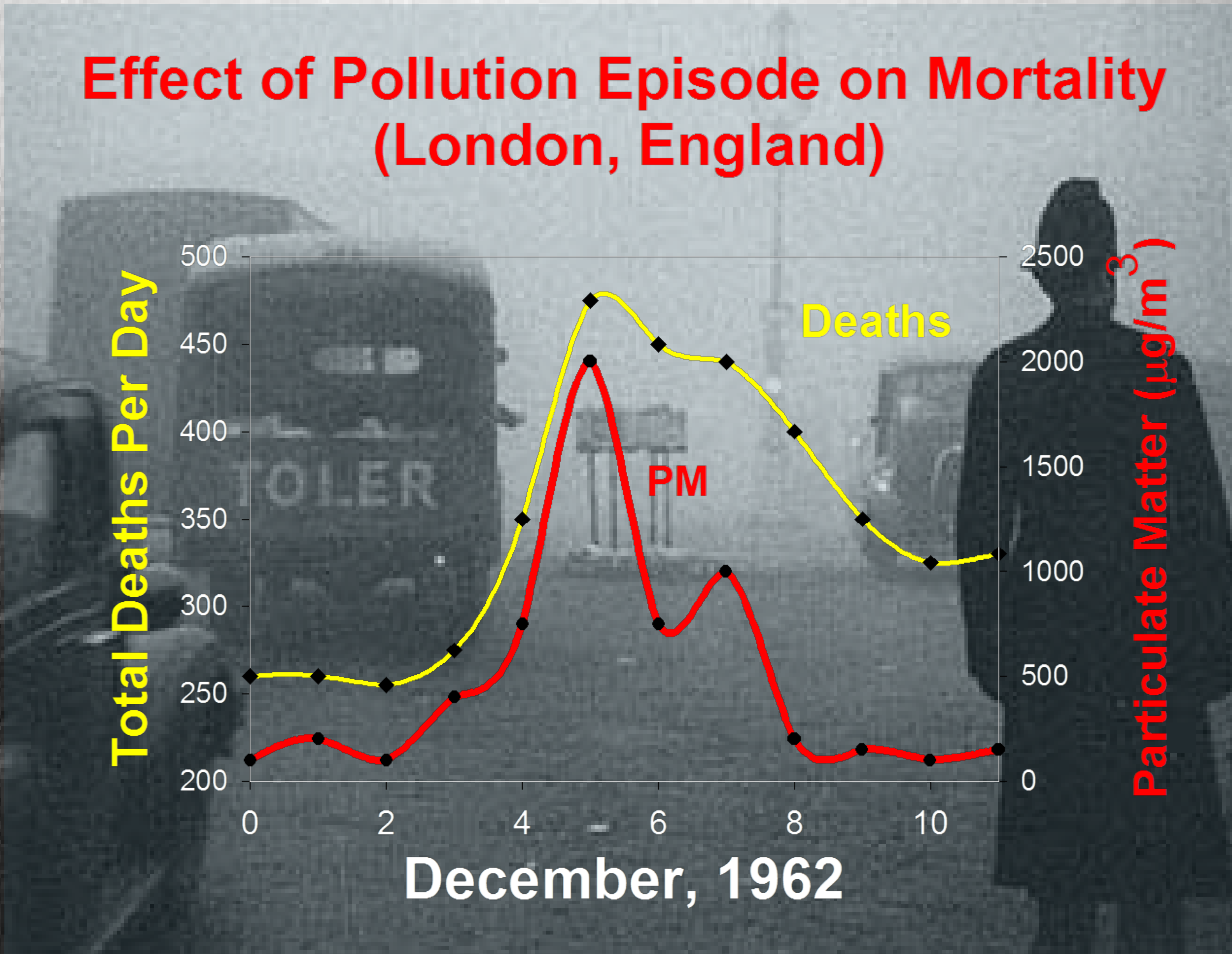
The Global Burden of Disease attributable to Ambient Air Pollution

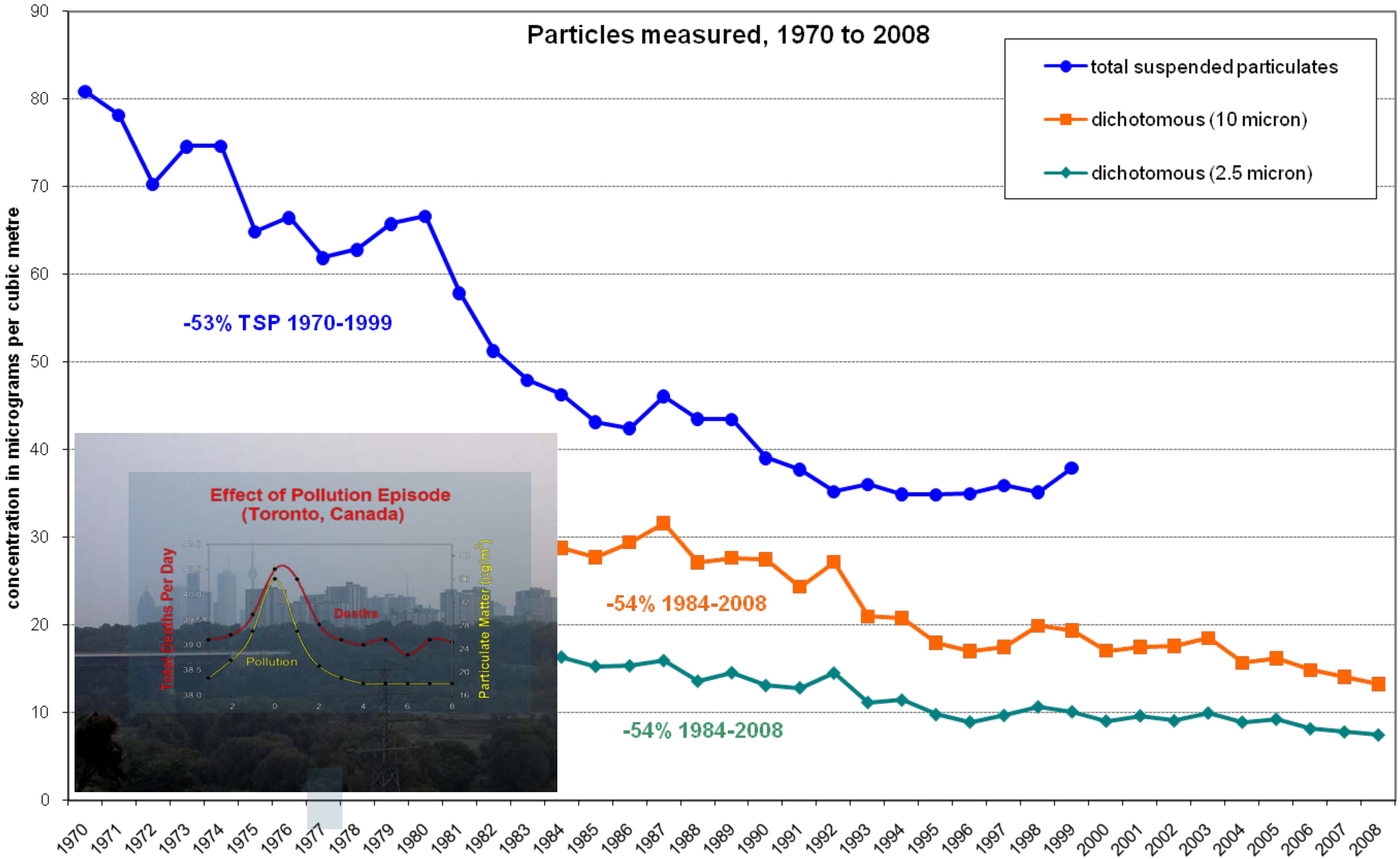
Richard T. Burnett, Ph.D.

on behalf of the GBD Ambient Air Pollution Core Group and

the GBD Collaboration

London Fog


Effect of Pollution Episode on Mortality
(London, England)
Total Deaths Per Day
500
450
400
350
300
250
200
Particulate Matter (µg/m3)
2500
2000
1500
1000
500
0
Deaths
PM
TOILER
0
2
4
6
8
10
December, 1962



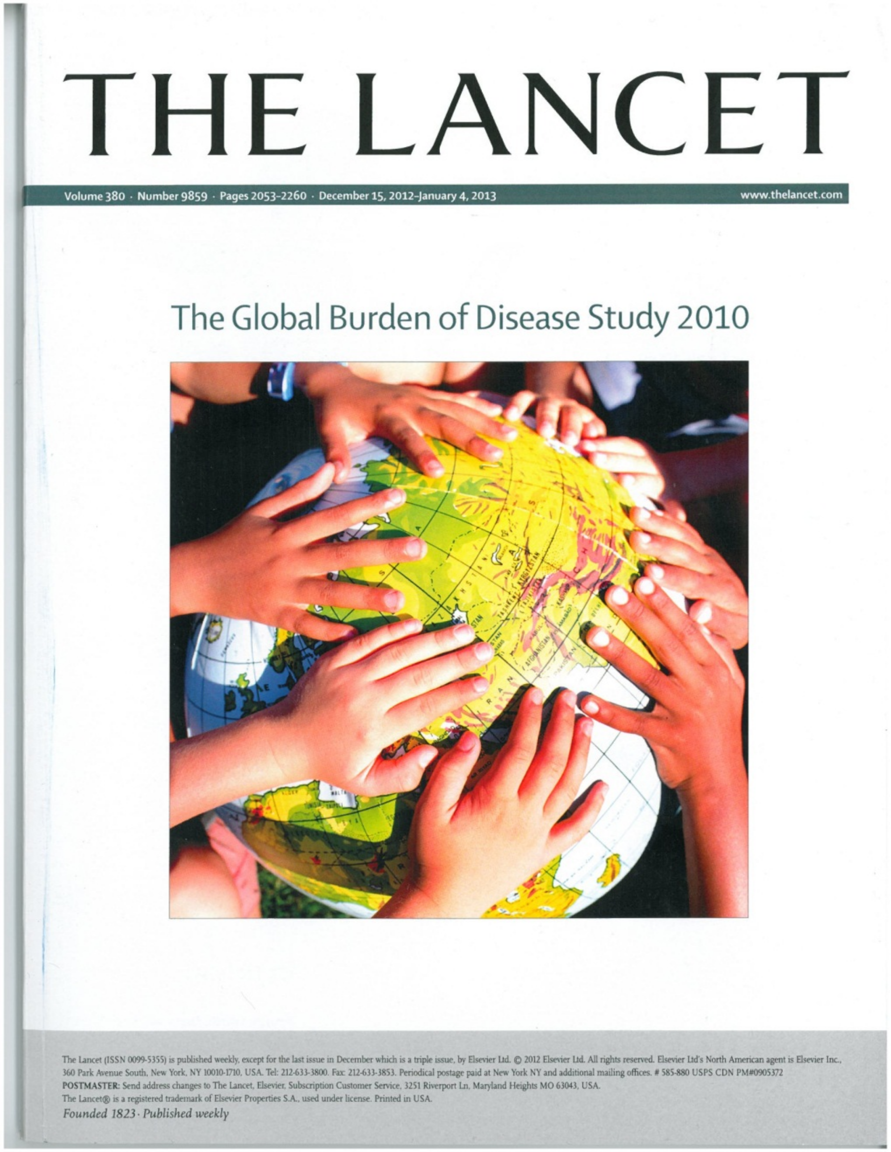
Particles measured, 1970 to 2008
total suspended particulates
dichotomous (10 micron)
dichotomous (2.5 micron)
-53% TSP 1970-1999
-54% 1984-2008
-54% 1984-2008
concentration in micrograms per cubic metre
0
10
20
30
40
50
60
70
80
90
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Effect of Pollution Episode
(Toronto, Canada)
Total Deaths Per Day
Particulate Matter (µg/m³)
Deaths
Pollution

Severe smog and air pollution in Beijing, where hospitals reported increases of up to 30% in the number of patients reporting breathing problems.

