas with less pollution initially
- From 1980 through 2000, improved air quality accounted for approximately 15% of change in life expectancy

Increased mortality associated with short term air pollution exposure

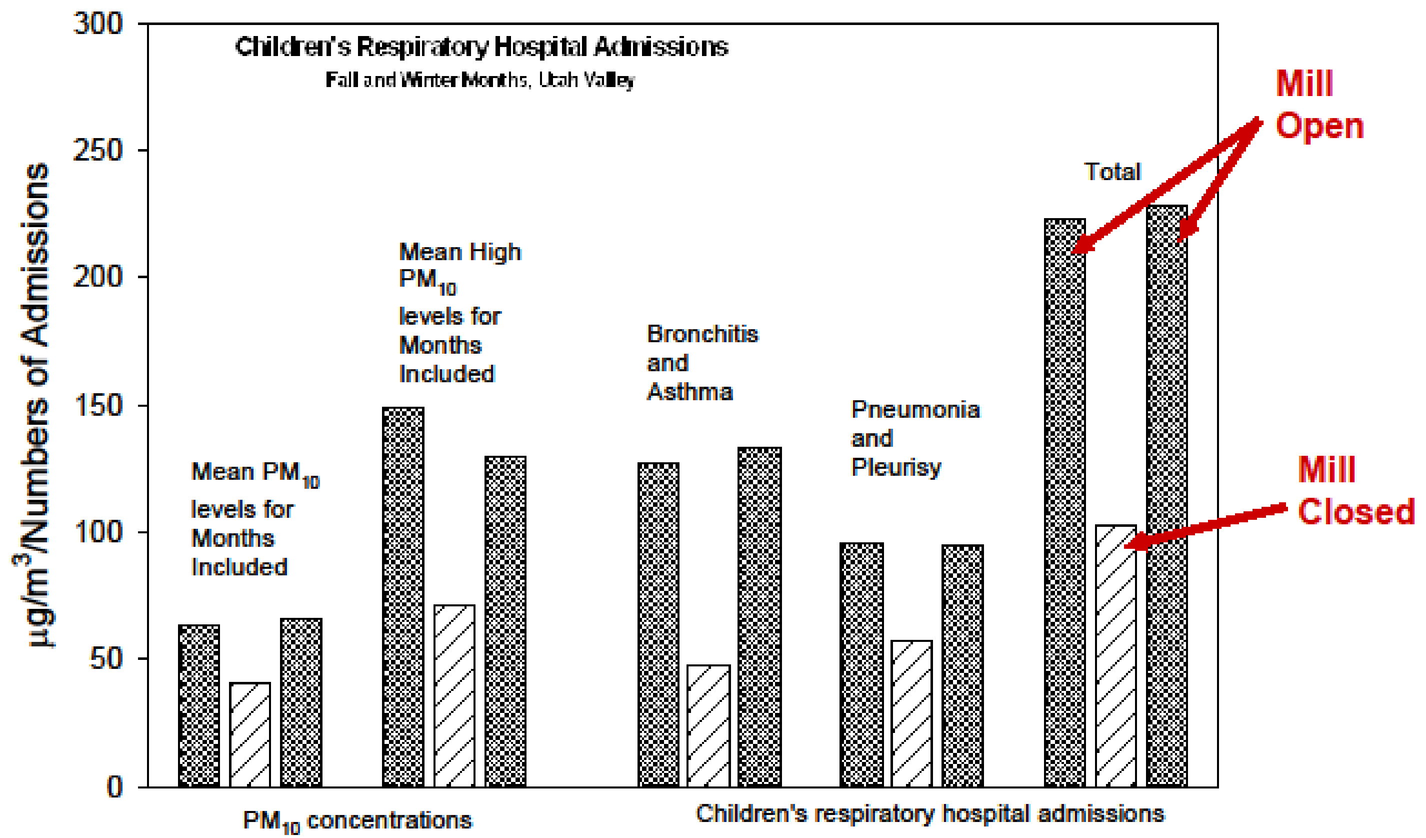
- Data from over 600 cities in 24 countries
- Rolling 2 day average exposure
- All cause mortality
- Effects even at levels considered “safe”



C Liu et al. N Engl J Med 2019;381:705-715

Geneva Steel Strike

When the steel mill was open, total children's hospital admissions for respiratory conditions **approx. doubled.**



Sources: Pope. Am J Pub Health.1989; Pope. Arch Environ Health. 1991

Wildfires and Health

How bad is this year's Utah wildfire season? Actually, not that bad so far — unless you're trying to breathe.

