HARVARD T.H. CHAN SCHOOL OF PUBLIC HEALTH

The current knowledge on adverse effects of low-level air pollution

Antonella Zanobetti

Department of Environmental Health

Harvard T.H. Chan School of Public Health

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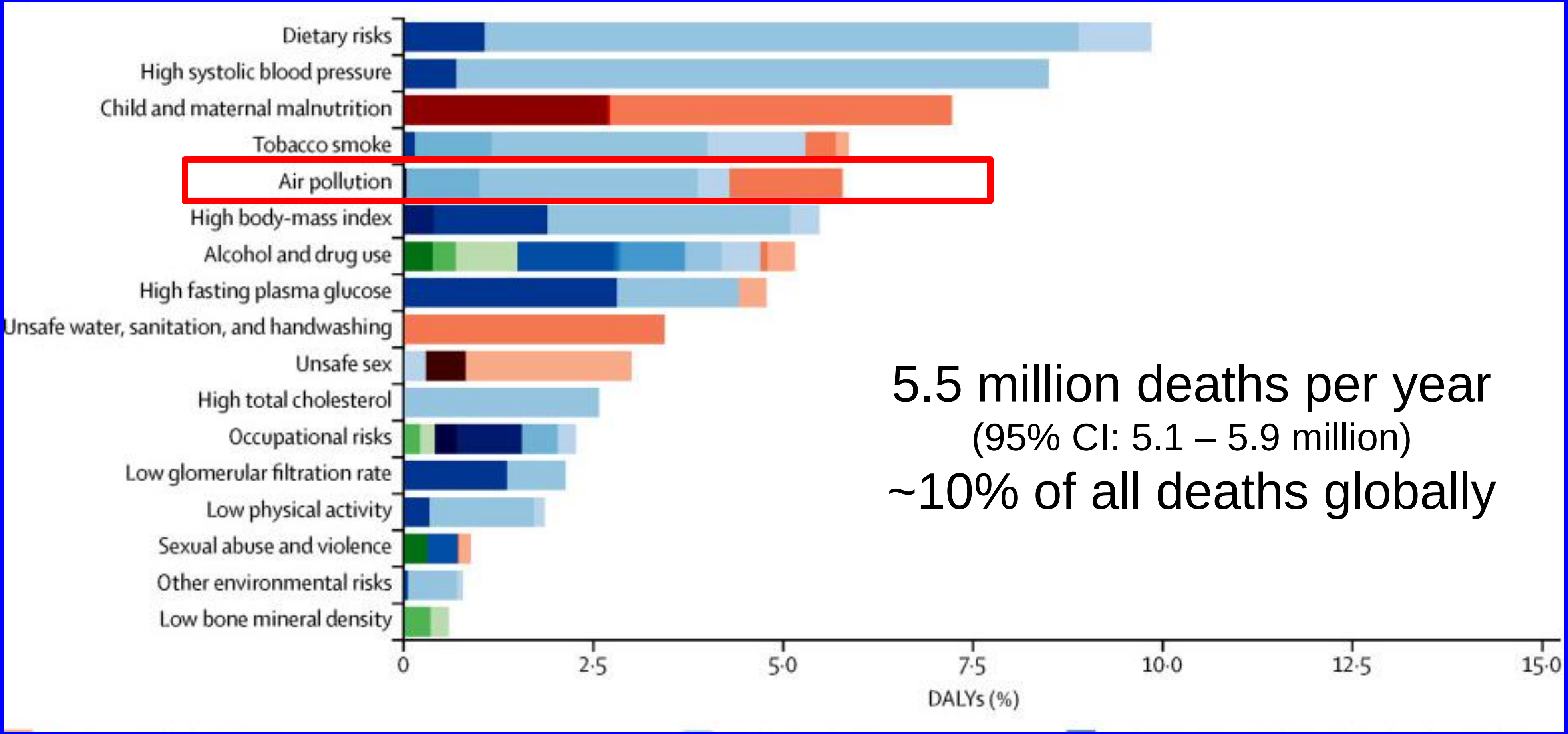
Recent Air Pollution Facts

Top Risk Factors Ranked by Attributable Burden of Disease in 2013 (disability adjusted life years)



#5: Ambient particulate matter pollution

Forouanzafar et al. The Lancet (2015)

Background

- As air pollution levels continue to decrease
  - Regulatory actions become more costly
  - Steps taken to quantify the public health benefits of cleaner air will be subject to intense scrutiny.

- The current dilemma is how to reconcile the increasing challenges and costs of further reducing air pollution levels with the mounting evidence of public health benefits of cleaner air.

Background

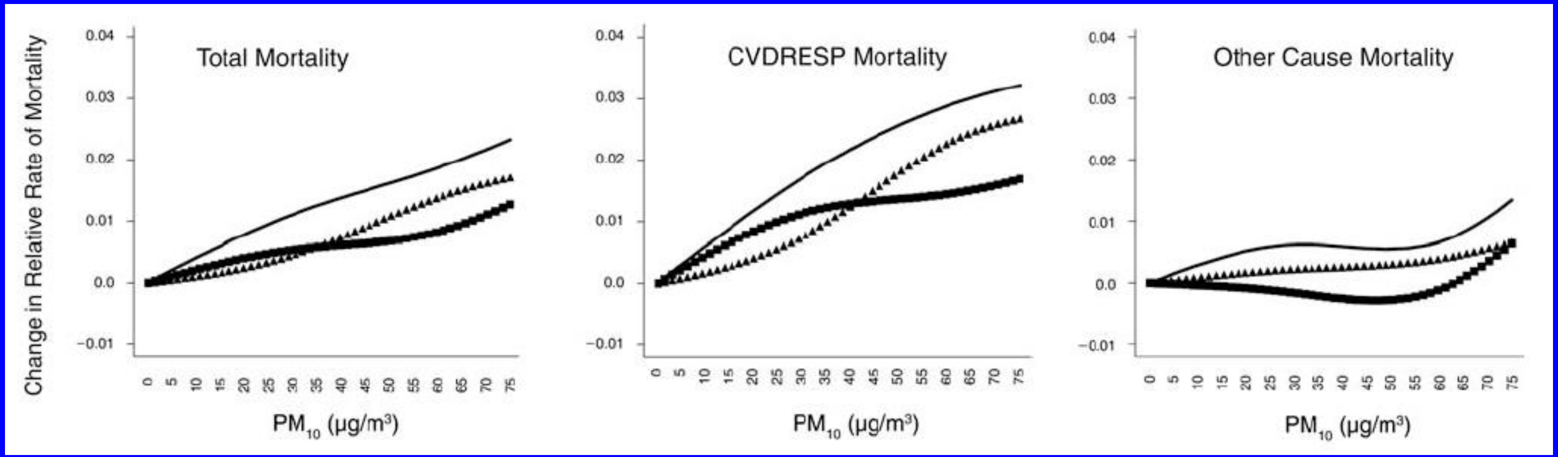
- Epidemiological studies provide:
  - strong evidence of the adverse health effects of air pollution
  - the main evidence for setting the National Ambient Air Quality Standards (NAAQS)
- New studies have included increasingly larger populations and more sophisticated analytical methods
- Many gaps of knowledge remain:
  - Health effects of short and long-term exposure to lower levels of air pollution
  - Uncertainty about the shape of the exposure response relationship