Photograph: HAP/Quirky China News / Rex Feat

Global Burden of Disease

- **A *systematic scientific* effort to quantify the *comparative* magnitude of *health loss* for 187 countries from 1990 to present.**
- **Covering 291 diseases and injuries, 1,160 sequelae of these diseases and injuries, and 67 risk factors or clusters of risk factors**
- **GBD study initiated in 2007 funded by Bill and Melinda Gates Foundation**
  - **Core Team at Institute of Health Metrics & Evaluation, University of Washington, Seattle**
- **Summary papers published in the Lancet**



THE LANCET

Volume 380 · Number 9859 · Pages 2053–2260 · December 15, 2012–January 4, 2013 www.thelancet.com

The Global Burden of Disease Study 2010

The Lancet (ISSN 0099-5355) is published weekly, except for the last issue in December which is a triple issue, by Elsevier Ltd. © 2012 Elsevier Ltd. All rights reserved. Elsevier Ltd's North American agent is Elsevier Inc., 360 Park Avenue South, New York, NY 10010-1710, USA. Tel: 212-633-3800. Fax: 212-633-3853. Periodical postage paid at New York NY and additional mailing offices. # 585-880 USPS CDN PM#0905372
POSTMASTER: Send address changes to The Lancet, Elsevier, Subscription Customer Service, 3251 Riverport Ln, Maryland Heights MO 63043, USA.
The Lancet® is a registered trademark of Elsevier Properties S.A., used under license. Printed in USA.
Founded 1823 · Published weekly

Articles

A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010

Stephen S Lim‡, Theo Vos, Abraham D Flaxman, Goodarz Danaei, Kenji Shibuya, Heather Adair-Rohani*, Markus Amann*, H Ross Anderson*, Kathryn G Andrews*, Martin Aryee*, Charles Atkinson*, Loraine J Bacchus*, Adil N Bahalim*, Kalpana Balakrishnan*, John Balmes*, Suzanne Barker-Collo*, Amanda Baxter*, Michelle L Bell*, Jed D Blore*, Fiona Blyth*, Carissa Bonner*, Guilherme Borges*, Rupert Bourne*, Michel Boussinesq*, Michael Brauer*, Peter Brooks*, Nigel G Bruce*, Bert Brunekreef*, Claire Bryan-Hancock*, Chiara Bucello*, Rachelle Buchbinder*, Fiona Bull*, Richard T Burnett*, Tim E Byers*, Bianca Calabria*, Jonathan Carapetis*, Emily Carnahan*, Zoe Chafe*, Fiona Charlson*, Honglei Chen*, Jian Shen Chen*, Andrew Tai-Ann Cheng*, Jennifer Christine Child*, Aaron Cohen*, K Ellicott Colson*, Benjamin C Cowie*, Sarah Darby*, Susan Darling*, Adrian Davis*, Louisa Degenhardt*, Frank Dentener*, Don C Des Jarlais*, Karen Devries*, Mukesh Dherani*, Eric L Ding*, E Ray Dorsey*, Tim Driscoll*, Karen Edmond*, Suad Eltahir Ali*, Rebecca E Engell*, Patricia J Erwin*, Saman Fahimi*, Gail Falder*, Farshad Farzadfar*, Alize Ferrari*, Mariel M Finucane*, Seth Flaxman*, Francis Gerry R Fowkes*, Greg Freedman*, Michael K Freeman*, Emmanuela Gakidou*, Santu Ghosh*, Edward Giovannucci*, Gerhard Gmel*, Kathryn Graham*, Rebecca Grainger*, Bridget Grant*, David Gunnell*, Hialy R Gutierrez*, Wayne Hall*, Hans W Hoek*, Anthony Hogan*, H Dean Hosgood III*, Damian Hoy*, Howard Hu*, Bryan J Hubbell*, Sally J Hutchings*, Sydney E Ibeanusi*, Gemma L Jacklyn*, Rashmi Jasrasaria*, Jost B Jonas*, Haidong Kan*, John A Kanis*, Nicholas Kassebaum*, Norito Kawakami*, Young-Ho Khang*, Shahab Khatibzadeh*, Jon-Paul Khoo*, Cindy Kok*, Francine Laden*, Ratilal Lalloo*, Qing Lan*, Tim Lathlean*, Janet L Leasher*, James Leigh*, Yang Li*, John Kent Lin*, Steven E Lipshultz*, Stephanie London*, Rafael Lozano*, Yuan Lu*, Joelle Mak*, Reza Malekzadeh*, Leslie Mallinger*, Wagner Marcenes*, Lyn March*, Robin Marks*, Randall Martin*, Paul McGale*, John McGrath*, Sumi Mehta*, George A Mensah*, Tony R Merriman*, Renata Micha*, Catherine Michaud*, Vinod Mishra*, Khayriyyah Mohd Hanafiah*, Ali A Mokdad*, Lidia Morawska*, Dariush Mozaffarian*, Tasha Murphy*, Mohsen Naghavi*, Bruce Neal*, Paul K Nelson*, Joan Miquel Nolla*, Rosana Norman*, Casey Olives*, Saad B Omer*, Jessica Orchard*, Richard Osborne*, Bart Ostro*, Andrew Page*, Kiran D Pandey*, Charles D H Parry*, Erin Passmore*, Jayadeep Patra*, Neil Pearce*, Pamela M Pelizzari*, Max Petzold*, Michael R Phillips*, Dan Pope*, C Arden Pope III*, John Powles*, Mayuree Rao*, Homie Razavi*, Eva A Rehfuess*, Jürgen T Rehm*, Beate Ritz*, Frederick P Rivara*, Thomas Roberts*, Carolyn Robinson*, Jose A Rodriguez-Portales*, Isabelle Romieu*, Robin Room*, Lisa C Rosenfeld*, Ananya Roy*, Lesley Rushton*, Joshua A Salomon*, Uchechukwu Sampson*, Lidia Sanchez-Riera*, Ella Sanman*, Amir Sapkota*, Soraya Seedat*, Peilin Shi*, Kevin Shield*, Rupak Shivakoti*, Gitanjali M Singh*, David A Sleet*, Emma Smith*, Kirk R Smith*, Nicolas J C Stapelberg*, Kyle Steenland*, Heidi Stöckl*, Lars Jacob Stovner*, Kurt Straif*, Lahn Straney*, George D Thurston*, Jimmy H Tran*, Rita Van Dingenen*, Aaron van Donkelaar*, J Lennert Veerman*, Lakshmi Vijayakumar*, Robert Weintraub*, Myrna M Weissman*, Richard A White*, Harvey Whiteford*, Steven T Wiersma*, James D Wilkinson*, Hywel C Williams*, Warwick Williams*, Nicholas Wilson*, Anthony D Woolf*, Paul Yip*, Jan M Zielinski*, Alan D Lopez†, Christopher J L Murray†, Majid Ezzati†

Summary

Background Quantification of the disease burden caused by different risks informs prevention by providing an account of health loss different to that provided by a disease-by-disease analysis. No complete revision of global disease burden caused by risk factors has been done since a comparative risk assessment in 2000, and no previous analysis has assessed changes in burden attributable to risk factors over time.

Methods We estimated deaths and disability-adjusted life years (DALYs; sum of years lived with disability [YLD] and years of life lost [YLL]) attributable to the independent effects of 67 risk factors and clusters of risk factors for 21 regions in 1990 and 2010. We estimated exposure distributions for each year, region, sex, and age group, and relative risks per unit of exposure by systematically reviewing and synthesising published and unpublished data. We used these estimates, together with estimates of cause-specific deaths and DALYs from the Global Burden of Disease Study 2010, to calculate the burden attributable to each risk factor exposure compared with the theoretical-minimum-risk exposure. We incorporated uncertainty in disease burden, relative risks, and exposures into our estimates of attributable burden.

Findings In 2010, the three leading risk factors for global disease burden were high blood pressure (7·0% [95% uncertainty interval 6·2–7·7] of global DALYs), tobacco smoking including second-hand smoke (6·3% [5·5–7·0]), and alcohol use (5·5% [5·0–5·9]). In 1990, the leading risks were childhood underweight (7·9% [6·8–9·4]), household air pollution from solid fuels (HAP; 7·0% [5·6–8·3]), and tobacco smoking including second-hand smoke (6·1% [5·4–6·8]). Dietary risk factors and physical inactivity collectively accounted for 10·0% (95% UI 9·2–10·8) of global DALYs in 2010, with the most prominent dietary risks being diets low in fruits and those high in sodium. Several risks that primarily affect childhood communicable diseases, including unimproved water and sanitation and childhood micronutrient deficiencies, fell in rank between 1990 and 2010, with unimproved water

Lancet 2012; 380: 2224–60

See Comment pages 2053, 2054, 2055, 2058, 2060, 2062, and 2063

See Special Report page 2067

See Articles pages 2071, 2095, 2129, 2144, 2163, and 2197

*Author listed alphabetically

†Joint senior authors

‡Corresponding author

See Online for appendix

For **interactive versions of figures 3, 4, and 6** see http://healthmetricsandevaluation.org/gbd/visualizations/regional

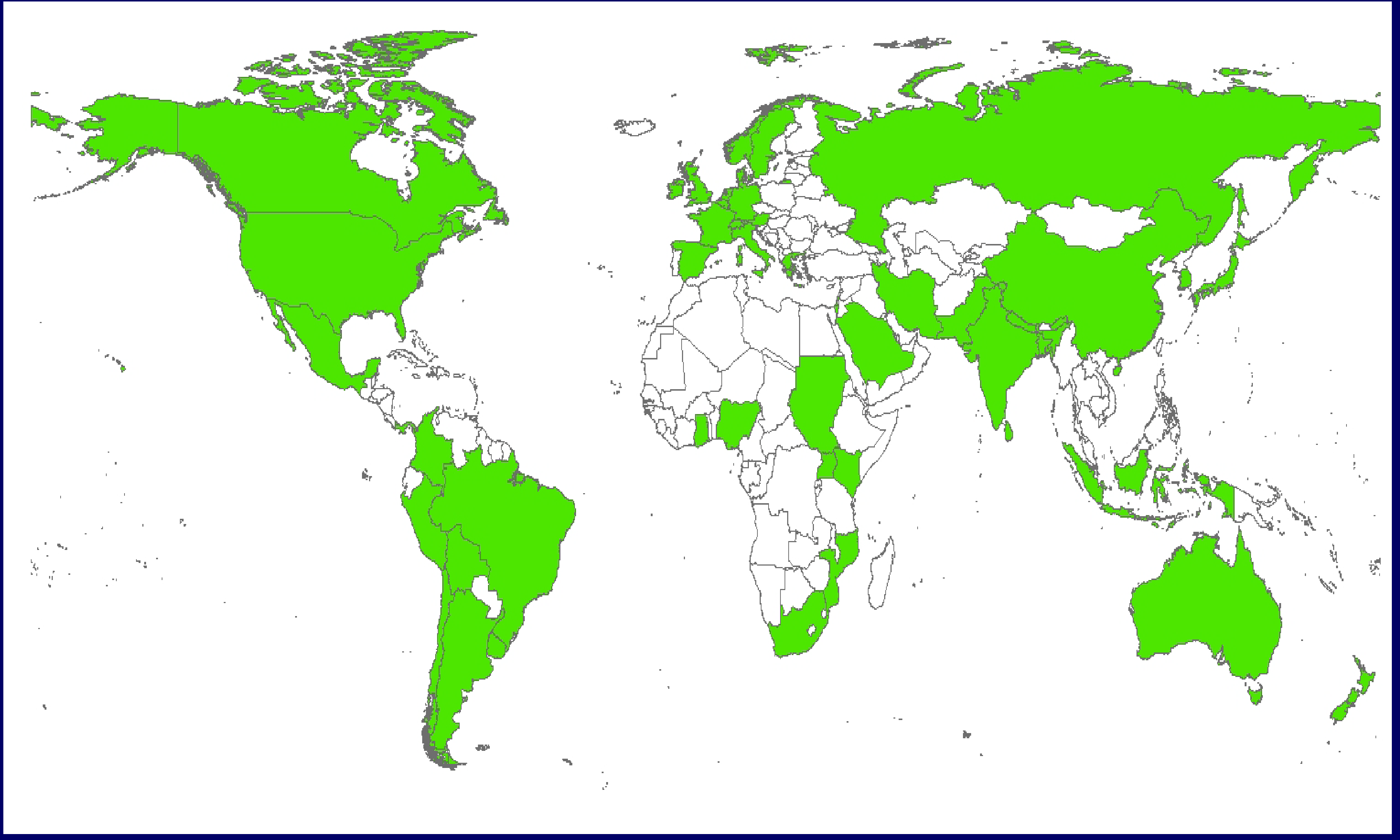
Institute for Health Metrics and Evaluation (S S Lim PhD, A D Flaxman PhD, K G Andrews MPH, C Atkinson BS, E Carnahan BA, K E Colson BA, R E Engell BA, G Freedman BA, M K Freeman BA, E Gakidou PhD, R Jasrasaria BA,