Salt Lake Tribune August 17, 2018

Constituents of wood smoke

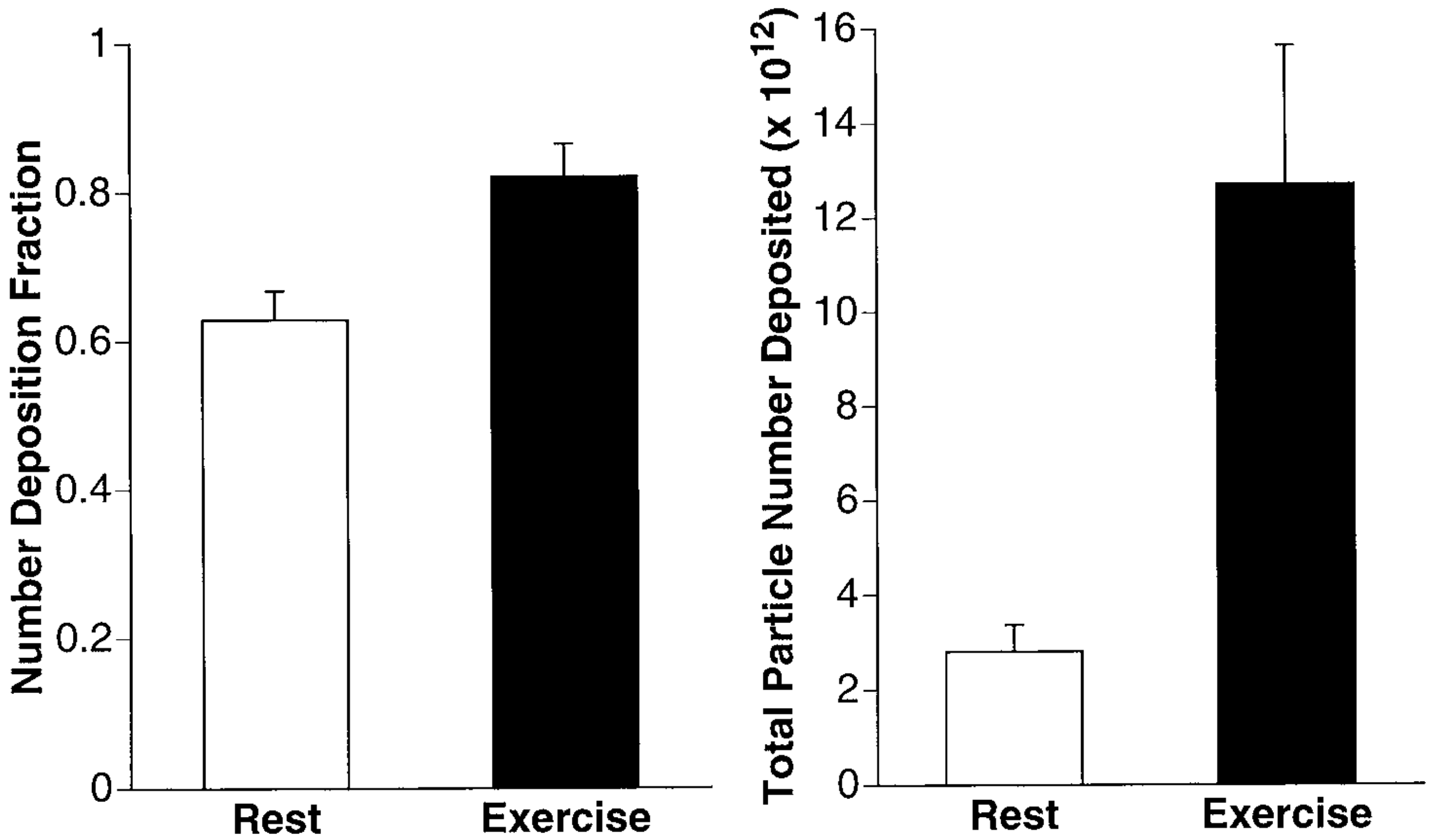
- Regulated pollutants
  - Fine particles, carbon monoxide, nitrogen oxides
- Respiratory irritants impairing cellular function
  - Phenols, cresols, acrolein, acetaldehyde
- Organic carcinogens
  - Benzene, formaldehyde, 1,3 butadiene
- Carcinogenic cyclic compounds
  - Polycyclic aromatic hydrocarbons
  - Dioxins

