Bad Air: An Introduction to Air Pollution Epidemiology

12th March 2020

Will Mueller

50 YEARS IOM science with purpose

About me…

- Education
  - Master of Applied Science (Environmental Science)
  - Master of Science (Epidemiology)
  - Part-time PhD student at LSHTM (Epidemiology)
- Experience
  - Caribbean Public Health Agency (Trinidad & Tobago)
  - Radiation Effects Research Foundation (Japan)
  - Imperial College London (UK)
- Currently…
  - Working as an epidemiologist at IOM in Scotland

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Overview

1. What is outdoor air pollution, what are the main sources and key pollutants?
2. What are the main types of epidemiological studies?
3. What health effects are caused by air pollution?
4. How can exposures be reduced?
5. Case study in Thailand – Biomass burning

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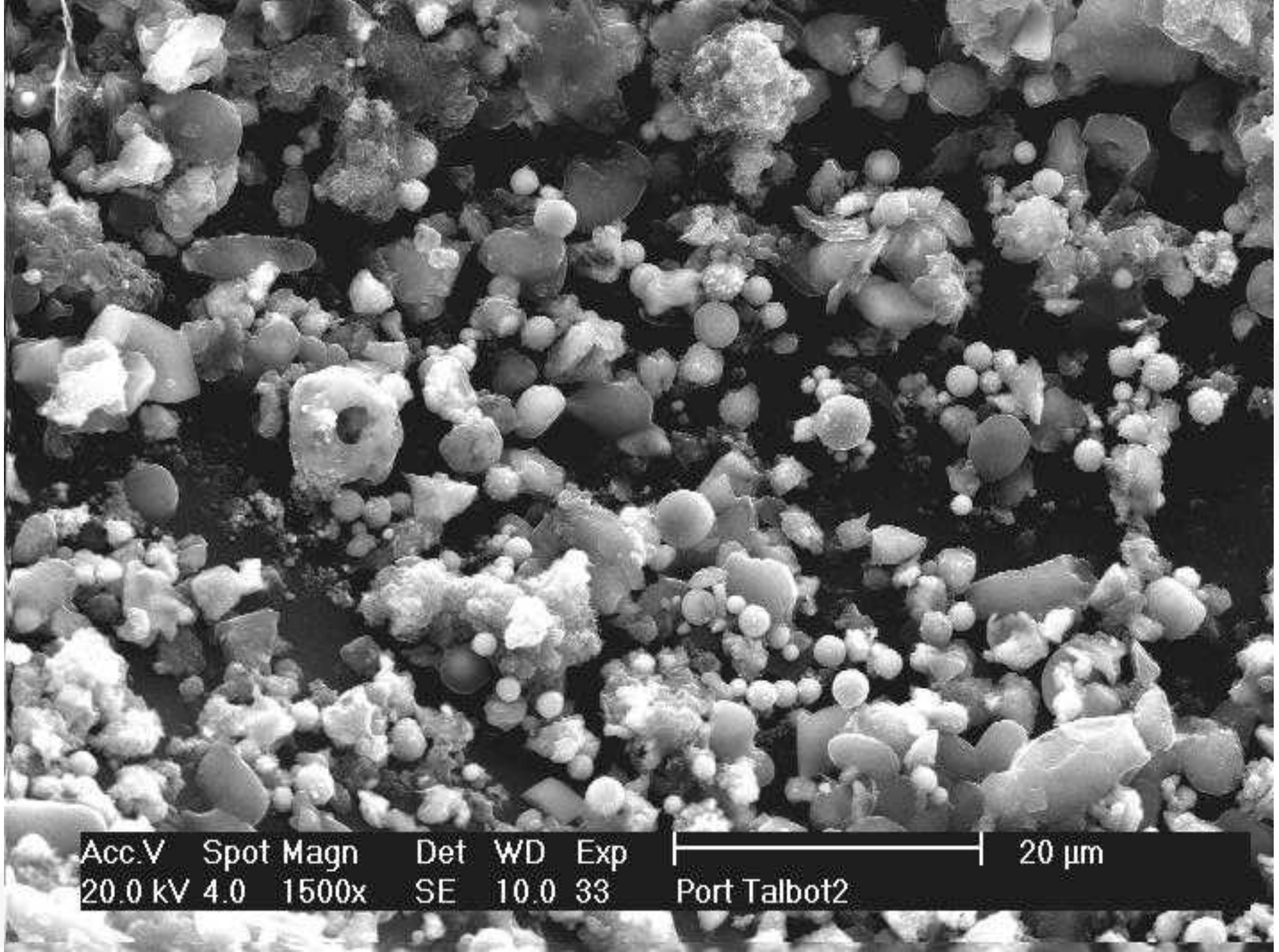
Outdoor air pollution is a mixture…

- …of particles (Particulate Matter: PM) and gases:
  - Nitrogen dioxide (NO_2) (traffic)
  - Sulphur dioxide (SO_2) (industry)
  - Carbon Monoxide (CO) (traffic)
  - Gases formed later: Ground-level ozone (O_3), from NO_x & volatile organic compounds (VOCs)
- PM is itself a mixture – varies by size, composition, surface properties
  - Primary particles from combustion, brakes and tyres, natural dusts, re-suspended road dusts
  - Secondary particles – nitrates and sulphates – formed over longer distances from gases (NO_2, SO_2)


Acc.V Spot Magn Det WD Exp
20.0 kV 4.0 1500x SE 10.0 33
20 µm
Port Talbot2

Measurement of Air Pollutants

- Mass (weight) per volume of air in units of $\mu g.m^{-3}$
  - Metric of concentration
  - Different time periods

- PM: Mass in in different size ranges:
  - TSP – Total suspended particles
  - PM_{10} (inhalable), $PM_{2.5}$ (fine)
  - $PM_{0.1}$ – nanoparticles / ultrafines

- Particle number – especially near roadside, high levels of ultrafines; e.g. >20,000 per ml, sometimes 100,000 per ml

- Gases are commonly measured in parts per million/billion (ppm/ppb)