2224 www.thelancet.com Vol 380 December 15/22/29, 2012

http://www.thelancet.com/themed/global-burden-of disease

GBD 2010 Team

488 authors from 303 institutions in 50 countries



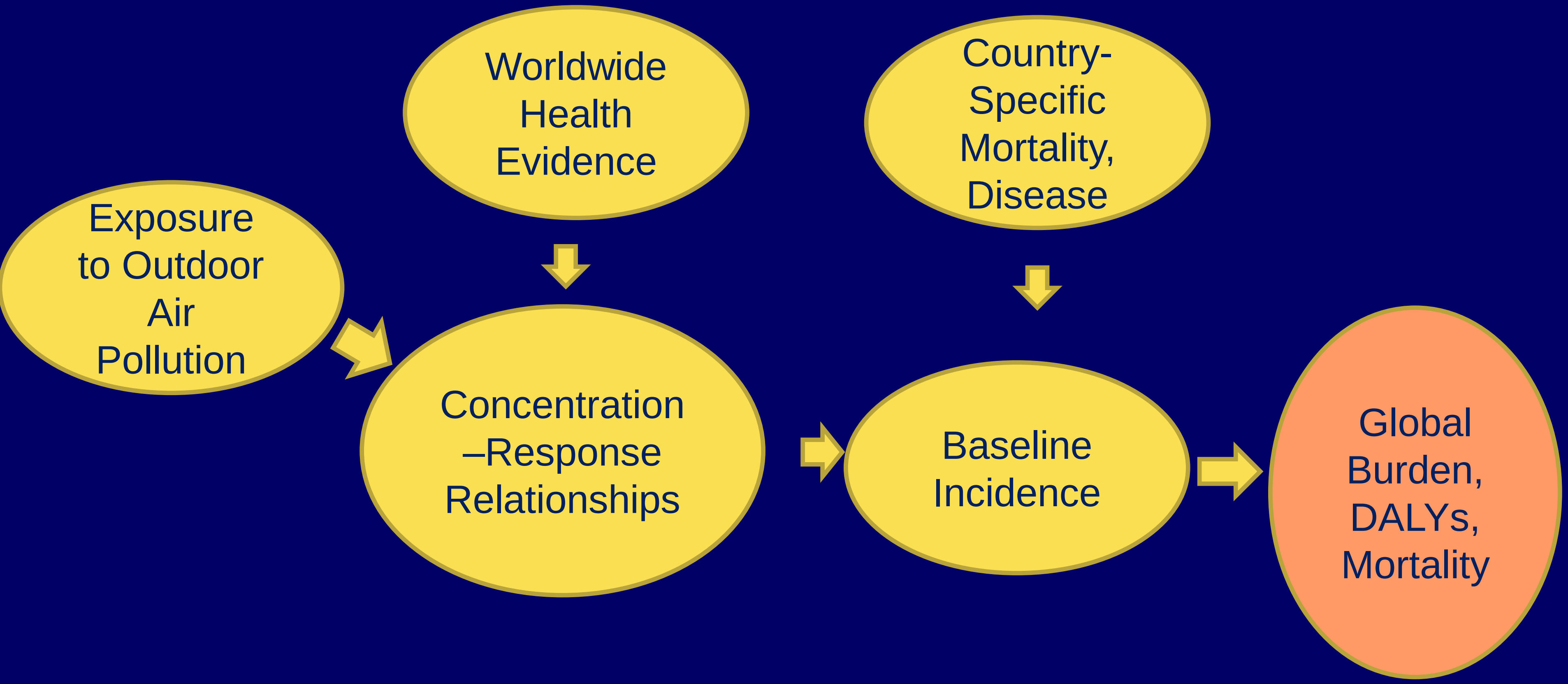
Ambient Air Pollution Expert Group

H Ross Anderson (Co-Chair)*	*SGHMS U London*
Markus Amann	*IIASA/Vienna*
Michelle Bell	*Yale University*
Michael Brauer*	*U British Columbia*
Bert Brunekreef	*U Utrecht*
Richard Burnett*	*Health Canada*
Aaron Cohen (Co-Chair)*	*Health Effects Institute*
Frank Dentener	*EC-JRC*
Majid Ezzati	*Harvard University*
Bryan Hubbell	*USEPA*
Kan Haidong	*Fudan University*
Michal Krzyzanowski	*WHO/Euro-Bonn*
Francine Laden	*Harvard University*
Stephanie London	*NIEHS*
Randall Martin	*Dalhousie University*
Sumi Mehta	*UN Fnd Clean Stoves Program*
Bart Ostro	*California EPA*
Kiran Dev Pandey	*World Bank*
Arden Pope	*Brigham Young U*
Beate Ritz	*UCLA*
Isabelle Romieu	*IARC*
Amir Sapkota	*U Maryland*
Kirk Smith	*UC Berkeley*
George Thurston	*New York University*
Rita van Dingenen	*EC –JRC*
Aaron van Donkelaar	*Dalhousie University*

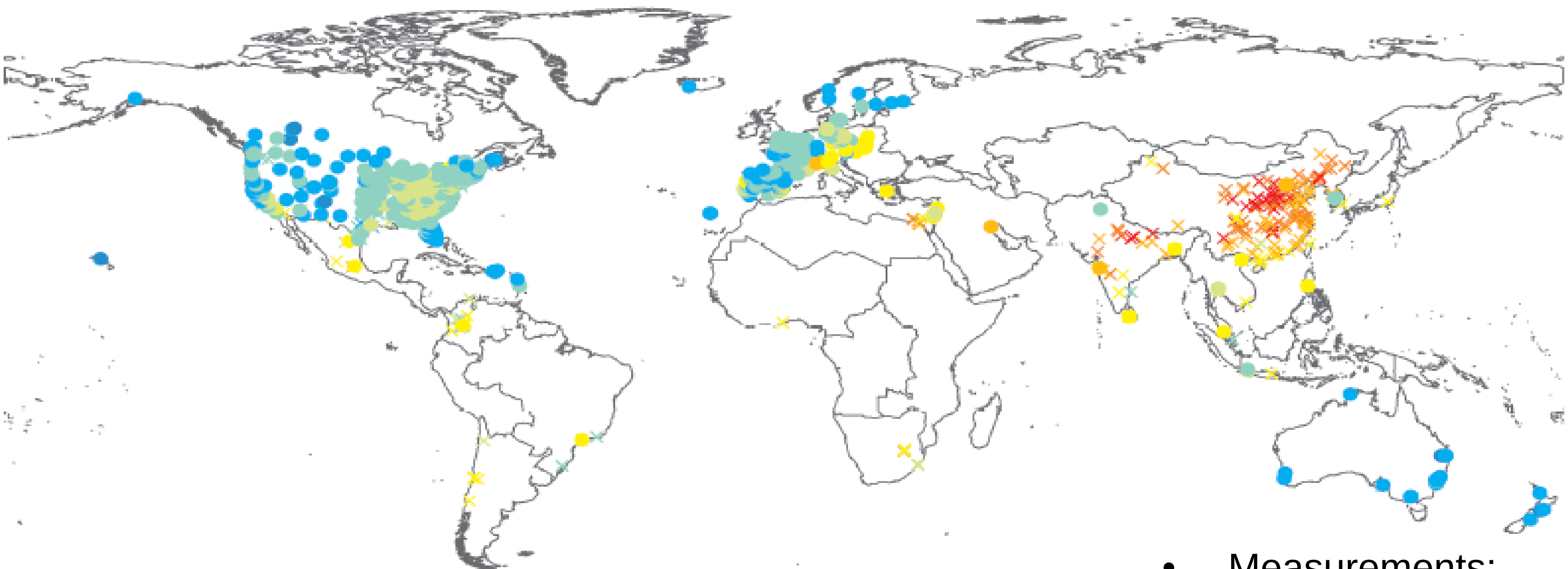
Comparative Risk Assessment : *Methods*

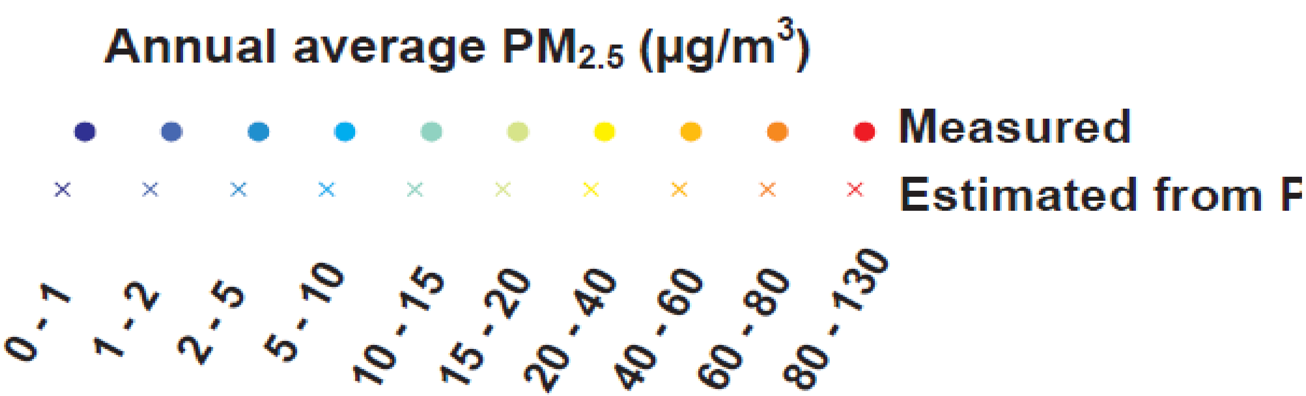
- Calculate the proportion of deaths or disease burden holding other independent factors unchanged
- Counterfactual analysis: What if risk exposure was at a different level – e.g., lower $PM_{2.5}$ or normal blood pressure or BMI?
- 79 risk factors and clusters of risk factors
- 20 age groups, both sexes, 187 countries, and for 1990, 2005, 2010, 2013

Estimating the Global Burden of Disease due to Ambient Air Pollution



PM ground-level measurements (2005)





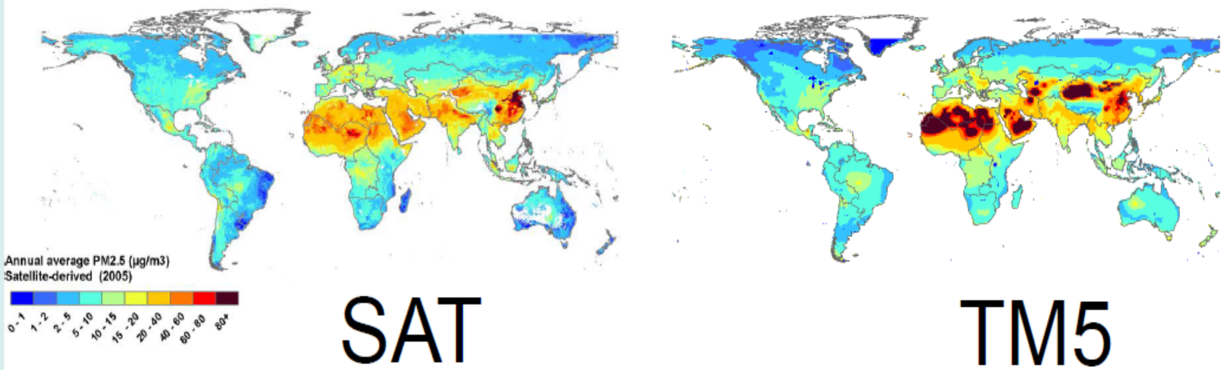
- Measurements: North America, Europe, Australasia
- Estimates (from PM_{10}): Asia, Latin America
- No info: 7 / 21 GBD region

Environmental Science & Technology
Article
pubs.acs.org/est

Exposure Assessment for Estimation of the Global Burden of Disease Attributable to Outdoor Air Pollution

Michael Brauer,*[,†] Markus Amann,[‡] Rick T. Burnett,[§] Aaron Cohen,[‖] Frank Dentener,[⊥] Majid Ezzati,[#] Sarah B. Henderson,[∇] Michal Krzyzanowski,[○] Randall V. Martin,[◆,¶] Rita Van Dingenen,[⊥] Aaron van Donkelaar,[◆] and George D. Thurston[+]

- **Global estimates of $PM_{2.5}$ at 10km x 10km scale**
- **Combined estimates from satellites (AOD), chemical transport models and ground-level measurements**
- **Estimates include contribution of all sources of $PM_{2.5}$**



- Final estimates based on average of (1.4 million) grid cell values (SAT, TM5) and calibrated (regression model) with measurements
  - 0.1° x 0.1° resolution
- Incorporate variance between two estimates and measurements in uncertainty assessment
- Unique contributions from each approach

