# Air pollution and health: A global perspective


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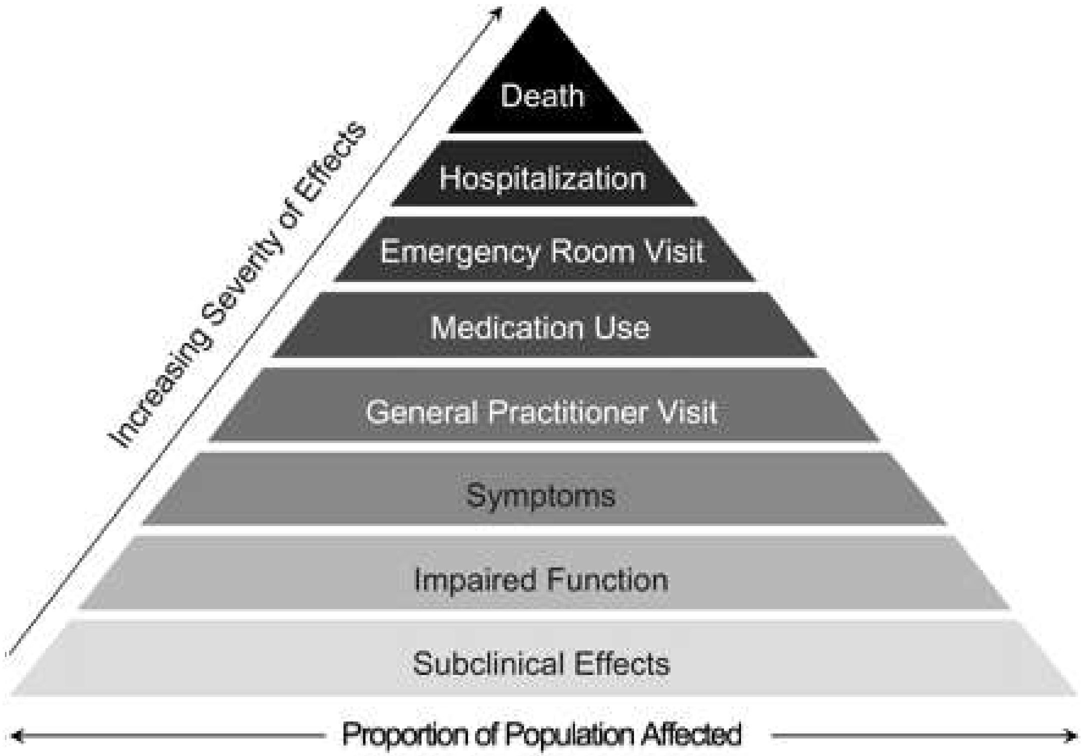
CASAP IX
CONGRESO COLOMBIANO Y CONFERENCIA INTERNACIONAL DE CALIDAD DE AIRE, CAMBIO CLIMÁTICO Y SALUD PÚBLICA

CASAP IX, Santa Marta, March 22, 2023

IHME
Institute for Health Metrics and Evaluation

# Air pollution and health

- On **days** with worse air quality, more people die*




Larrieu et al. Am J Epidemiol, 2009

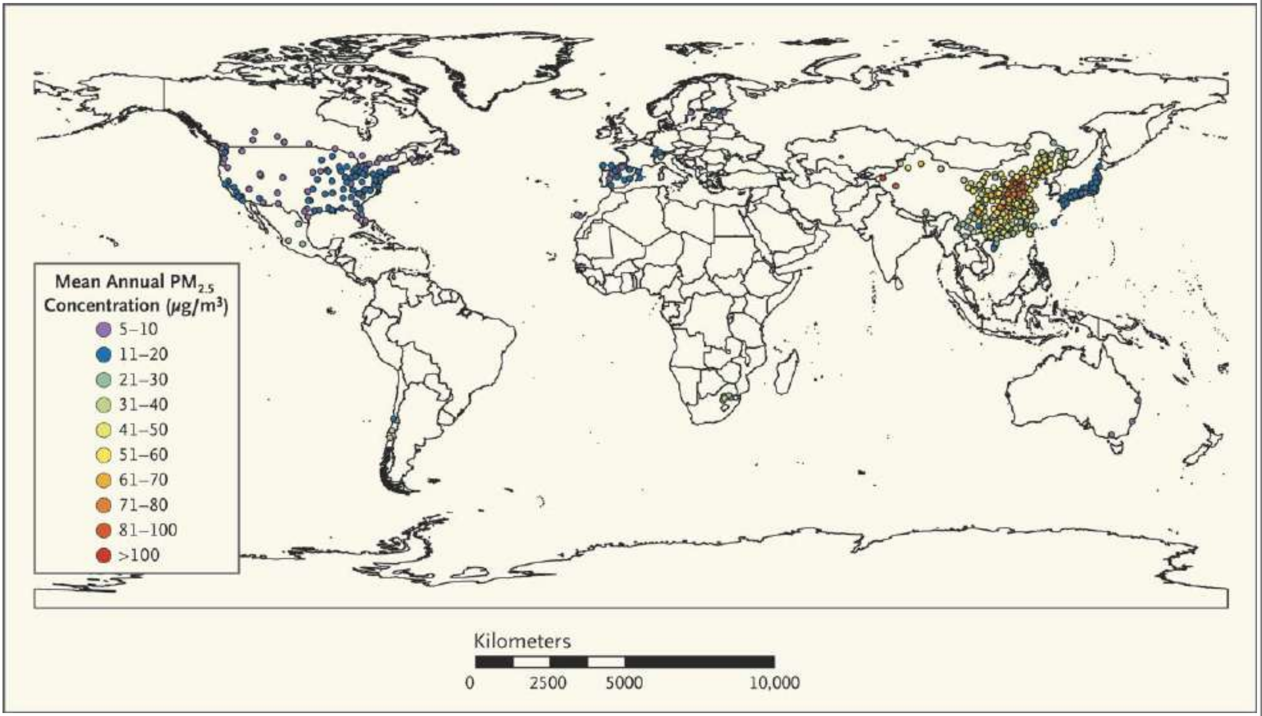
*out-of-hospital, >65 yrs

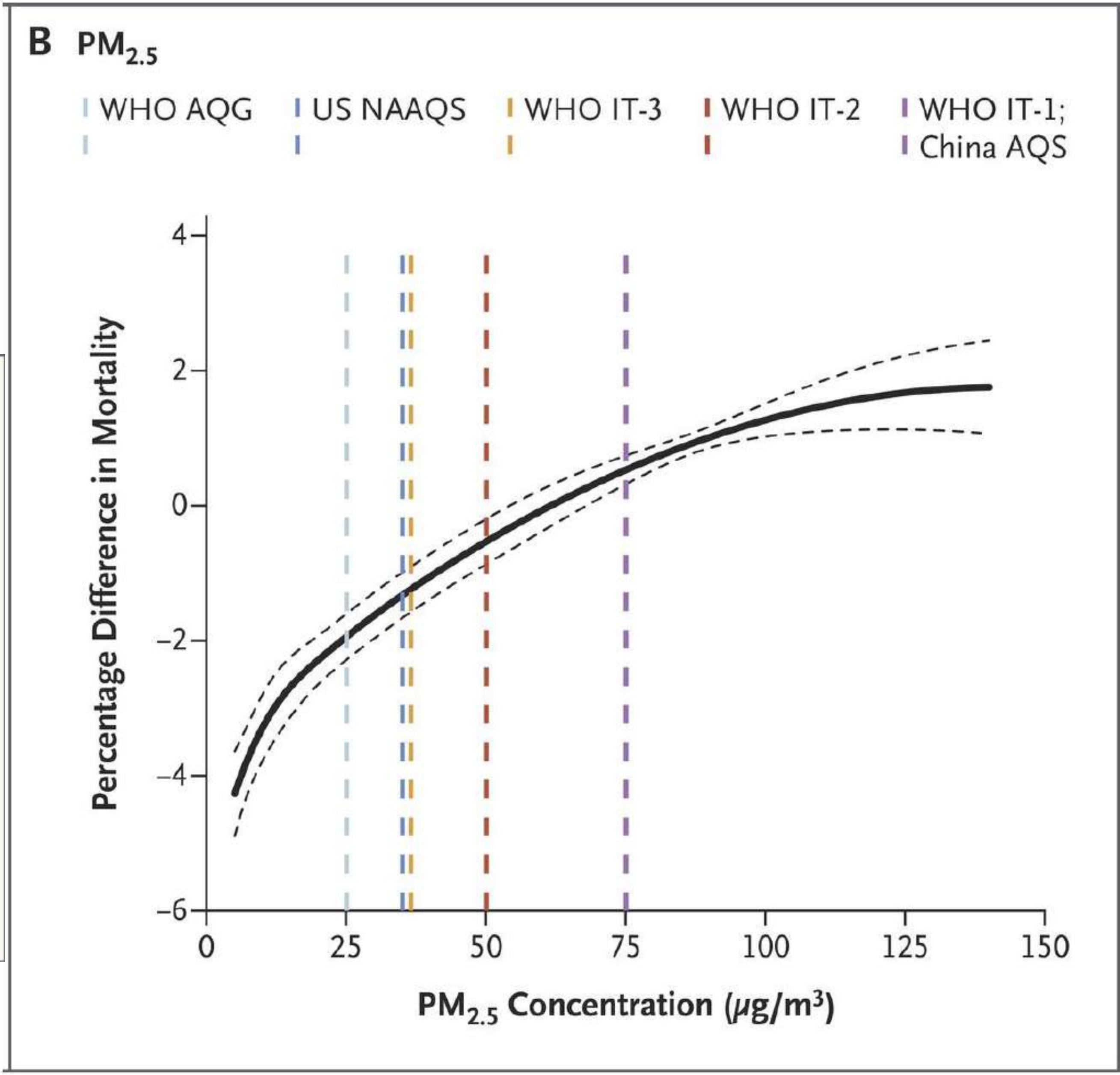
The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812 AUGUST 22, 2019 VOL. 381 NO. 8

# Ambient Particulate Air Pollution and Daily Mortality in 652 Cities

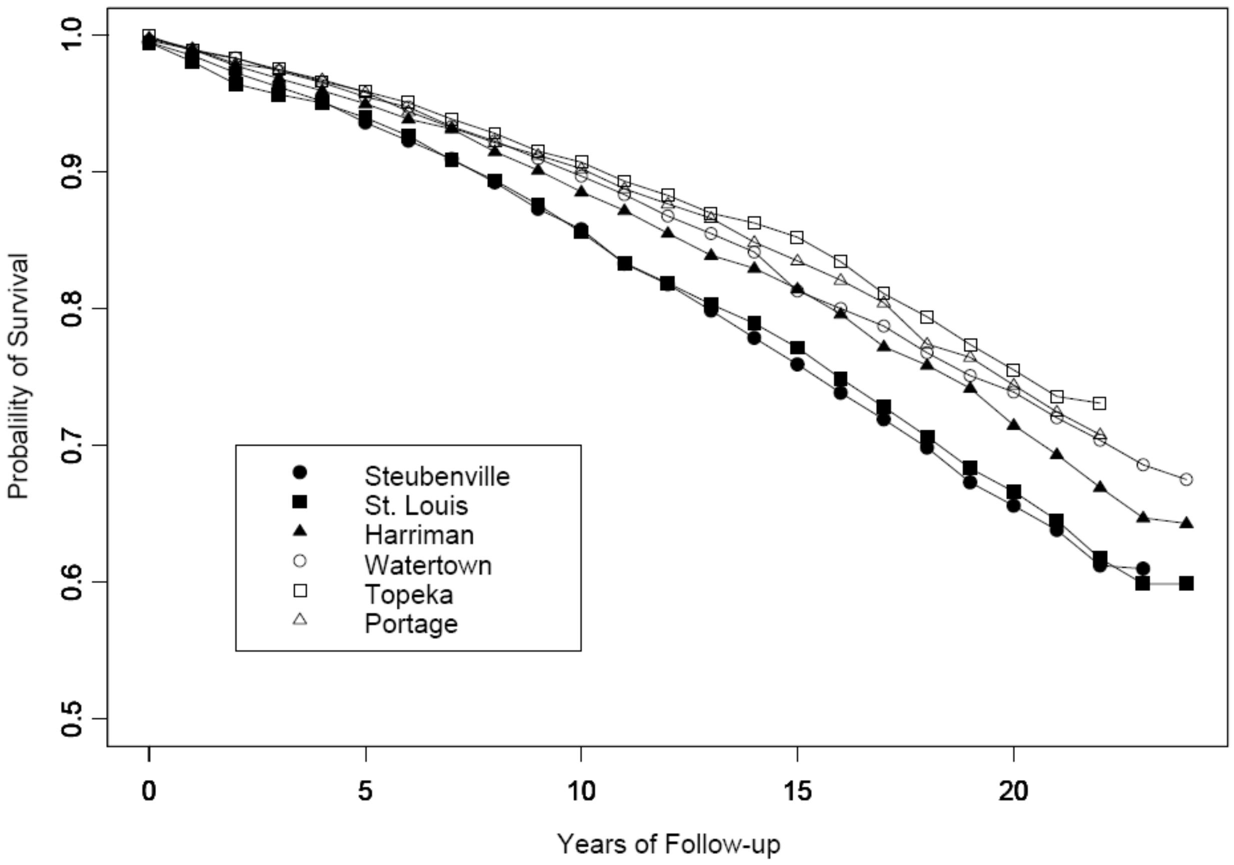
C. Liu, R. Chen, F. Sera, A.M. Vicedo-Cabrera, Y. Guo, S. Tong, M.S.Z.S. Coelho, P.H.N. Saldiva, E. Lavigne, P. Matus, N. Valdes Ortega, S. Osorio Garcia, M. Pascal, M. Stafoggia, M. Scortichini, M. Hashizume, Y. Honda, M. Hurtado-Díaz, J. Cruz, B. Nunes, J.P. Teixeira, H. Kim, A. Tobias, C. Íñiguez, 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



# Air pollution and health

- On **days** with worse air quality, more people die*
- In **more polluted cities**, people die earlier than in less polluted cities…



THE LANCET
Planetary Health



ARTICLES | VOLUME 4, ISSUE 6, E235-E245, JUNE 01, 2020

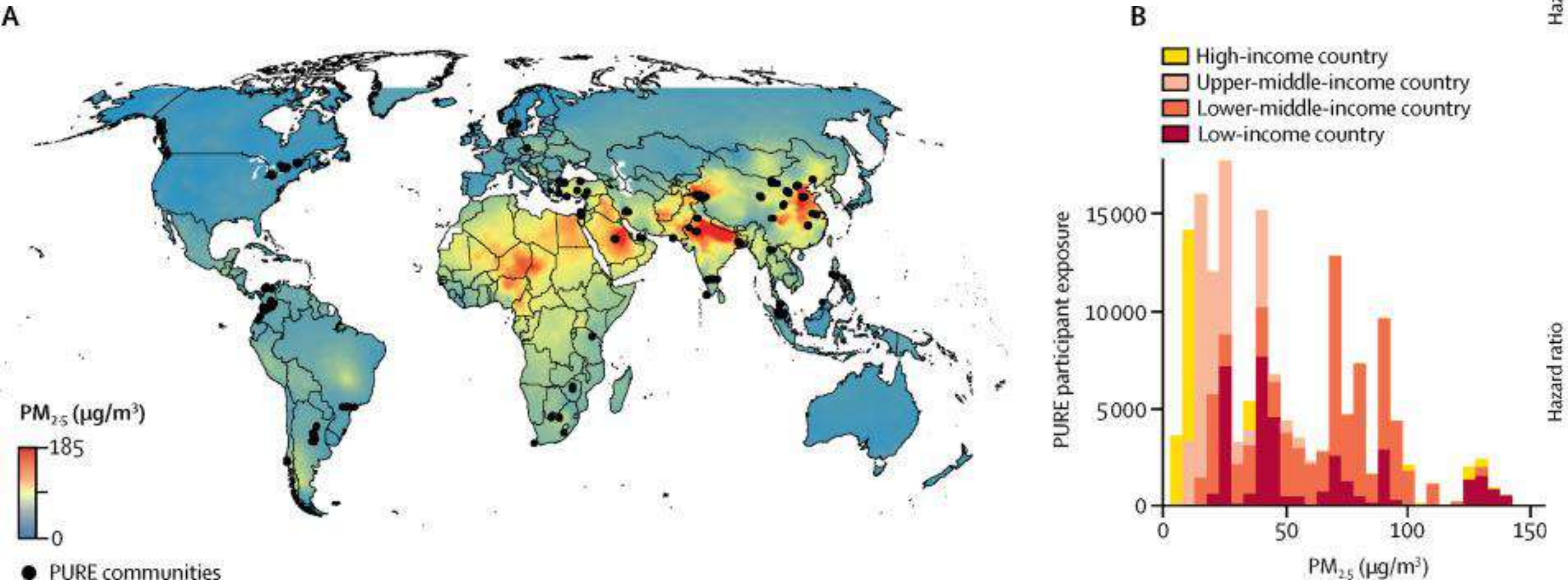


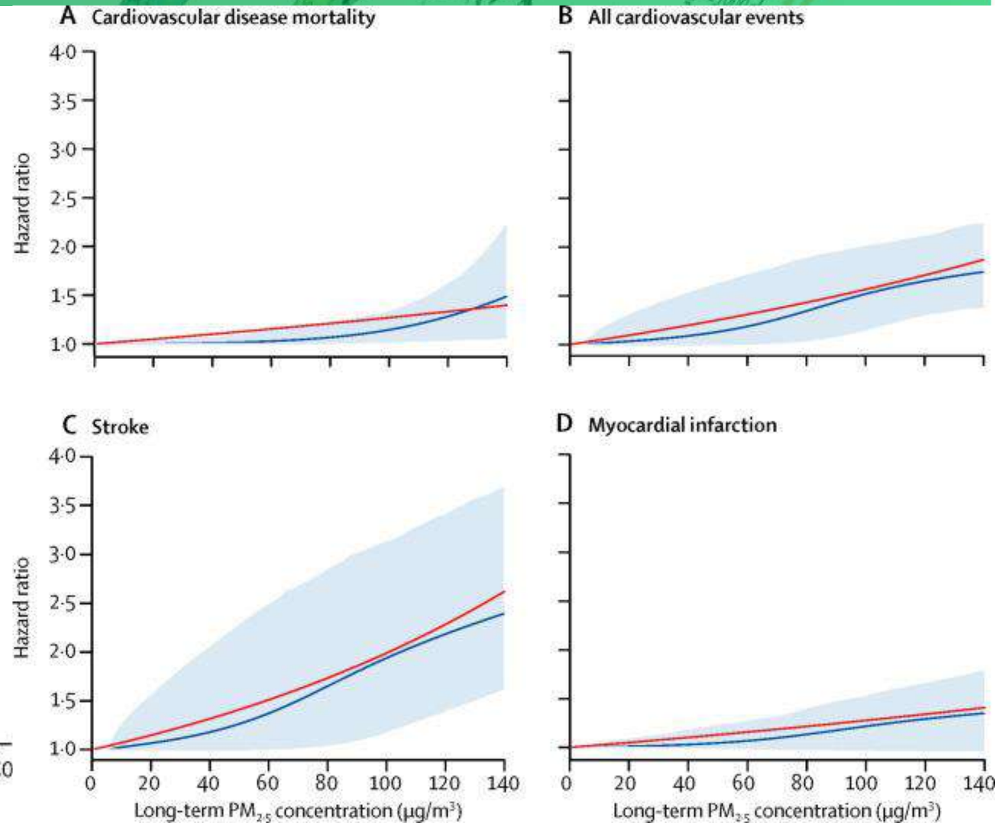
# Associations of outdoor fine particulate air pollution and cardiovascular disease in 157 436 individuals from 21 high-income, middle-income, and low-income countries (PURE): a prospective cohort study

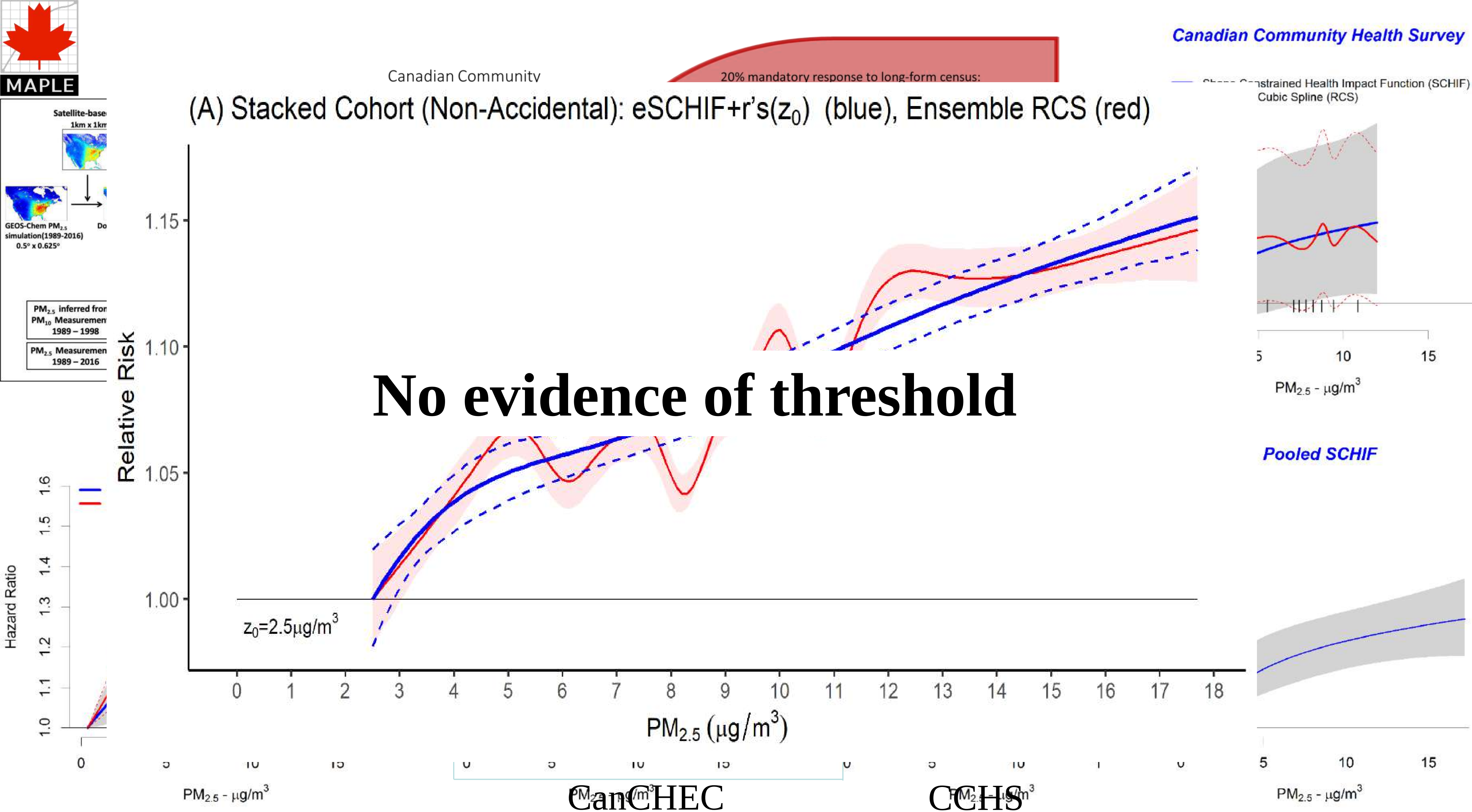
Perry Hystad, PhD • Andrew Larkin, PhD • Sumathy Rangarajan, MSc • Khalid F AlHabib, MBBS • Prof Álvaro Avezum, PhD • Kevser Burcu Tumerdem Calik, MD • et al. Show all authors