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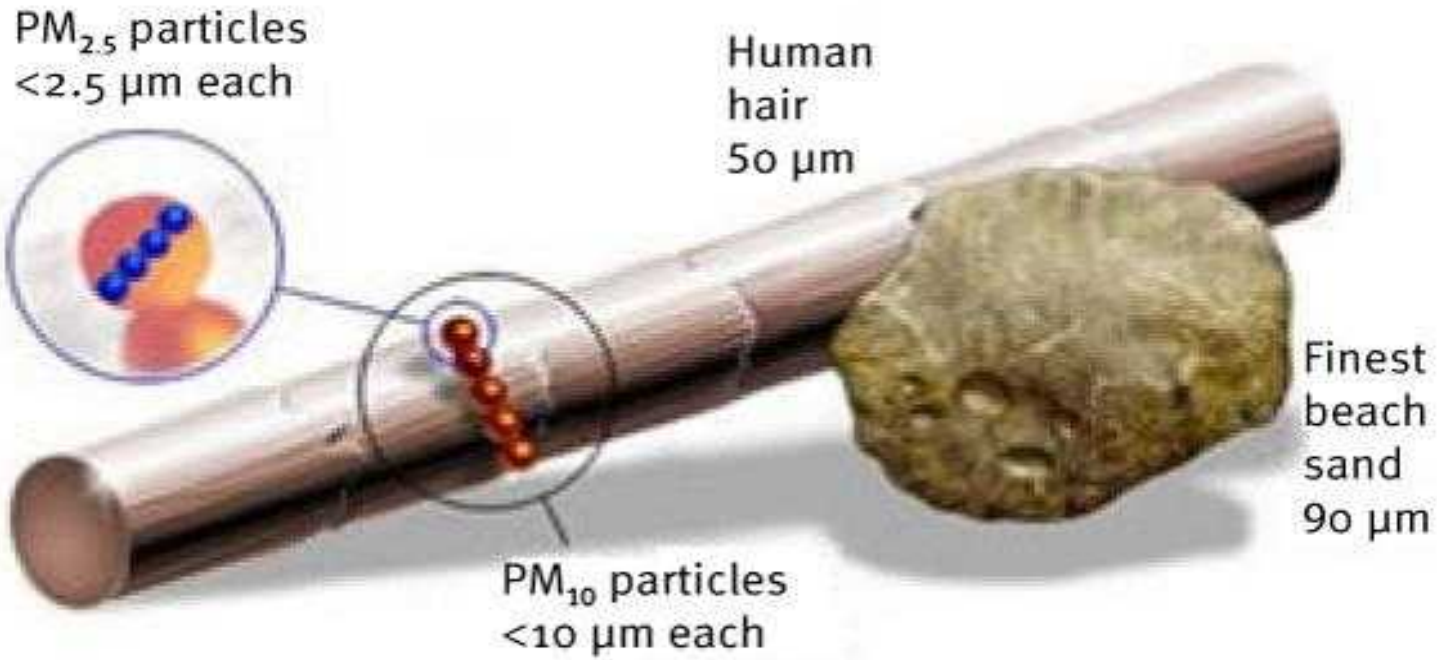
$PM_{2.5}$

- Small particles that are inhaled into the deep areas of the lung



Types of Epidemiology Studies

Role of epidemiology with air pollution

- Studies look for an increase in risk of common diseases and causes of ill-health and death in populations, e.g. cardio-respiratory, cancer
- Account for other factors that may increase the risk of disease
- Although we can't identify individuals and say: "This person was killed by air pollution", we can at a population level and for sub-groups:
  - Estimate the increase in risk, i.e. what is the % increase in deaths or hospital admissions etc for a given level of pollution?
  - Estimate the impact in specific populations
  - Establish exposure-response or concentration-response relationships

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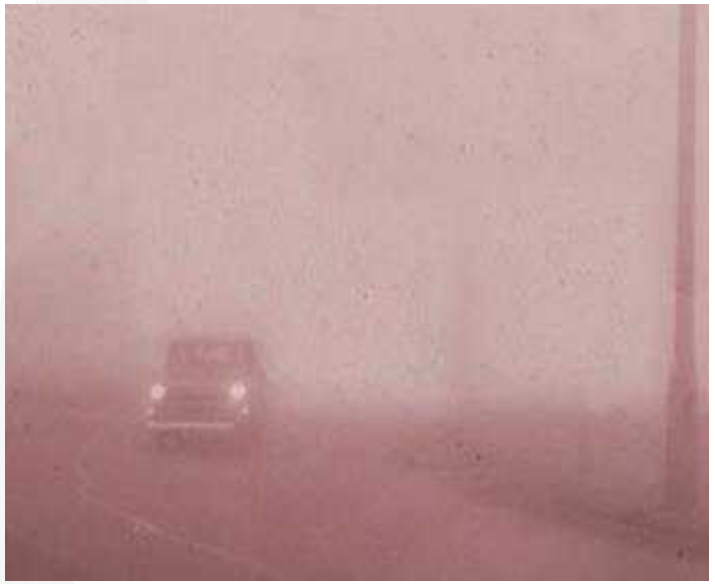
Epidemiology studies types of air pollution and health

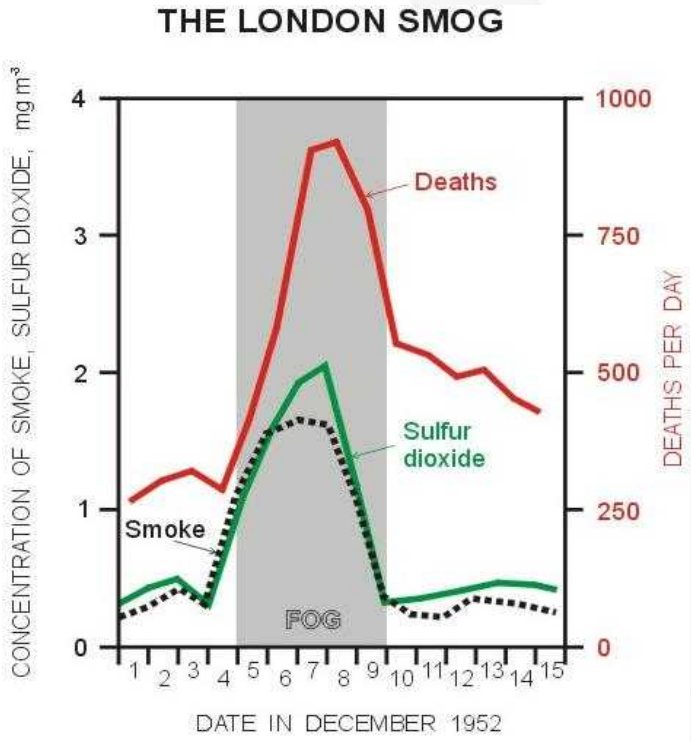
1. From air pollution episodes, e.g., the London smog

2. Time series: By studying the same population over time, e.g. within a city
   - How air pollution varies day by day
   - How health varies day by day
   - What other factors that affect health vary day by day

3. Cohort: By studying populations exposed long-term to different levels and kinds of air pollution

Air Pollution Episodes: London Smog of 1952





1. Very high levels of PM and SO_2 together
2. Increased mortality and morbidity immediately following
3. Causality accepted (though pollutant mechanisms unknown)
4. Policy response - Eliminate episodes: stop domestic coal burning

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More modern air pollution episodes…

Wildfires: Greece, August 2009

Crop burning: Delhi, India November (~annually)

‘Ordinary’ or ‘low’ levels of air pollution are more damaging…

- Episodes matter and they catch attention (media and public)
- But air pollution at ‘ordinary’ levels causes greater problems
  - Because the whole population is exposed everyday
  - Even if the risks to any one person on any one day are small…
    …The aggregate effects over a year are higher than from episodes
- Studies show that ‘ordinary’ levels of air pollution lead to more
  - Deaths
  - Hospital admissions, visits to GPs
  - Asthma attacks
  - Days off work and off school; days of restricted activity
  - Respiratory and other symptoms
  - The list keeps growing…