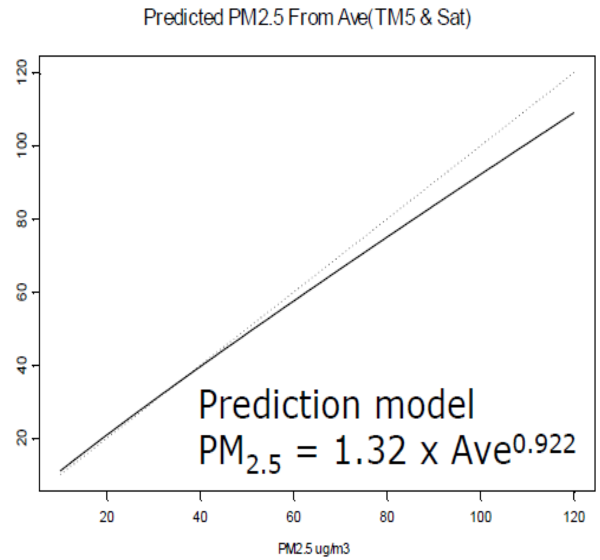
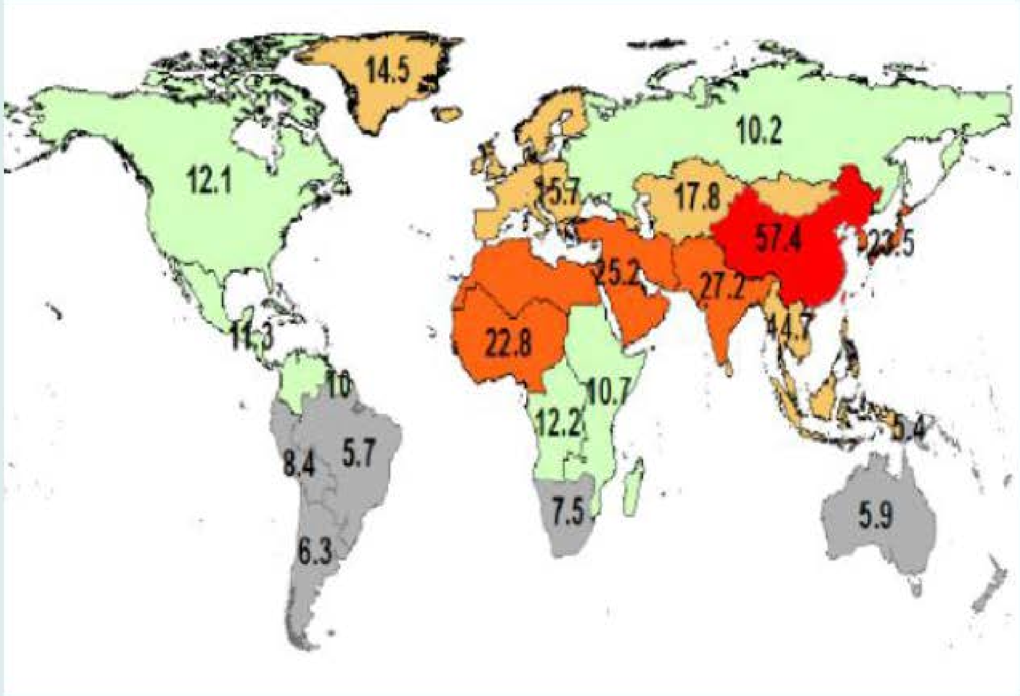
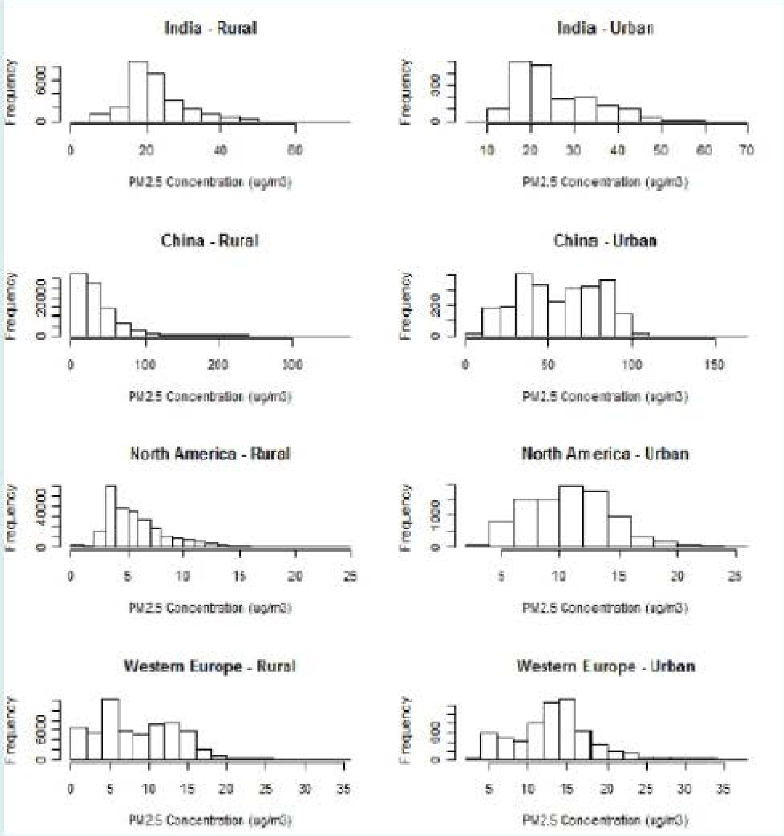


Figure 1.



2005 population-weighted regional estimated average $PM_{2.5}$

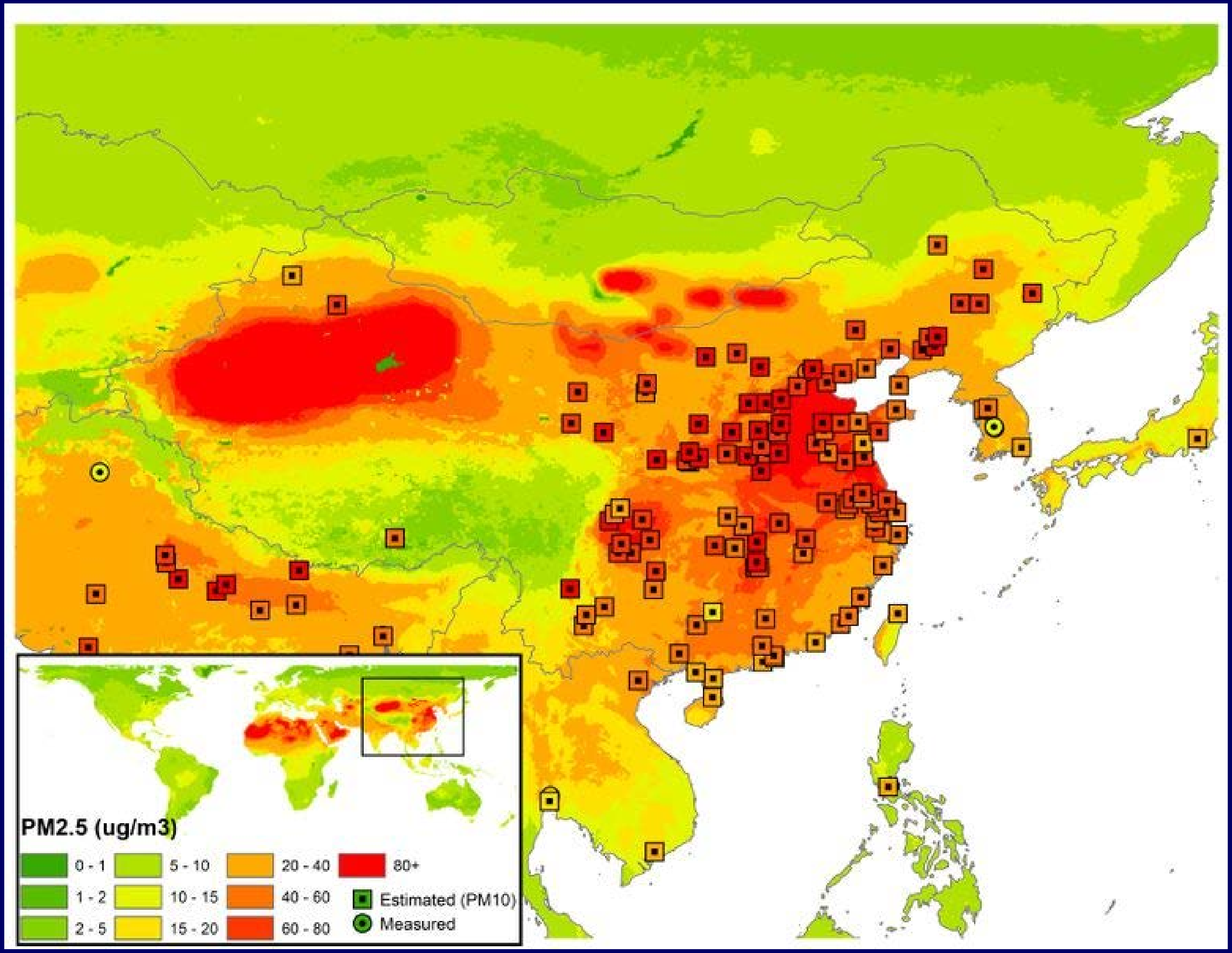
Figure 2. Brauer M, et al *Env Sci Technol* 2012



Distributions of selected regional 2005 estimated $PM_{2.5}$ by urban and rural areas

- **1.4 million grid cells in total**
- **Linked to global gridded population (including urban-rural indicators)**
- **Allows for country-level burden estimation**

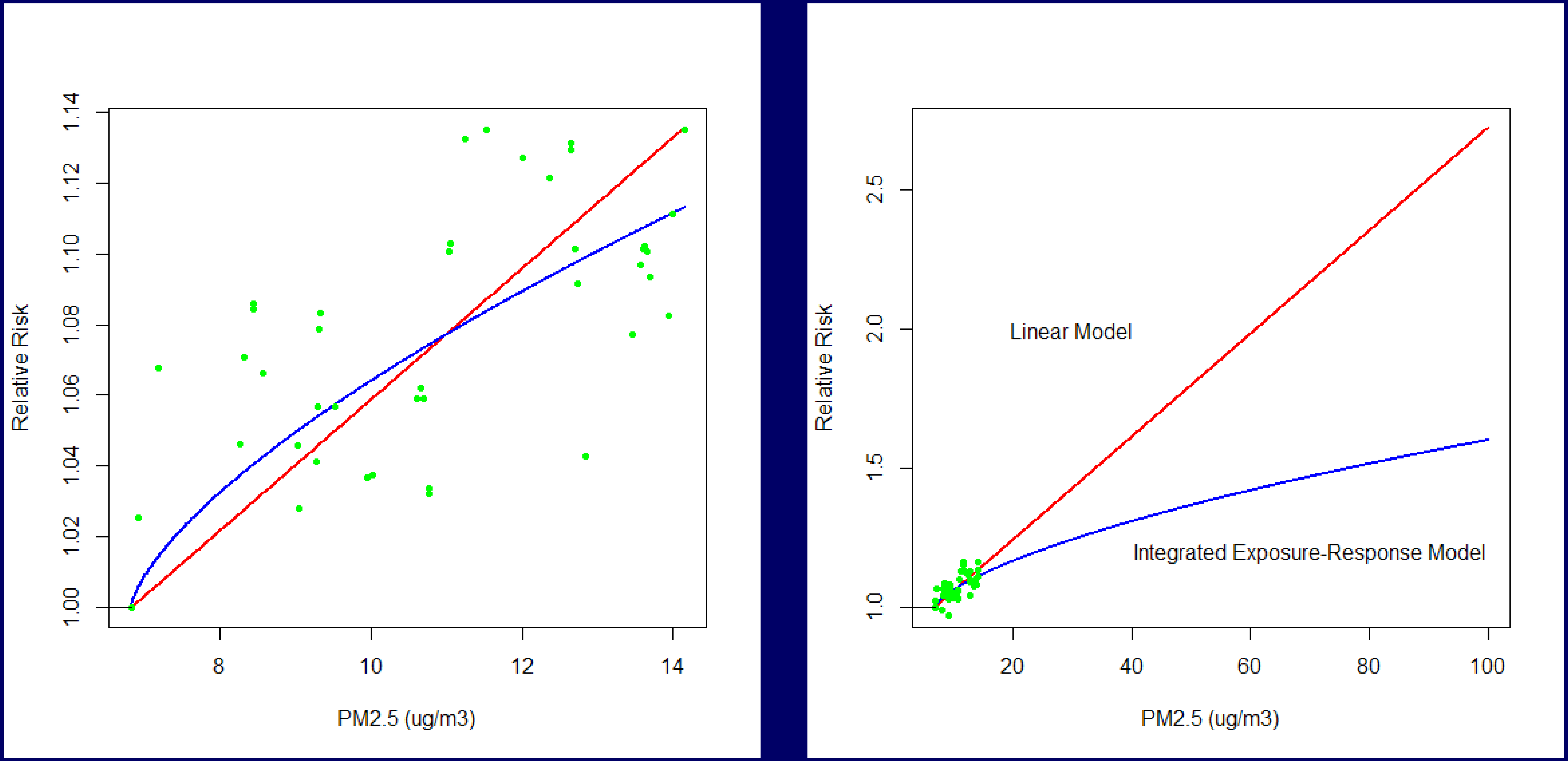
Estimated 2010 levels of $PM_{2.5}$ in China