Current knowledge on adverse effects of low-level air pollution

Studies around the world:

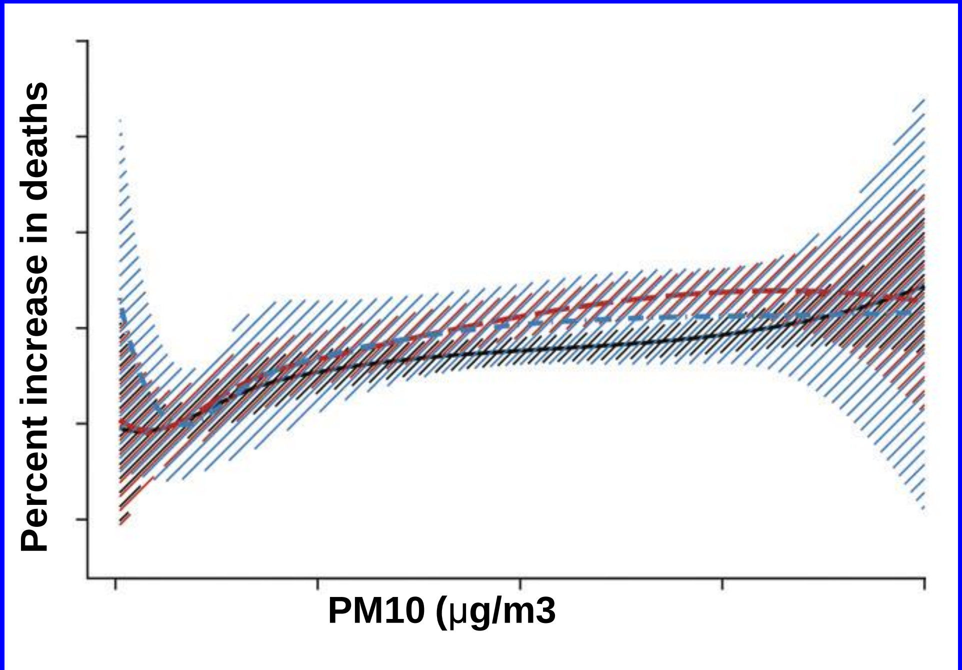
- Examined associations between short-term and long-term exposure to air pollution and mortality or morbidity
- Health effects below NAAQS using:
  - The concentration-response relationship as a way to show health effect at low concentrations
  - Threshold
- Focus on improving exposure assessment
  - Accurate exposure (LUR, Spatio-temporally resolved predictions with AOD) could reduce uncertainty and measurement error

Short term exposure studies PM10 and mortality (EPA PM ISA 2009)



Daniels et al. (2004) 20 cities from the NMMAPS data

1987-1994



- Schwartz (2004) analysis of PM_{10} and mortality in 14 U.S. cities using thresholds

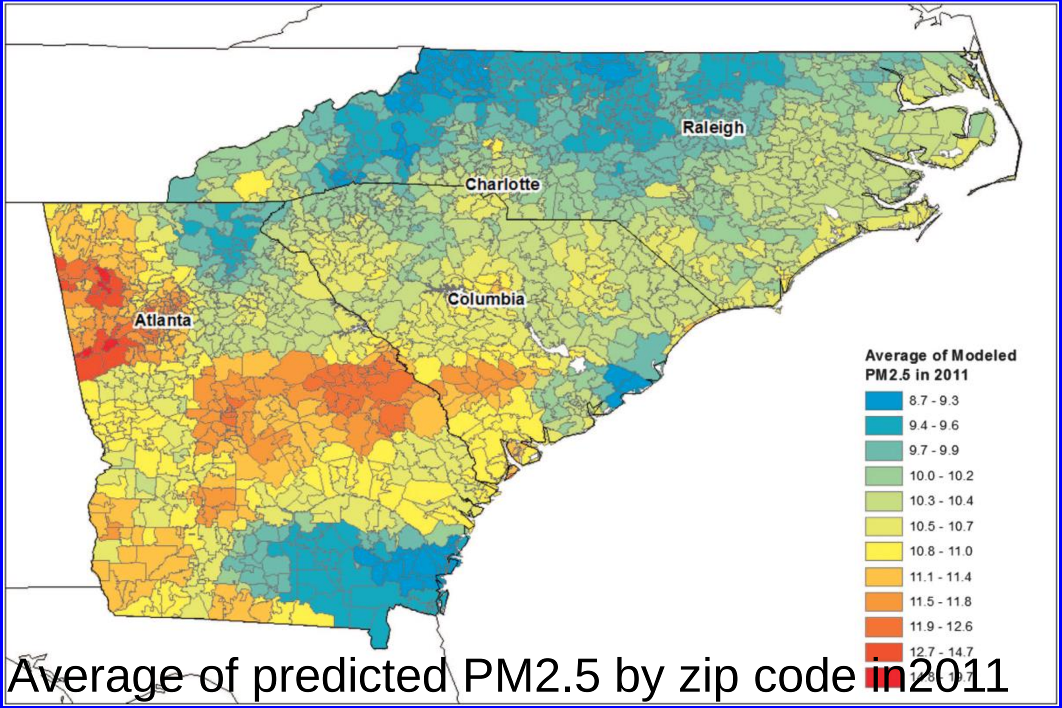
- Samoli et al (2005)
- Exposure–response curves of PM10 and total, cardiovascular, and respiratory mortality in 22 European cities in the APHEA project

Short term exposure studies PM2.5, PM10 and mortality after 2009

Study reference	Study population	Mean PM2.5	Method	Findings
PM2.5				
Samoli et al., 2013	10 European cities	13.6-27.7	threshold	No threshold, linear
Cao et al. 2011	Xi'an, China	182	splines	No threshold, linear
Yorifuji et al. 2015	Tokyo, Japan	17	threshold	Linear
Li et al., 2013	Beijing	75	threshold	Linear at low concentrations, plateaued > 150 μg/m3.
PM10				
Samoli et al., 2013	10 European cities	25.0-44.4	threshold	No threshold, linear
Zeng et al., 2015	7 Chinese cities	72-130	penalized spline	Linear, but varied across cities
Lu et al., 2015	Nanjing, China	109	penalized spline	Linear at low concentrations, plateaued > 150 μg/m3.
Shuang et al., 2013	Urumqi, China	144	spline	almost linear or J-shaped
Kan et al. , 2010	Shanghai, China	102	penalized spline	Linear at low concentrations, plateaued > 150 μg/m3.
Wong et al, 2010	Hong-Kong	51.6	penalized spline	Linear at low concentrations, plateaued > 150 μg/m3.
Balakrishnan et al., 2011	Chennai, India	48-108	penalized spline	No threshold, linear
Rajarathnam et al., 2011	Delhi, India	221	penalized spline	Linear at low concentrations, plateaued > 150 μg/m3.