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Time series studies of daily air pollution and deaths

- Evidence of the effects has been growing since the 1980s
- Studies are typically in large cities, over several years; i.e. they track much the same population over time (short-term effects):
  - Daily concentrations of air pollutants
  - Daily deaths or hospital admissions
  - Other factors that might affect daily deaths
- Lots of these studies are published because they use routinely collected data

Daily air pollution and deaths

- There is a 'triggering' effect of higher daily PM on the population
- Liu et al. (2019) published a summary of effects from 652 cities in 24 countries during 1986 to 2015
- $PM_{2.5}$ average effect of **<u>0.68%</u>** (95% CI, 0.59 to 0.77) per 10 μg/m^3
- Estimation takes account of other factors (season, climate)

Ambient Particulate Air Pollution and Daily Mortality in 652 Cities

C. Liu, R. Chen, F. Sera, A.M. Vicedo-Cabrera, Y. Guo, S. Tong, M.S.Z.S. Coelho, P.H.N. Saldiva, E. Lavigne, P. Matus, N. Valdes Ortega, S. Osorio Garcia, M. Pascal, M. Stafoggia, M. Scortichini, M. Hashizume, Y. Honda, M. Hurtado-Díaz, J. Cruz, B. Nunes, J.P. Teixeira, H. Kim, A. Tobias, C. Íñiguez, B. Forsberg, C. Åström, M.S. Ragettli, Y.-L. Guo, B.-Y. Chen, M.L. Bell, C.Y. Wright, N. Scovronick, R.M. Garland, A. Milojevic, J. Kyselý, A. Urban, H. Orru, E. Indermitte, J.J.K. Jaakkola, N.R.I. Ryti, K. Katsouyanni, A. Analitis, A. Zanobetti, J. Schwartz, J. Chen, T. Wu, A. Cohen, A. Gasparrini, and H. Kan

Global coverage of $PM_{2.5}$ monitors

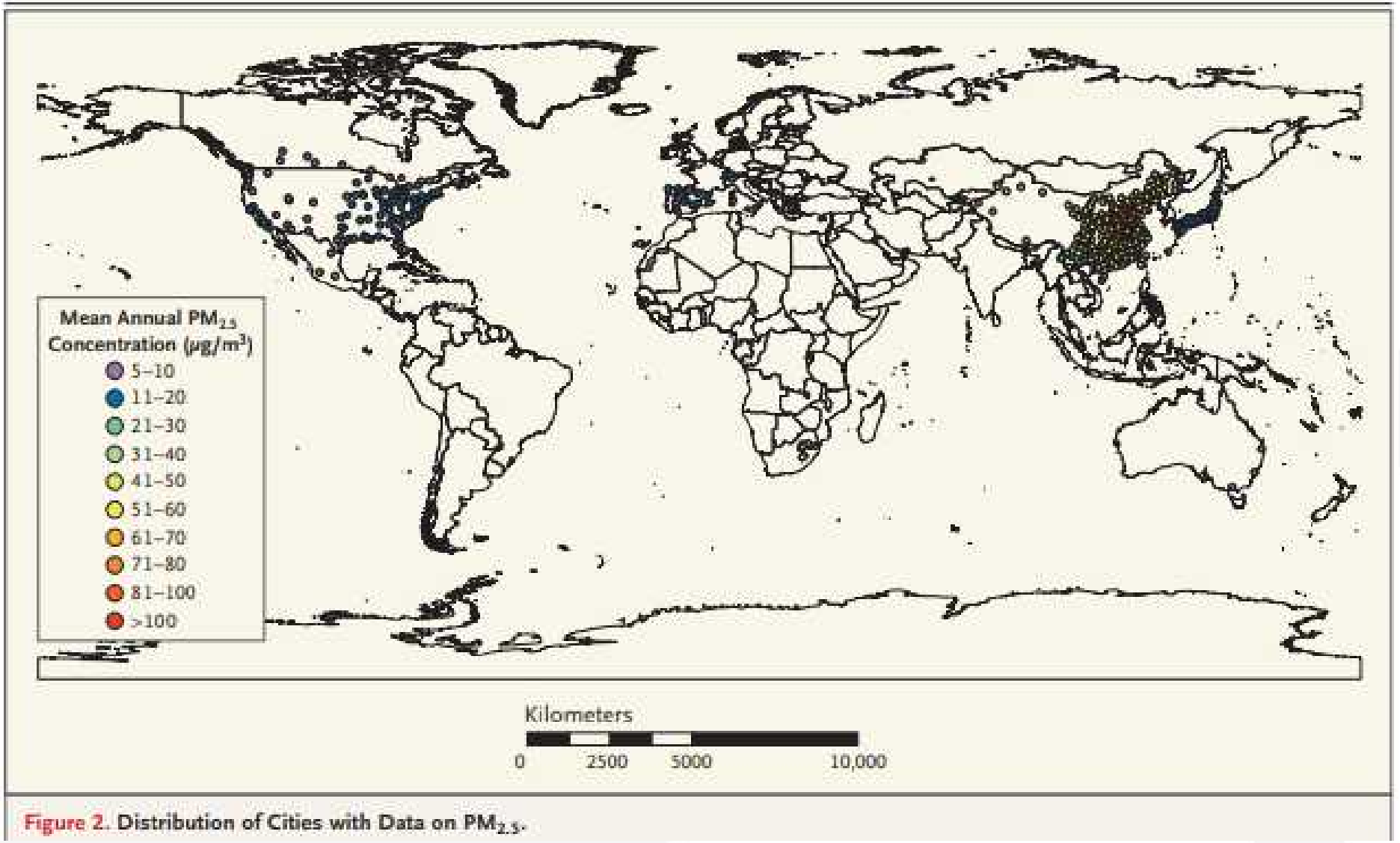

Figure 2. Distribution of Cities with Data on $PM_{2.5}$.

Liu et al., 2019. *New England Journal of Medicine.*

Daily variations – policy implications

- Public health significance unclear / contested
  - Those at risk of earlier death believed to be people with pre-existing serious cardio-respiratory disease: harvesting/ displacement?
  - Do all earlier deaths matter equally? What about years of life lost (YLL)?