Open Access • Published: June, 2020 • DOI: https://doi.org/10.1016/S2542-5196(20)30103-0 • Check for updates





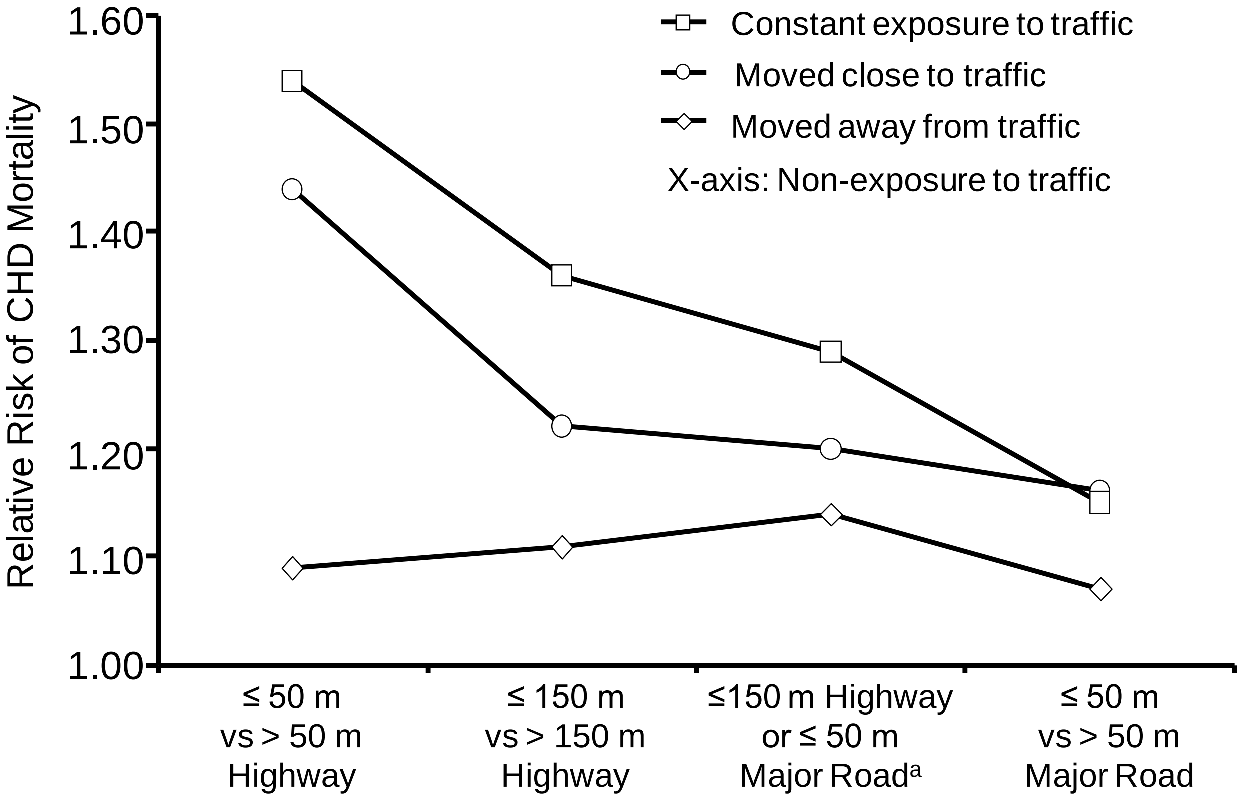





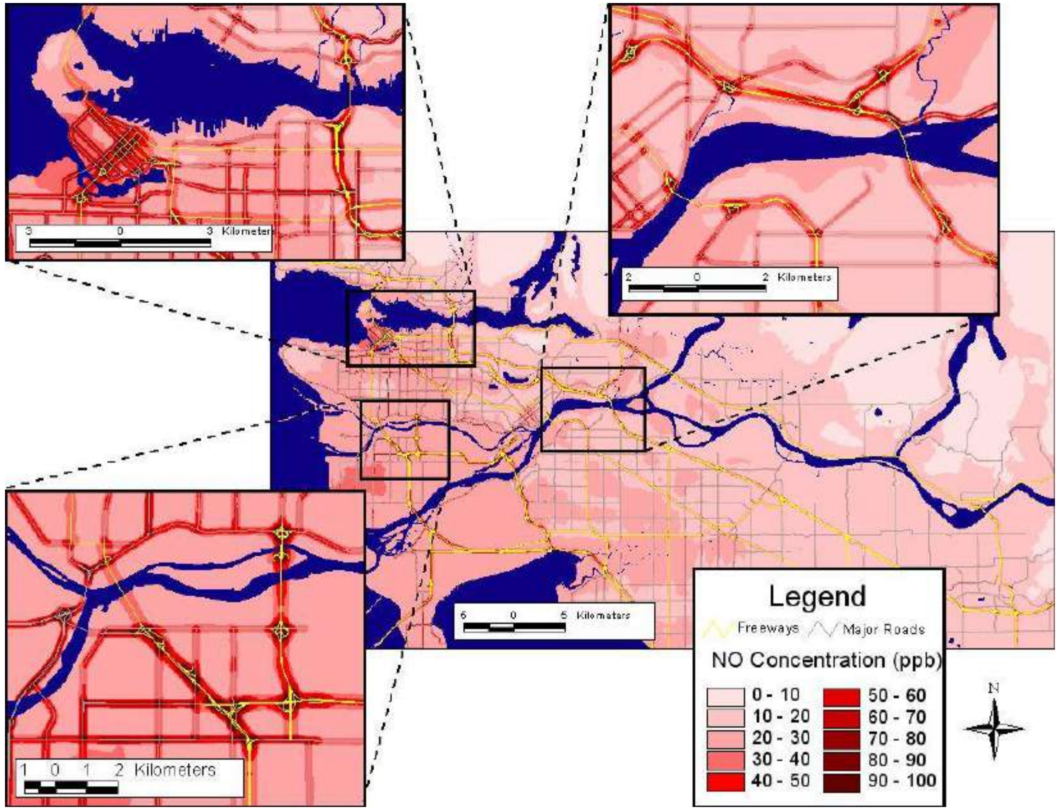

Pappin et al., 2019; Christidis et al., 2019

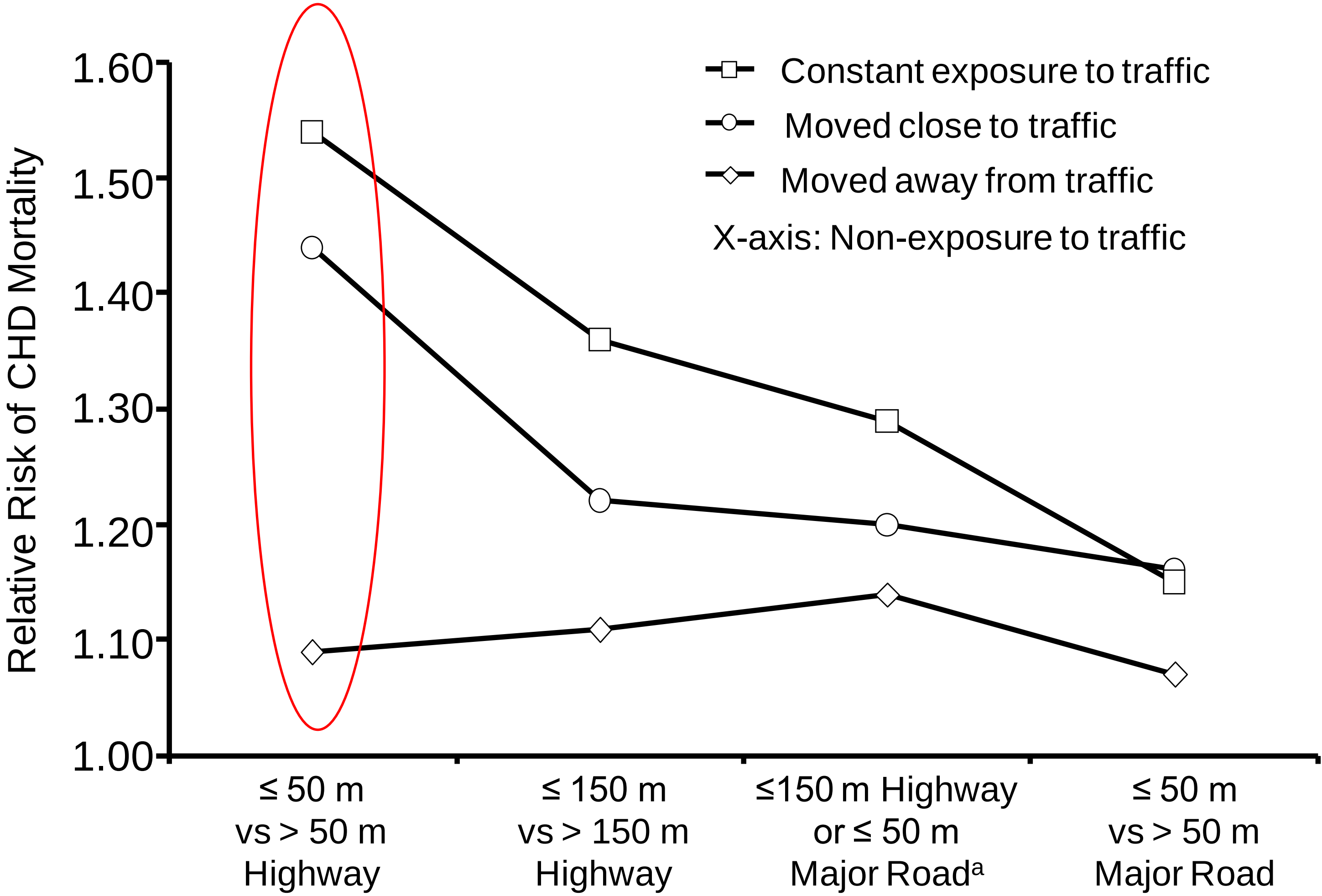
# Air pollution and health

- On **days** with worse air quality, more people die*
- In **more polluted cities**, people die earlier than in less polluted cities…
- …and, in the **most polluted areas** of cities, there is an increased risk of dying



# Traffic-related air pollution




Coronary heart disease (CHD) mortality

Henderson SB et al. Environmental Science and Technology. 2007; 41 (7):2422 -2428; Gan WQ et al. Changes in residential proximity to road traffic and the risk of death from coronary heart disease. Epidemiology. 2010 Sep;21(5):642-9.

# WHO Global Air Quality Guidelines 2021

## Setting ambitious goals for air quality to protect public health

- Released September 22, 2021

# What the AQGs provide…

Summary of recommended AQG levels and interim targets

| Pollutant | Averaging time | IT1 | IT2 | IT3 | IT4 | AQG level |
|---|---|---|---|---|---|---|
| $PM_{2.5}$, µg/m³ | Annual | 35 | 25 | 15 | *10* | **5** |
| $PM_{2.5}$, µg/m³ | 24-hour[a] | 75 | 50 | 37.5 | *25* | **15** |
| $PM_{10}$, µg/m³ | Annual | 70 | 50 | 30 | *20* | **15** |
| $PM_{10}$, µg/m³ | 24-hour[a] | 150 | 100 | 75 | *50* | **45** |
| $O_3$, µg/m³ | Peak season[b] | 100 | 70 | – | – | **60** |
| $O_3$, µg/m³ | 8-hour[a] | 160 | 120 | – | – | **100** |
| $NO_2$, µg/m³ | Annual | *40* | 30 | 20 | – | **10** |
| $NO_2$, µg/m³ | 24-hour[a] | 120 | 50 | – | – | **25** |
| $SO_2$, µg/m³ | 24-hour[a] | 125 | 50 | – | – | **40** |
| CO, mg/m³ | 24-hour[a] | 7 | – | – | – | **4** |

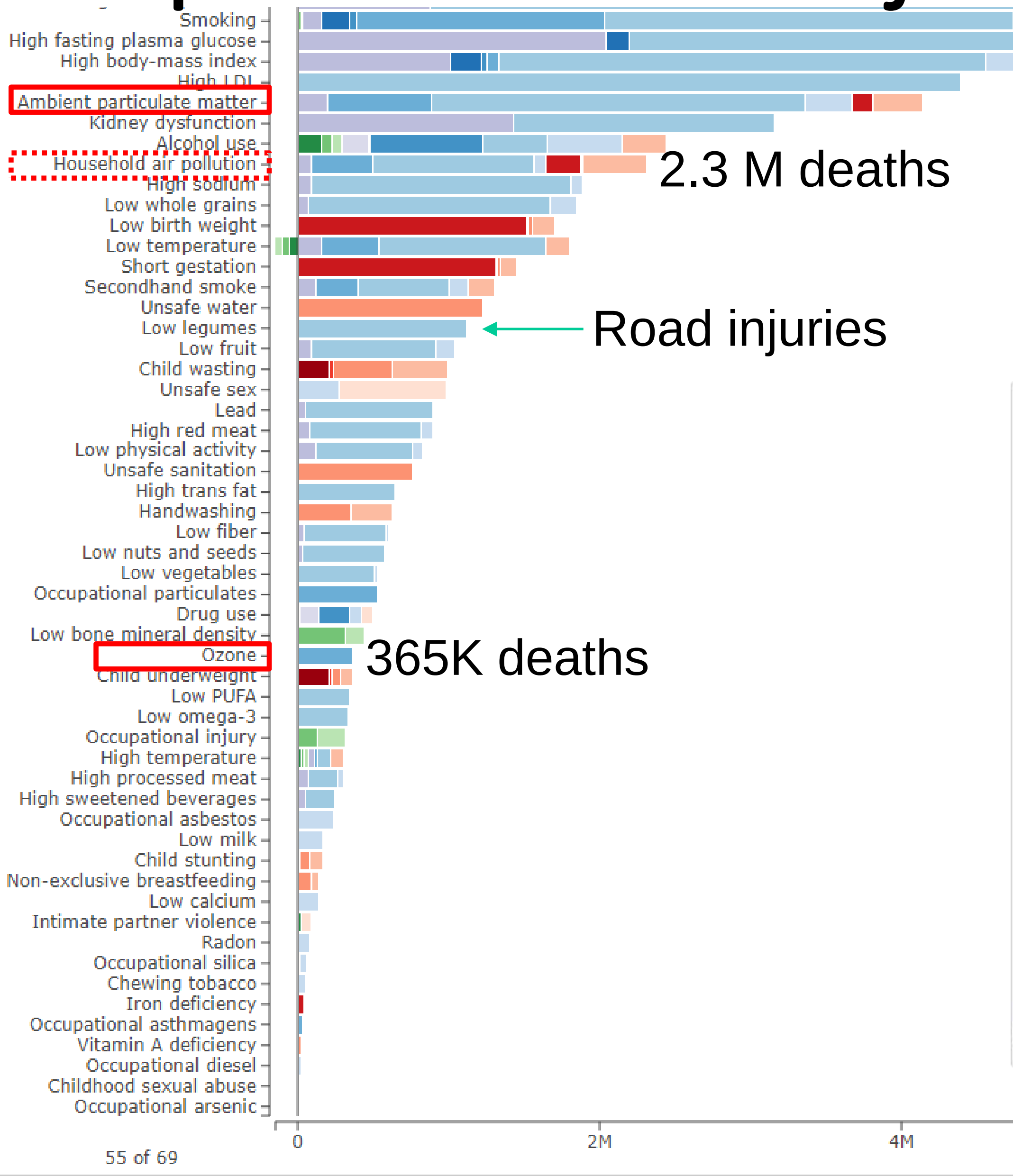
**Air quality guideline levels** for both long- and short-term exposure in relation to critical health outcomes.

**Interim targets** to guide reduction efforts for the achievement of the air quality guideline levels.

**Good practice statements** for management of **Black Carbon, Ultrafine particles, Desert Dust**: types of health-relevant PM (evidence insufficient for quantitative guideline levels

# Continuous improvement of air quality

# Air pollution is a major risk factor for global health

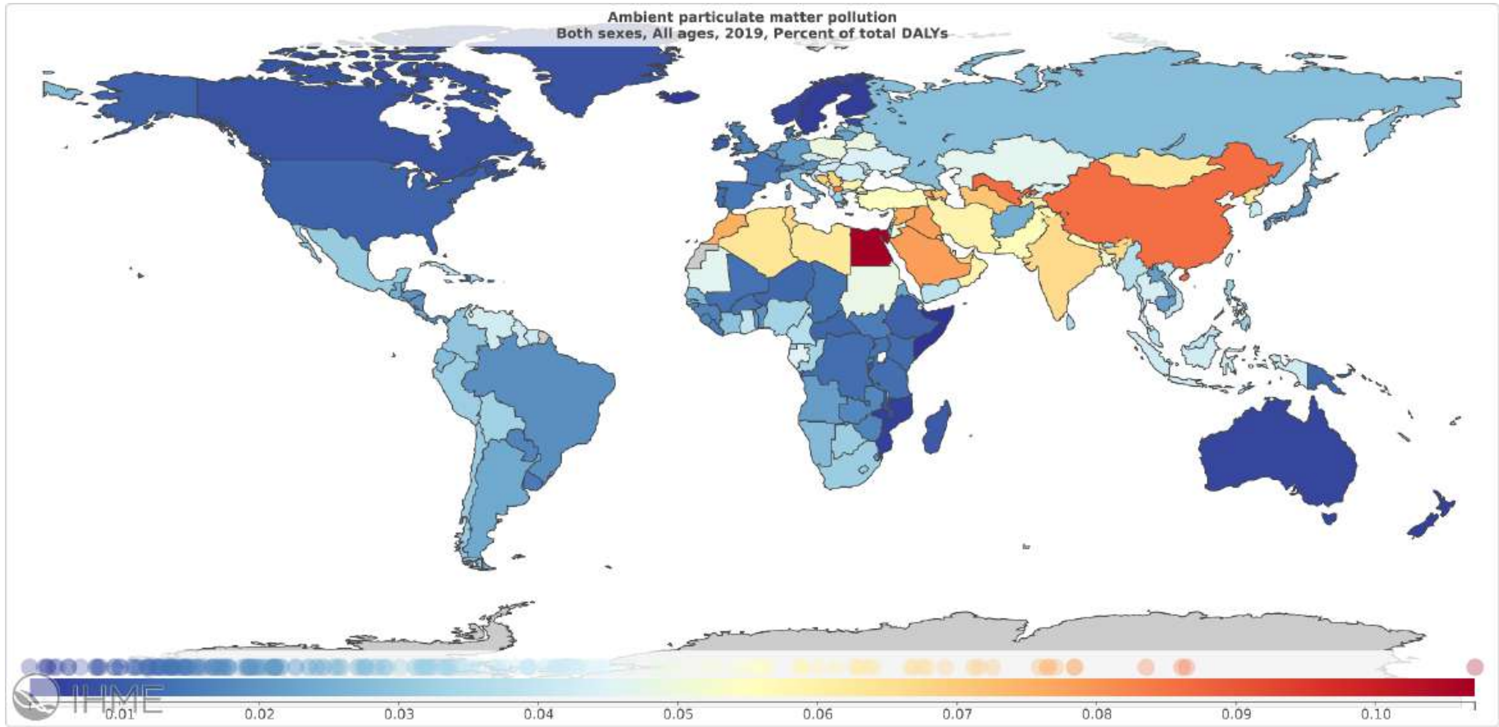



4.1 M deaths ~7% of all deaths

$5 trillion/yr welfare losses

$225 billion/yr lost labour income

` 1 year loss of life expectancy (global mean)




2019

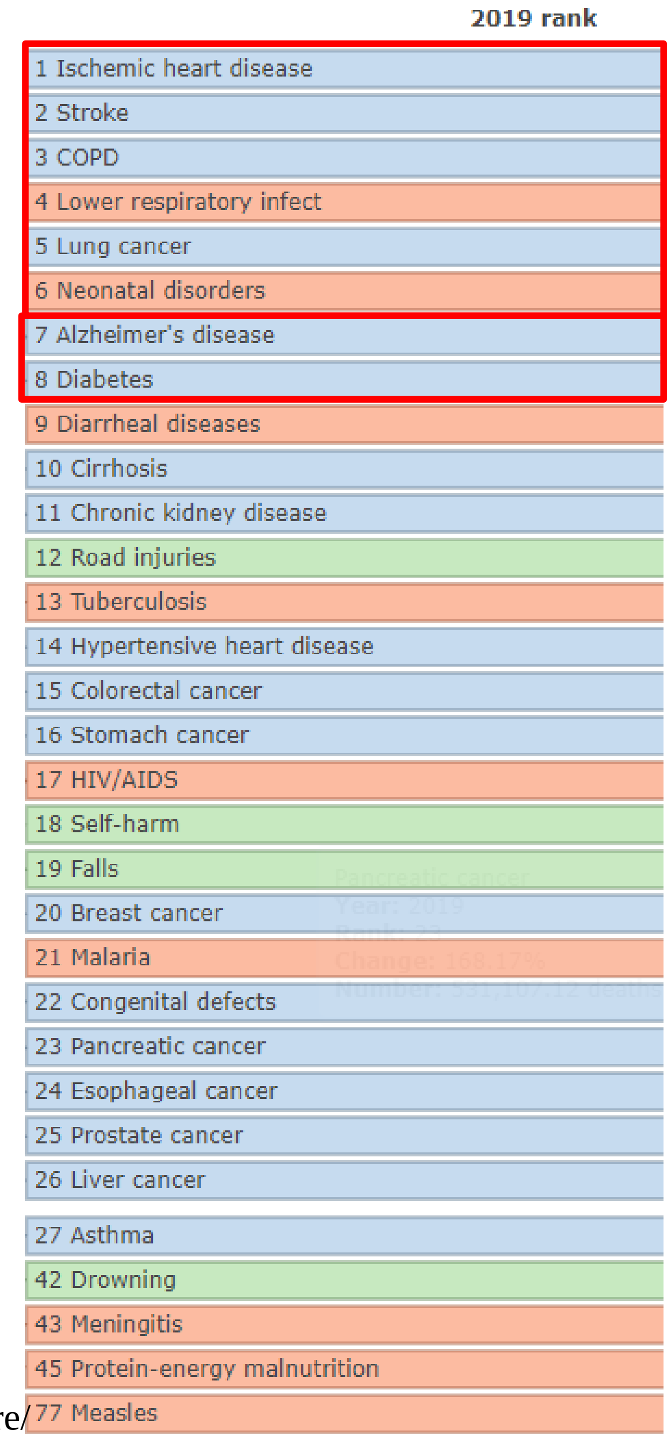
World Bank. 2016. *The cost of air pollution : strengthening the economic case for action*

# Air pollution and health

- Ambient air pollution (individual) **risk** is small…but large **exposed population = large population risk**
- Air pollution as a contributing risk factor to major diseases