Acute effect of fine particulate matter on mortality in 3 Southeastern states

- Evaluate the acute effect of $PM_{2.5}$ on mortality, stratified by EPA standards, rural/urban, individual characteristics
- 848,270 non-accidental death
- $PM_{2.5}$: zip code predictions from satellite, mean 11.1 $\mu g/m^3$



Average of predicted PM2.5 by zip code in2011

Increase in $PM_{2.5}$ lag 01 per 10 $\mu g/m^3$

1.56% (95% CI: 1.19, 1.94)

In zip code with $PM_{2.5}$ <12 $\mu g/m^3$

2.06% (1.97–2.15)

In zip code with $PM_{2.5}$ <35 $\mu g/m^3$

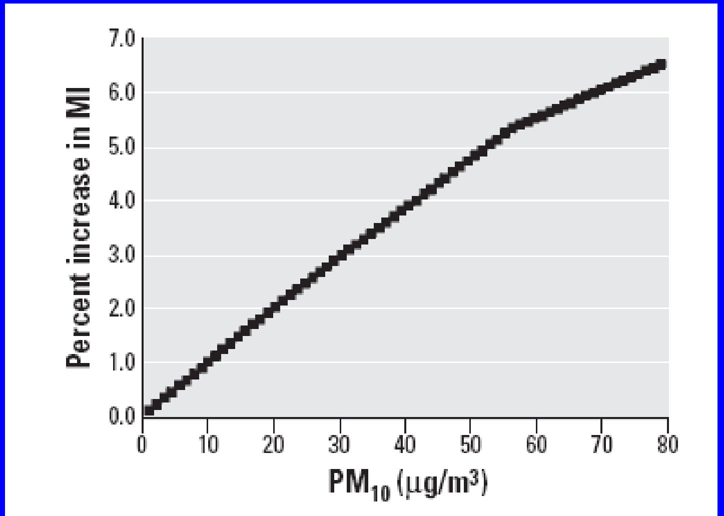
2.08% (1.99–2.17)

Lee M et al J Exp Sci Environ Epi 2015, 1-7

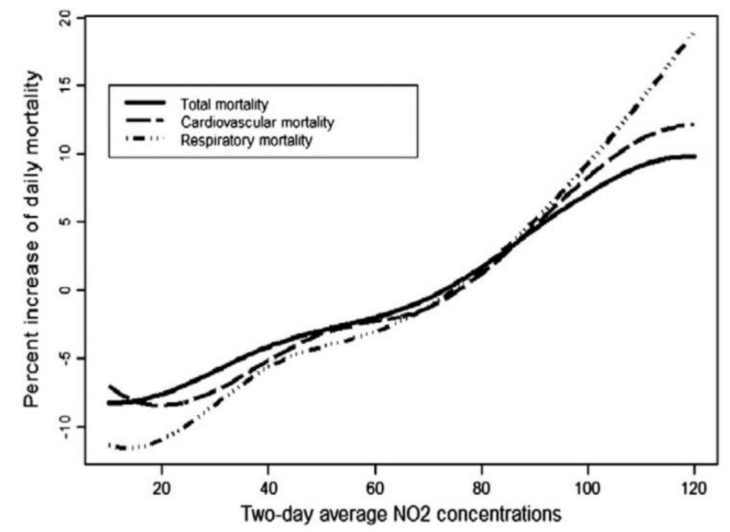
Short term exposure studies PM and admissions

- The limited literature supports a no threshold, log-linear model, which is consistent with the observations made in studies that examined the PM-mortality relationship
- Pediatric asthma ED visits among children in Atlanta hospitals during 1993–2004 (Strickland et al., 2010)
- EMECAS project, cardiovascular hospital admissions in 14 Spanish and air pollutants (Ballester et al., 2006)
- PM_{10} and CHF hospital admissions among Medicare beneficiaries (Wellenius et al, 2005)

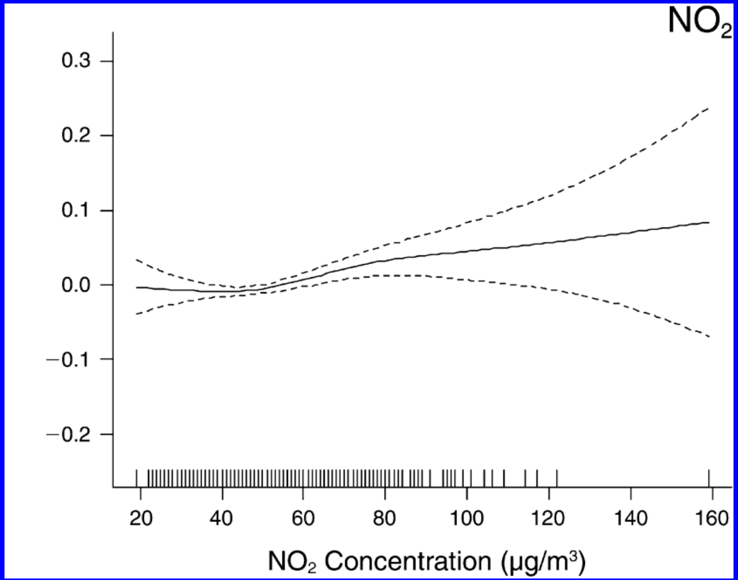
- MI hospital admissions among older adults in 21 U.S. cities
- Steeper slope occurring below 50 µg/m^3 (Zanobetti and Schwartz, 2005)



Short term exposure studies NO2 and mortality



China Air Pollution and Health Effects Study: concentration-response curve for the association between total and cause-specific mortality and NO_2
(Chen et al 2012)



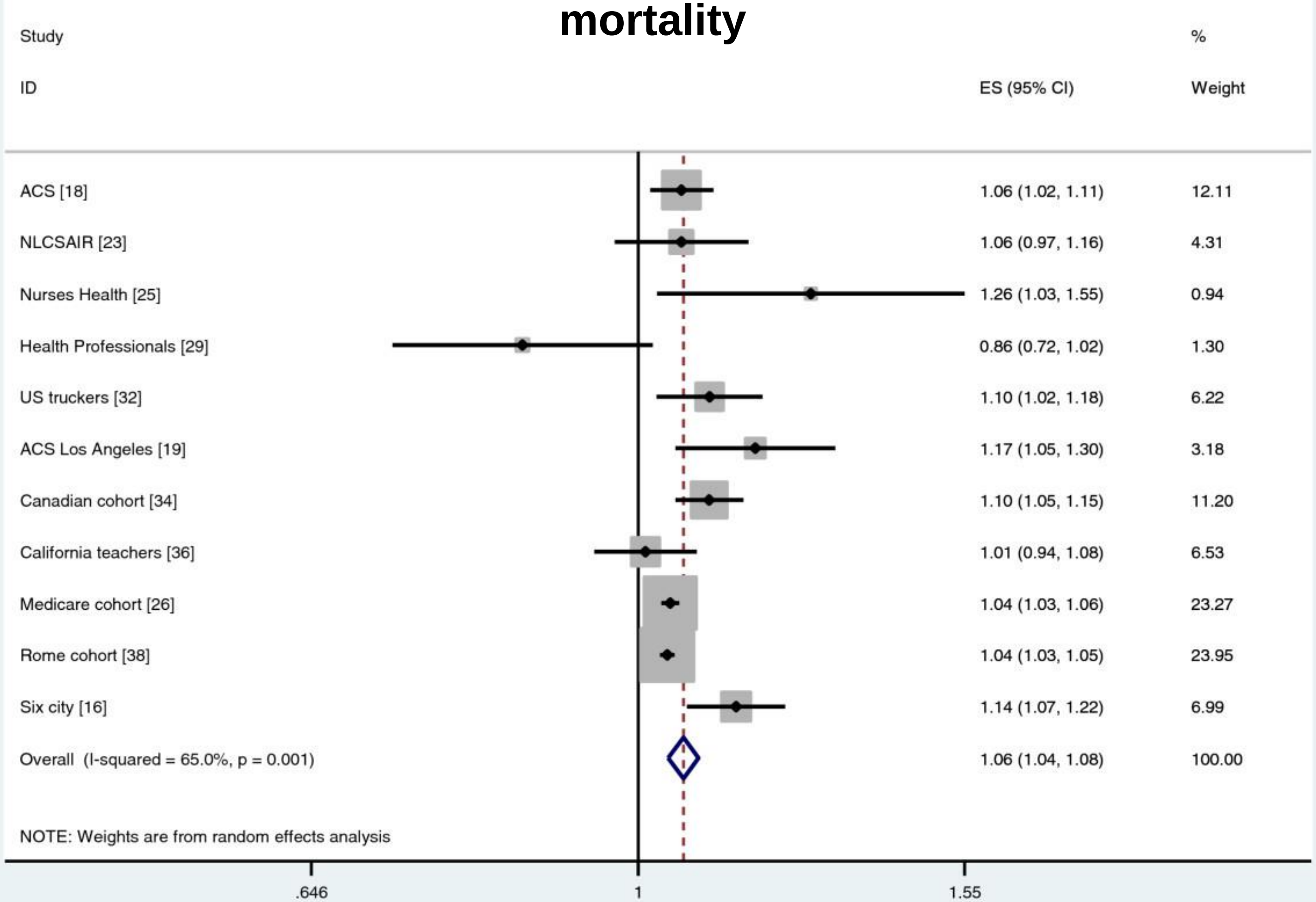
Dose–response curves for NO_2 concentrations. PAPA India
(Rajarathnam et al. 2011)