Diseases affected by air pollution are the top 5 causes of the global burden of disease in 2010
(Lozano R et al. 2012)

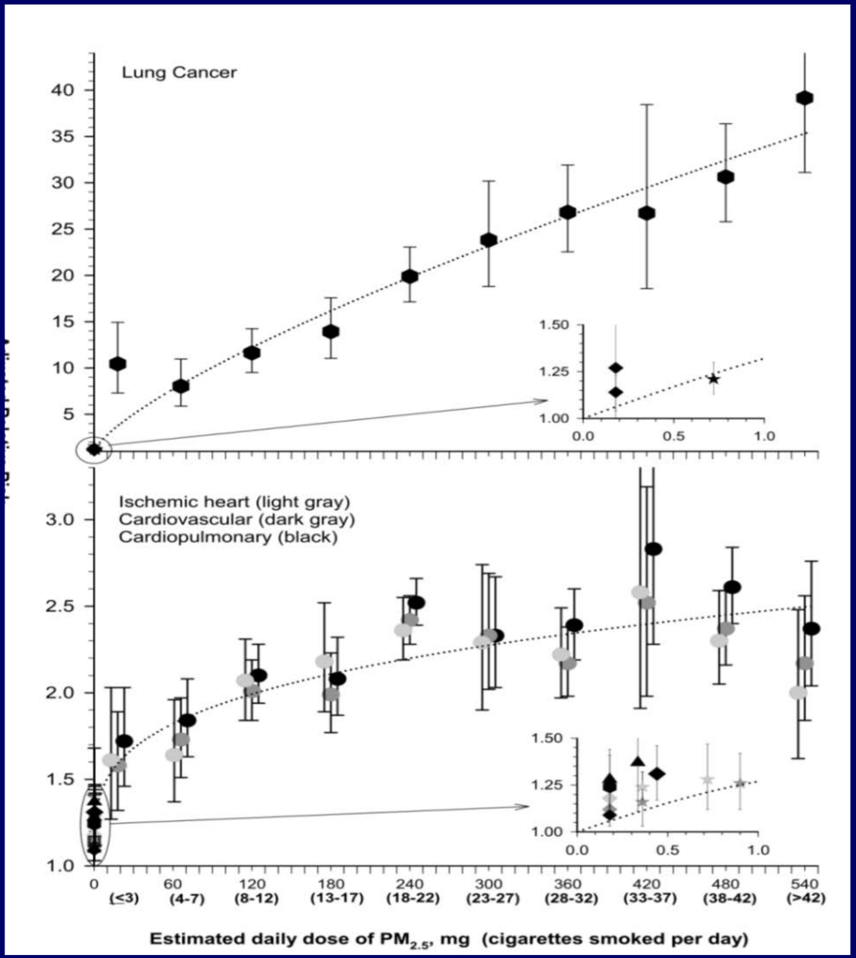
2010		
Disorder	Mean rank (95% UI)	% change (95% UI)
1 Ischaemic heart disease	1·0 (1 to 1)	35 (29 to 39)
2 Stroke	2·0 (2 to 2)	26 (14 to 32)
3 COPD	3·4 (3 to 4)	–7 (–12 to 0)
4 Lower respiratory infections	3·6 (3 to 4)	–18 (–24 to –11)
5 Lung cancer	5·8 (5 to 10)	48 (24 to 61)
6 HIV/AIDS	6·4 (5 to 8)	396 (323 to 465)
7 Diarrhoea	6·7 (5 to 9)	–42 (–49 to –35)
8 Road injury	8·4 (5 to 11)	47 (18 to 86)
9 Diabetes	9·0 (7 to 11)	93 (68 to 102)
10 Tuberculosis	10·1 (8 to 13)	–18 (–35 to –3)
11 Malaria	10·3 (6 to 13)	21 (–9 to 56)
12 Cirrhosis	11·8 (10 to 14)	33 (25 to 41)
13 Self-harm	14·1 (11 to 20)	32 (8 to 49)
14 Hypertensive heart disease	14·2 (12 to 18)	48 (39 to 56)
15 Preterm birth complications	14·4 (12 to 18)	–28 (-39 to -17)
16 Liver cancer	16·9 (14 to 20)	63 (49 to 78)
17 Stomach cancer	17·0 (13 to 22)	–2 (–10 to 5)
18 Chronic kidney disease	17·4 (15 to 21)	82 (65 to 95)
19 Colorectal cancer	18·5 (15 to 21)	46 (36 to 63)
20 Other cardiovascular and circulatory	19·7 (18 to 21)	46 (40 to 55)

Needed: a risk model for $PM_{2.5}$ exposure over the entire global range



A model for estimating the global attributable burden: Integrated exposure-response function (IER)

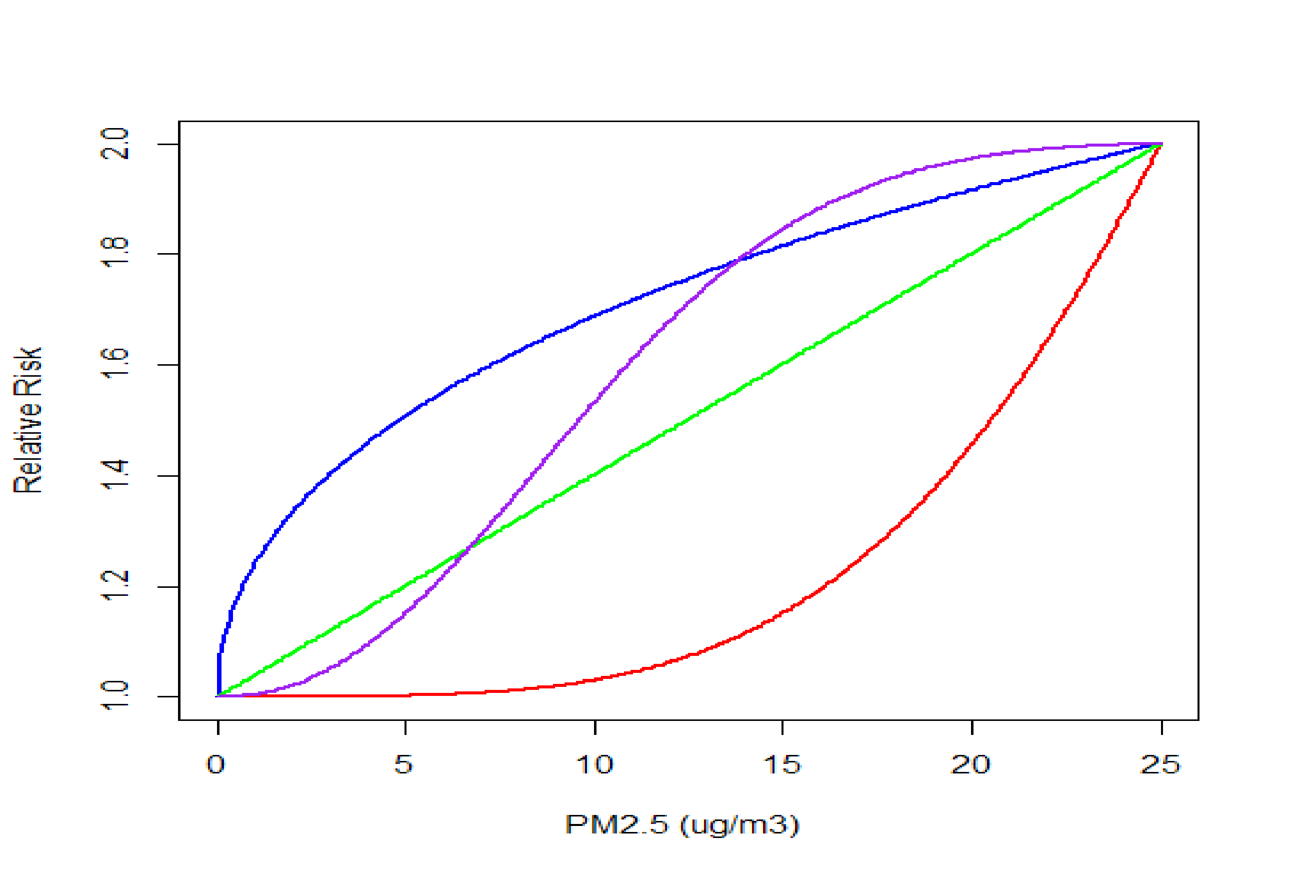
- **All cohort studies of $PM_{2.5}$ and mortality from chronic disease have been conducted in the US and Western Europe**
- **New models needed to estimate exposure-response functions at high levels of PM in Asia, other regions**
- **IERs estimate E-R functions using results of studies of second-hand smoke (SHS) , household air pollution (HAP), and active tobacco smoking (ATS) (Burnett R et al. 20114 EHP)**
- **Key model assumptions:**
  - **Risk is a function of $PM_{2.5}$ inhaled dose regardless of source (Pope et al. 2009; 2011)**
  - **Consistent with risk observed in current cohort studies**
  - **Predict risk for highest $PM_{2.5}$ concentrations consistent with risks from SHS, HAP, active smoking**



From: Pope CA et al. EHP 2011

Integrated Exposure Response Function – IER

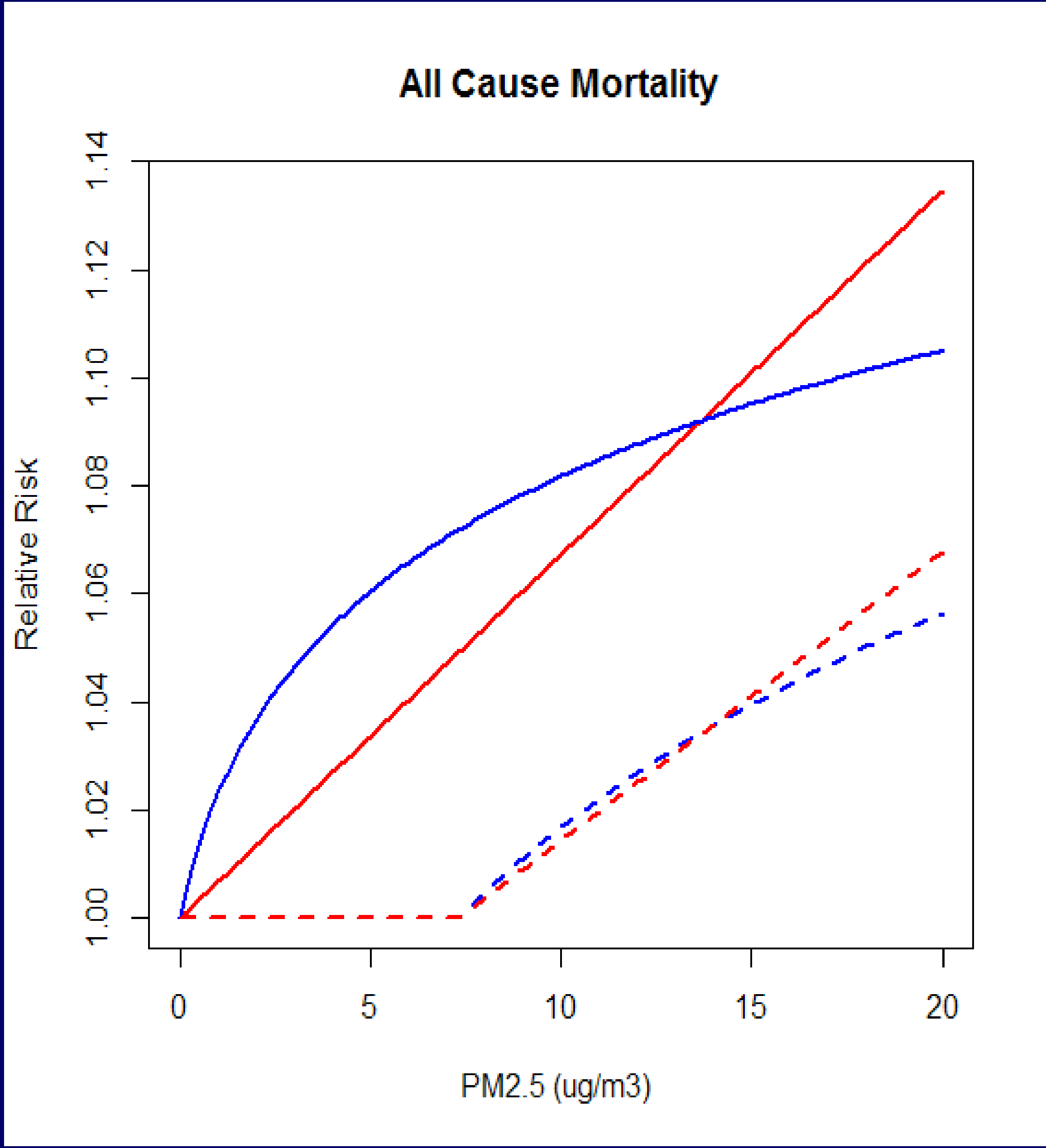
$$RR_{IER}(z) = \begin{cases} 1, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots, & z < z_{cf} \\ 1 + \alpha\left(1 - e^{-\gamma (z - z_{cf})^{\delta}}\right), \ldots\ldots, & z \geq z_{cf} \end{cases}$$