- Policy implications – control peaks or average exposure?
  - Health effects not just on high-pollution days – remove the high pollution days and practically unchanged
  - No evidence of a threshold
  - Control annual average PM levels

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Cohort studies of long-term exposure and mortality

- Large studies of individuals exposed to different levels of pollution – typically in different cities
- The 'game-changer' was two major US cohort studies
  - Six-Cities – Dockery et al., 1993
  - American Cancer Society (ACS) – Pope et al., 1995
- Study differences in mortality in the populations of the different cities, adjusting for other factors
  - At the individual level – age, gender, smoking, SES…
  - At the city level – climate, region, deprivation…
- No evidence of threshold

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Harvard Six Cities cohort study

The New England Journal of Medicine

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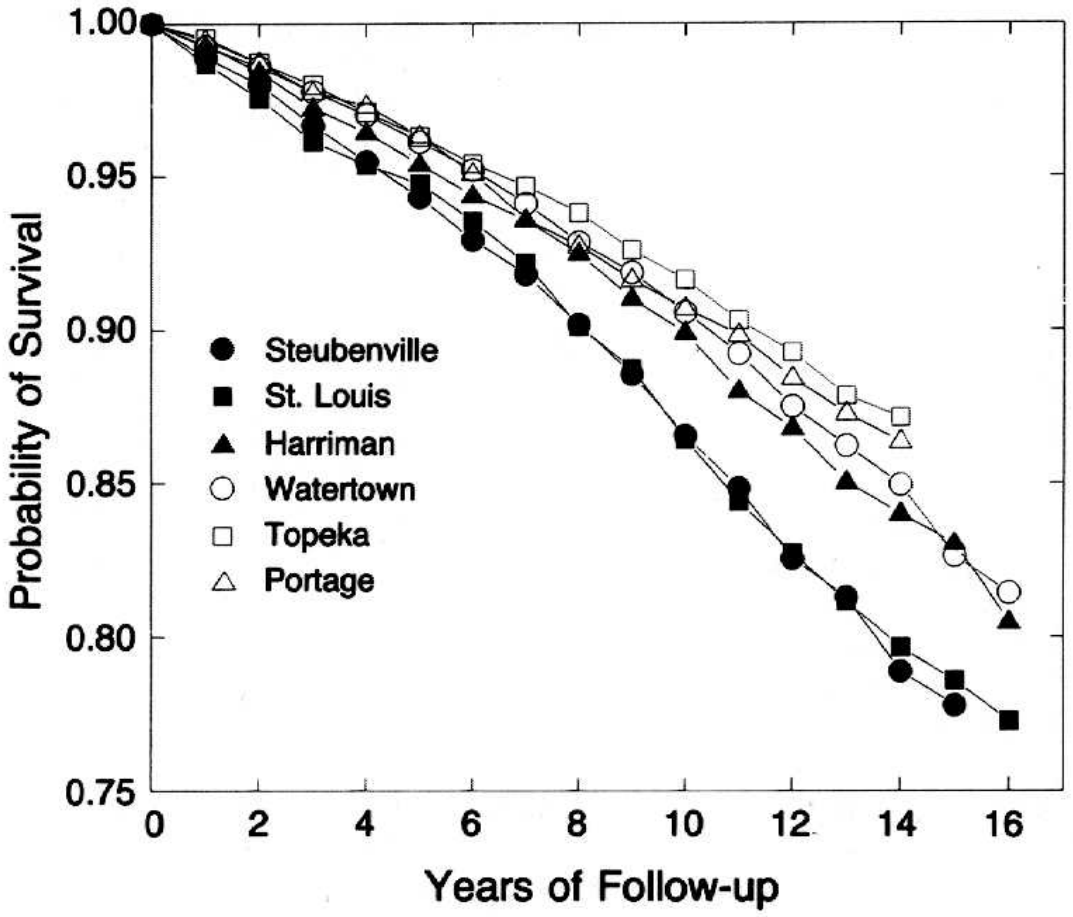
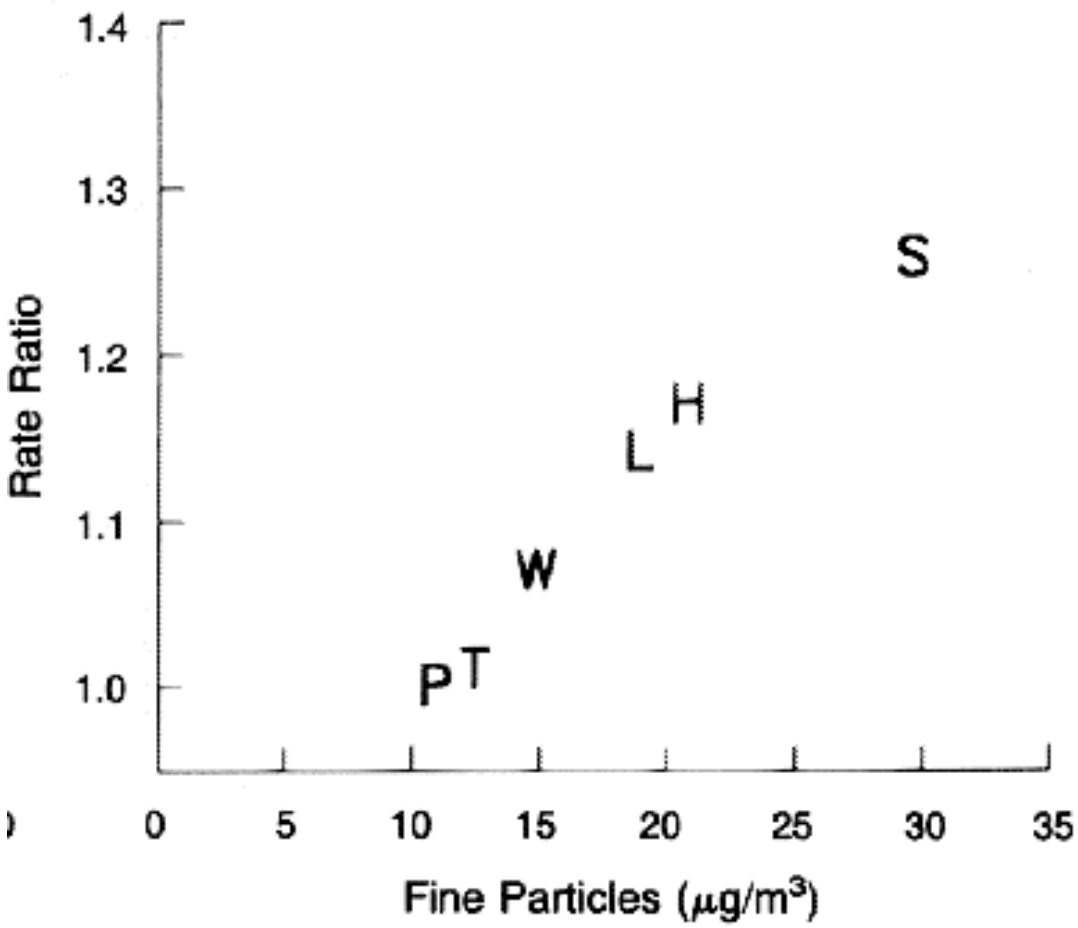
Volume 329 DECEMBER 9, 1993 Number 24