# Air pollution affects the top 8 global causes of death

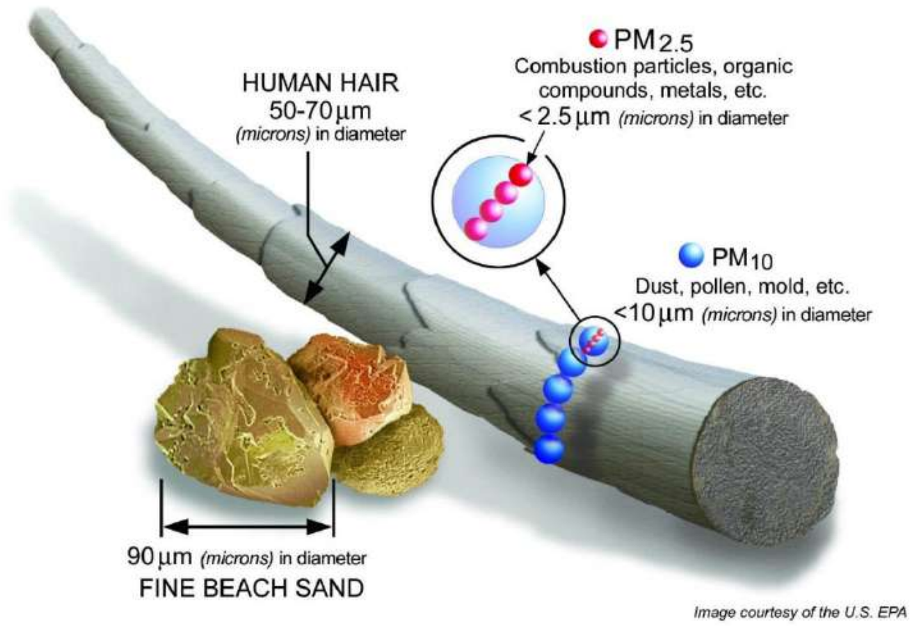
- Ischemic Heart Disease mortality/incidence: PM
- Stroke mortality/incidence: PM
- COPD mortality: PM, ozone
- ALRI mortality/incidence: PM
- Lung Cancer mortality: PM
- Low birthweight/short gestation -> neonatal
- Type 2 Diabetes mortality / incidence: PM
- **Childhood asthma: NO2; Dementia: PM**



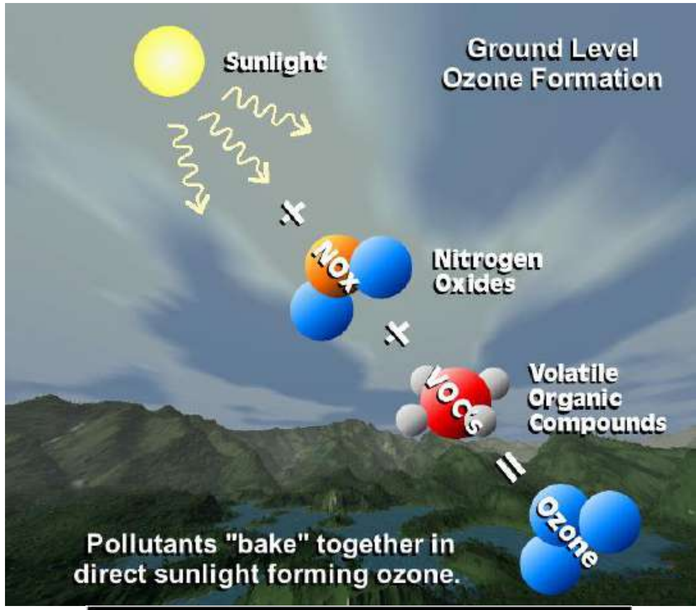

https://vizhub.healthdata.org/gbd-compare/

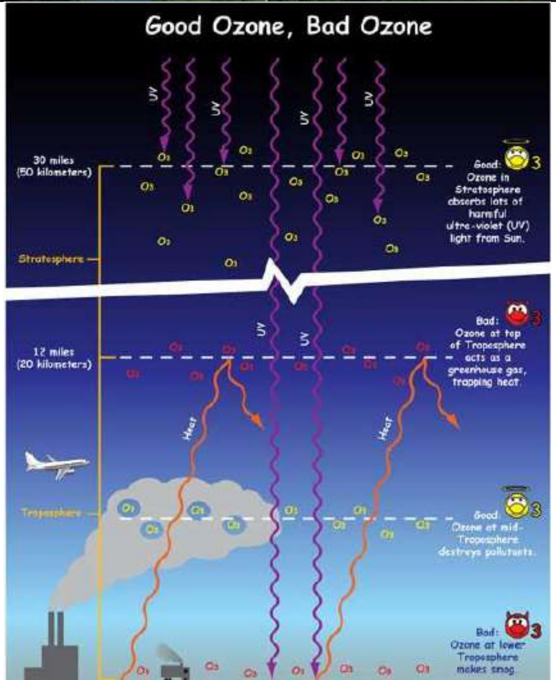
# Key pollutants for health impact

## Particulate Matter (PM)

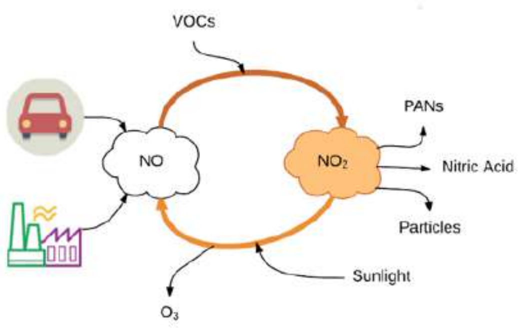



## Ozone ($O_3$)




## Nitrogen Dioxide ($NO_2$)

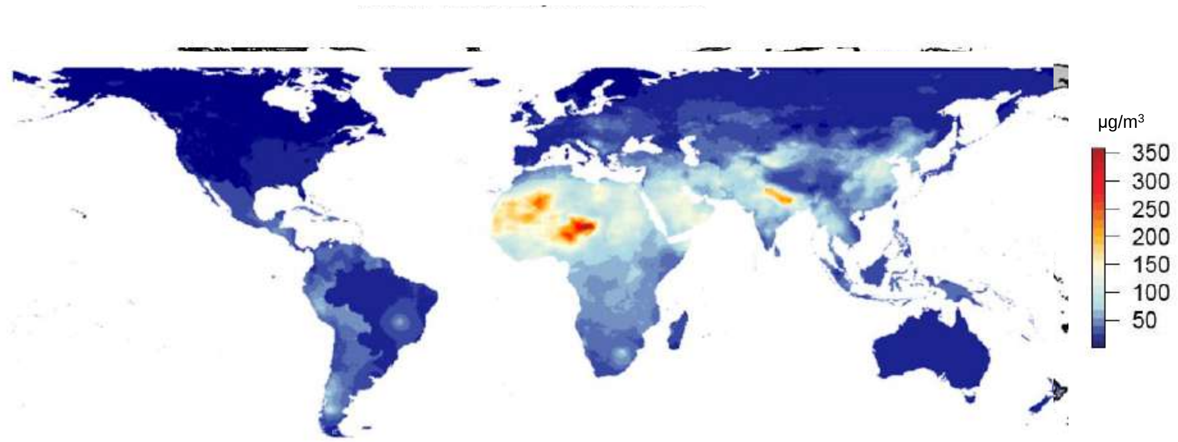



*Jorge Uzon—AFP/Getty Images*

# Combining satellite and ground monitoring to estimate exposure

$$\log(PM_{2.5st}) = \beta_{0st} + \beta_{1st}\log(SAT_s) + \beta_{3..P}X_{st} + \varepsilon_{st}$$

**Bayesian Hierarchical Model (DIMAQ2)**




**Spatially varying determinants of AOD-$PM_{2.5}$ relationship (from chemical transport model, other) + hierarchical random effects**

Ground measurements, GBD 2021
**N = 18,406 unique locations,** from 120 countries

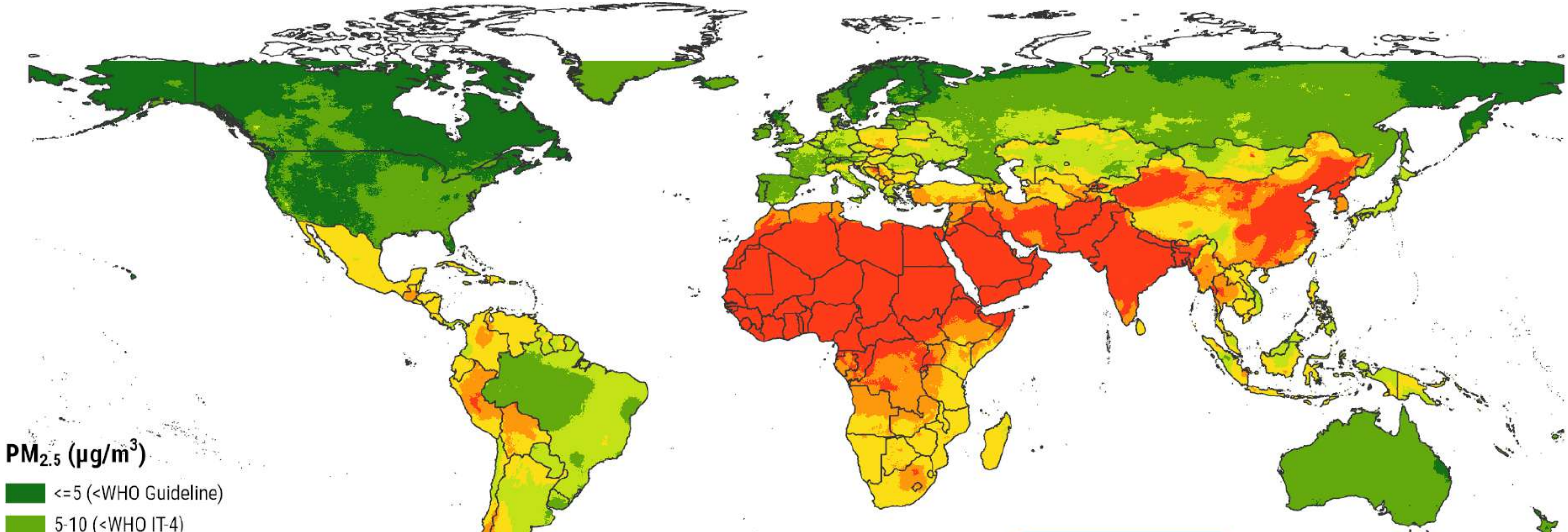
GBD 2021 evaluation:
Mean $R^2$ = 0.91 (95% UI 0.87 – 0.93)
Mean Pop-weighted RMSE = 8.5 (6.2 – 12.8) μg/m3

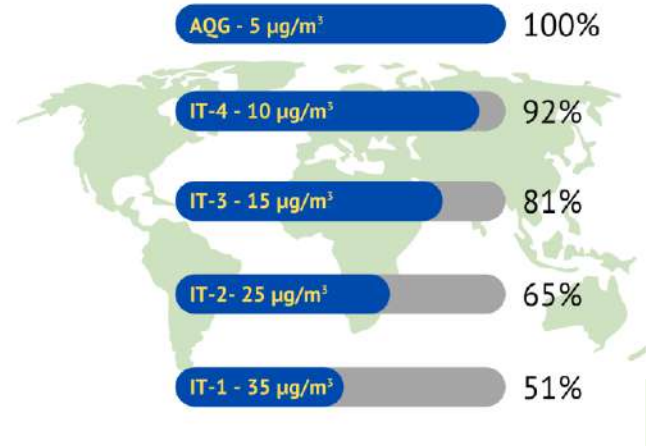
~11 x 11 km resolution (also 1 x 1 km) , annual average

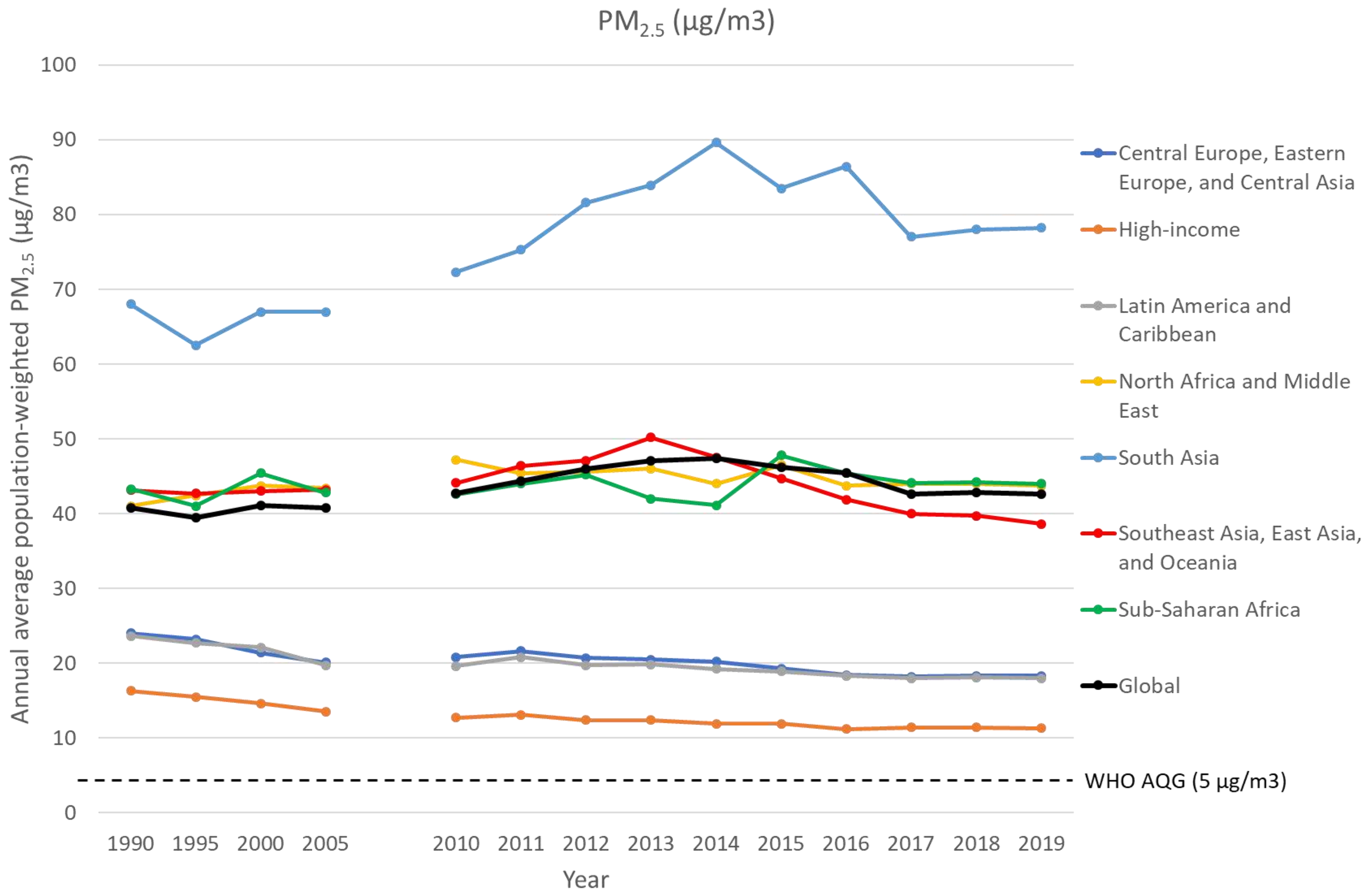
IHME GBD

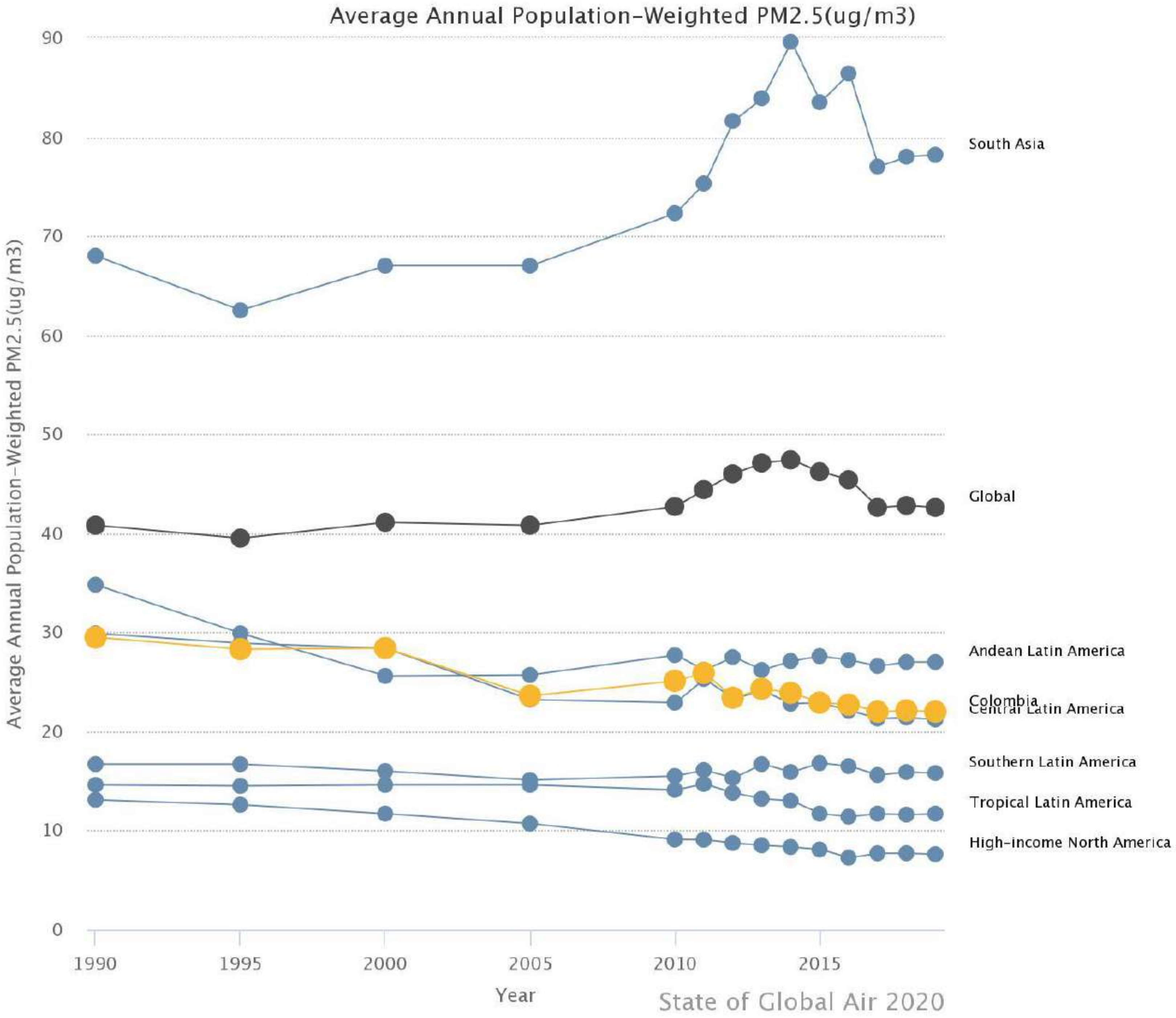
Shaddick et al. 2018. Data integration model for air quality: a hierarchical approach to the global estimation of exposures to ambient air pollution. J. R. Stat. Soc. C, 67: 231–253.
Shaddick et al. 2018. Data Integration for the Assessment of Population Exposure to Ambient Air Pollution for Global Burden of Disease Assessment. Environ Sci Technol. 2018 Aug 21;52(16):9069-9078.

# ~Entire global population lives in areas > WHO AQG

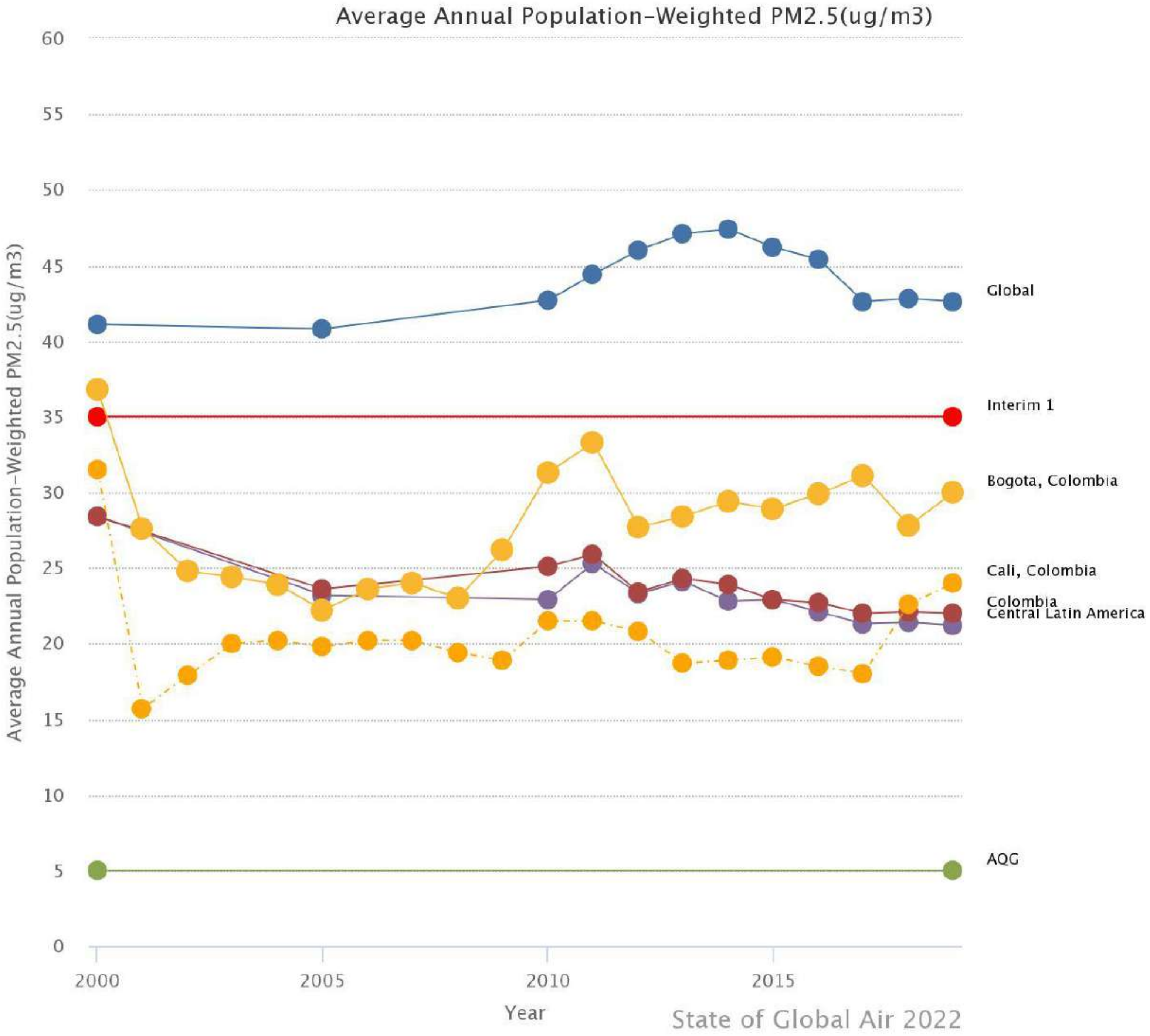


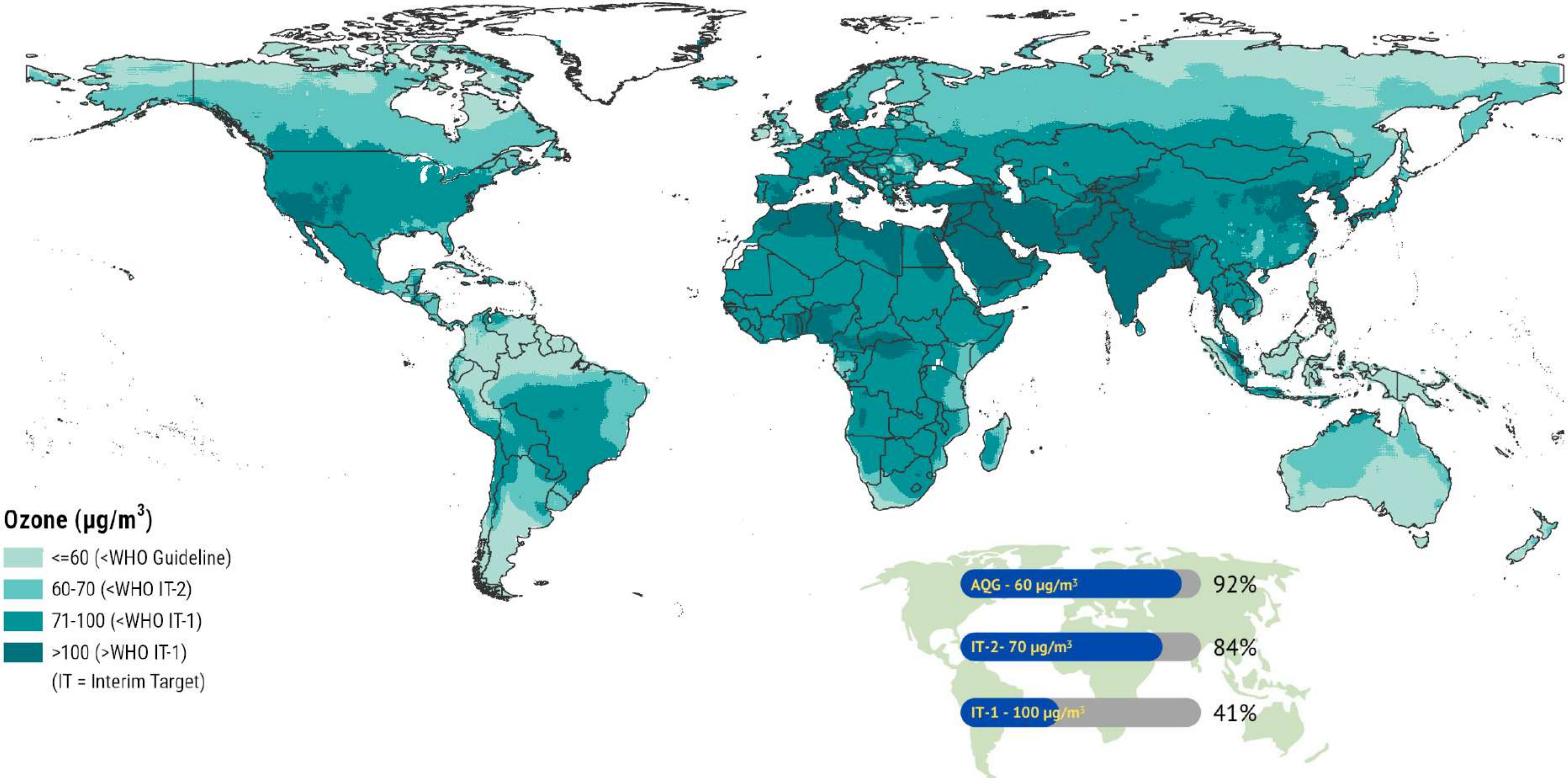

PM2.5 (µg/m3)
Annual average population-weighted PM2.5 (µg/m3)
100
90
80
70
60
50
40
30
20
10
0
1990
1995
2000
2005
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Year
Central Europe, Eastern Europe, and Central Asia
High-income
Latin America and Caribbean
North Africa and Middle East
South Asia
Southeast Asia, East Asia, and Oceania
Sub-Saharan Africa
Global
WHO AQG (5 µg/m3)