Accommodates variety of shapes even within ambient range

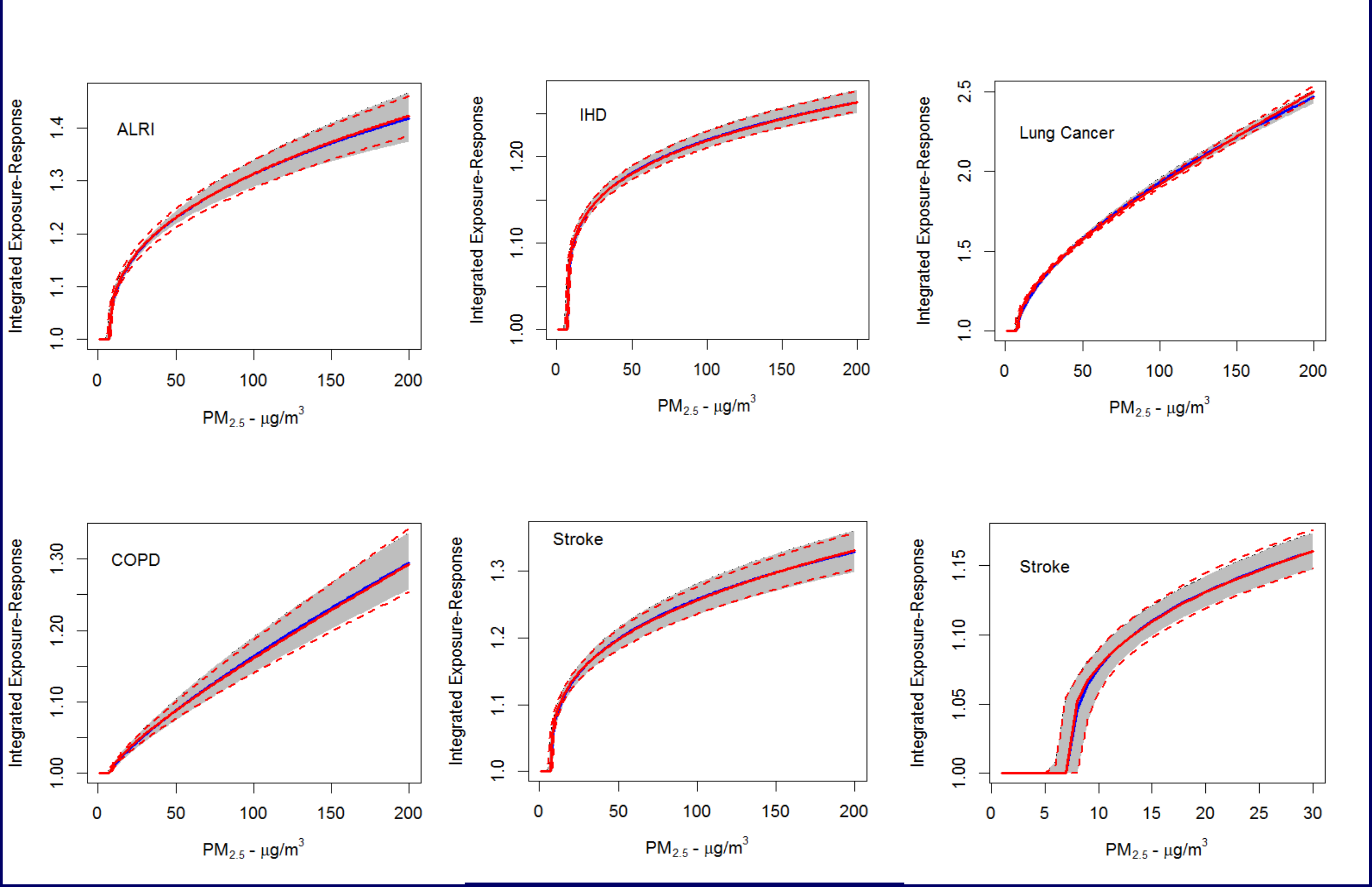
Theoretical Minimum Risk Exposure Distribution (TMRED)

- **The availability of convincing evidence from epidemiological studies that support a continuous reduction in risk of disease**
- **A distribution that is theoretically possible at the population level**
- **Assumed no benefit below lowest observed concentrations in ambient air pollution cohort studies**
- **Also assumed that estimates of risk below the 5th percentile of exposure distribution are too unstable to clearly identify shape**
- **GBD (2012) assumed TMRED was a Uniform distribution between minimum and 5th percentiles of cohorts studies**
  - **U(5.8 μg/m³, 8.8 μg/m³)**
  - **Mean 7.3 μg/m³**

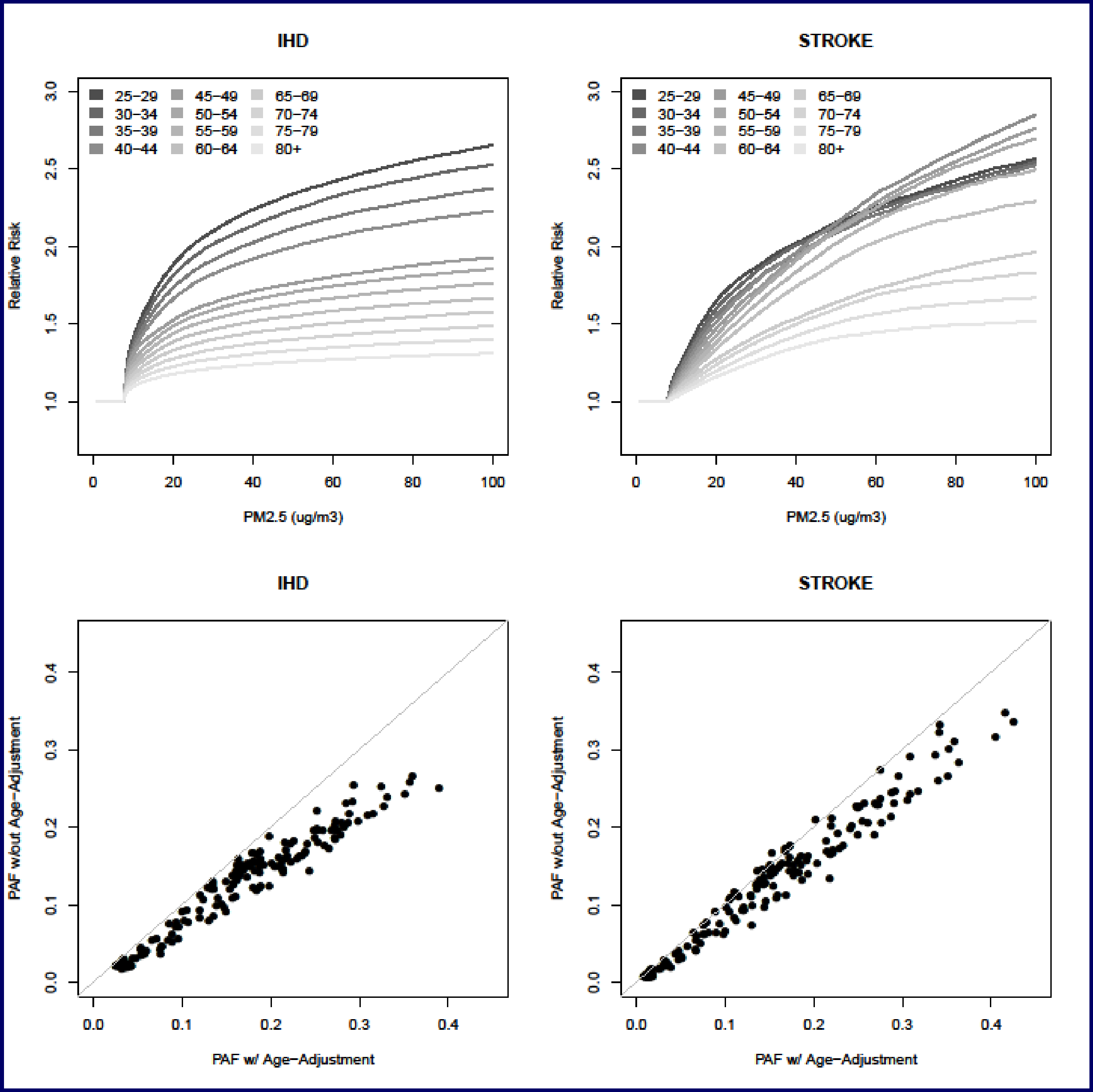


Shape of c-r function sensitive to TMRED

GBD 2013 IER Risk Functions



Modification of Ambient Air Pollution Relative Risk by Age



Burnett et al. 2013 In preparation

GBD risk functions predict risks from recent Chinese cohort study

Journal of Hazardous Materials 186 (2011) 1594–1600

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Association between long-term exposure to outdoor air pollution and mortality in China: A cohort study

Jie Cao[a,1], Chunxue Yang[b,c,1], Jianxin Li[a], Renjie Chen[b,c], Bingheng Chen[b], Dongfeng Gu[a,**], Haidong Kan[b,c,*]

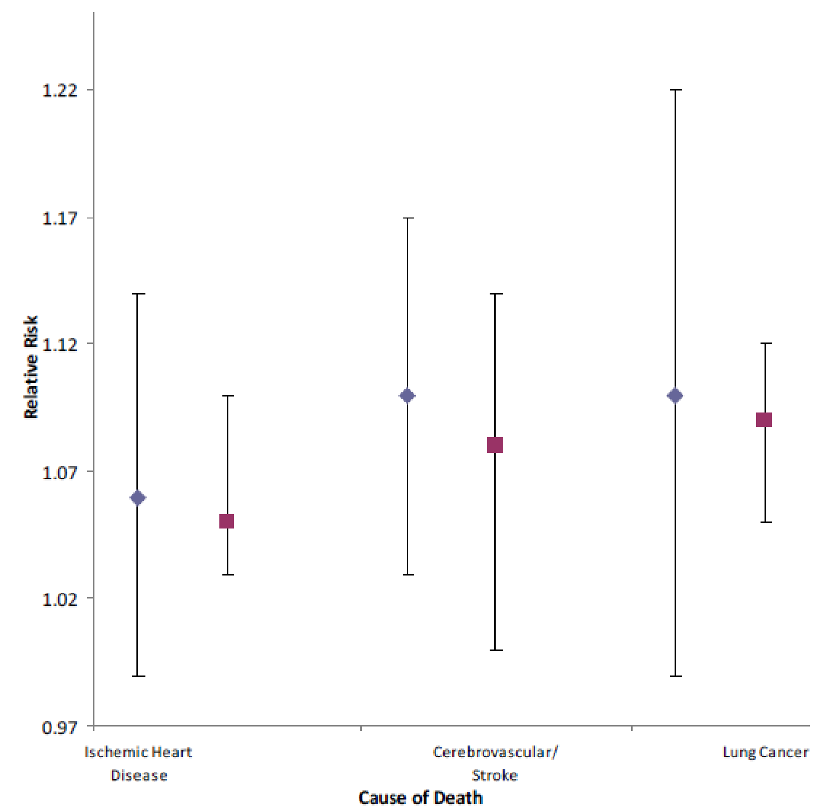
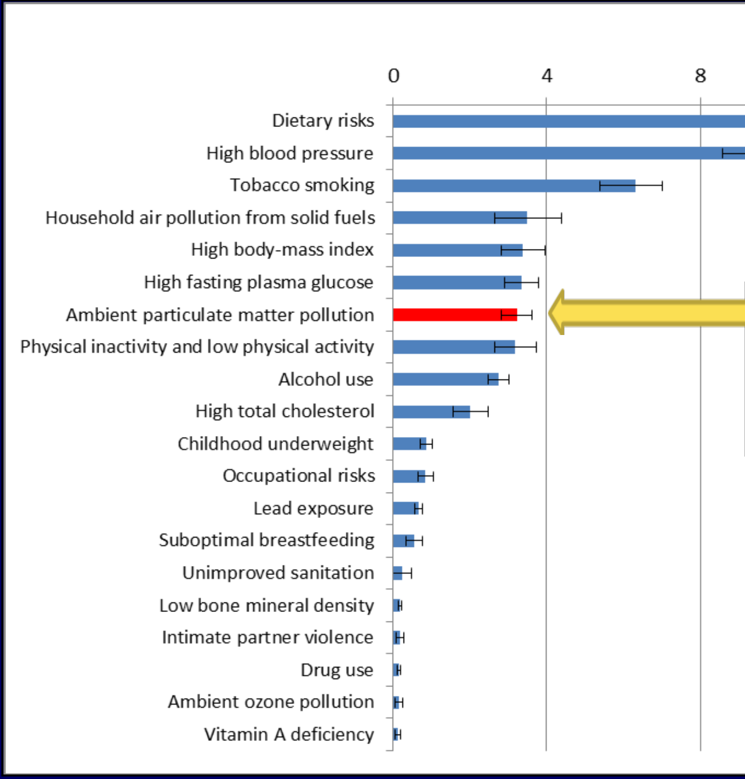