AN ASSOCIATION BETWEEN AIR POLLUTION AND MORTALITY IN SIX U.S. CITIES

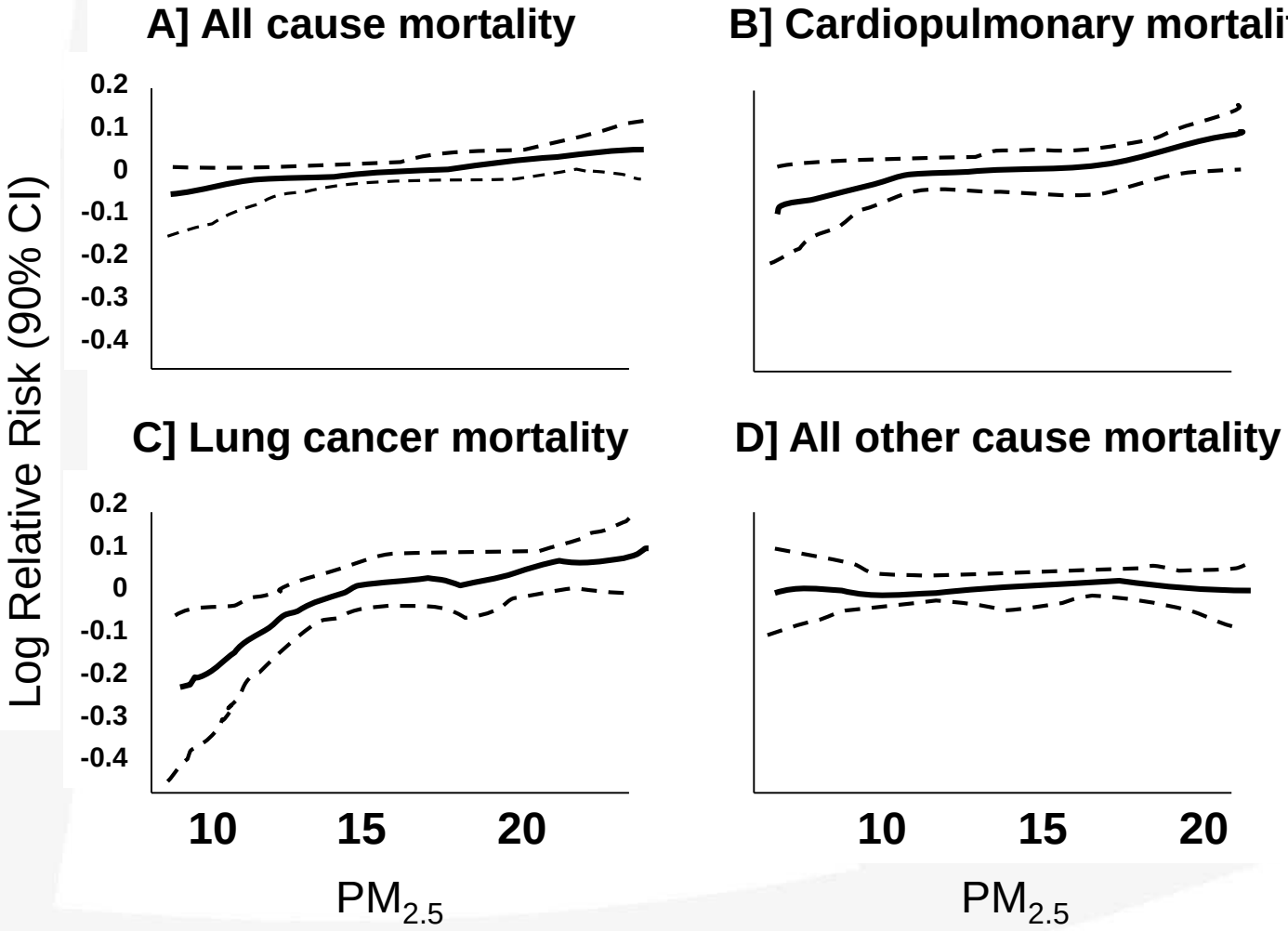
Douglas W. Dockery, Sc.D., C. Arden Pope III, Ph.D., Xiping Xu, M.D., Ph.D., John D. Spengler, Ph.D., James H. Ware, Ph.D., Martha E. Fay, M.P.H., Benjamin G. Ferris, Jr., M.D., and Frank E. Speizer, M.D.





Dockery et al., 1993

$PM_{2.5}$ and mortality: Shape of the relationship



Pope et al (2002), ACS

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

C. Arden Pope III, PhD
Richard T. Burnett, PhD
Michael J. Thun, MD
Eugenia E. Calle, PhD
Daniel Krewski, PhD
Kazuhiko Ito, PhD
George D. Thurston, ScD

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

- Most of the mortality increase is from cardiopulmonary disease

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Summary: Air pollution damages human health

- 1950s onwards: Air pollution **episodes** cause increased death and ill-health on the same day or on the days immediately following

- Late 1980s onwards: **Daily pollution** at 'normal' levels causes increased death and ill-health on the same day or on the days immediately following:
  - There is no known 'safe level' (threshold), for the population as a whole
  - Increased risks of death believed to be among people with pre-existing disease

- Mid 1990s onwards: The dominant effect is increased risk of mortality in adults from **long-term exposure**, especially $PM_{2.5}$, NO_2 and to some extent O_3
  - Again, there is no known 'safe level'
  - The risks seem to apply to the whole population (i.e., not just those with disease)
  - 6% increase in age-specific death rates per 10 $\mu g.m^{-3}$ $PM_{2.5}$

Exposure reduction strategies

- Although public interest focuses on pollution episodes and ‘hotspots’, the biggest gains are from reducing average exposure across the population as a whole
  - Not just on high pollution days
  - Not just in high pollution areas
  - Not just for particular groups of individuals
- Logical consequence of what we have seen:
  - Air pollution affects everybody
  - There is no safe level
  - Biggest effects are related to long-term average exposure
- Need to take account also of inequalities

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Air pollution and health inequalities

1. Inequalities in relative risk, i.e. in % change in health effect per unit pollution
   i. Varies by age, gender, sometimes by location
   ii. SES: ACS Study – higher mortality risks with lower educational status

2. Inequalities in background rates and so in public health effects, even when exposures and risk coefficients are the same:
   i. These arise because typically air pollution "amplifies" existing differences in background rates of mortality and morbidity, by some % increase
   ii. Older people, poorer people, people with serious disease, have higher background rates of mortality and morbidity – and so the same % increase has a bigger impact per 100,000 people exposed.

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Is all $PM_{2.5}$ equally toxic?

- Issue is controversial scientifically and is very important practically, on what to control, e.g.
  - Are primary particles, especially primary combustion particles, more harmful per $\mu g/m^3$ than secondary particles?
- Expert groups agree that almost certainly there is variation BUT…
- …the evidence is far from clear-cut and WHO Expert Groups, and others (COMEAP, US EPA) say the evidence is not good enough to quantify
- Recent COMEAP statement (2015a) says we can't say what component is worse, not even qualitatively.