Short term exposure studies

- Compared to the $PM_{2.5}$ studies, more studies explored the shape of the association between PM_{10} and mortality.
- Most studies found a linear positive concentration-response relationship between PM_{10}, $PM_{2.5}$, NO_2 and mortality or admissions
- Most of the new studies were conducted in Asia
- Most studies in Asia found a linear positive association at lower concentrations that flattened at higher concentrations.

Long-term air pollution exposure and cardio-respiratory mortality: a review

Meta-analysis of the association between $PM_{2.5}$ and all-cause mortality



Hoek G. et al, 2013 Environmental Health, **12**:43

The pooled effect estimate per 10 μg/m³ increase in $PM_{2.5}$ exposure:

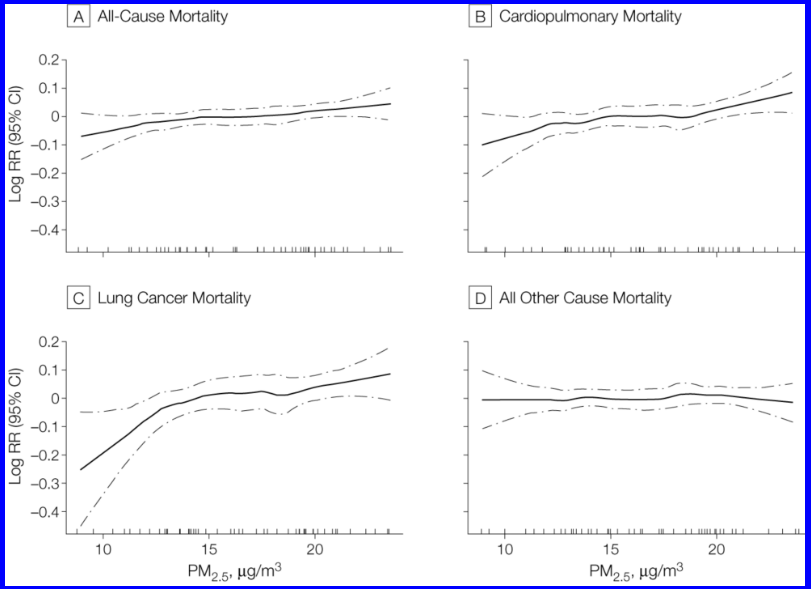
All-cause mortality: 6% (95% CI: 4, 8%)

Cardiovascular mortality: 11% (5, 16%)

Early long term concentration response relationship PM_{10} and mortality

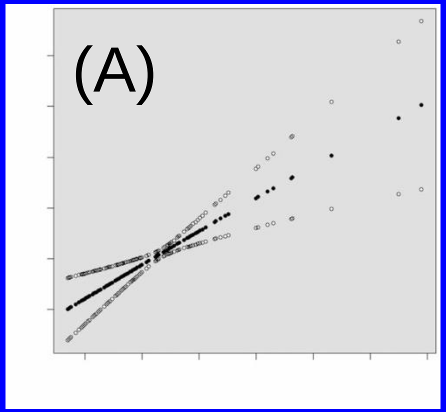
- Pope CA III et al. 2002 ACS study
  - Nonparametric smoothed exposure response relationships between cause-specific mortality and $PM_{2.5}$
- Associations were not significantly different from linear

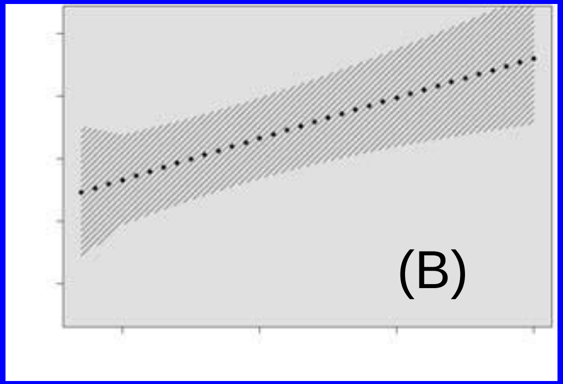
JAMA. 2002;287(9):1132-1141



- Schwartz et al 2008 follow-up of the Harvard Six Cities Study
  - penalized splines (A)
  - Bayesian model averaging (B)
- Concentration–response curve is linear and continues below NAAQS

EHP. 2008; 116(1)





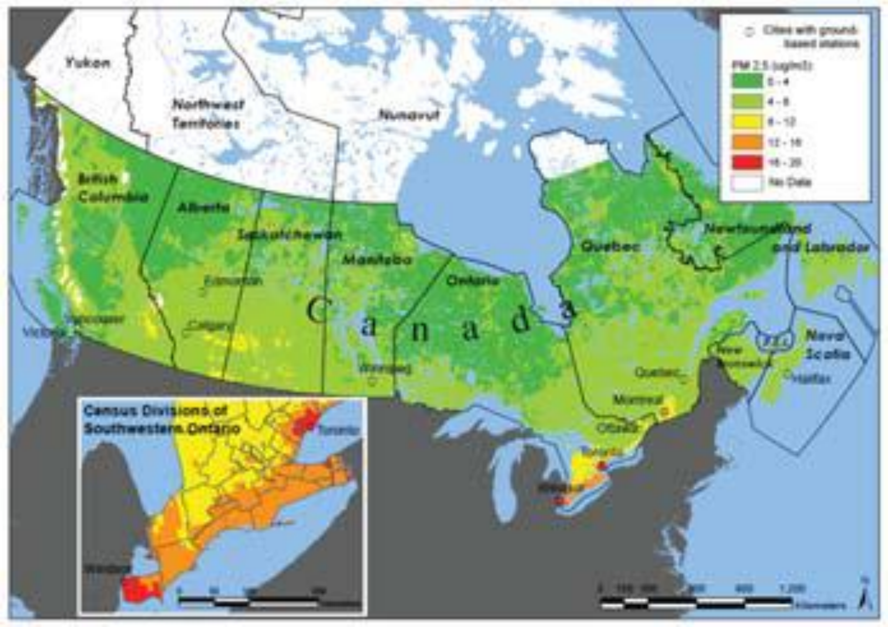
The estimated concentration–response relation between PM2.5 and the risk of death in the Six Cities Study