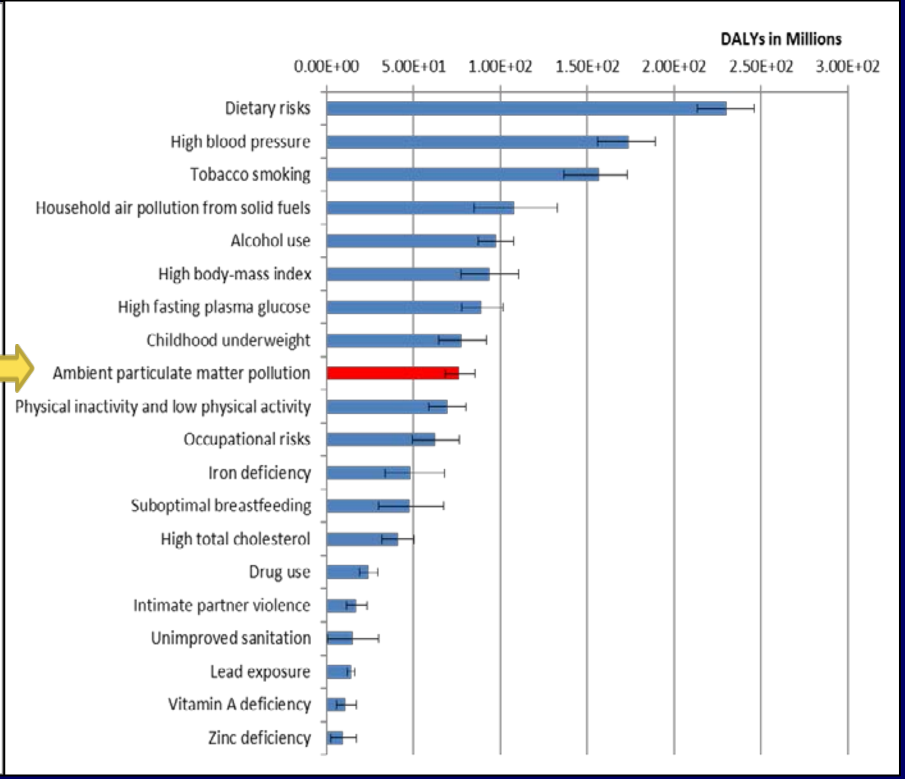
Figure 5: Predicted relative risk for changes among $PM_{2.5}$ quartiles observed in the China Cohort (40, 91, 106, and 127 μg/m^3) for the China Cohort study (Cao et al., 2011; blue diamond) and the Integrated Exposure-Response model (red square) by cause of death with 95% confidence intervals represented by error bars.

Burnett et al. 2013 Submitted

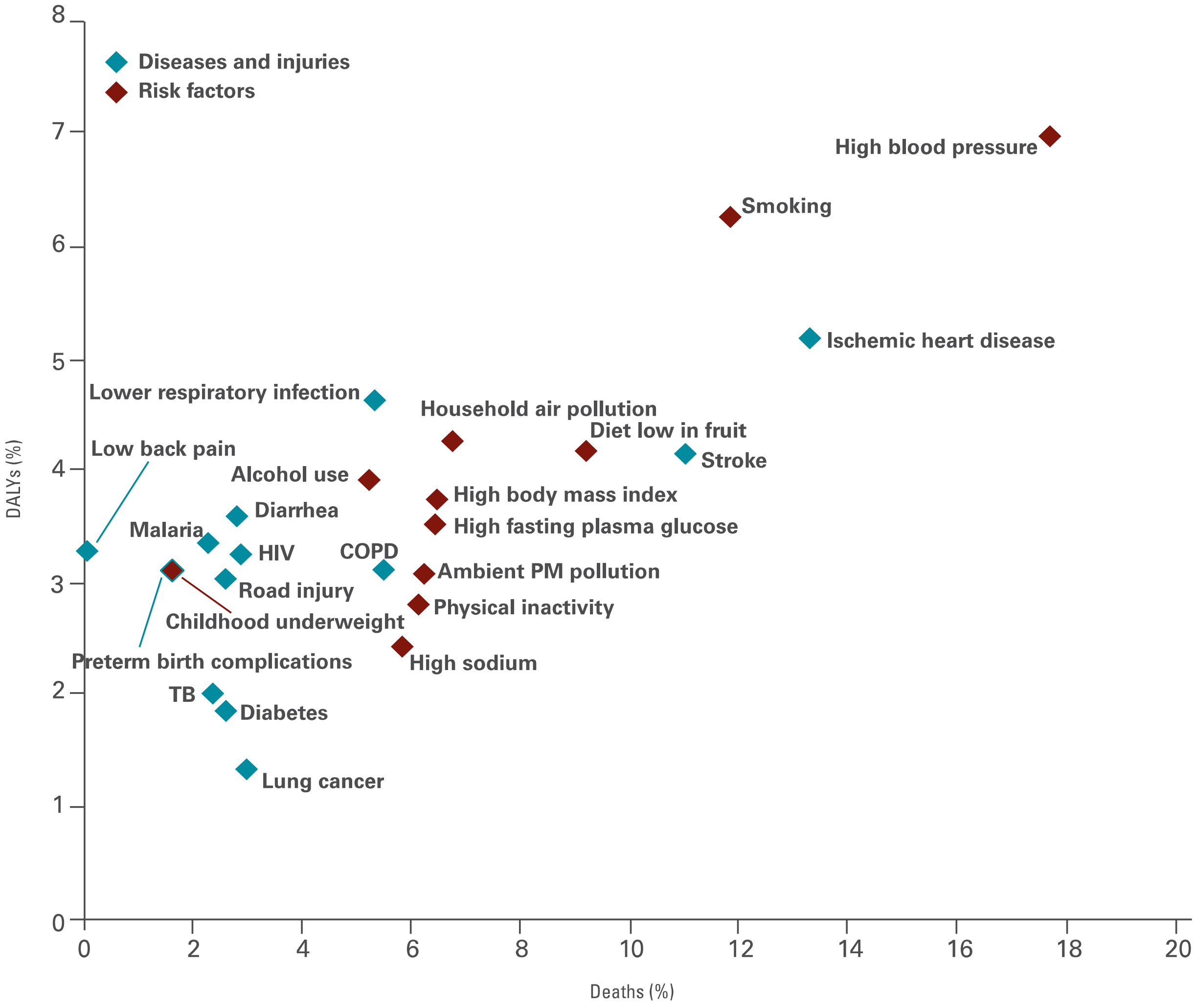
Risk Factors for global deaths and DALYs in 2010



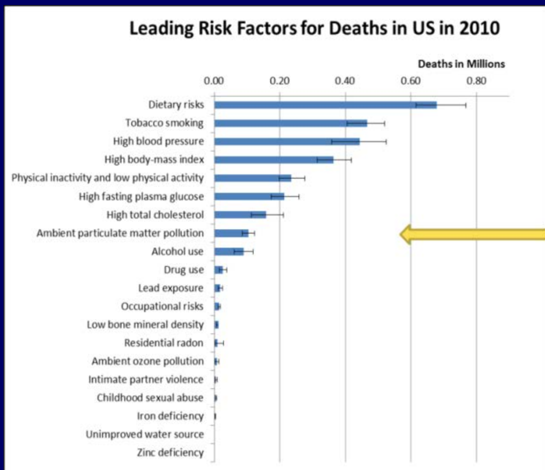
3.2 million deaths and 76 million DALYs



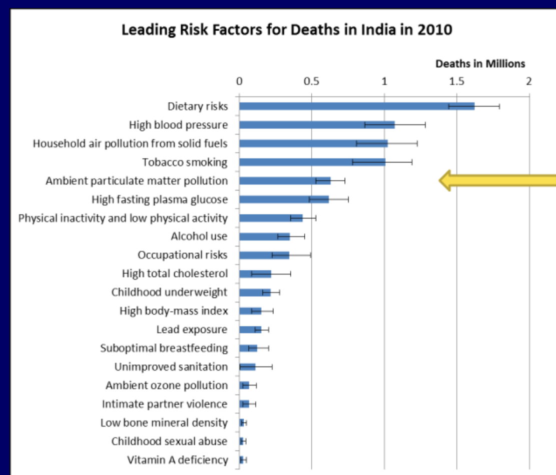
Air Quality is an Important Global Health Issue



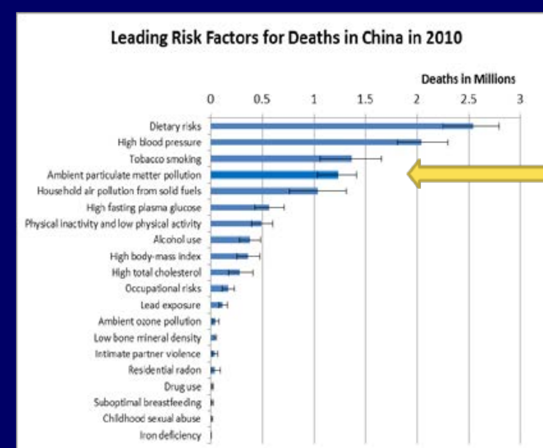
Top 20 Mortality Risk Factors in the US, India, and China in 2010