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Air pollution is not just a local issue

- Local emissions affect local public health, BUT pollution travels
- Over time and distance gases (NO_2, SO_2) interact with e.g. ammonia in the atmosphere, leading to additional (secondary) PM
- And so:
  - Local emissions affect public health at a distance – about 50% of the effects of NO_2 and SO_2 emissions in the UK occur elsewhere
  - Distant emissions affect public health locally – a substantial proportion of PM pollution in UK cities comes from wider regional and international emissions
  - This has major implications for control:
    - Local measures are essential
    - But so is international co-operation and regulation

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Summary: Implications for control

- Everybody is exposed, every day
- There is no 'safe level' for the population as a whole
  - Control is not 'simply' an issue of hotspots and pollution episodes
  - The main health effects come from sustained exposure and so evidence supports control based on exposure reduction
- There is a need to control PM, ozone and NO_2, especially annual average PM and NO_2
- And the issue is not just local – air pollution travels
  - Local emissions affect other places
  - Local pollution is partly from elsewhere
  - Local controls matter but co-operation across cities, regions, countries matters too

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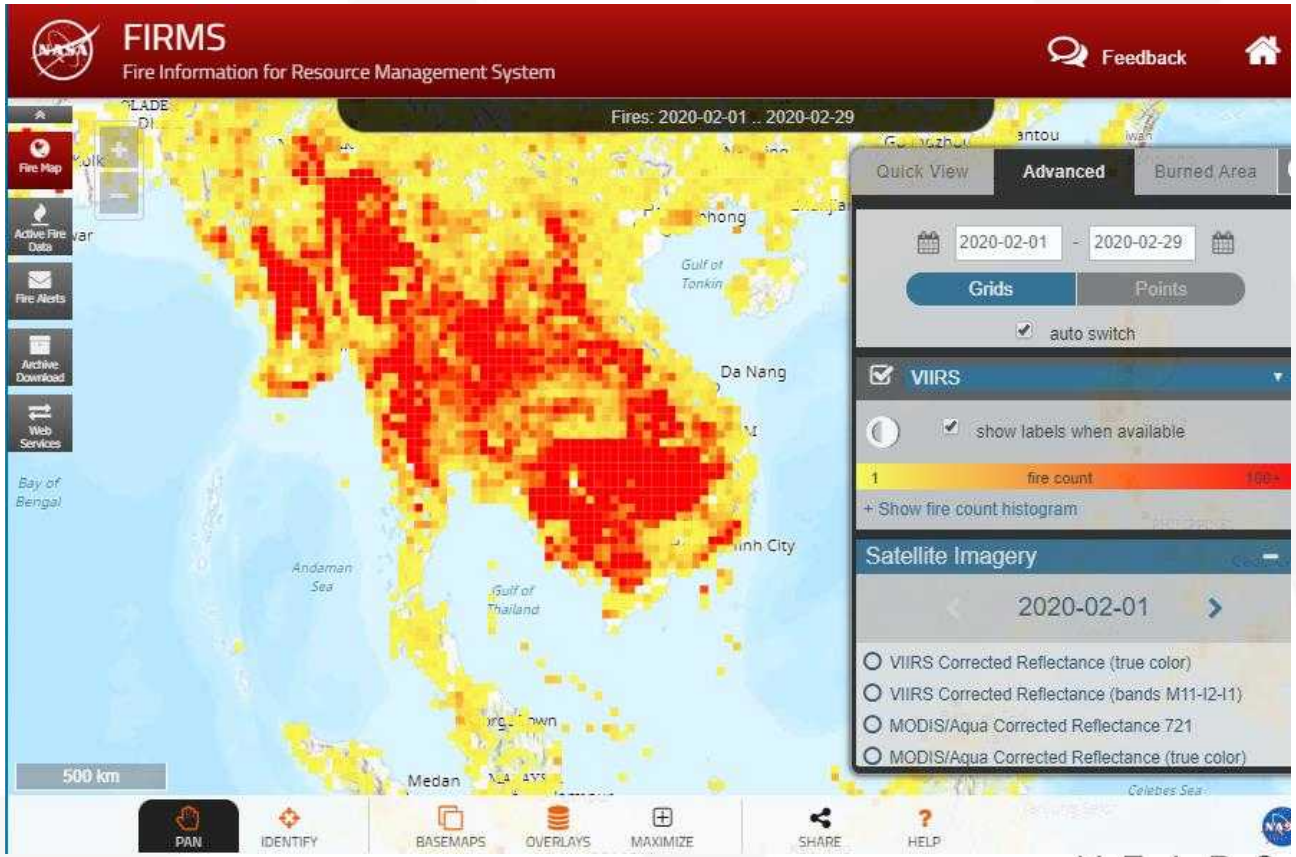
Case Study in Thailand: Exposure to Biomass Burning

- Background
  - Thailand experiences high PM concentrations from crop and forest burning
  - Risk from exposure to biomass burning is unclear
- Objective
  - Compare risks of hospital visits from biomass burning and other sources



https://firms.modaps.eosdis.nasa.gov/

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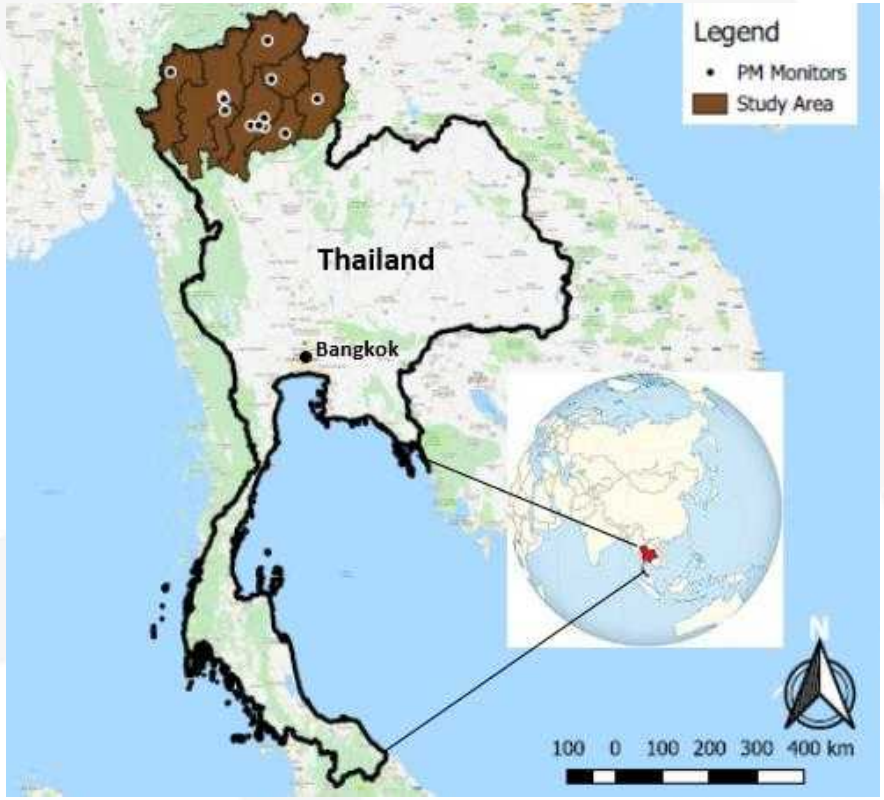
Methods