Wildfires are major health events

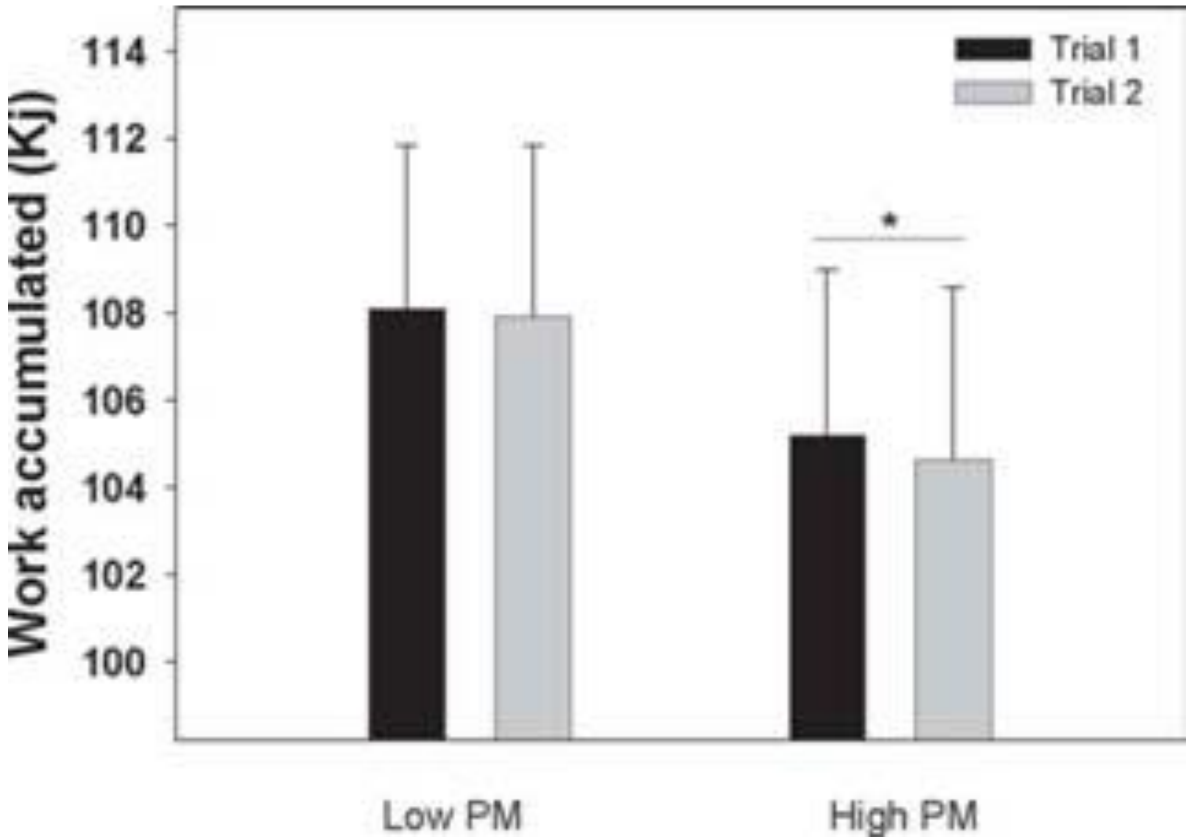
- Wildfire activity around the world is associated with
  - Increased emergency room visits
  - Increased acute respiratory distress hospital visits
  - Increased hospital admissions for respiratory illness
  - Increased use of asthma medications
  - Decreased lung function
  - Increased evidence of inflammation in the blood
  - Increased mortality (over age 65)

What should we tell our patients about exercise?