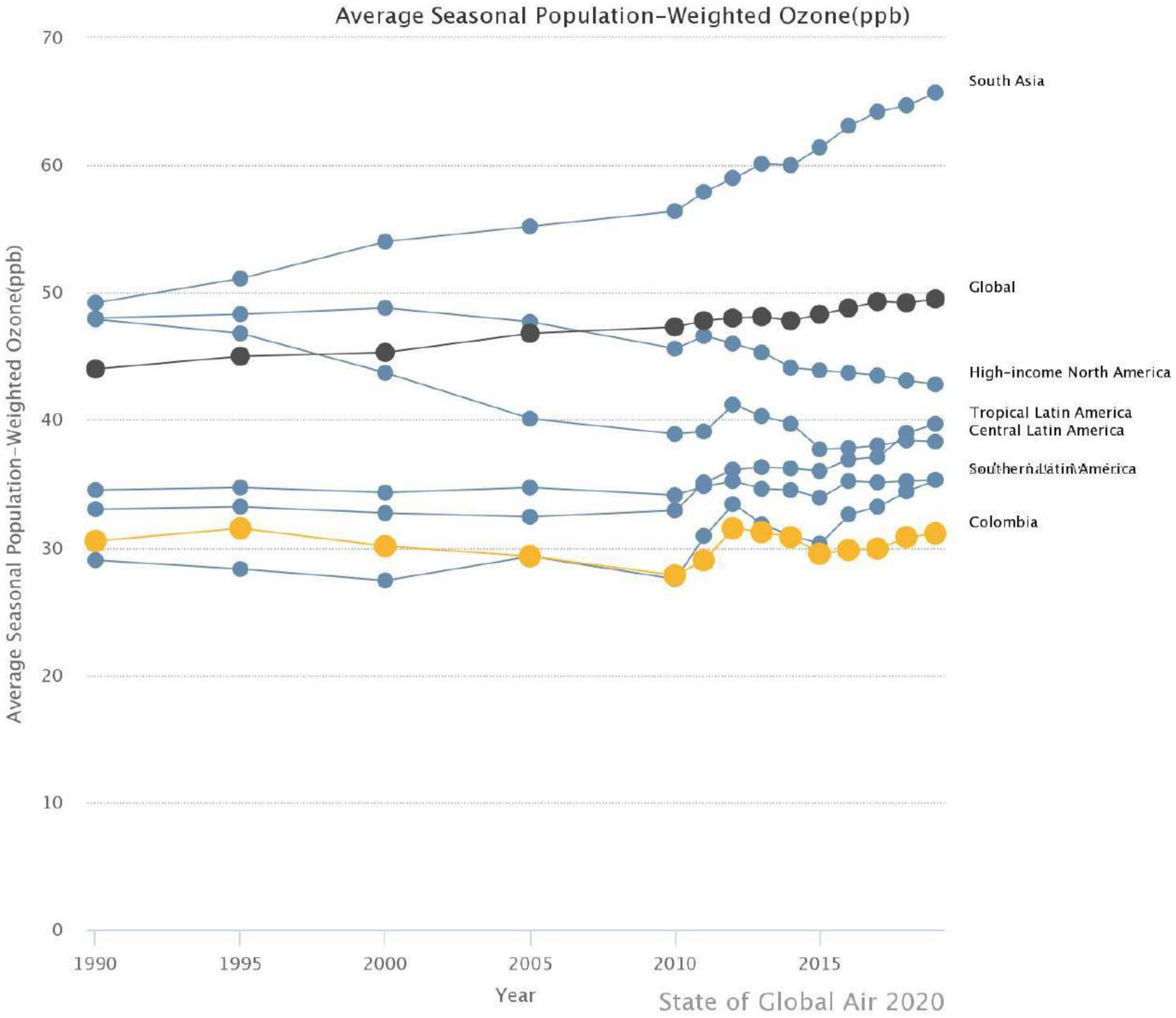


Average Annual Population-Weighted PM2.5(ug/m3)
90
80
70
60
50
40
30
20
10
0
Average Annual Population-Weighted PM2.5(ug/m3)
South Asia
Global
Andean Latin America
Colombia
Central Latin America
Southern Latin America
Tropical Latin America
High-income North America
1990
1995
2000
2005
2010
2015
Year
State of Global Air 2020

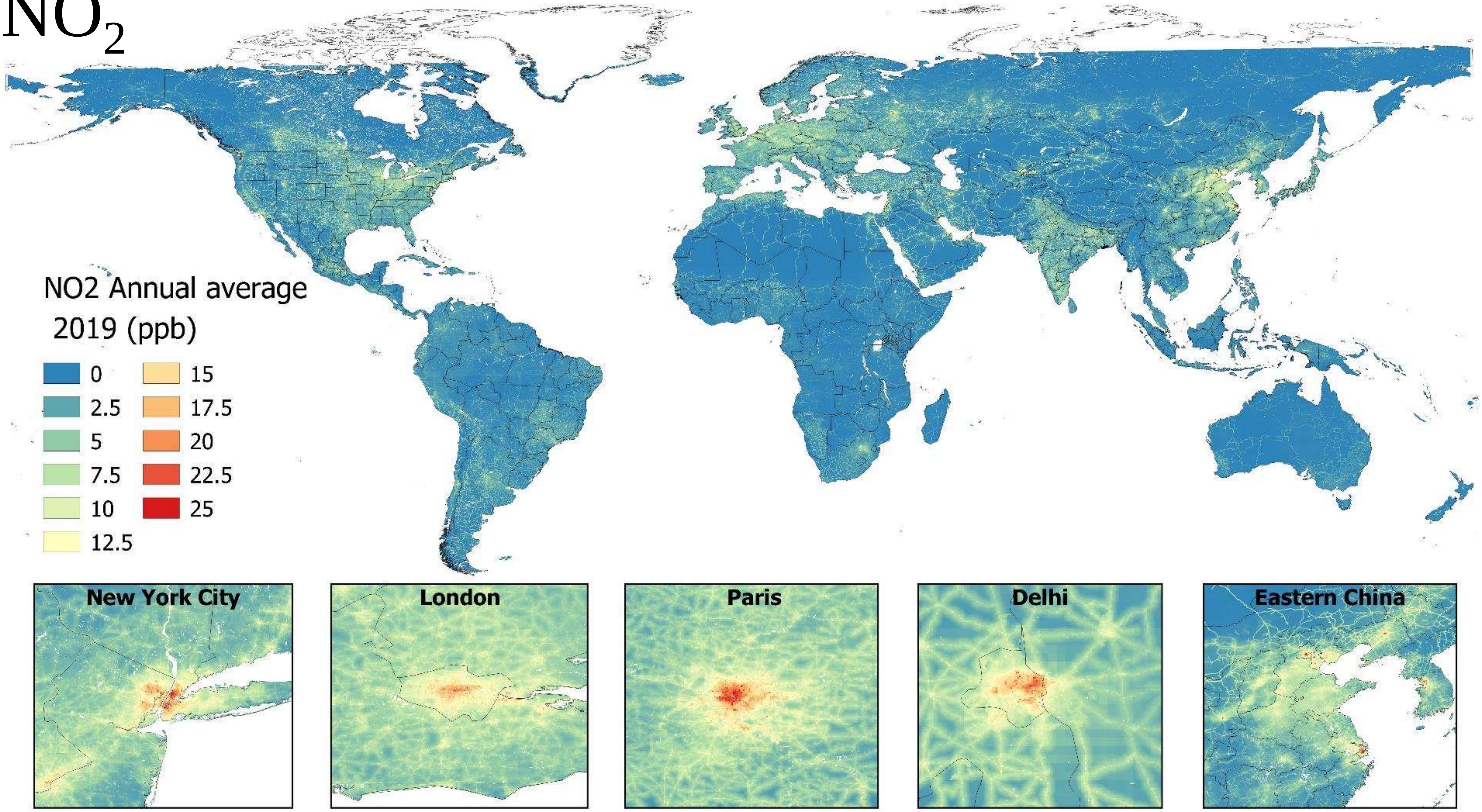


Average Annual Population-Weighted PM2.5(ug/m3)
Average Annual Population-Weighted PM2.5(ug/m3)
60
55
50
45
40
35
30
25
20
15
10
5
0
2000
2005
2010
2015
Year
Global
Interim 1
Bogota, Colombia
Cali, Colombia
Colombia
Central Latin America
AQG
State of Global Air 2022

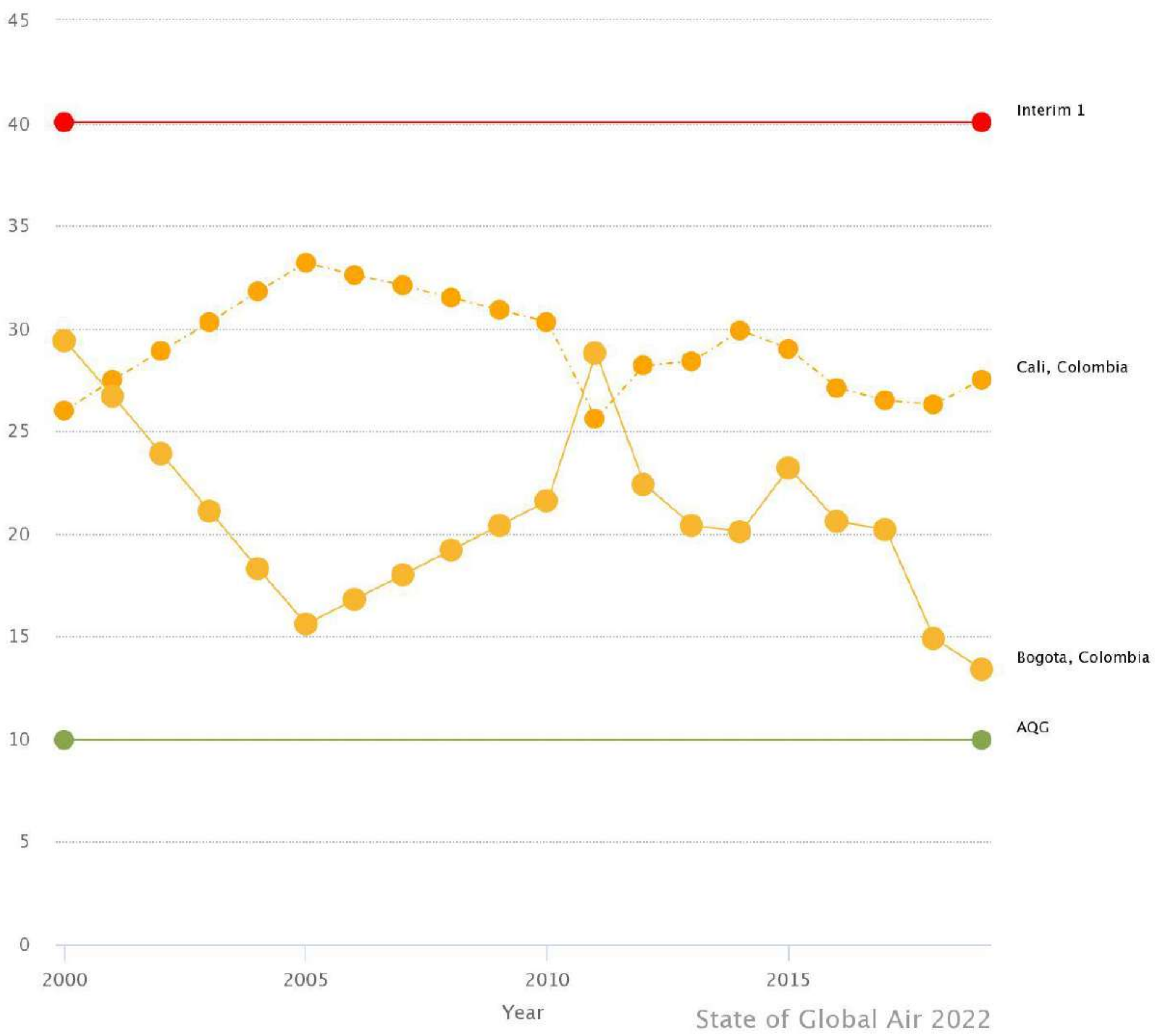

Ozone (µg/m3)
<=60 (<WHO Guideline)
60-70 (<WHO IT-2)
71-100 (<WHO IT-1)
>100 (>WHO IT-1)
(IT = Interim Target)
AQG - 60 µg/m3
92%
IT-2- 70 µg/m3
84%
IT-1 - 100 µg/m3
41%


Average Seasonal Population-Weighted Ozone(ppb)
70
60
50
40
30
20
10
0
Average Seasonal Population-Weighted Ozone(ppb)
South Asia
Global
High-income North America
Tropical Latin America
Central Latin America
Southern Latin America
Colombia
1990
1995
2000
2005
2010
2015
Year
State of Global Air 2020

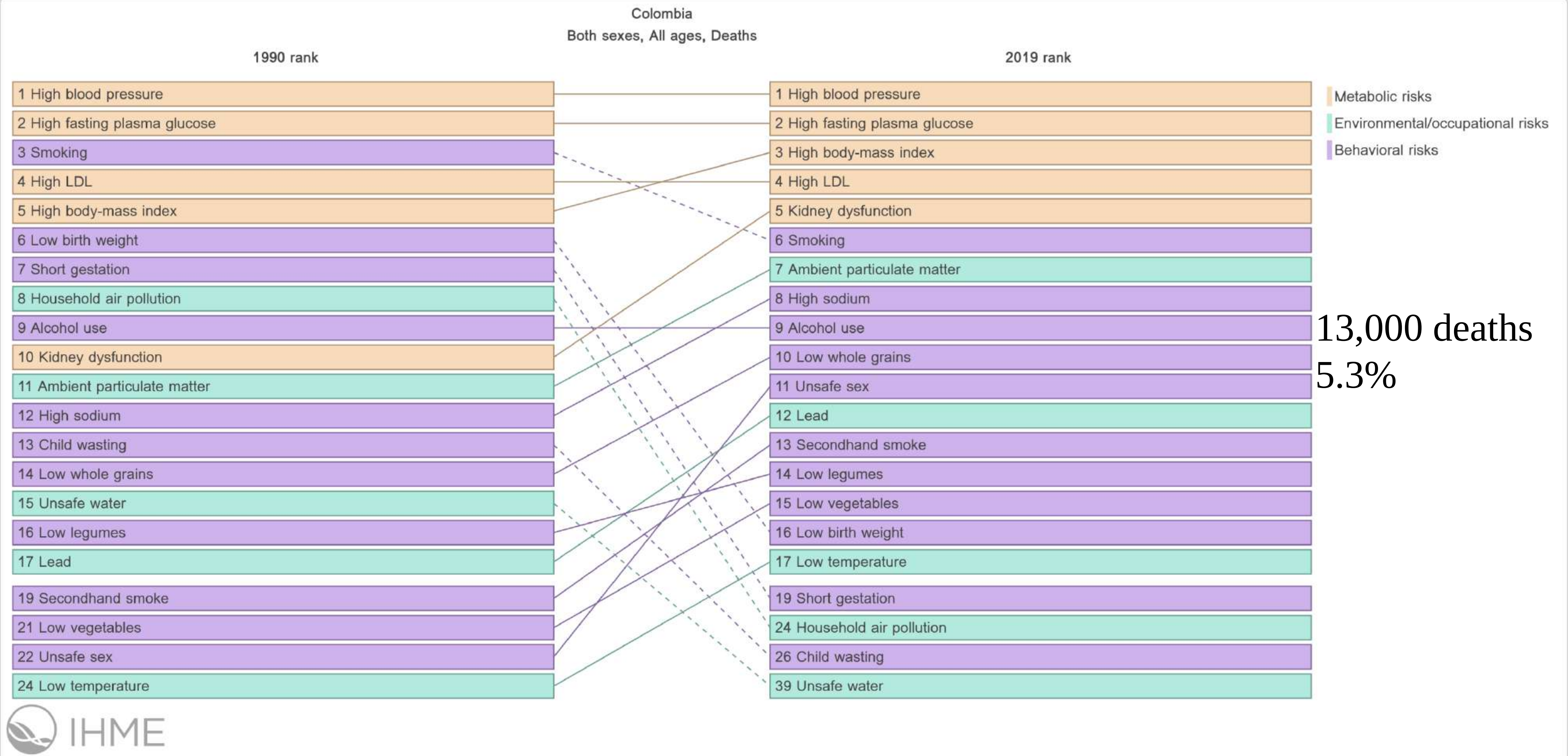
# $NO_2$


NO2 Annual average
2019 (ppb)
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
New York City
London
Paris
Delhi
Eastern China

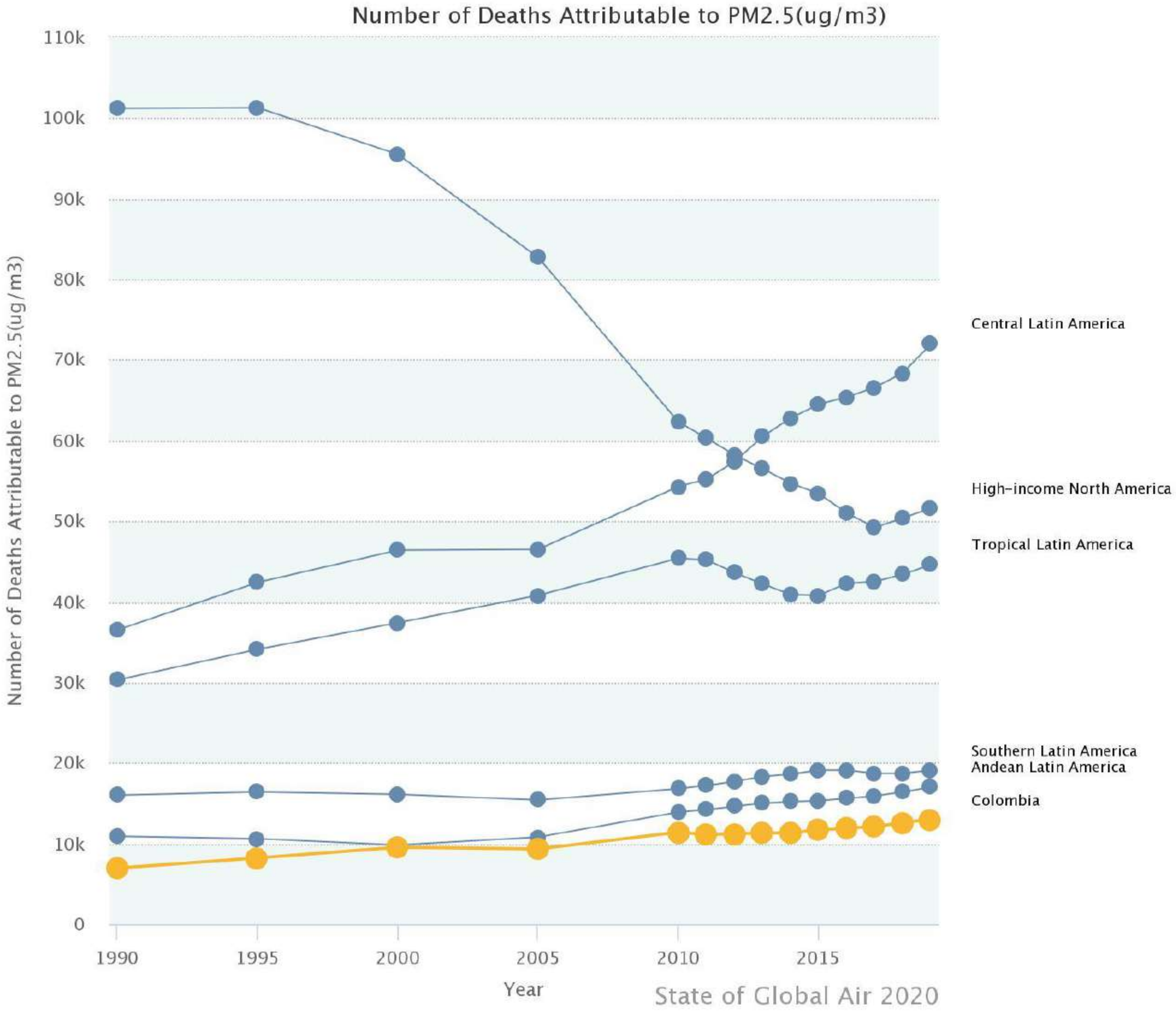
Annual mean $NO_2$ (ppb)