- Exposure data:
  - Daily means of PM_{10}, CO, NO_2, O_3 from ground monitoring network
- Health outcomes (hospital visits):
  - Chronic lower respiratory disease (ICD10: J40-J47)
  - Ischaemic heart disease (ICD10: I20-I25)
  - Cerebrovascular disease (ICD10: I60-I69)
- Time series study during 2014-2017
- Effect modification of biomass burning based on 99th percentile of PM_{10} levels



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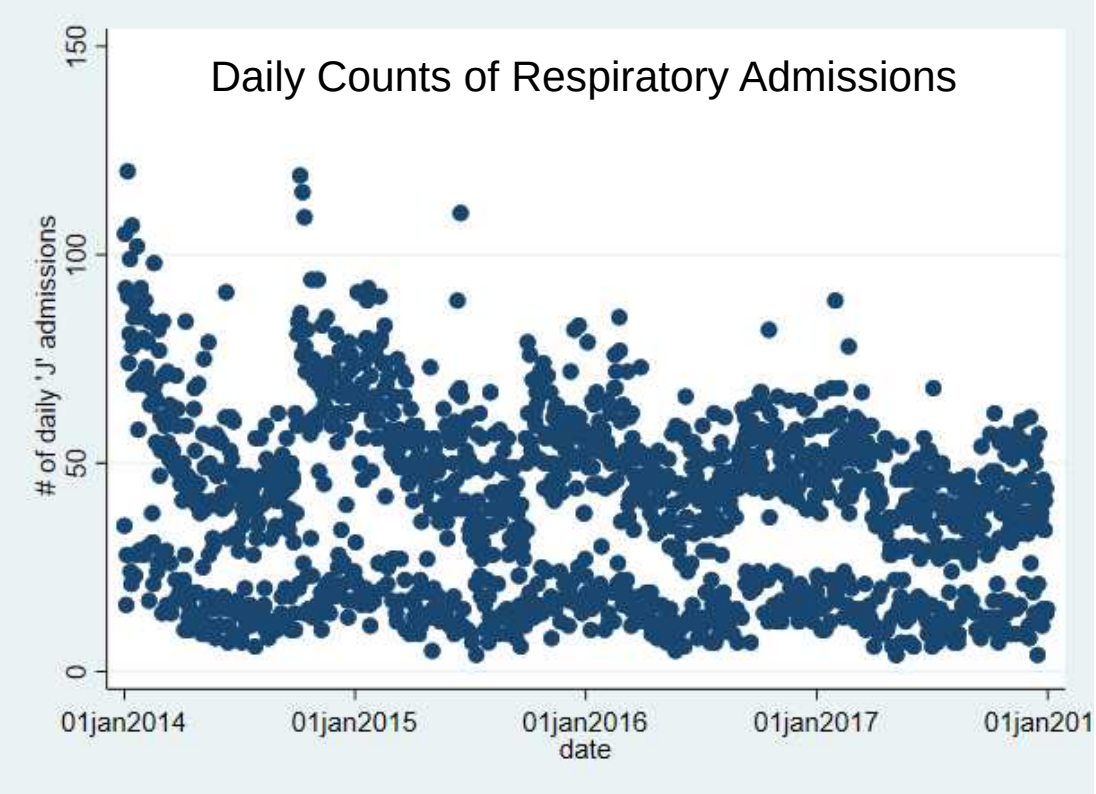
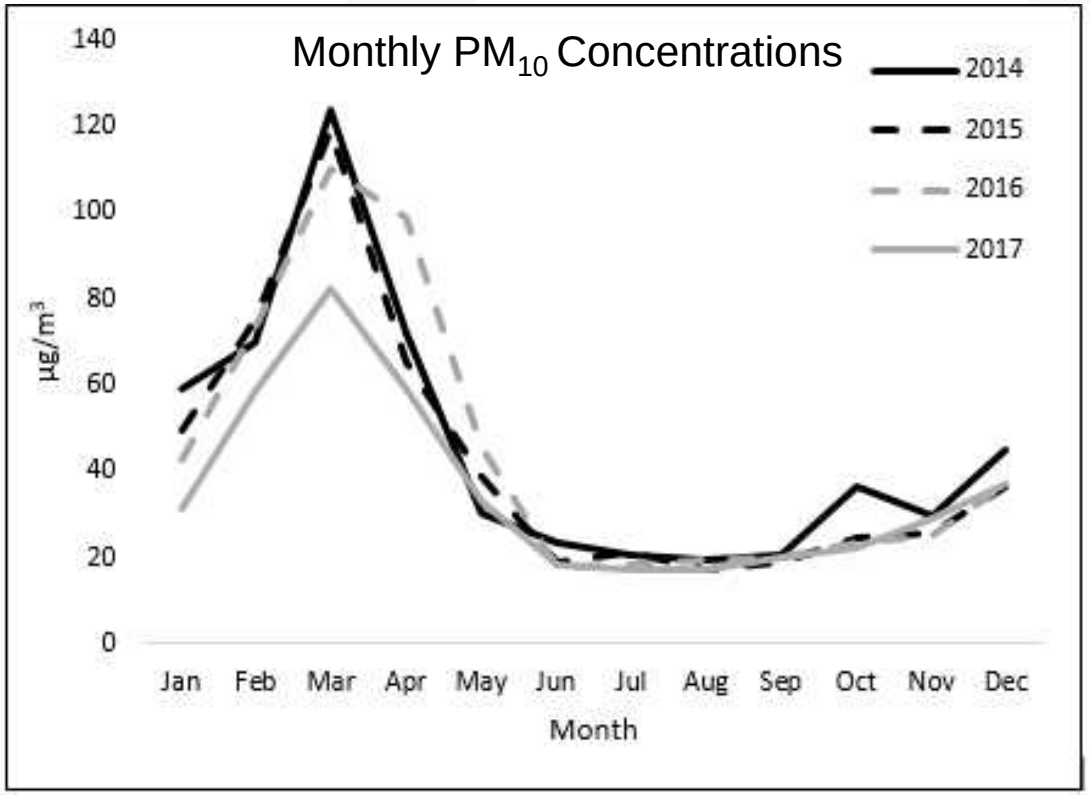
Results