Ambient $PM_{2.5}$ caused an estimated 103,000 deaths

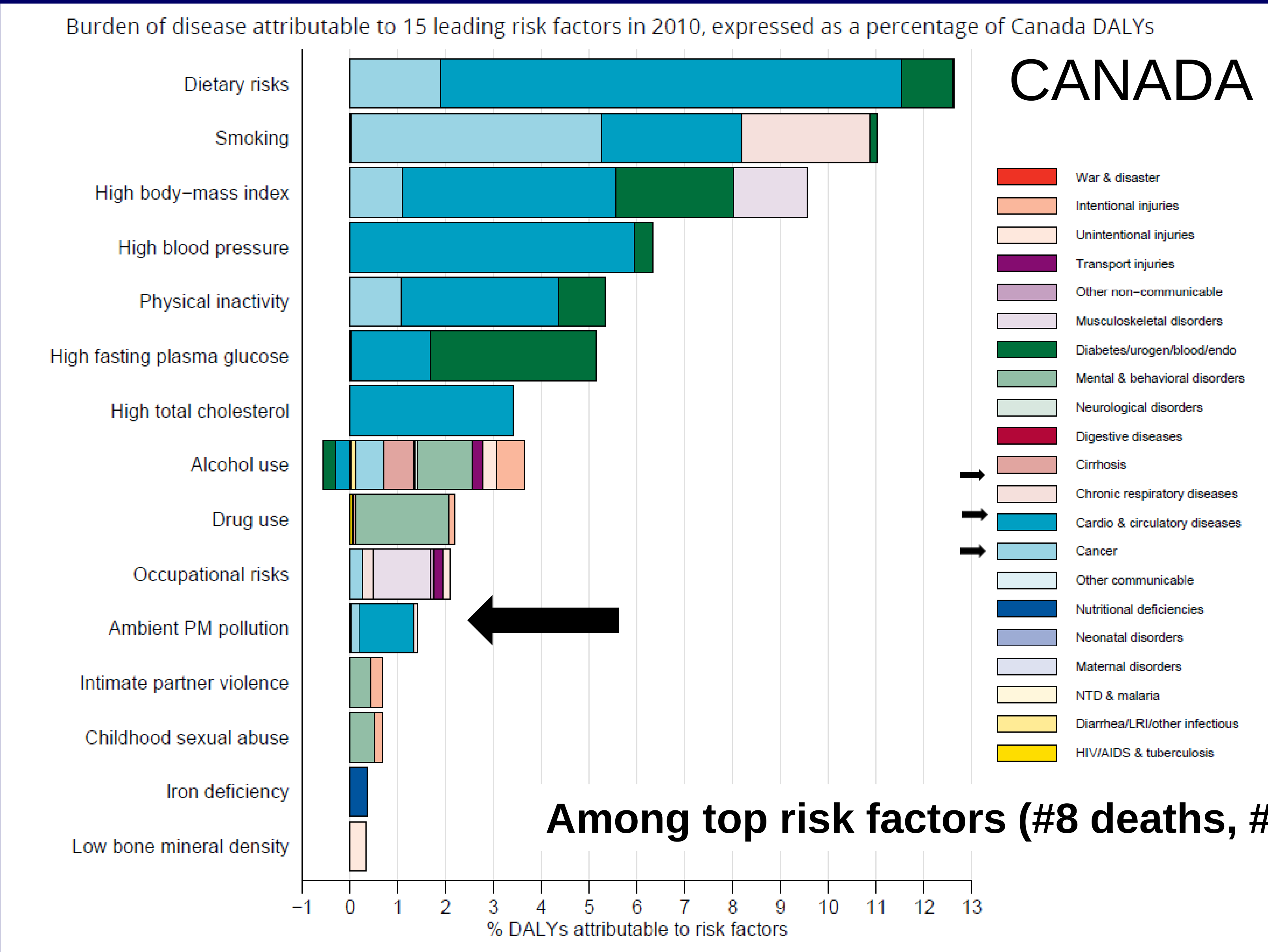


Ambient $PM_{2.5}$ caused an estimated 627,000 deaths



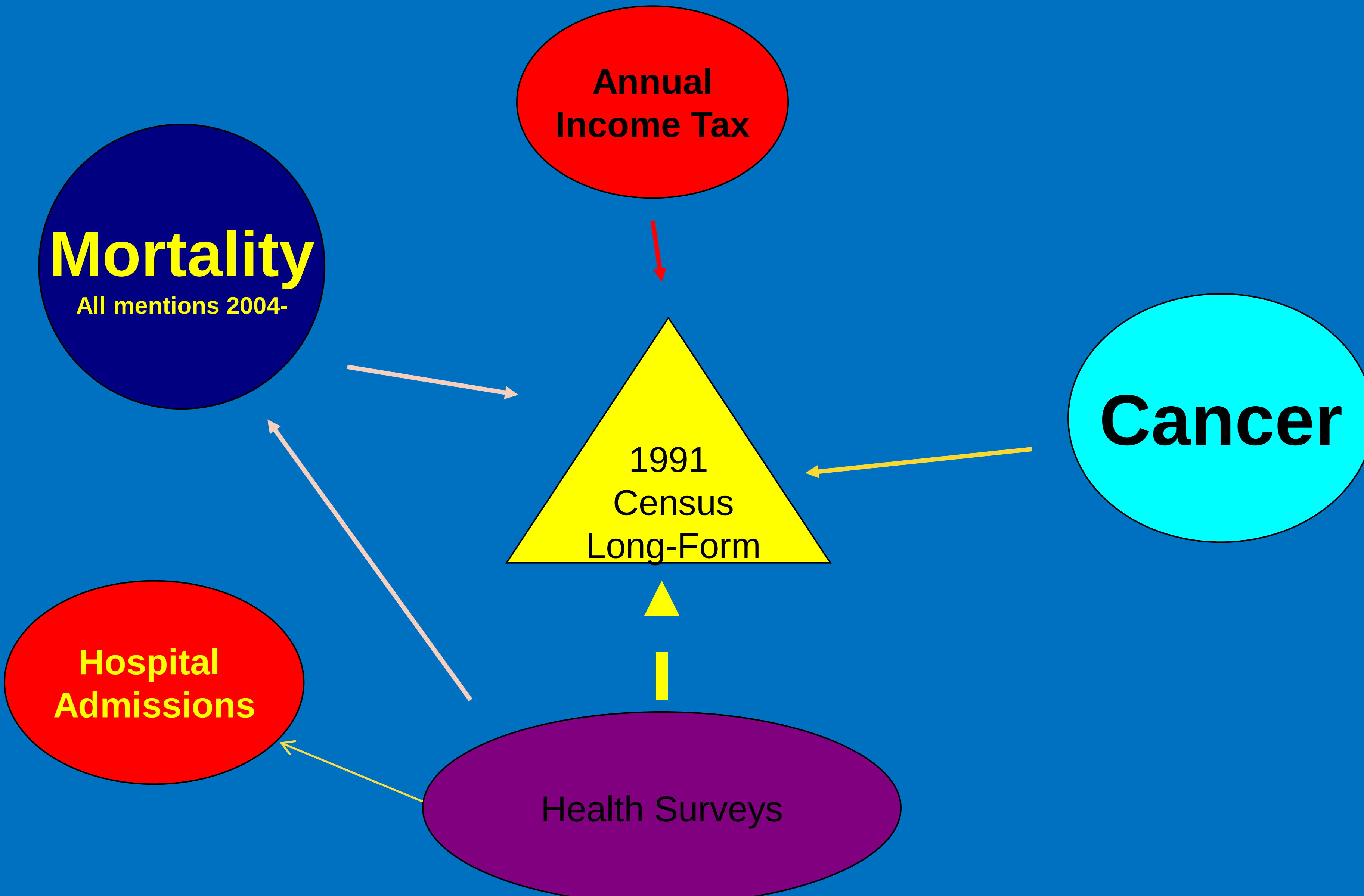
Ambient $PM_{2.5}$ caused an estimated 1,234,000 deaths; 14.9% of all deaths in 2010

CANADA (2010)

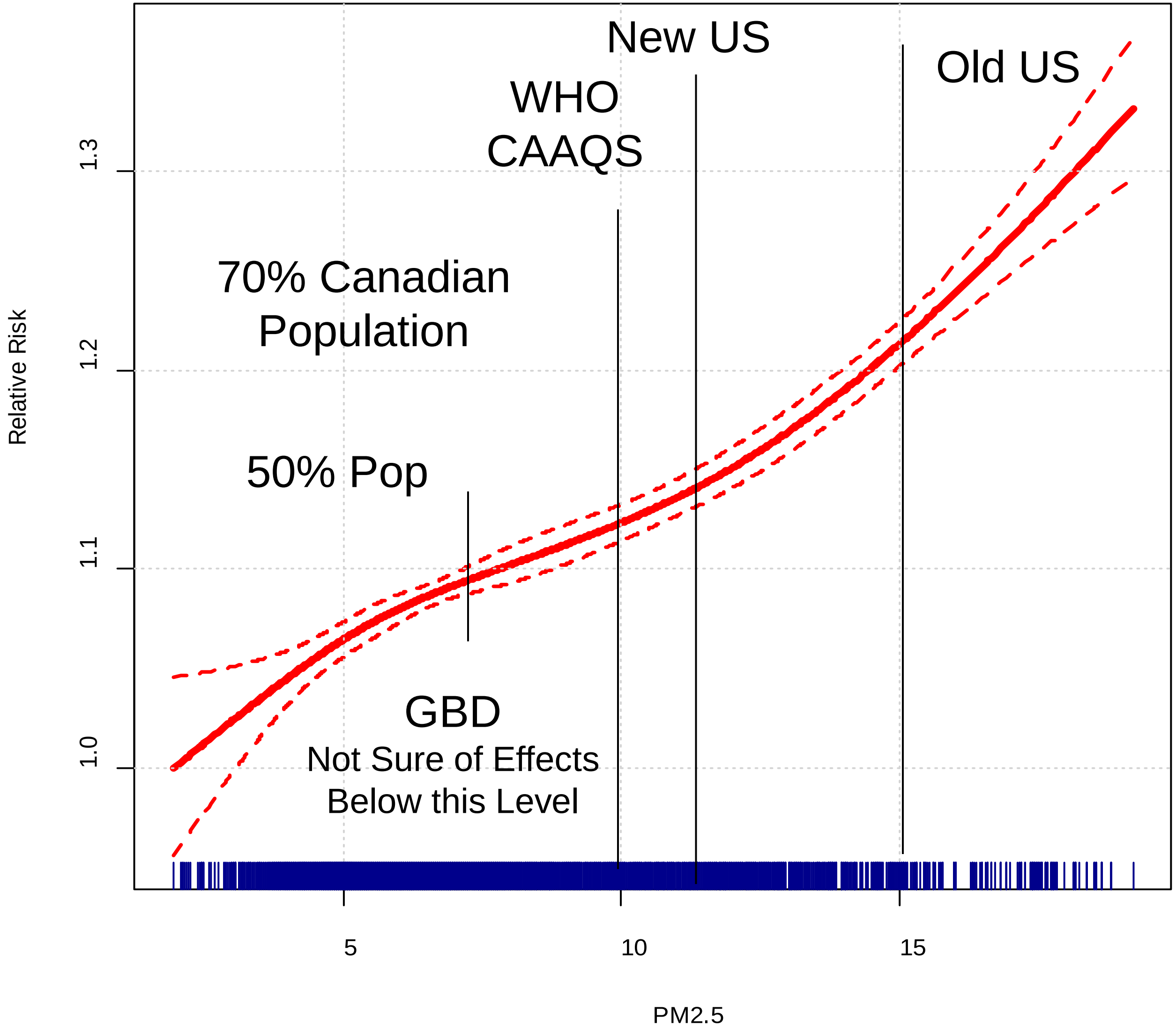


Among top risk factors (#8 deaths, #11 DALYs)

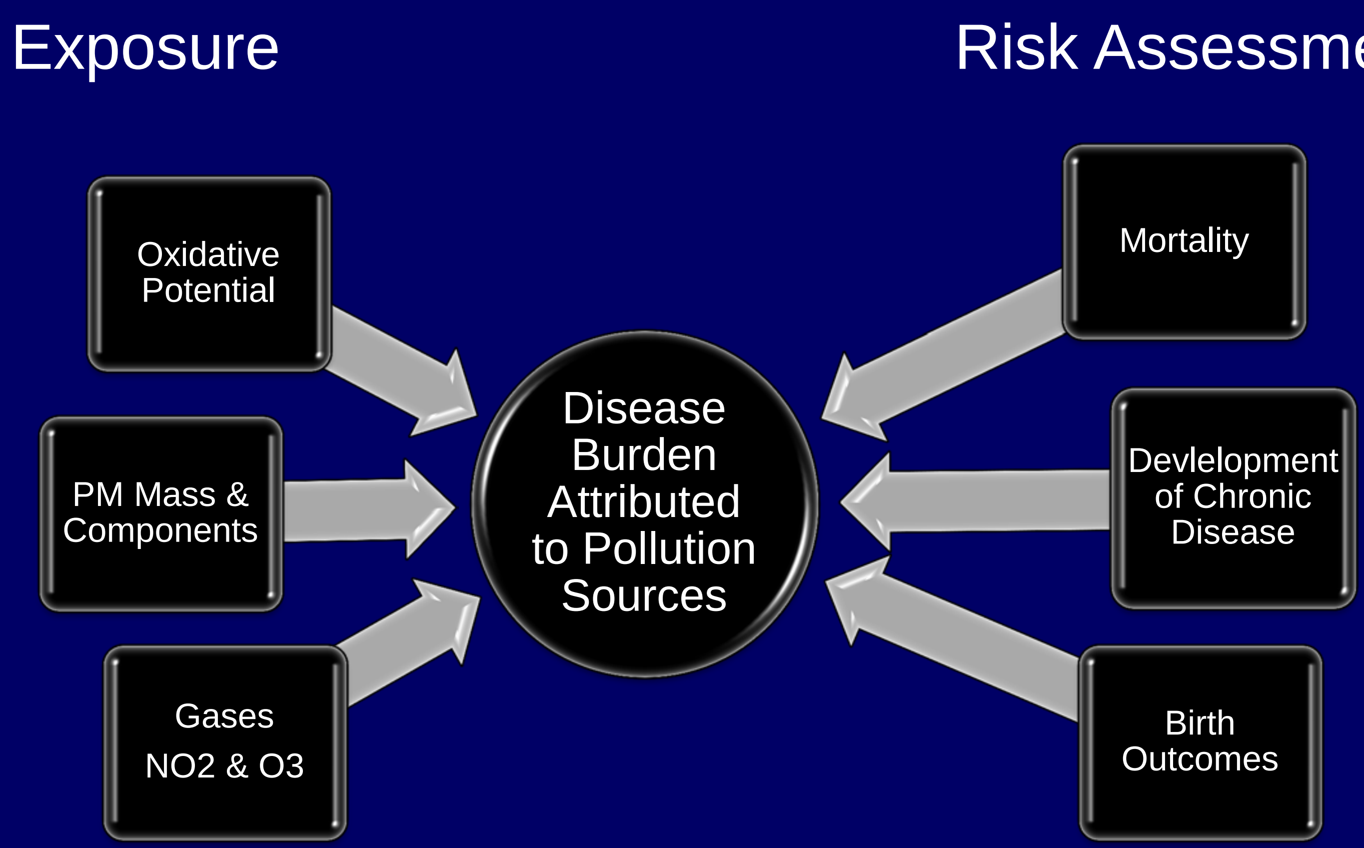
Canadian Census Cohort Study Design



CAAQS & Cost Benefit Analysis



Outdoor Pollution Exposure and Risk Assessment - OPERA



Science Support for Policy Development