Long term exposure and effects at low concentrations: new studies

Study reference	Study population	Unit	PM2.5	Mean PM2.5	Method	Findings
Crouse DL et al 2012	Canadian Census CanCHEC	Zip code	Satellite	8.7	natural splines	Supralinear
Crouse DL et al 2015	Canadian Census CanCHEC	Zip code	Satellite	8.9	natural splines	Linear
Hales et al. 2012	New Zealand Census Mortality Study	Census track	LUR model	8	quintiles	Linear
Cesaroni et al. 2013	Rome, 2001 Italian census	Address	Dispersion model	23	natural splines	Linear
Beelen R et al. 2014	22 European cohorts	Address	LUR model	6.6-31	Threshold	Linear
Shi L et al. 2016	New England, US	Zip code	Satellite	8.2	natural splines and threshold	Linear
Fisher PH et al 2015	Dutch national databases on mortality	Address	LUR model	29	natural splines	Linear

Risk of Non-accidental and Cardiovascular Mortality in Relation to Long-term Exposure to Low Concentrations of Fine Particulate Matter: A Canadian National-Level Cohort

- Investigated the association between long-term exposure to ambient $PM_{2.5}$ and mortality
- CanCHEC: subset of the 1991–2001 Canadian census mortality follow-up study

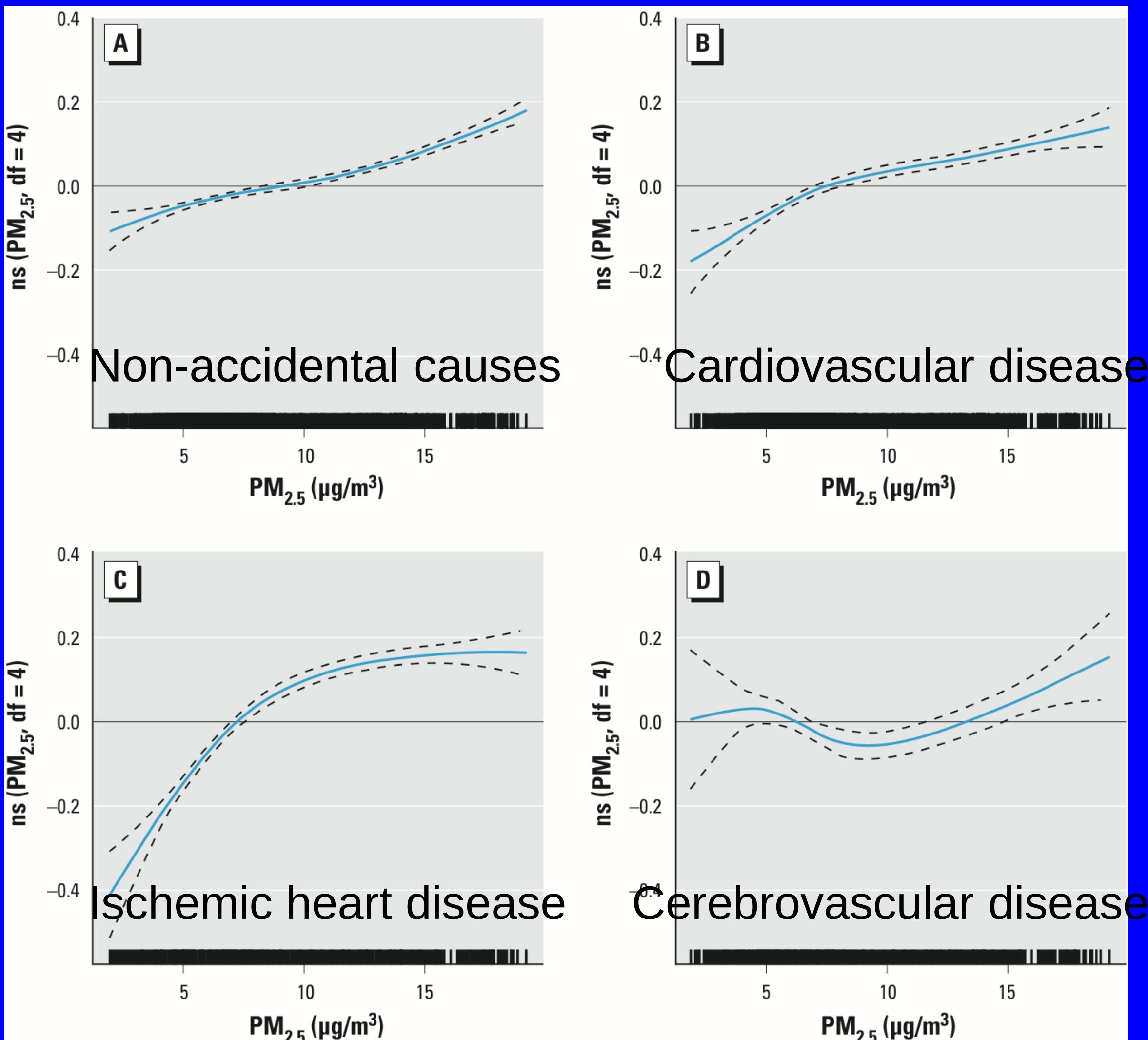


✓ 2.1 million subjects
✓ 200,000 non-accidental deaths
✓ mean age 45.3 years.
✓ $PM_{2.5}$ derived from satellite
  ✓ Zipcode
✓ Mean $PM_{2.5}$: 8.7 $\mu g/m^3$

Crouse DL et al. Environ Health Perspect. 2012; 120(5):708-14

Concentration–response curves

Natural spline models with 4 df, standard Cox models stratified by age and sex, adjusted for all individual-level covariates, urban/rural indicator, and ecological covariates.



Positive significant association between $PM_{2.5}$ and mortality

HR: 1.15 (95% CI: 1.13, 1.16)

Plots suggest that associations with mortality were present at concentrations of $PM_{2.5}$ of only a few micrograms per cubic meter.