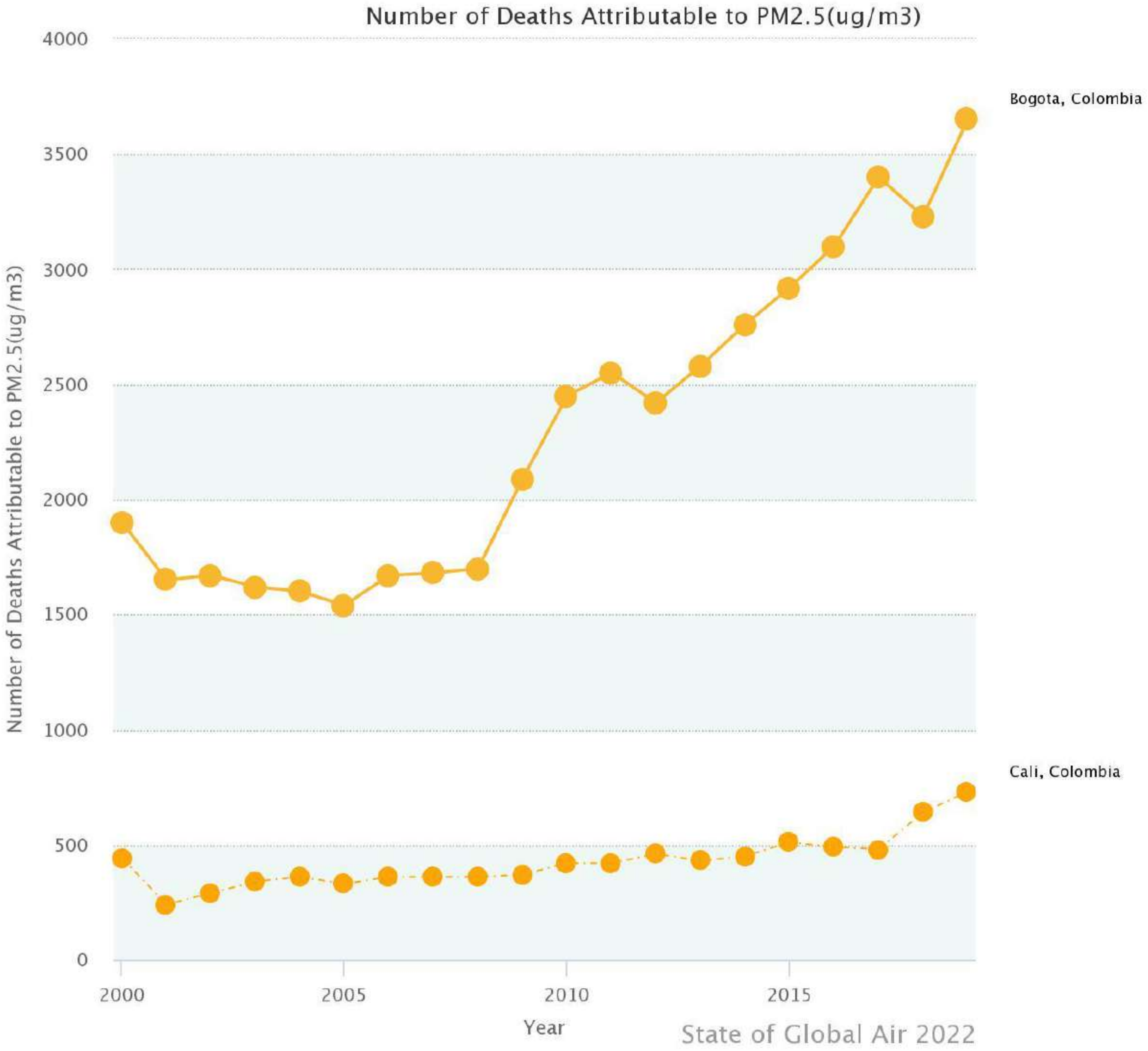


# Comparative risk assessment: Colombia

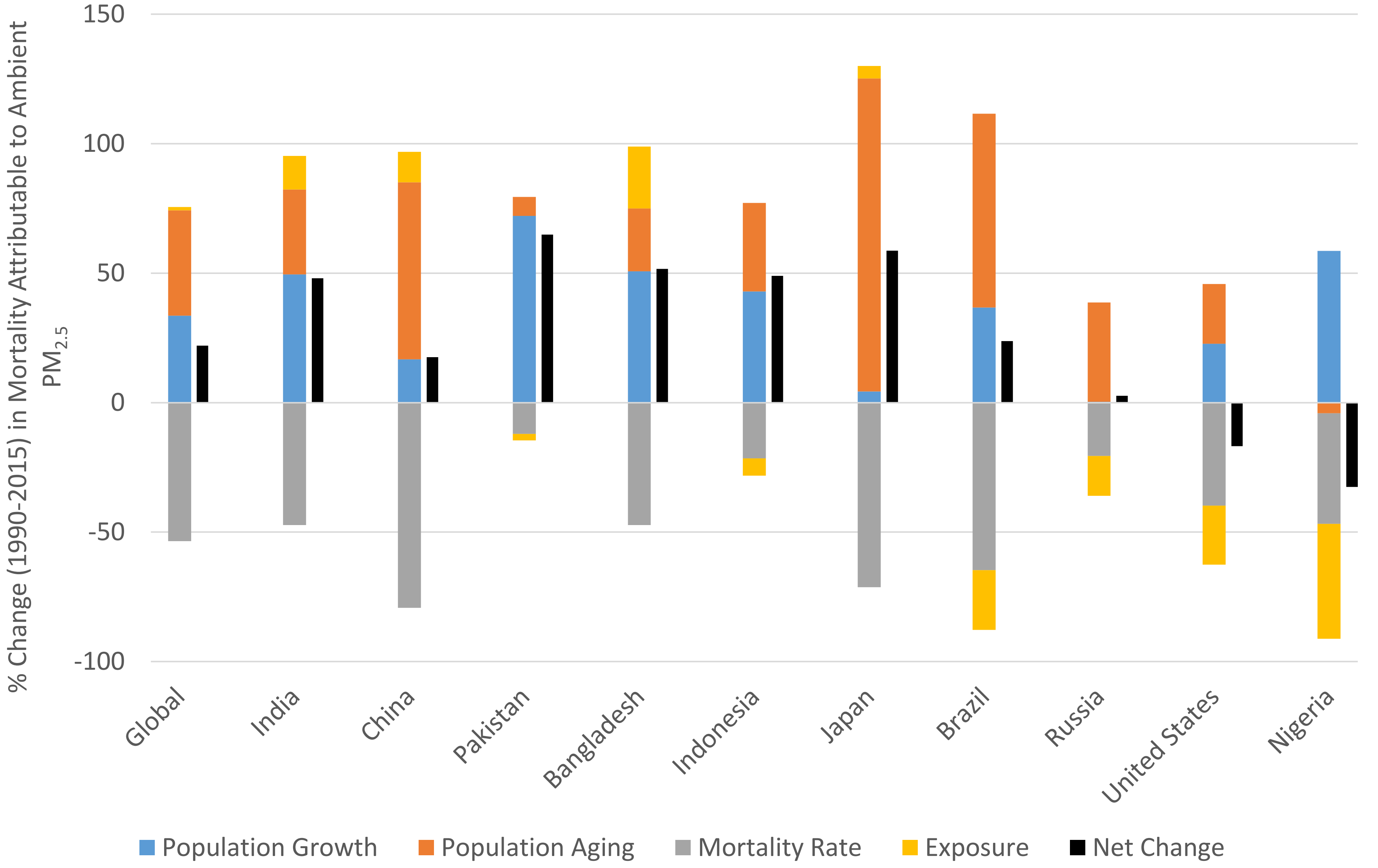



13,000 deaths
5.3%

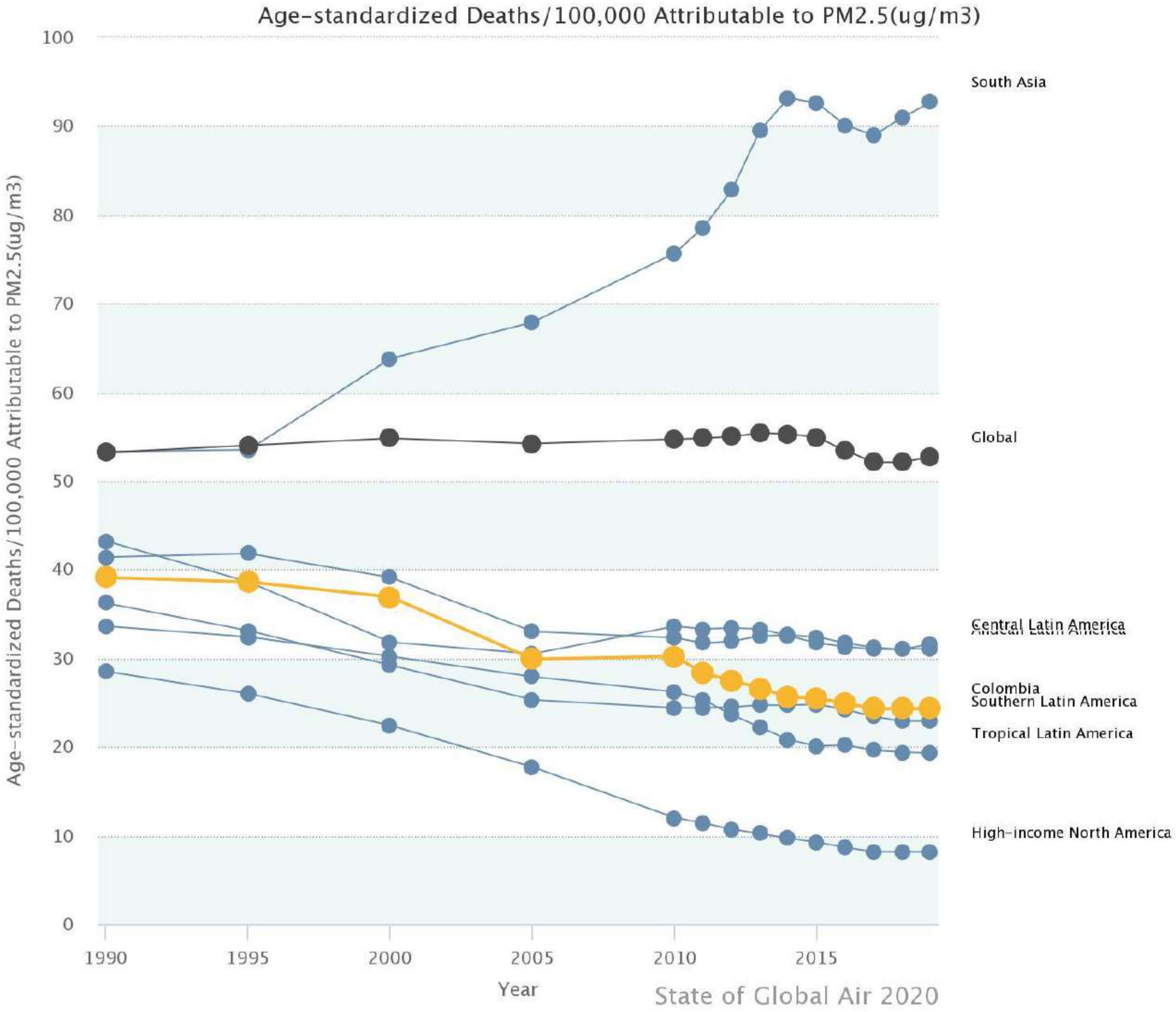

Number of Deaths Attributable to PM2.5(ug/m3)
110k
100k
90k
80k
70k
60k
50k
40k
30k
20k
10k
0
Number of Deaths Attributable to PM2.5(ug/m3)
1990
1995
2000
2005
2010
2015
Year
State of Global Air 2020
Central Latin America
High-income North America
Tropical Latin America
Southern Latin America
Andean Latin America
Colombia


Number of Deaths Attributable to PM2.5(ug/m3)
4000
3500
3000
2500
2000
1500
1000
500
0
Number of Deaths Attributable to PM2.5(ug/m3)
Bogota, Colombia
Cali, Colombia
2000
2005
2010
2015
Year
State of Global Air 2022

# Demographics plays a key role in health trends

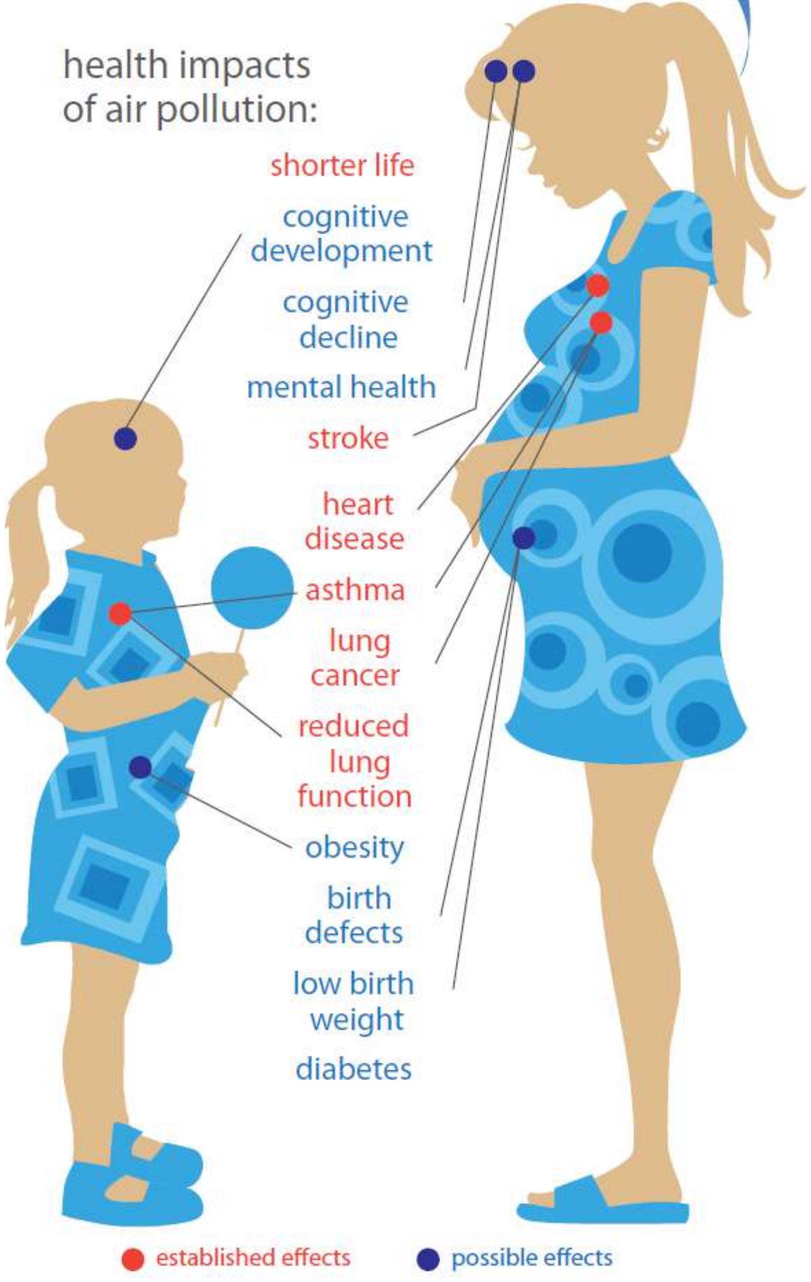



Cohen AJ, Brauer M et al. [Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015.]
Lancet. 2017 May 13;389(10082):1907-1918. doi: 10.1016/S0140-6736(17)30505-6.


Age-standardized Deaths/100,000 Attributable to PM2.5(ug/m3)
100
90
80
70
60
50
40
30
20
10
0
Age-standardized Deaths/100,000 Attributable to PM2.5(ug/m3)
1990
1995
2000
2005
2010
2015
Year
South Asia
Global
Central Latin America
Andean Latin America
Colombia
Southern Latin America
Tropical Latin America
High-income North America
State of Global Air 2020

# Emerging issues

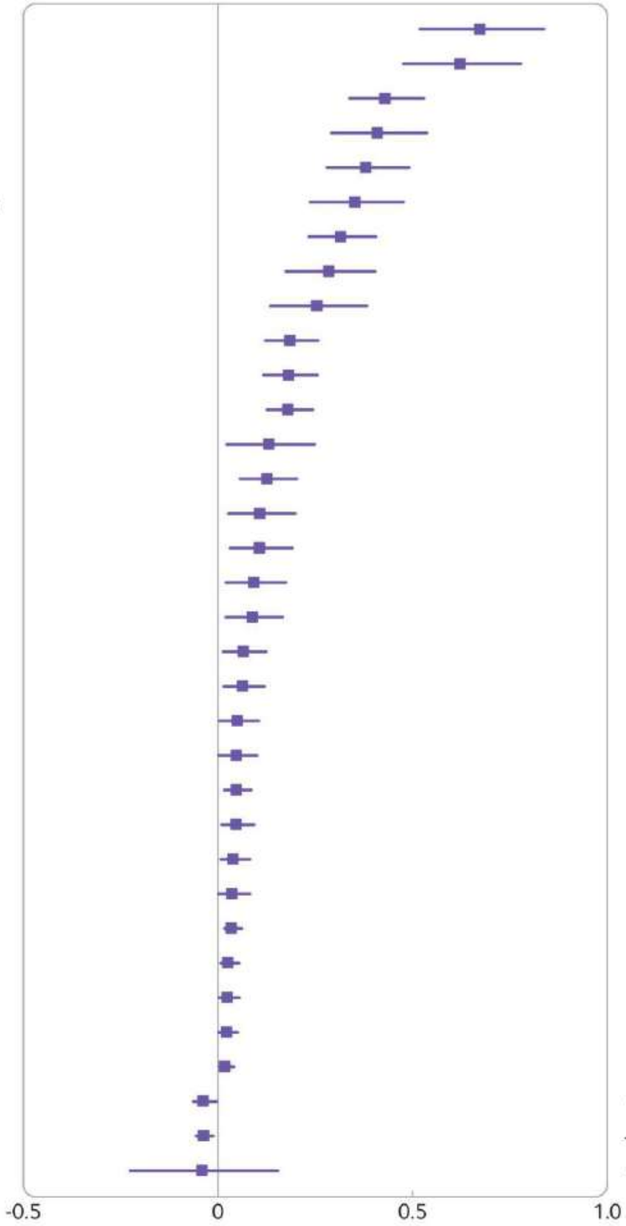
- Additional outcomes (ASD, ADHD, CKD, mental health)
- Differential impacts of sources and particle composition
- Climate change




Hystad P, Yusuf S, Brauer M. [Air pollution health impacts: the knowns and unknowns for reliable global burden calculations.](#) Cardiovasc Res. 2020 Sep 1;116(11):1794-1796.

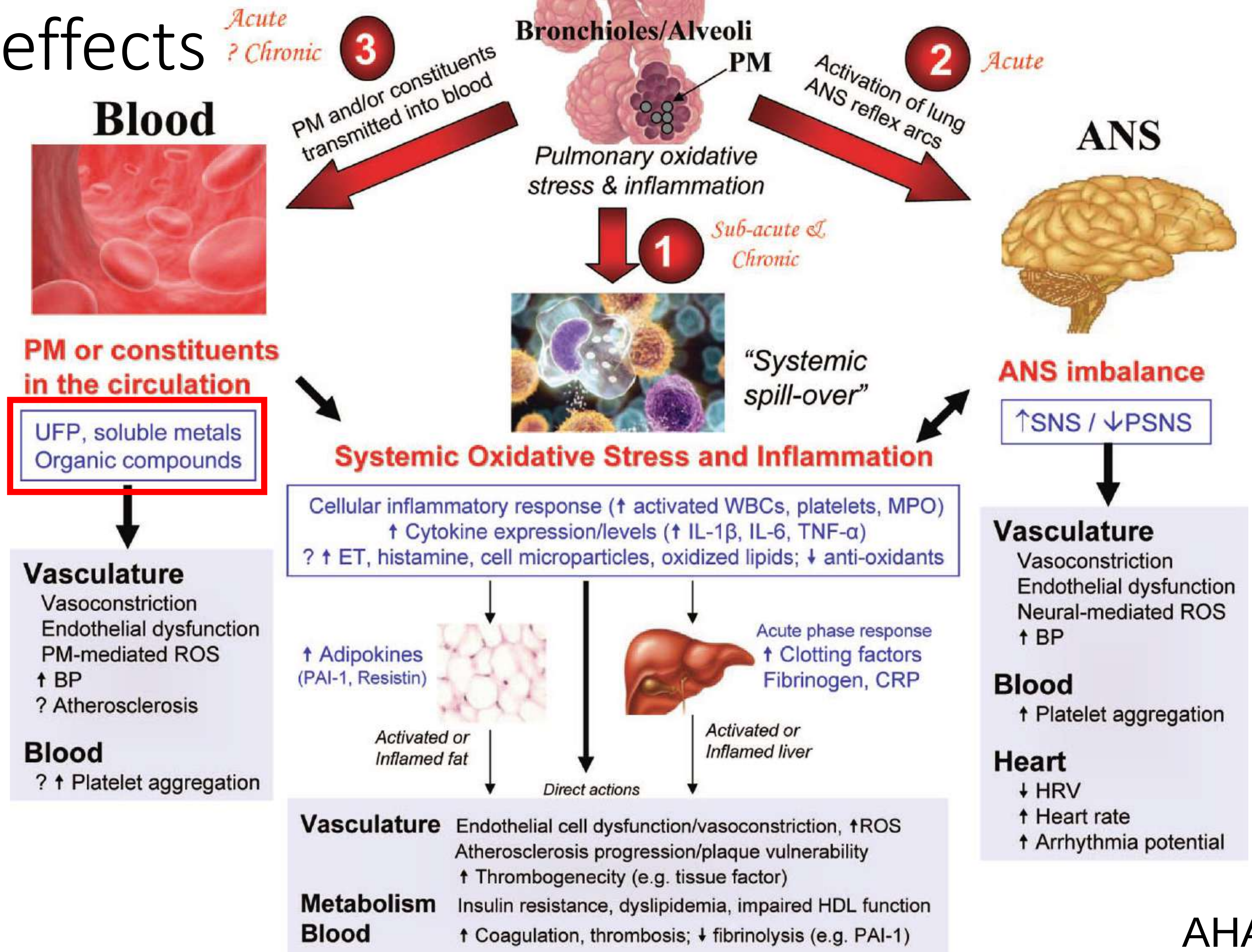
## Absolute increases in risk of hospital admission associated with each 1 μg/m3

| CCS | Disease descriptions | Absolute increase in risk of admission to hospital per 10 million person days associated with each 1 μg/m³ increase in lag 0-1 $PM_{2.5}$ |
|---|---|---|
| 108 | Congestive heart failure; non-hypertensive | 0.68 (0.52 to 0.84) |
| 122 | Pneumonia | 0.63 (0.48 to 0.78) |
| 55 | Fluid and electrolyte disorders* | 0.43 (0.34 to 0.53) |
| 2 | Septicemia* | 0.41 (0.29 to 0.54) |
| 159 | Urinary tract infections* | 0.39 (0.28 to 0.49) |
| 127 | Chronic obstructive pulmonary disease and bronchiectasis | 0.36 (0.24 to 0.48) |
| 157 | Acute and unspecified renal failure* | 0.32 (0.23 to 0.41) |
| 100 | Acute myocardial infarction | 0.29 (0.17 to 0.40) |
| 106 | Cardiac dysrhythmias | 0.26 (0.13 to 0.38) |
| 50 | Diabetes mellitus with complications | 0.19 (0.12 to 0.26) |
| 129 | Aspiration pneumonitis; food/vomitus | 0.19 (0.12 to 0.26) |
| 59 | Deficiency and other anemia | 0.18 (0.13 to 0.24) |
| 101 | Coronary atherosclerosis and other heart disease | 0.14 (0.02 to 0.25) |
| 197 | Skin and subcutaneous tissue infections* | 0.13 (0.06 to 0.20) |
| 153 | Gastrointestinal hemorrhage | 0.11 (0.03 to 0.20) |
| 131 | Respiratory failure; insufficiency; arrest | 0.11 (0.03 to 0.19) |
| 145 | Intestinal obstruction without hernia* | 0.10 (0.02 to 0.17) |
| 245 | Syncope* | 0.09 (0.02 to 0.17) |
| 135 | Intestinal infection* | 0.07 (0.01 to 0.12) |
| 117 | Other circulatory disease | 0.07 (0.02 to 0.12) |
| 118 | Phlebitis; thrombophlebitis and thromboembolism* | 0.05 (0.00 to 0.10) |
| 95 | Other nervous system disorders | 0.05 (0.00 to 0.10) |
| 151 | Other liver diseases | 0.05 (0.02 to 0.09) |
| 154 | Non-infectious gastroenteritis* | 0.05 (0.01 to 0.09) |
| 211 | Other connective tissue disease | 0.04 (0.01 to 0.08) |
| 130 | Pleurisy; pneumothorax; pulmonary collapse | 0.04 (0.00 to 0.08) |
| 134 | Other upper respiratory disease | 0.04 (0.02 to 0.06) |
| 252 | Malaise and fatigue | 0.03 (0.01 to 0.05) |
| 246 | Fever of unknown origin* | 0.03 (0.00 to 0.05) |
| 248 | Gangrene* | 0.03 (0.00 to 0.05) |
| 79 | Parkinson's disease | 0.02 (0.00 to 0.04) |
| 115 | Aortic; peripheral; and visceral artery aneurysms | -0.03 (-0.06 to 0.00) |
| 123 | Influenza | -0.03 (-0.06 to -0.01) |
| | Negative outcome control: injury and poisoning | -0.04 (-0.23 to 0.15) |