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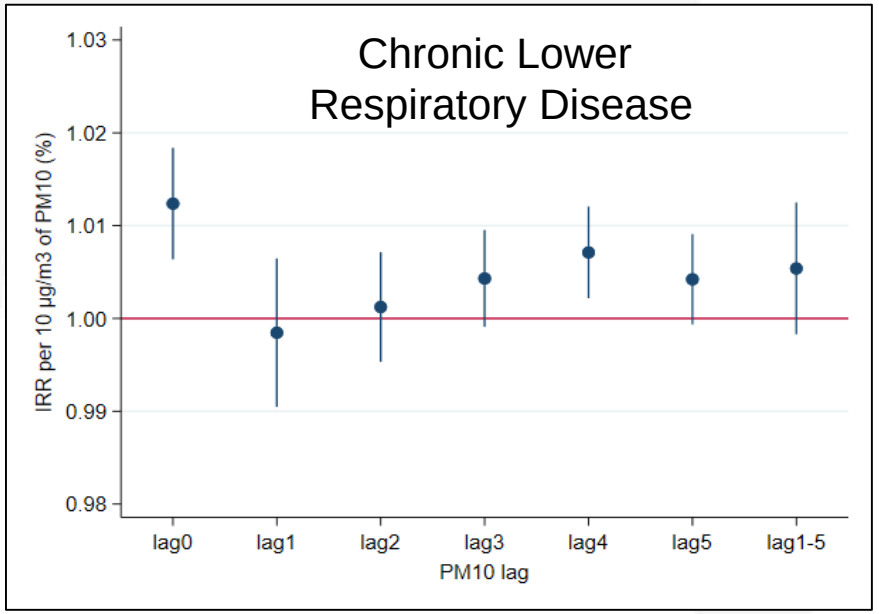
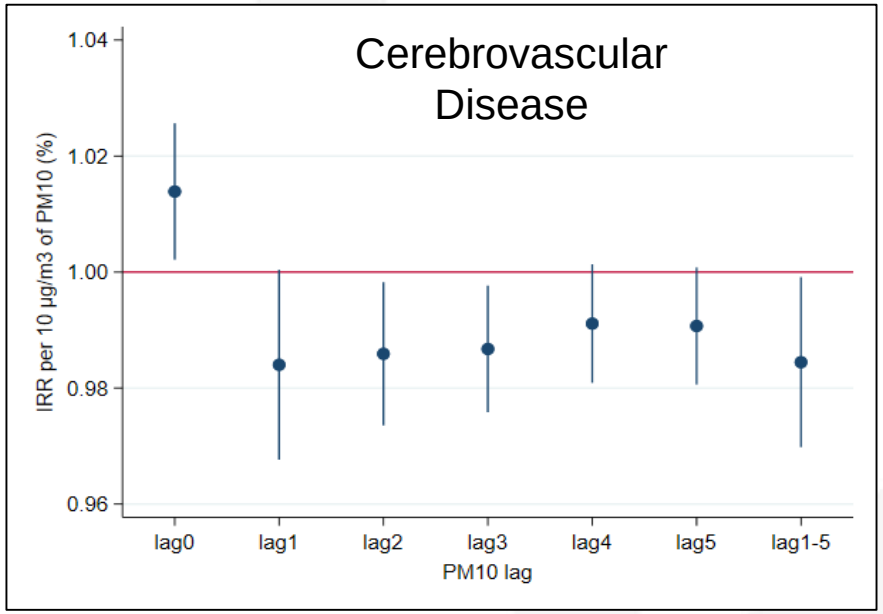
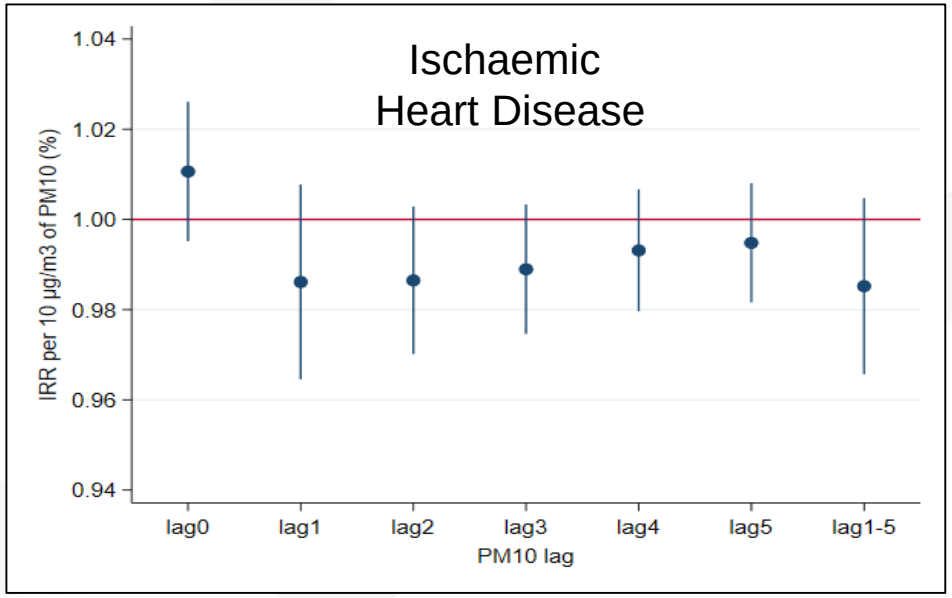
Results: Risks per 10 µg/m³ of PM_{10}







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Results

- Incidence Rate Ratios:
  - Chronic lower respiratory disease
    - Non-Biomass Burning: **1.012 (95% CI = 1.006 to 1.019)**
    - Biomass burning: 1.003 (95% CI = 0.983 to 1.024)
  - Ischaemic Heart Disease
    - Non-Biomass Burning: 1.011 (95% CI = 0.995 to 1.026)
    - Biomass burning: 1.041 (95% CI = 0.984 to 1.103)
  - Cerebrovascular Disease
    - Non-Biomass Burning: **1.014 (95% CI = 1.002 to 1.026)**
    - Biomass burning: 0.966 (95% CI = 0.914 to 1.020)

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Discussion & Next Steps

- Significant risks for respiratory & cerebrovascular visits
- Unclear if differences for burning vs non-burning are from particle toxicity or lowered risk at higher exposures
- Manuscript is under review…
- Assessment of PM_{10} during pregnancy and birthweight

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Future Research Areas for Air Pollution Epidemiology…

- Understanding contributions from personal exposures
  - Indoor vs outdoor
- Assessing differences between sources, e.g. $PM_{2.5}$
- Expanding research to developing countries
- Investigating novel health endpoints:
  - Birth outcomes (e.g. low birth weight, preterm birth)
  - Type II diabetes
  - Neurodegenerative diseases

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Thank you for joining!

Feel free to contact me with any questions at:

will.mueller@iom-world.org

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Discussion Questions

1. Can you think of any ways to:
   i) Reduce your own contribution to air pollution?
   ii) Reduce your exposure to air pollution?

2. Are you concerned about air pollution in
   i) Cyprus?
   ii) Elsewhere?