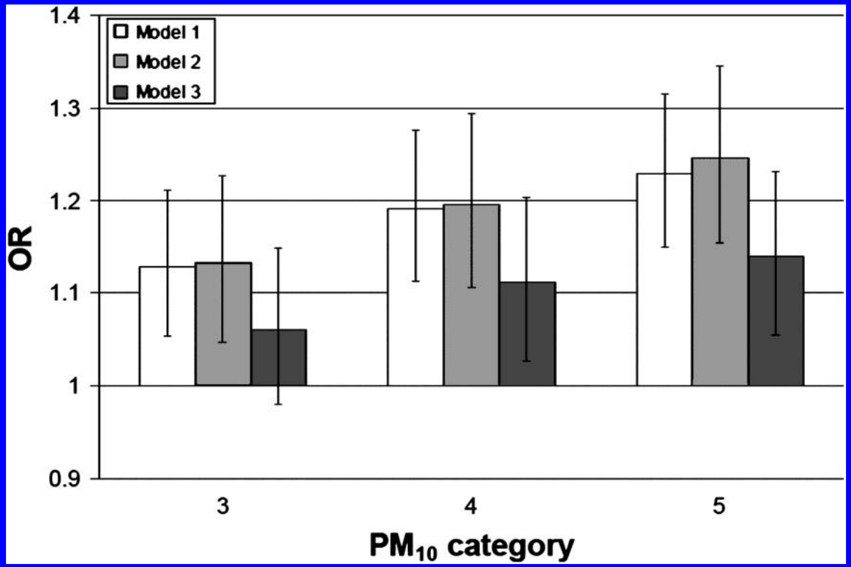
Ambient $PM_{2.5}$, O_3, and NO_2 Exposures and Associations with Mortality over 16 Years of Follow-Up in the Canadian Census Health and Environment Cohort (CanCHEC)

- Five additional years of follow-up, 16 years total
- Tracking subjects' annual residential histories
- Improved estimates of satellite-derived $PM_{2.5}$
  - Assigning time-varying exposures
- Added exposure estimates for ozone (O_3) and nitrogen dioxide (NO_2)
- Corrected the risk estimates for smoking using indirect methods
- Multi-pollutants models

Concentration-response for $PM_{2.5}$ and NO_2: Supralinear
Characterized by larger risk for low concentrations compared with higher values

Crouse DL et al. Environ Health Perspect. 2015; 123(1)

Air pollution and mortality in New Zealand: cohort study



OR and 95% CI of all-cause mortality for people living in the three non-referent PM10 categories, compared with quintiles 1 and 2 combined.

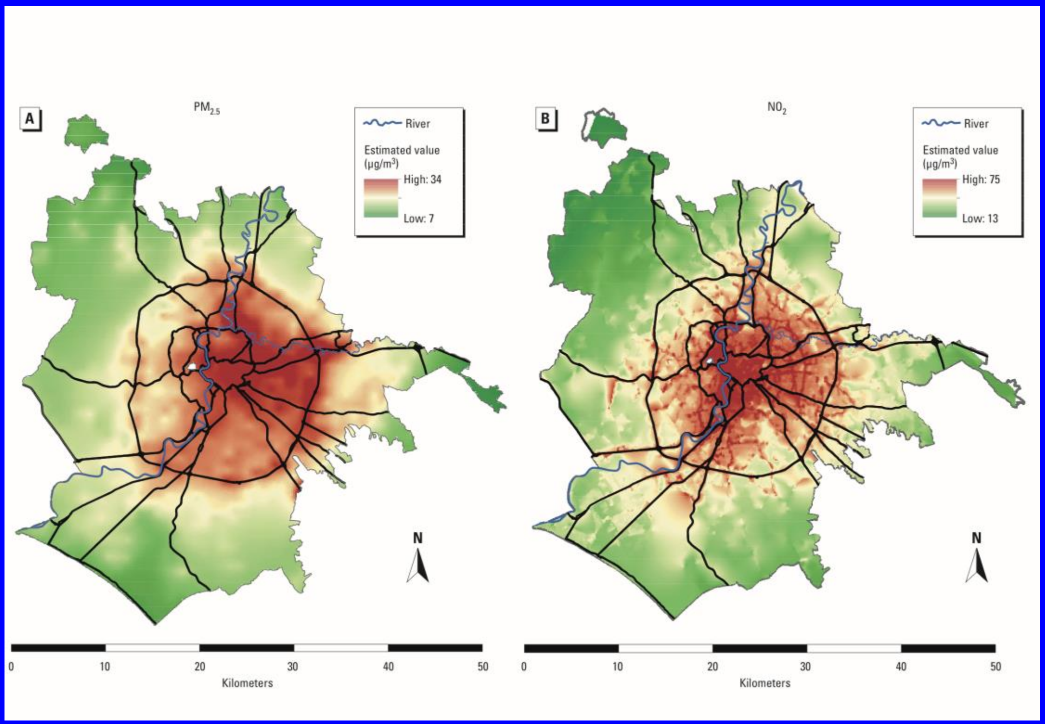
- ✓ New Zealand Census Mortality Study:
  - 75% of the New Zealand population
- ✓ 1.06 million adults living in urban areas
- ✓ 17,937 total deaths
- ✓ PM_{10}: census tract from LUR models, aggregated into quintiles
- ✓ Average PM_{10}: 8 μg/m^3 (0.1- 19)

- Investigated associations between cause-specific mortality rates and average exposure to PM_{10} in urban areas with relatively low levels of air pollution.
- There was an approximately linear increase in mortality with increasing average PM_{10} exposure

Hales S et al. J Epidemiol Community Health 2012;66:468-473

Long-Term Exposure to Urban Air Pollution and Mortality in a Cohort of More than a Million Adults in Rome

- Investigated the association of exposure to NO_2, $PM_{2.5}$, and traffic indicators on cause-specific mortality to evaluate the form of the concentration–response relationship
- Population-based cohort enrolled at the 2001 Italian census with 9 years of follow-up.