Yaguang Wei et al. BMJ 2019;367:bmj.l6258

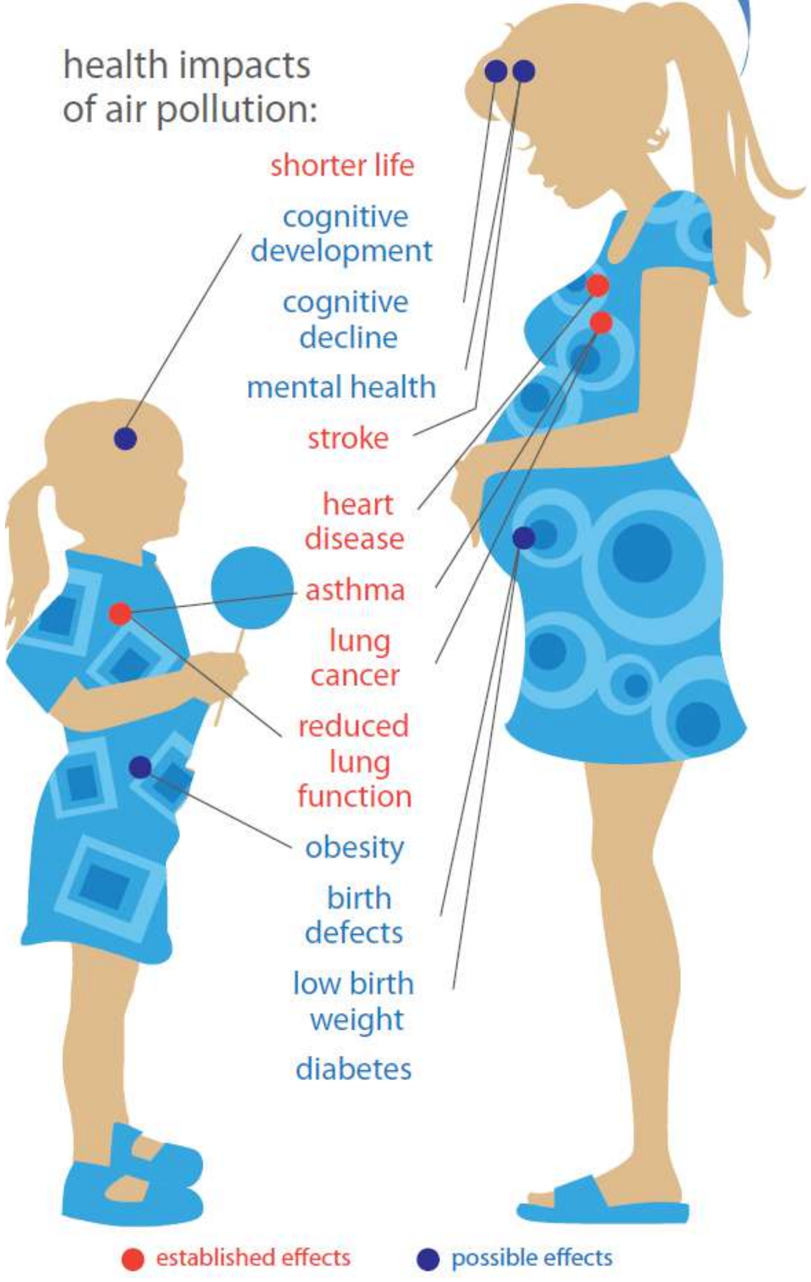
# Systemic effects




AHA, 2010

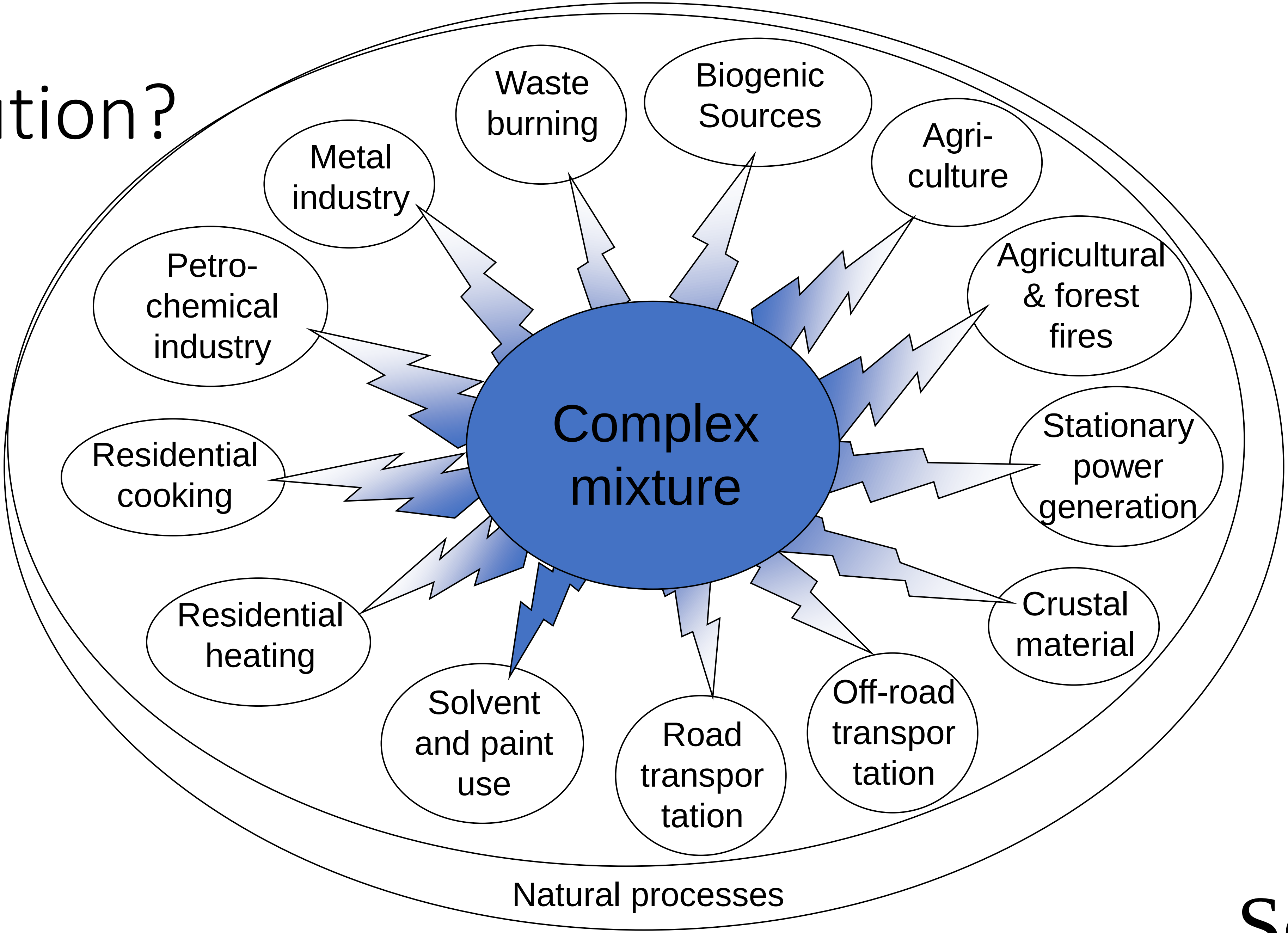
# Emerging issues

- Additional outcomes (ASD, CKD, mental health)
- Differential impacts of sources and particle composition?




Hystad P, Yusuf S, Brauer M. Air pollution health impacts: the knowns and unknowns for reliable global burden calculations. Cardiovasc Res. 2020 Sep 1;116(11):1794-1796.

# What is
# air pollution?




## Sources

# Global Burden of Disease – Major Air Pollution Sources (GBD-MAPS) Project

**Goal**: Identify major sources of global $PM_{2.5}$ pollution & quantify attributable disease burden

1 **CEDS Emissions**

+

2 GEOS-Chem

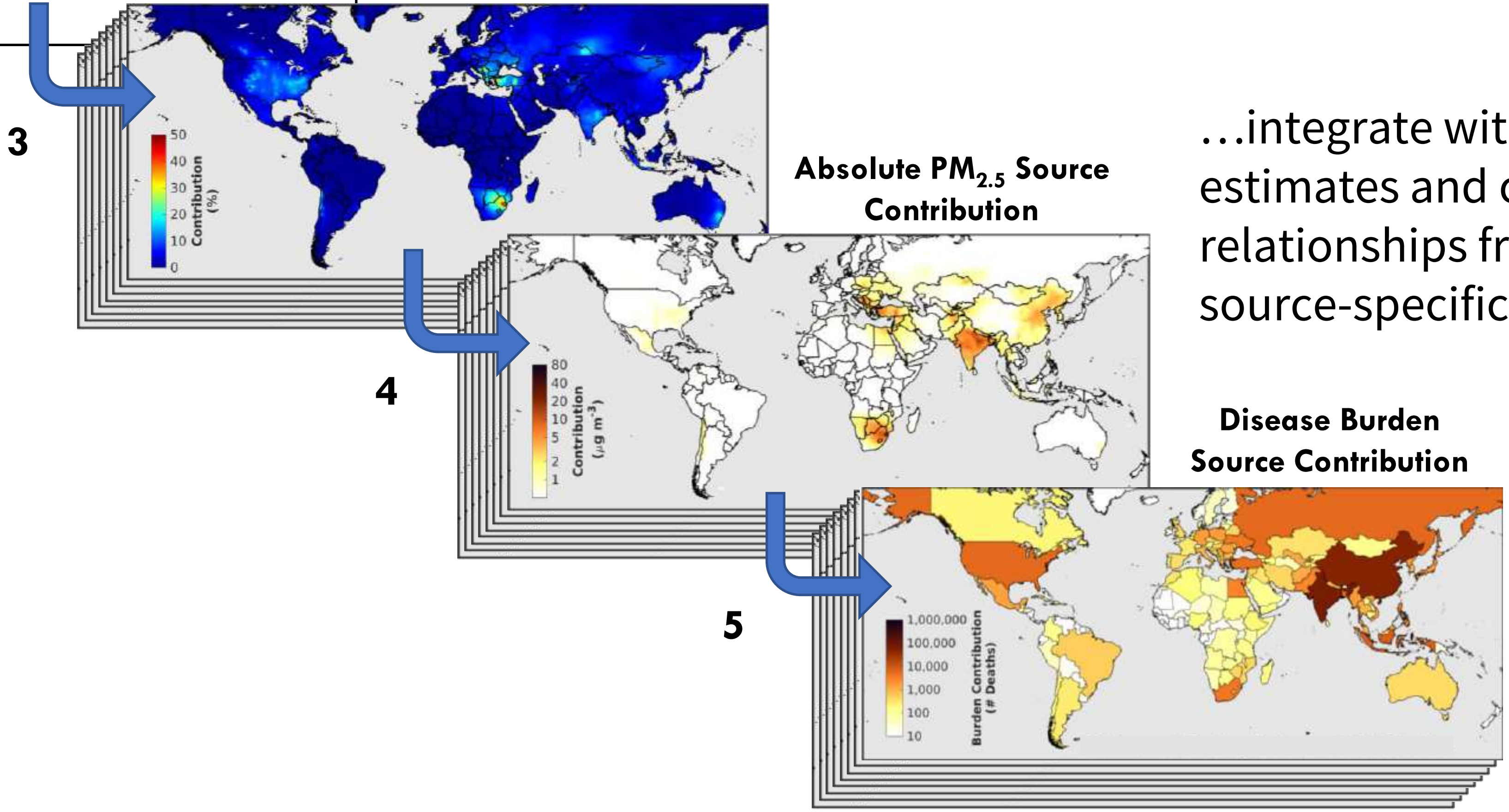
**Approach**:
Conduct emissions sensitivity simulations with a global atmospheric chemistry transport model…

…integrate with $PM_{2.5}$ exposure estimates and concentration response relationships from the GBD to quantify source-specific disease burdens

**Modeled $PM_{2.5}$ Fractional Source Contribution**

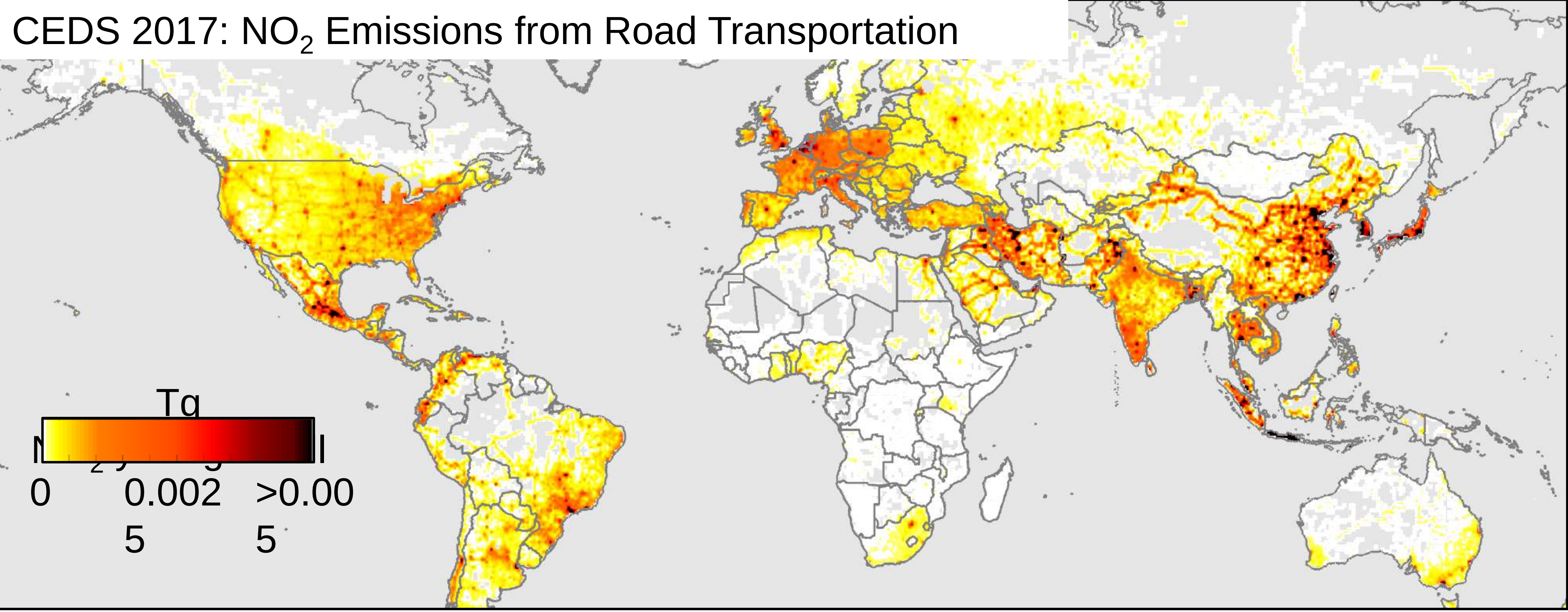
**Absolute $PM_{2.5}$ Source Contribution**

**Disease Burden Source Contribution**

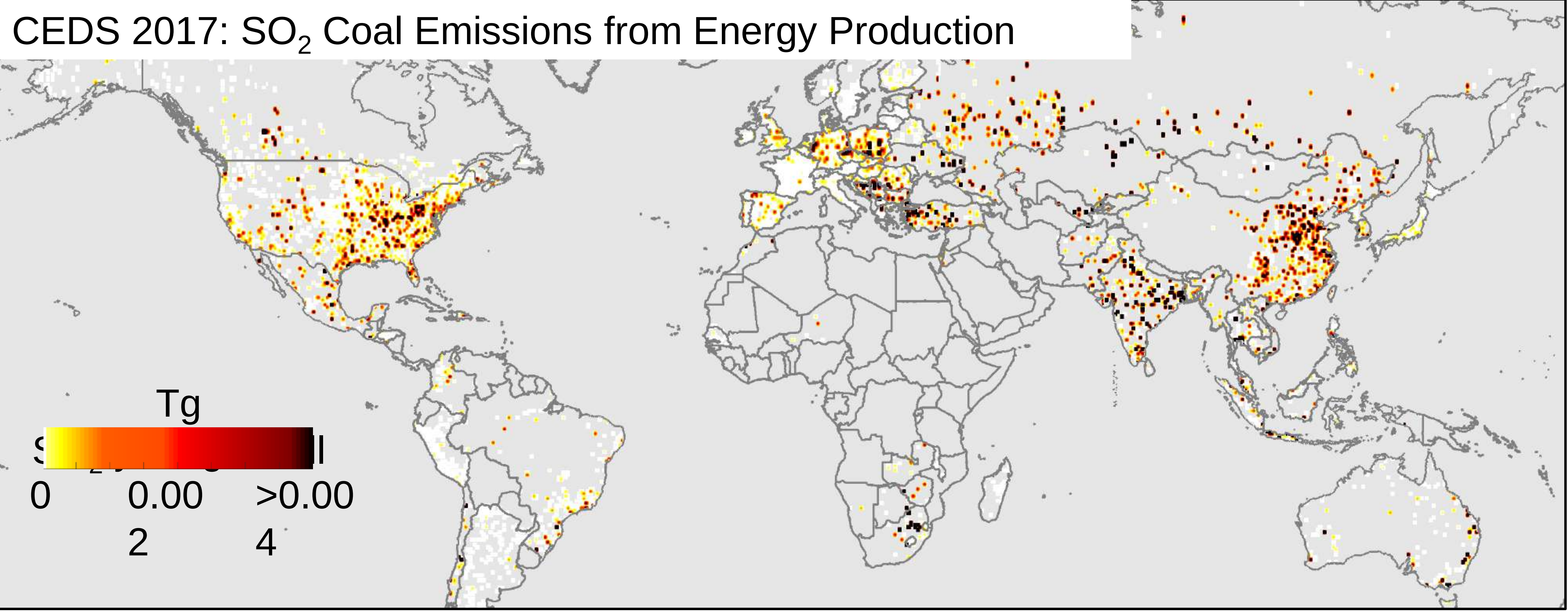



HEI
HEALTH EFFECTS INSTITUTE

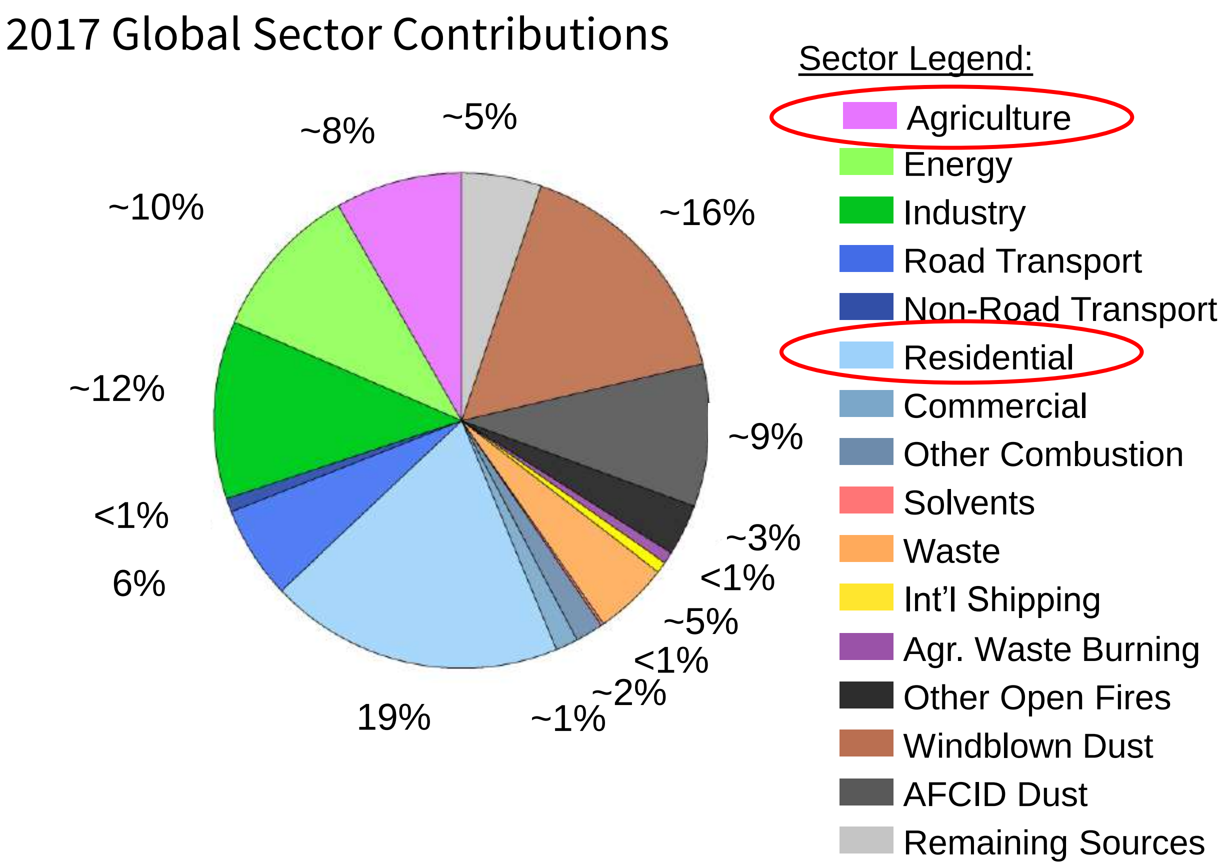
# CEDS 2017: $NO_2$ Emissions from Road Transportation