Increased lung particle deposition during exercise



Impact of particulate air pollution on cycle work capacity



Rundell K W Br J Sports Med 2012;46:407-412

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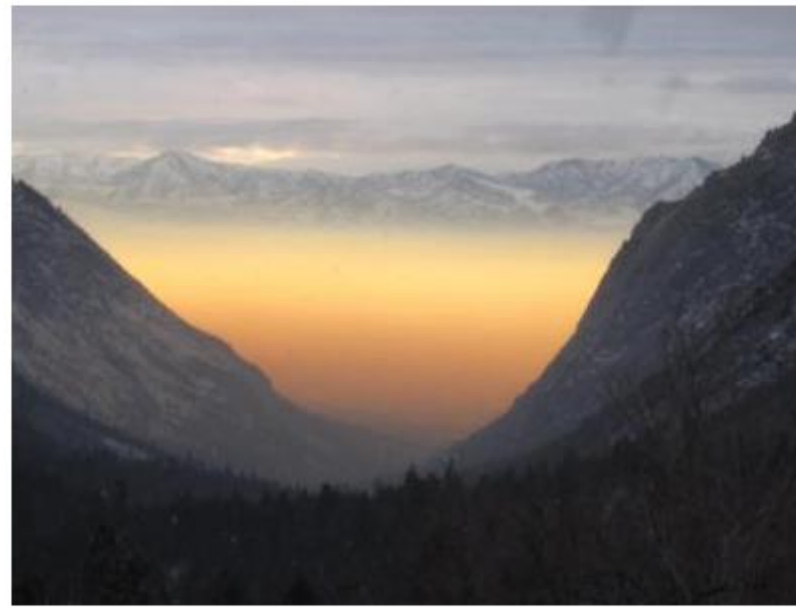
What do I tell my patients?

- Pay attention to air quality; note if your symptoms change.
- When air quality is poor, it is particularly important to use your medications properly.
- During "bad air" days:
  - Exercise away from roadways
  - Exercise indoors
  - Stay indoors
- Starting to think about masks for high-risk individuals when outdoors



Air Quality Index

Action Forecast

Unrestricted Action

Voluntary Action

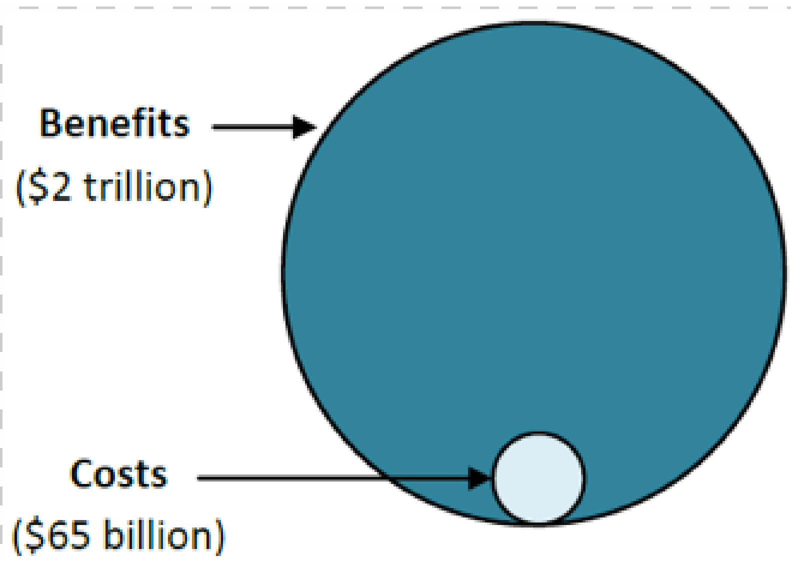
Mandatory Action

Health Forecast

Air Quality Index (AQI)	PM 2.5	Ozone
Good	0 - 12.0 µg/m^3	0 - 0.054 ppm
Moderate	12.1 - 35.4 µg/m^3	0.055 - 0.070 ppm
Unhealthy for Sensitive Groups	35.5 - 55.4 µg/m^3	0.071 - 0.085 ppm
Unhealthy	55.5 - 150.4 µg/m^3	0.086 - 0.105 ppm
Very Unhealthy	150.5 - 250.4 µg/m^3	0.106 - 0.200 ppm
Hazardous	Above 250.5 µg/m^3	Above 0.201 ppm
	Based on a 24-hour average.	Based on an 8-hour average.

Cost-benefit of the Clean Air Act 1990-2020

	Cases prevented (2020)
Adult mortality – particles	230,000
Infant mortality – particles	280
Mortality – ozone	7100
Chronic bronchitis	75,000
Acute myocardial infarction	200,000
Asthma exacerbation	2,400,000
Emergency room visits	120,000
Lost school days	5,400,000
Lost work days	17,000,000



Clean Air Act 40th anniversary celebration

Thanks- happy to take questions