1,265,058 adults

144,441 deaths

NO_2 : land use regression model, annual estimate at each address

$PM_{2.5}$: dispersion model, annual estimate at each address

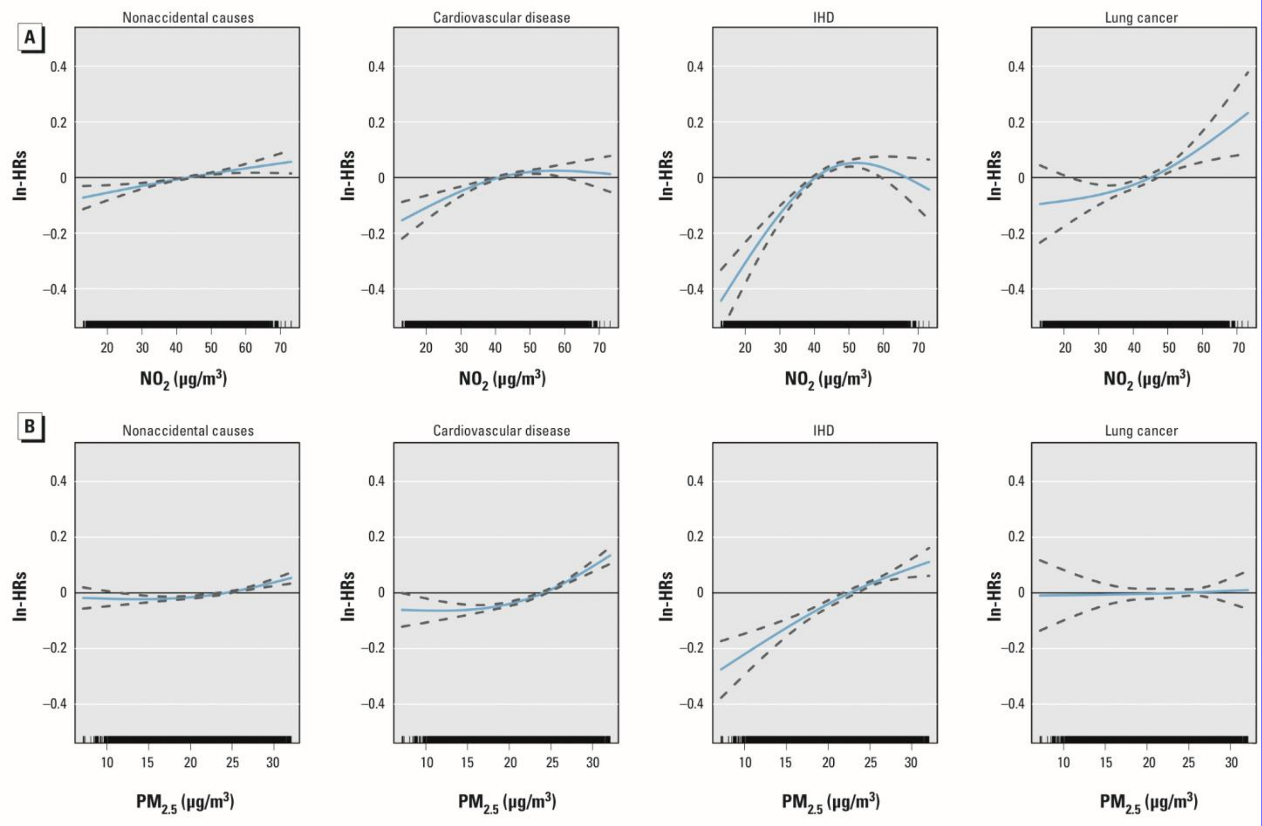
Mean $PM_{2.5}$: 23 µg/m3

Cesaroni G et al. Environ Health Perspect. 2013; 121:324-331

Estimated concentration–response curves for non-accidental causes, cardiovascular disease, IHD, and lung cancer for NO_2 (*A*) and $PM_{2.5}$ (*B*).

Cox models adjusted for sex, marital status, place of birth, education, occupation, and area-based socioeconomic position

There was no evidence of deviation from linearity of the effects of either NO_2 or $PM_{2.5}$ on non-accidental, cardiovascular, and lung-cancer mortality



Long-term exposures to both NO_2 and $PM_{2.5}$ were associated with an increase in non-accidental mortality

HR = 1.03 (95% CI: 1.02, 1.03) per 10-μg/m³ NO_2

HR = 1.04 (95% CI: 1.03, 1.05) per 10-μg/m³ $PM_{2.5}$

Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multi center ESCAPE project

PM2.5	HR (95% CI)	N
No threshold	1·07 (1·02–1·13)	322 159
<20 μg/m3	1·07 (1·01–1·13)	304 759
<10 μg/m3	1·02 (0·87–1·19)	68 527

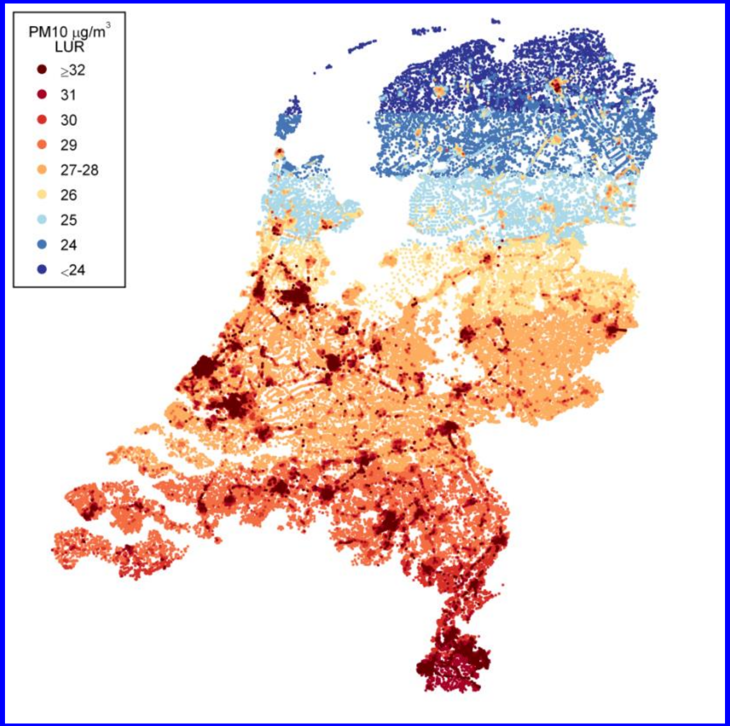
- ✓ 22 European cohorts
- ✓ 367,251 participants
- ✓ 29,076 deaths
- ✓ $PM_{2.5}$: LUR models
  - ✓ Address
- ✓ Mean $PM_{2.5}$: 6.6 – 31 μg/m^3

- Long-term exposure to fine particulate air pollution was associated with natural-cause mortality across the 22 European cohorts
- Associations remained significant over concentration below the existing European annual mean limit value of 25 μg/m^3

Beelen R et al. the Lancet, 2014

Air Pollution and Mortality in Seven Million Adults: The Dutch Environmental Longitudinal Study (DUELS)

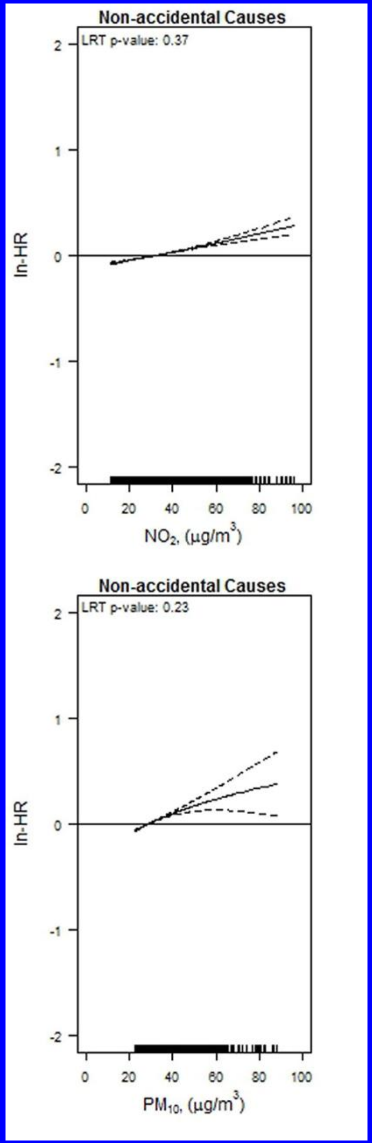
Evaluate the associations between long-term exposure to air pollution and non-accidental and cause-specific mortality Dutch national databases on mortality (2004 – 2011)



- ✓ 7,218,363 adults
- ✓ 668,206 total deaths
- ✓ PM_{10} and NO_2: LUR models
- ✓ Address

HR: 1.08 (95% CI: 1.07, 1.09)