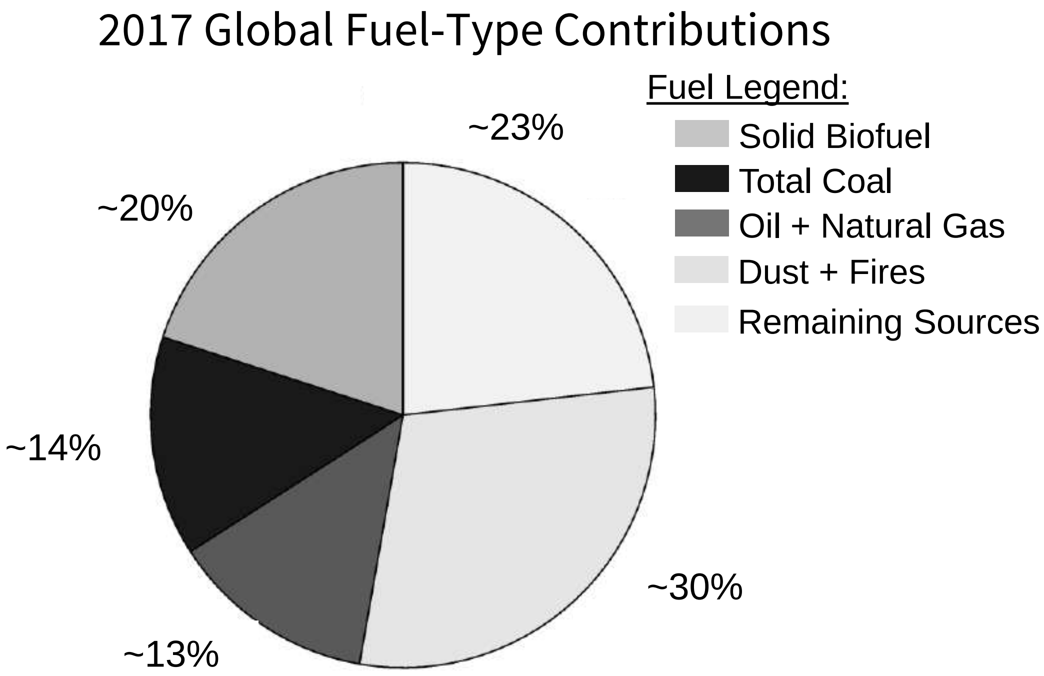


# CEDS 2017: $SO_2$ Coal Emissions from Energy Production



# Global fuel combustion contributes to ~50%; fossil fuels ~27%

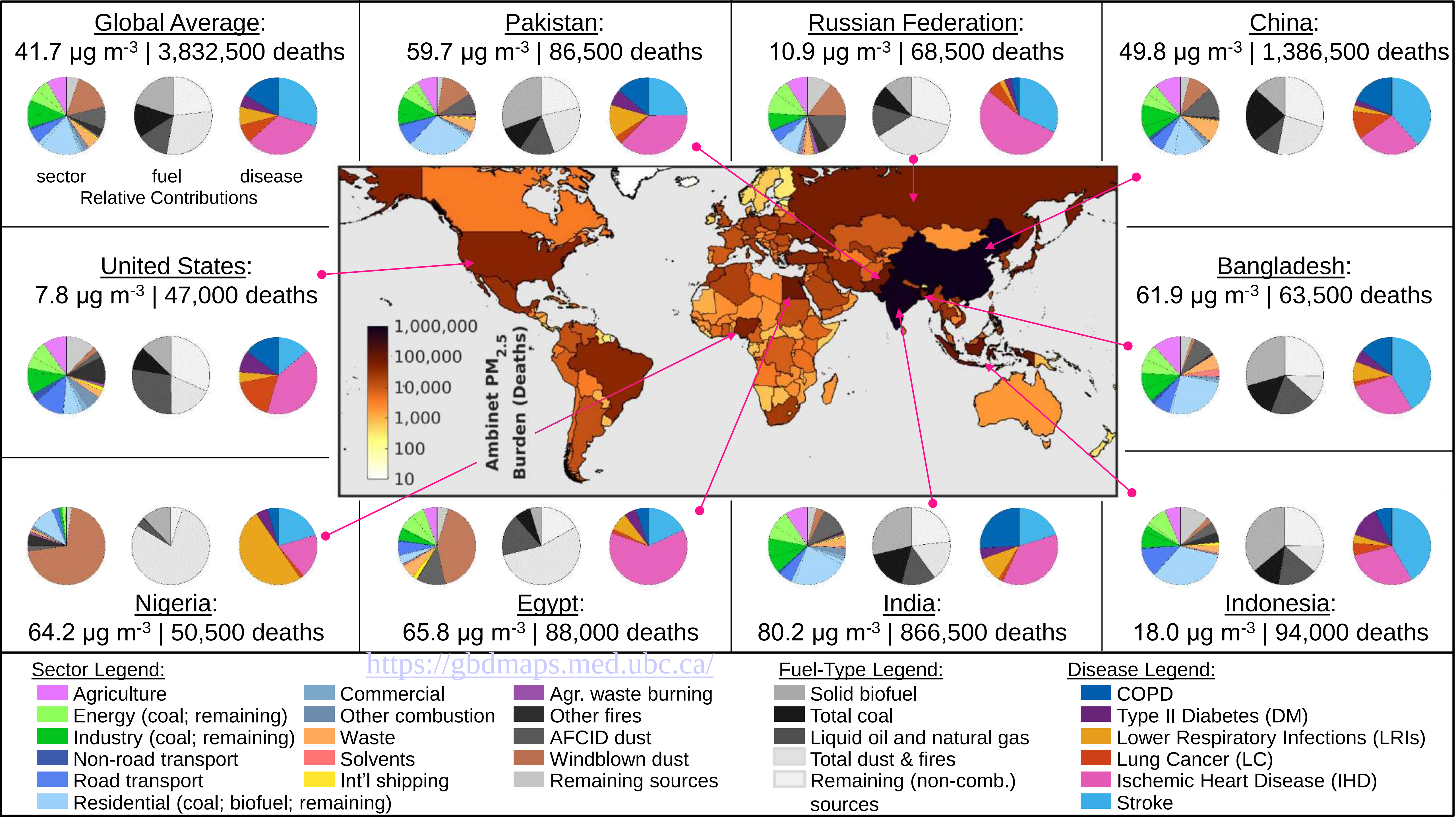



Fossil-fuels contribute to 27%

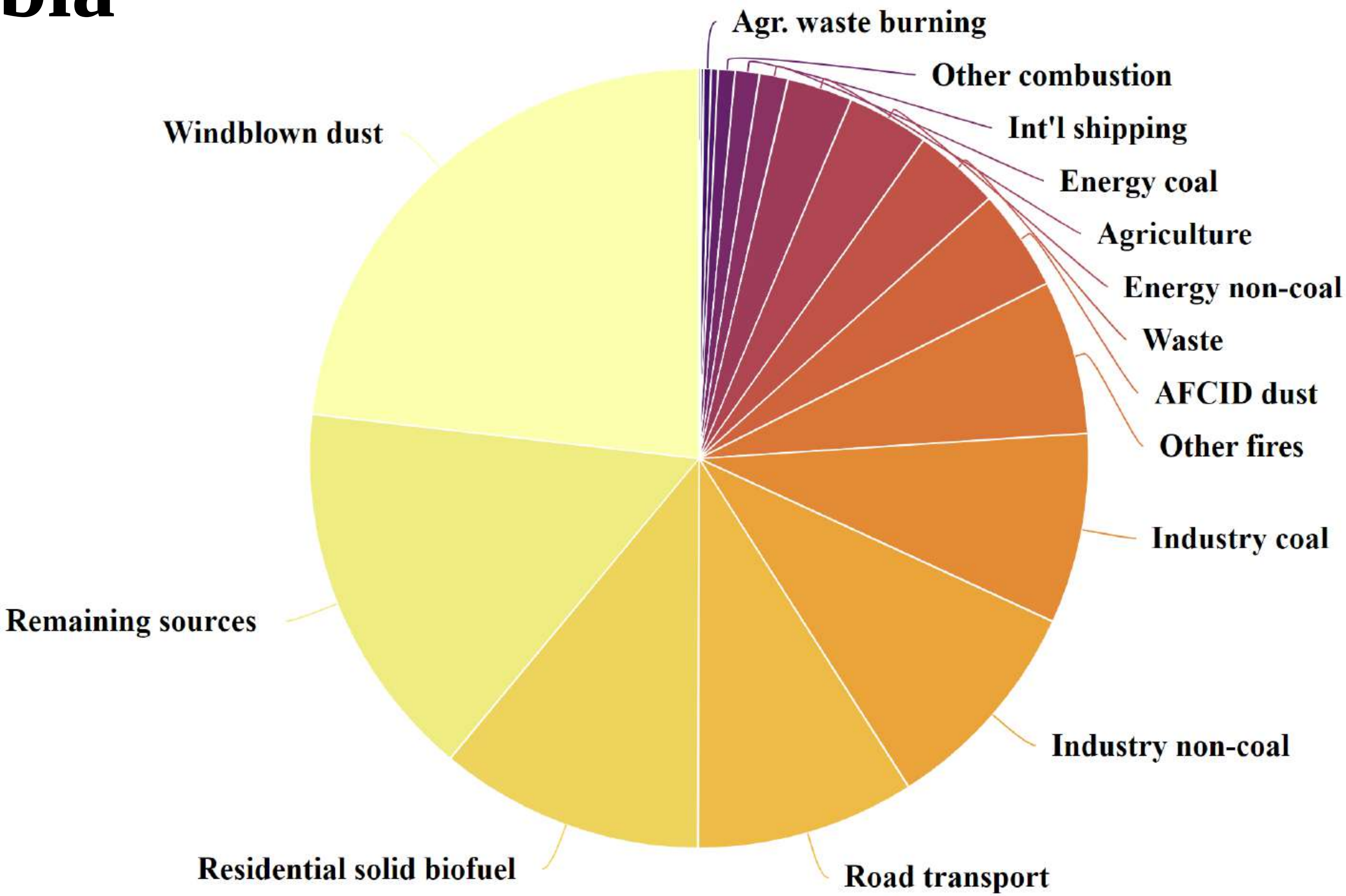
[Source sector and fuel contributions to ambient $PM_{2.5}$ and attributable mortality across multiple spatial scales.](#) Nat Commun. 2021 Jun 14

[Interactive data visualization](https://gbdmaps.med.ubc.ca/) https://gbdmaps.med.ubc.ca/



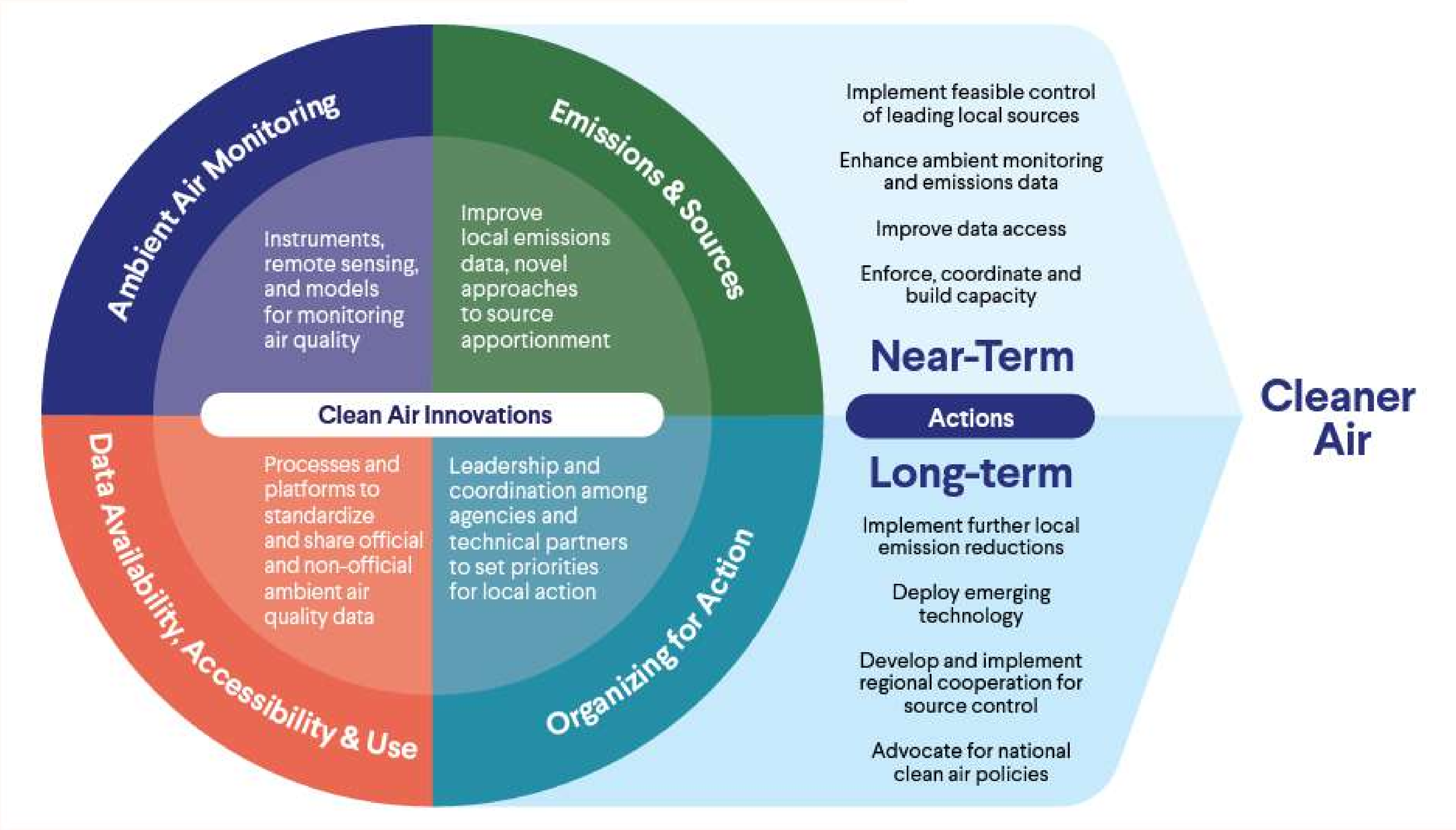
Global Average:
41.7 μg m-3 | 3,832,500 deaths
sector
fuel
disease
Relative Contributions
Pakistan:
59.7 μg m-3 | 86,500 deaths
Russian Federation:
10.9 μg m-3 | 68,500 deaths
China:
49.8 μg m-3 | 1,386,500 deaths
United States:
7.8 μg m-3 | 47,000 deaths
Bangladesh:
61.9 μg m-3 | 63,500 deaths
1,000,000
100,000
10,000
1,000
100
10
Ambinet PM2.5 Burden (Deaths)
Nigeria:
64.2 μg m-3 | 50,500 deaths
Egypt:
65.8 μg m-3 | 88,000 deaths
India:
80.2 μg m-3 | 866,500 deaths
Indonesia:
18.0 μg m-3 | 94,000 deaths
https://gbdmaps.med.ubc.ca/
Sector Legend:
Agriculture
Energy (coal; remaining)
Industry (coal; remaining)
Non-road transport
Road transport
Residential (coal; biofuel; remaining)
Commercial
Other combustion
Waste
Solvents
Int'l shipping
Agr. waste burning
Other fires
AFCID dust
Windblown dust
Remaining sources
Fuel-Type Legend:
Solid biofuel
Total coal
Liquid oil and natural gas
Total dust & fires
Remaining (non-comb.) sources
Disease Legend:
COPD
Type II Diabetes (DM)
Lower Respiratory Infections (LRIs)
Lung Cancer (LC)
Ischemic Heart Disease (IHD)
Stroke

# Colombia



Agr. waste burning
Other combustion
Int'l shipping
Energy coal
Agriculture
Energy non-coal
Waste
AFCID dust
Other fires
Industry coal
Industry non-coal
Road transport
Residential solid biofuel
Remaining sources
Windblown dust

## Innovations to promote clean air action: Overall framework




Accelerating City Progress on Clean Air: Innovation and Action Guide. Vital Strategies

# Climate change

The NEW ENGLAND JOURNAL of MEDICINE

EDITORIALS

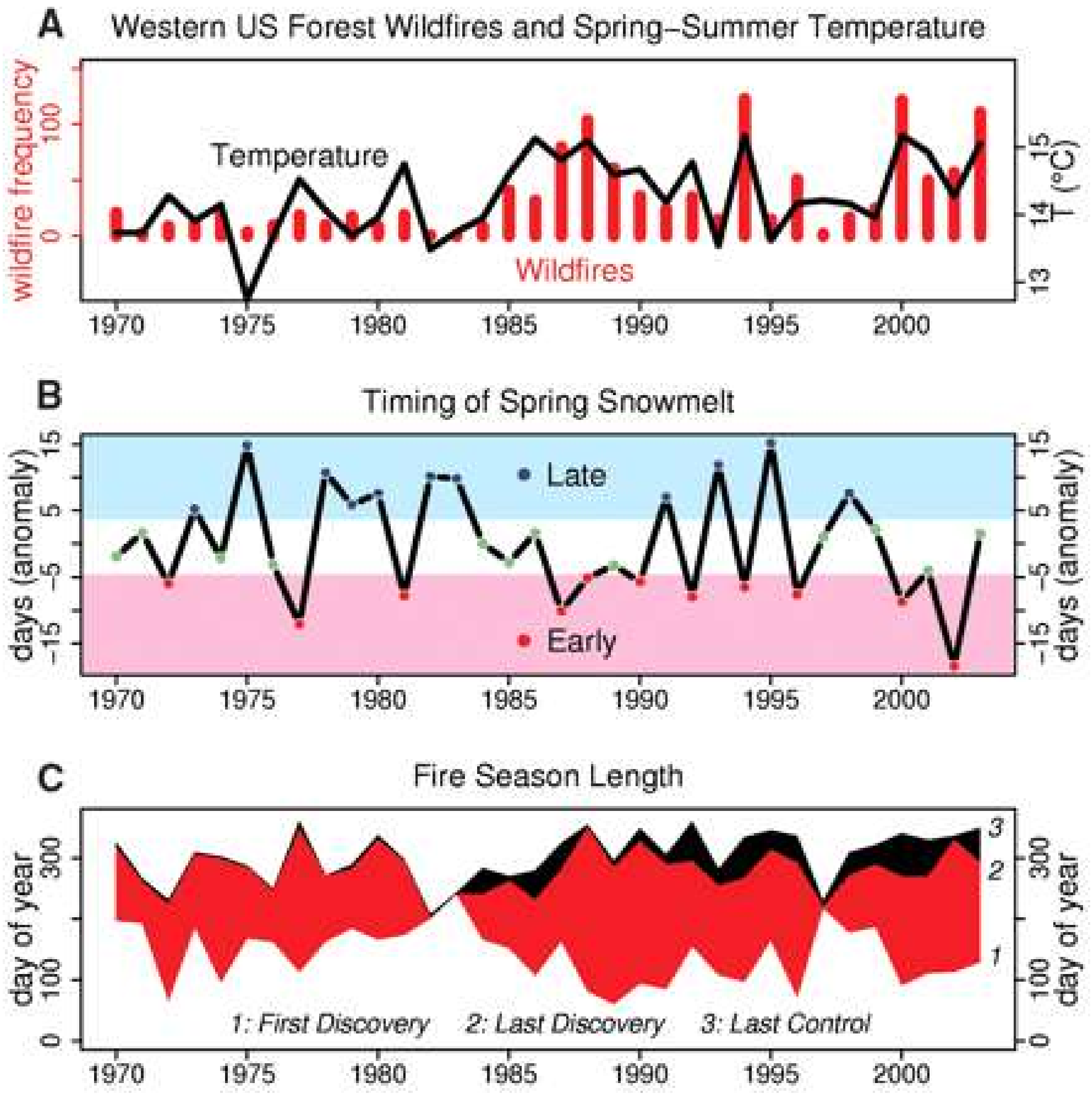
## Call for Emergency Action to Limit Global Temperature Increases, Restore Biodiversity, and Protect Health

SEPTEMBER 9, 2021

## Climate change is 'greatest threat to global public health,' 200+ medical journals warn

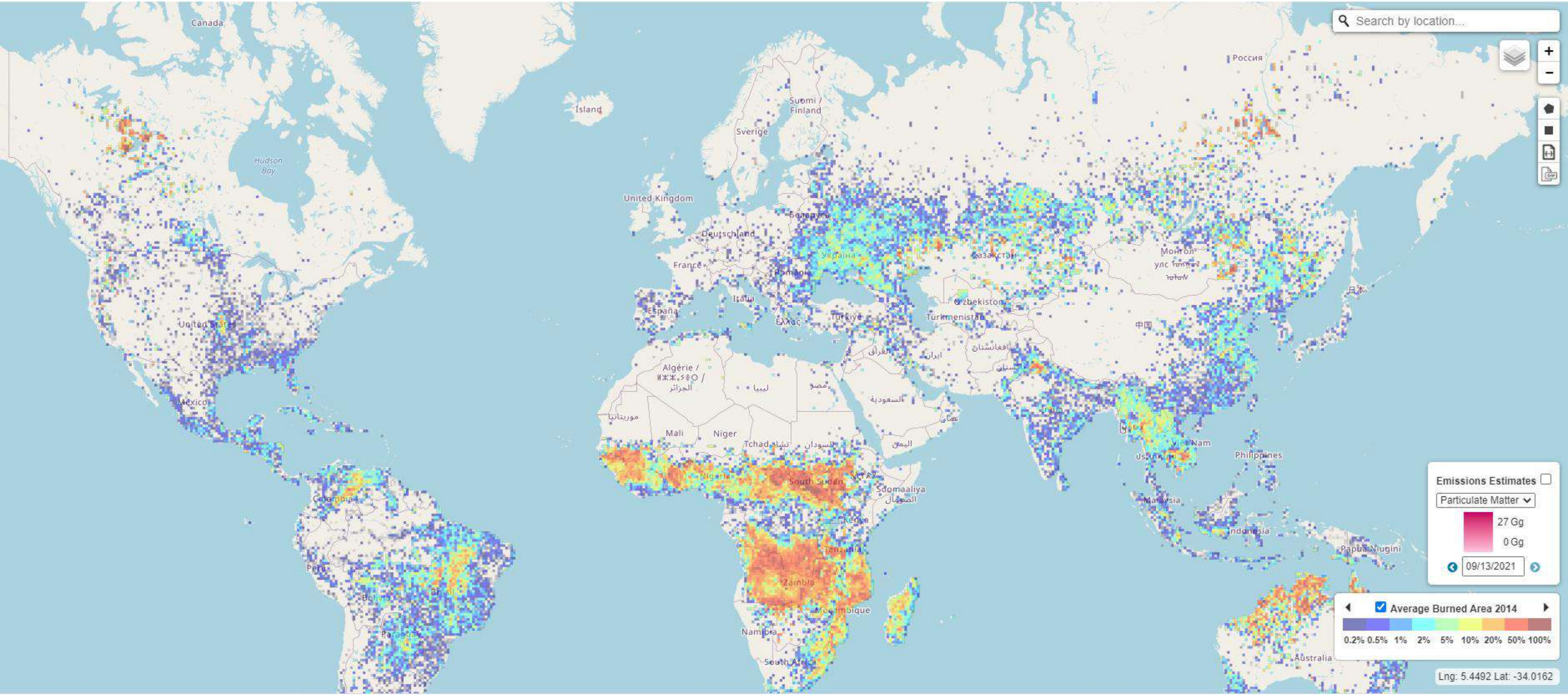
# Changing climate increases wildfires

- Fires are
  - Larger
  - More frequent
- Fire season is longer
  - Reduced winter rains
  - Earlier snowmelt
  - Increased spring/summer temperatures
  - Increased lightning




A L Westerling et al. Science 2006;313:940-943

# Landscape fires are everywhere



Review

A Section 508–conformant HTML version of this article is available at http://dx.doi.org/10.1289/ehp.1409277.