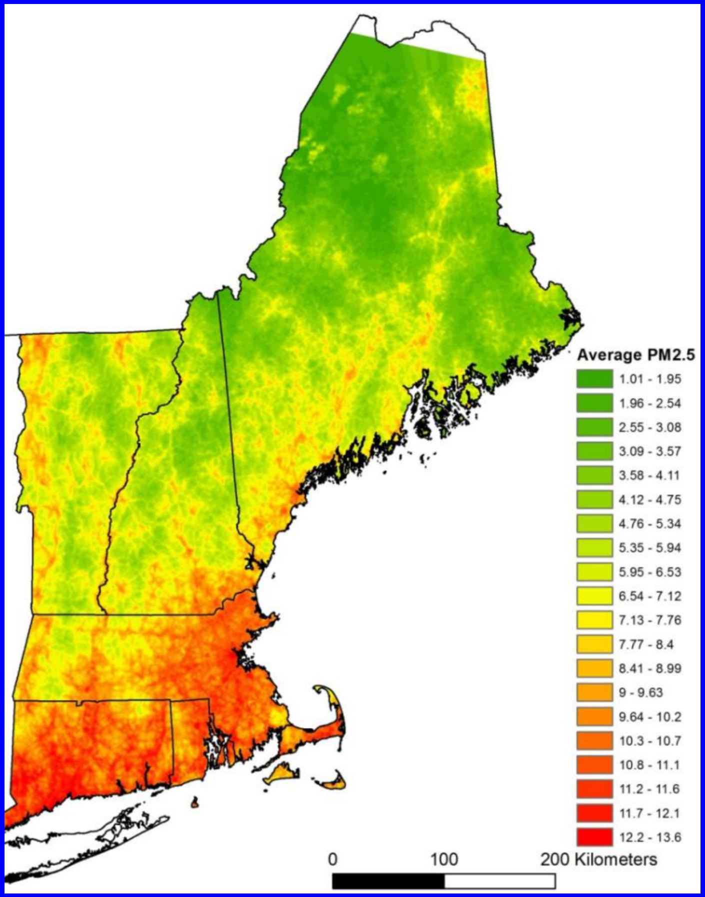
Associations between PM_{10} and non-accidental mortality did not deviate significantly from linear



Fisher PH, et al. Environ Health Perspect, 2015

Low-Concentration $PM_{2.5}$ and Mortality: Estimating Acute and Chronic Effects in a Population-Based Study

Simultaneously estimate acute and chronic health effects of $PM_{2.5}$ in a population-based cohort (≥ 65 years of age) in New England region, and at low-concentration $PM_{2.5}$



Medicare enrollees (2003-2008)

- Daily count of death for each ZIP code
- Full cohort: 551,024 deaths

$PM_{2.5}$: Spatio-temporally resolved predictions

- Short term exposure (2-day average), mean 8.2 µg/m^3
- Long term exposure (365-day average), mean 8.1

Restricted to:

annual concentrations below 10 µg/m^3 (268,050 deaths).

daily concentrations below 30 µg/m^3 (422,637 deaths).

Shi L, et al. Environ Health Perspect 124:46–52, 2016

Percent increase in mortality for a 10 μg/m^3 increase for $PM_{2.5}$

$PM_{2.5}$ exposure type	Model	Percent increase	*p*-value
Short-term $PM_{2.5}$ exposure	Low daily exposure [a]	$\boxed{2.14\ (1.34, 2.95)}$	<.001
	Full cohort	2.14 (1.38,2.89)	<.001
Long-term $PM_{2.5}$ exposure	Low chronic exposure [b]	$\boxed{9.28\ (0.76, 18.52)}$	0.032
	Full cohort	7.52 (1.95,13.40)	0.007

[a] Restricted only to person time with daily $PM_{2.5}$ less than 30 μg/m^3.
[b] Restricted only to person time with chronic $PM_{2.5}$ less than 10 μg/m^3.

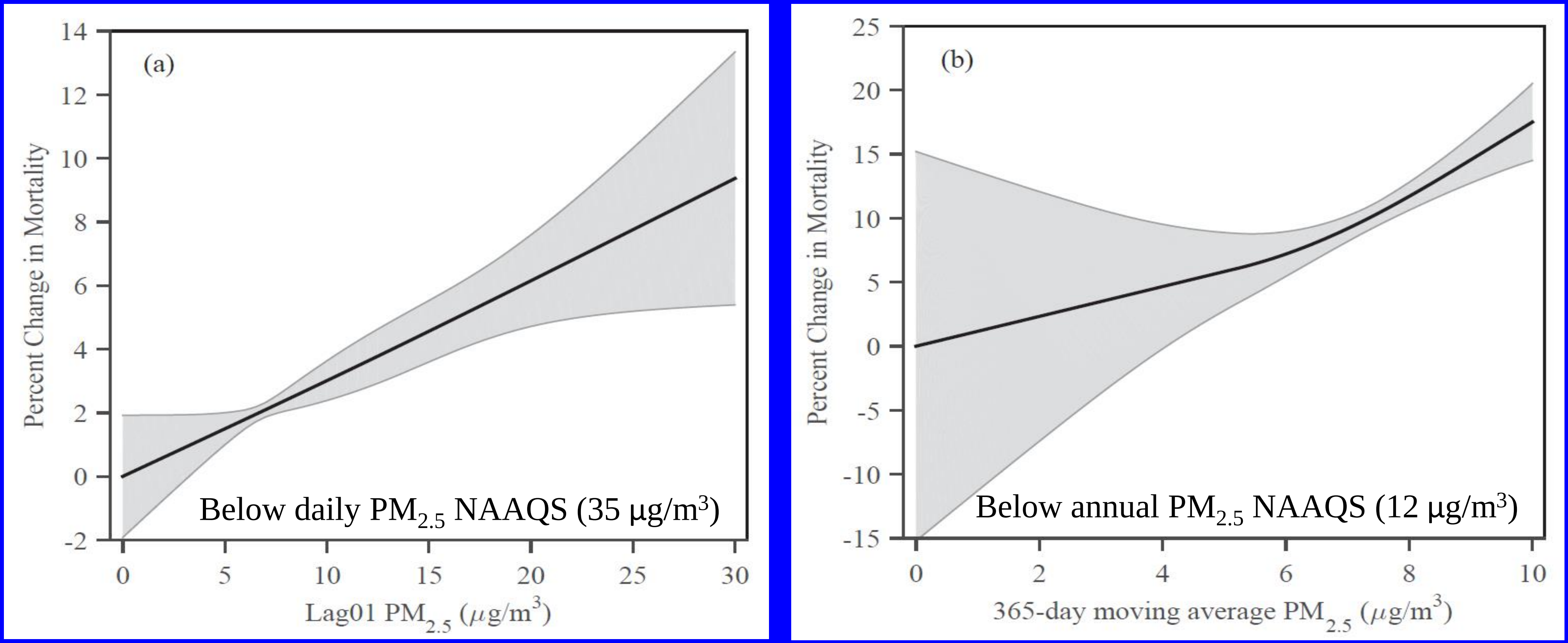
Using a mutually adjusted model, both short- and long-term exposure to $PM_{2.5}$ were associated with all-cause mortality, even for exposure levels not exceeding the newly revised U.S. EPA standards

adverse health effects occur at low levels of fine particles

Shi et al., EHP,2015

Dose-response relationship for low-concentration $PM_{2.5}$ and mortality

Improving air quality below the current $PM_{2.5}$ NAAQS can still yield health benefits



Summary

- Epidemiologic studies have reported associations of air pollution with health effects in the general population even at levels below current air quality standards.

- Pollution levels in US have decreased
  - Cities have max air pollution concentration below NAAQS

- Changes in the standards require additional studies to elucidate whether health effects occur at levels below the current NAAQS levels

THANK YOU!