# Critical Review of Health Impacts of Wildfire Smoke Exposure

*Colleen E. Reid,[1,2] Michael Brauer,[3] Fay H. Johnston,[4,5] Michael Jerrett,[1,6] John R. Balmes,[1,7] and Catherine T. Elliott[3,8]*

- **Respiratory**
  - **Asthma and COPD exacerbation**
    - Cough, wheezing, difficulty breathing, shortness of breath

    → emergency room visits, hospitalization, death
  - **Respiratory infections (COVID-19)**
- **Cardiovascular**
  - angina episodes, heart attacks, stroke, cardiac arrest, heart failure → death
- **Emerging evidence**
  - Diabetes, birth outcomes
- **Interaction with extreme heat events (e.g. Moscow 2012)**
- **Long term impacts of repeated events?**

# Climate change scenarios



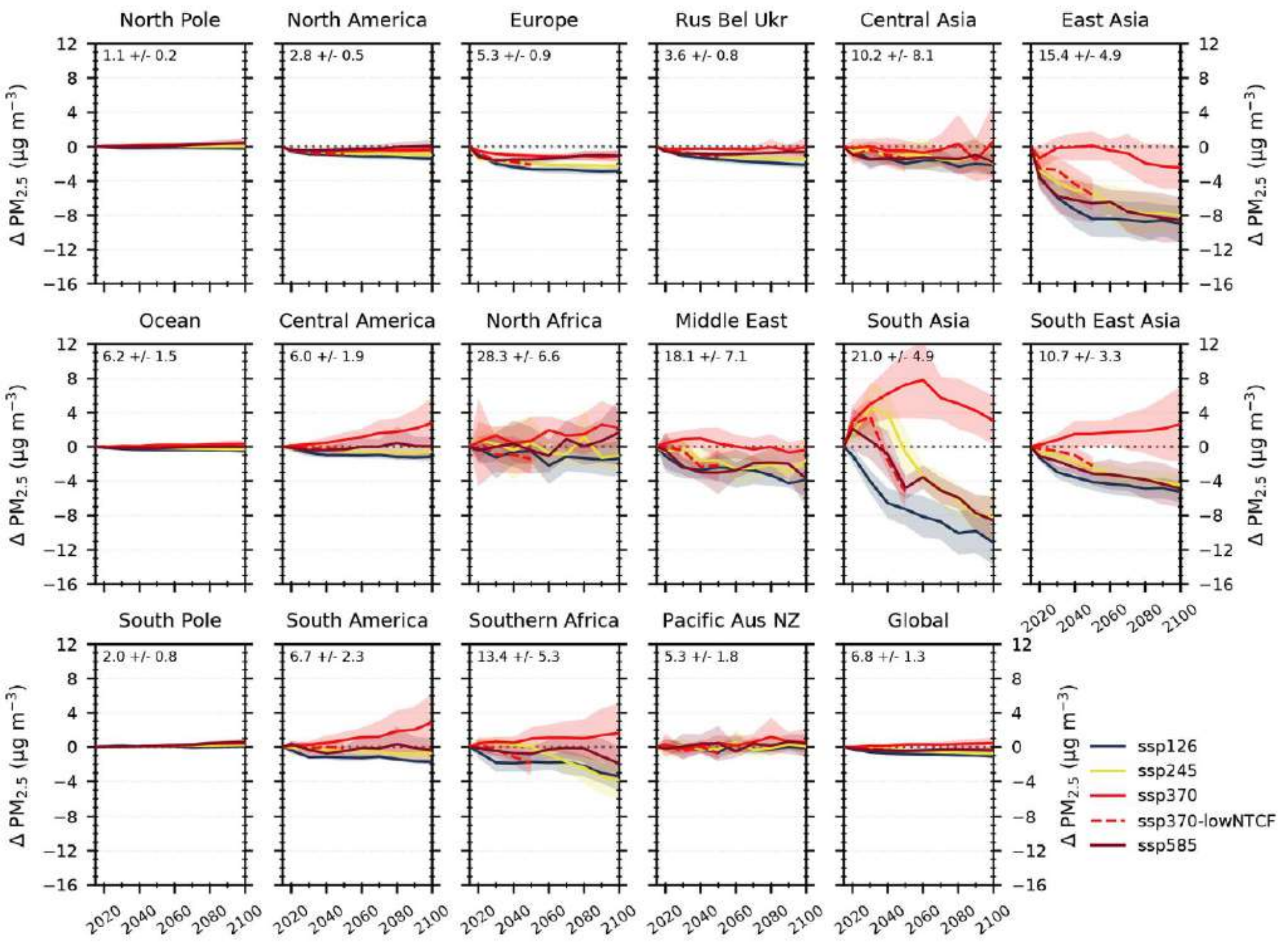



**Figure 14.** Future global and regional changes in annual mean surface $PM_{2.5}$, relative to 2005–2014 mean, for the different SSPs used in CMIP6. Each line represents a multi-model mean across the region, with shading representing the ±1 SD of the mean. See Table 1 for details of models contributing to each scenario. The multi-model regional mean value (±1 SD) for the years 2005–2014 is shown in the top left corner of each panel.

Turnock et al. Historical and future changes in air pollutants from CMIP6 models. Atmos. Chem. Phys., 20, 14547–14579, 2020 https://doi.org/10.5194/acp-20-14547-2020

# Implications

- Air pollution is a major global health threat
- Increasing burden with aging population and high prevalence of chronic diseases
  - Large exposure decreases required to offset **demographics**
  - Steep exposure-response relationships to near-background levels → **continued benefits of air pollution reduction**
- Climate change requires a **renewal of efforts**…but mitigation actions offer **strong potential for reductions in air pollution health impacts.**
- We'll get there…the question is how long will it take

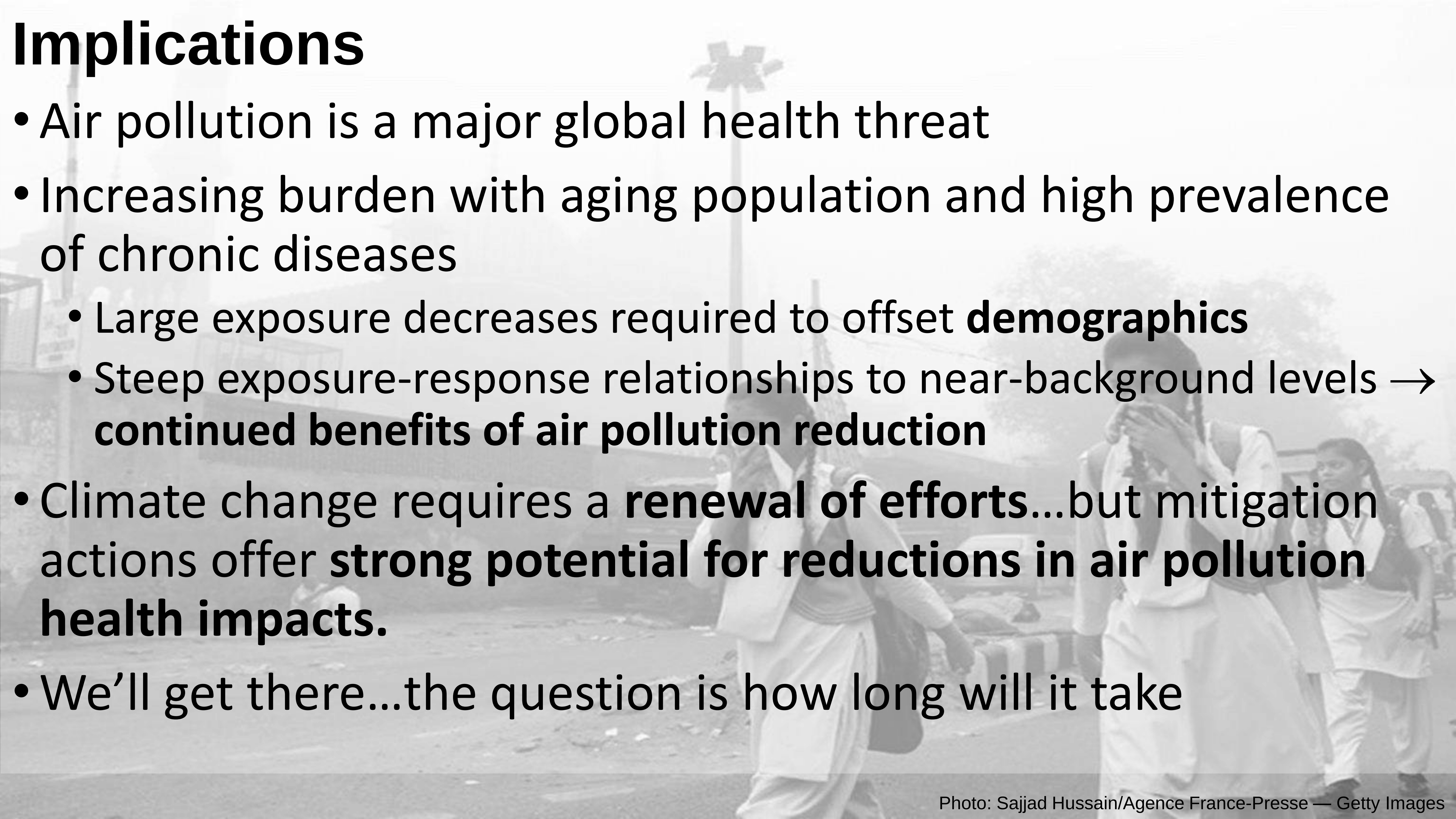


Photo: Sajjad Hussain/Agence France-Presse — Getty Images

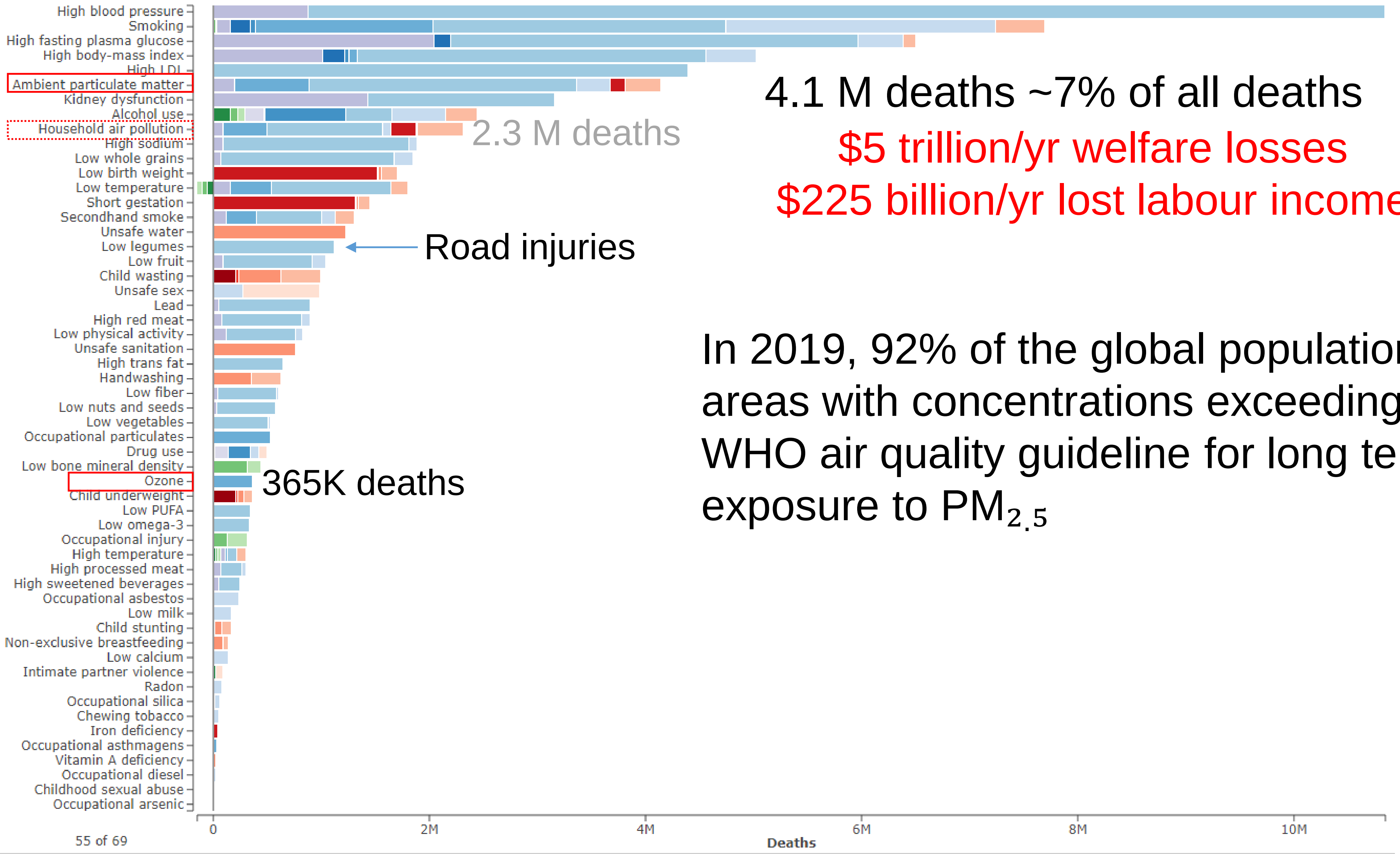
# Gracias!


- **Monitoring** air quality and health effects;
- Public **reporting** on air quality;
- Establishing air quality **legislation**, regulations and standards;
- Preparing air quality **action** plans;
- Implementing and **enforcing** air quality rules;
- Evaluating and **revising** air quality standards and plans;
- And protecting environmental human rights **defenders**

michael.brauer@ubc.ca

# EXTRA SLIDES

# Air pollution is a major risk factor for global health




4.1 M deaths ~7% of all deaths

$5 trillion/yr welfare losses

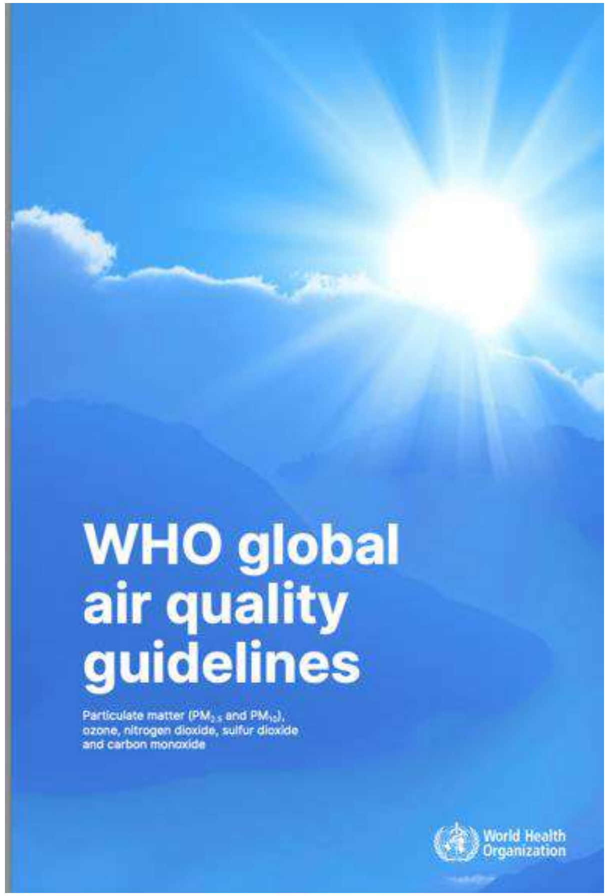
$225 billion/yr lost labour income

In 2019, 92% of the global population lived in areas with concentrations exceeding 2005 WHO air quality guideline for long term exposure to $PM_{2.5}$

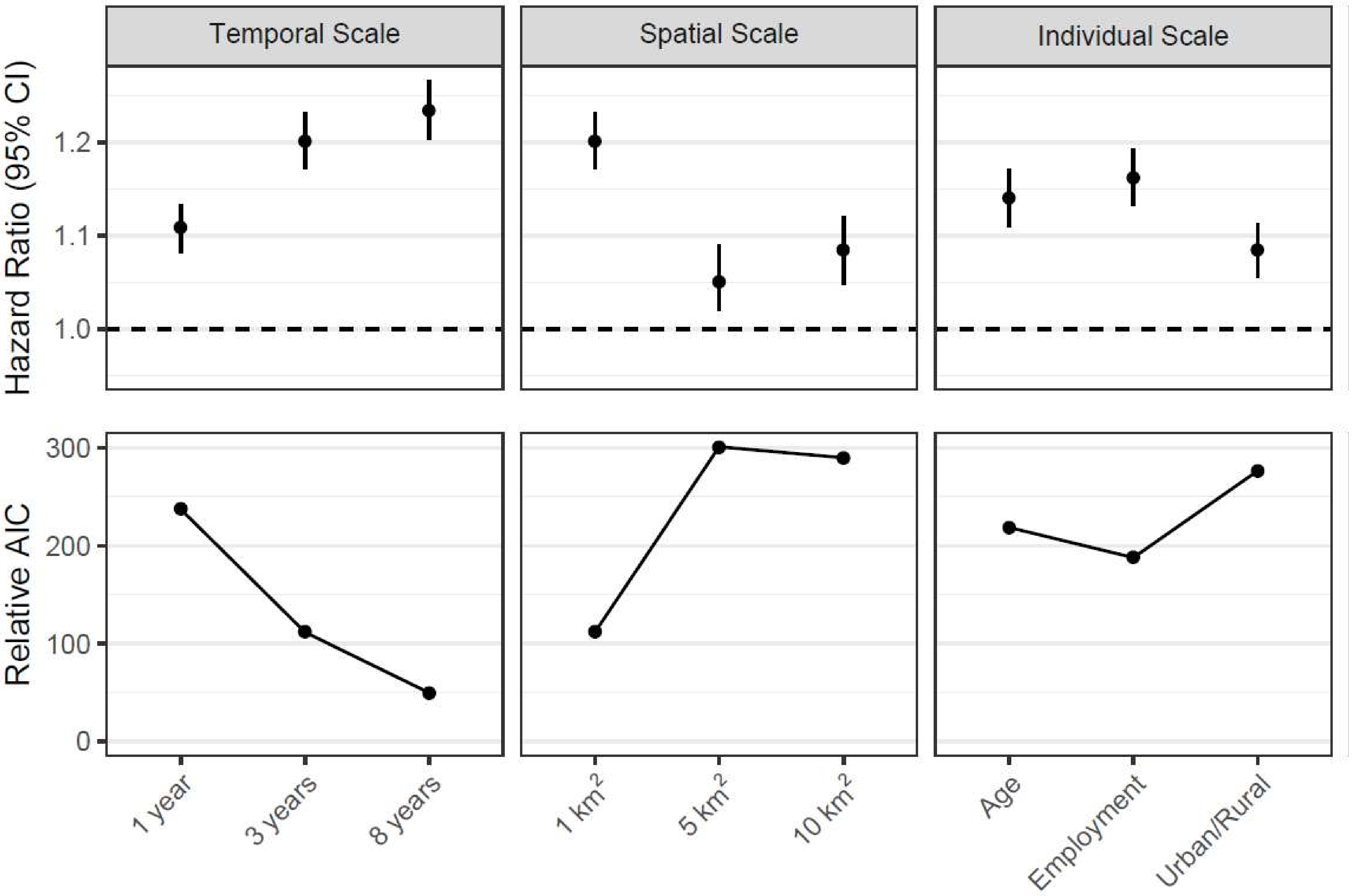
2019

World Bank. 2016. *The cost of air pollution : strengthening the economic case for action*

# What's new in the AQGs 2021?

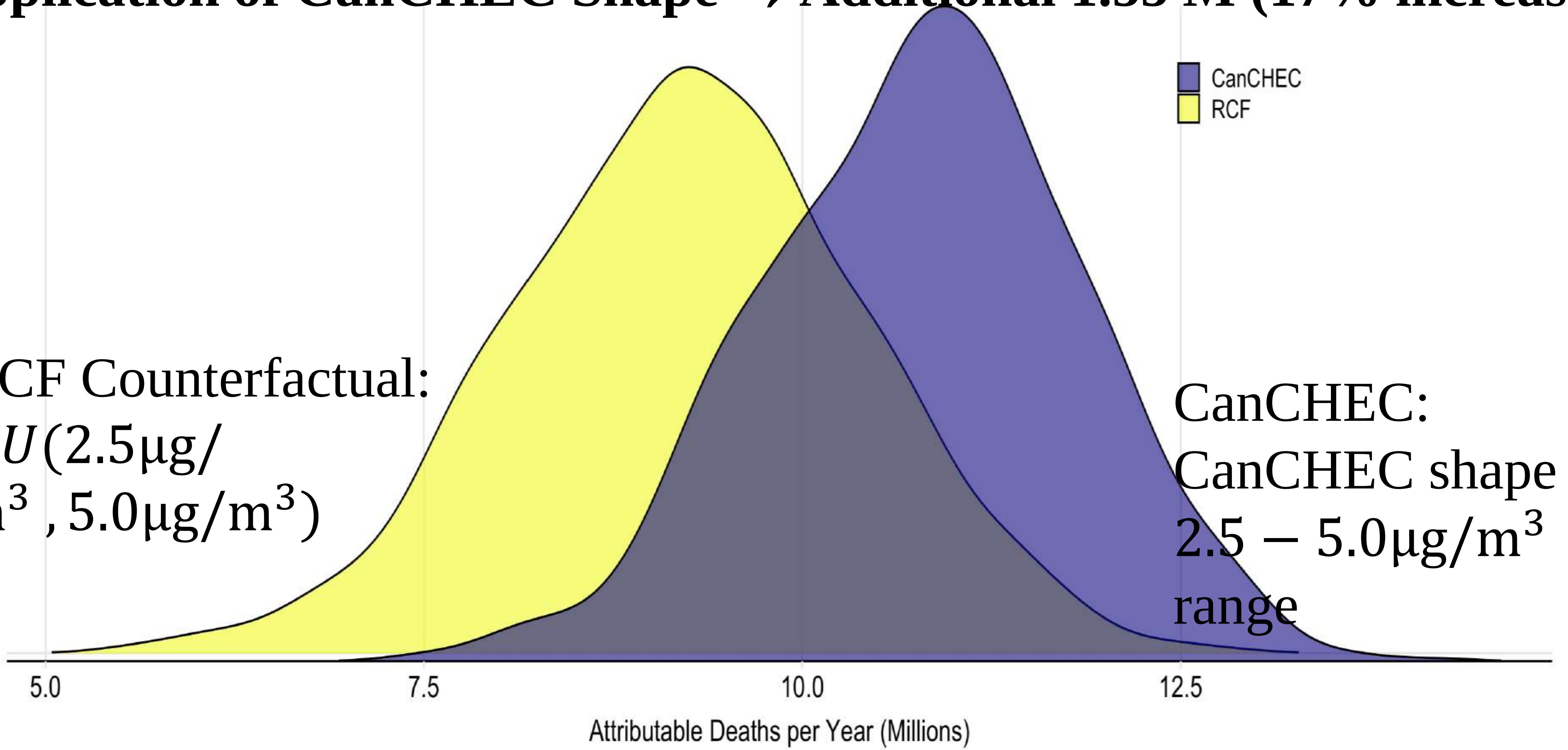



- Since 2005 update, increases in quality and quantity of evidence of air pollution impacts on health
  - Studies of short-term exposure impacts from locations outside of North America, western Europe
  - Studies of long-term exposure impacts at low levels
  - Expanding health outcomes affected by air pollution
  - Scientific methodology and scale of studies
- Improved insight on sources of emissions and the contribution of air pollutants to the global burden of disease.
- After a systematic review of the accumulated evidence, **several updated AQG levels are now lower than 15 years ago.**
- New AQG levels for **peak-season $O_3$**; **24-h $NO_2$ and CO**; **new interim targets.**



Temporal Scale
Spatial Scale
Individual Scale
Hazard Ratio (95% CI)
1.2
1.1
1.0
Relative AIC
300
200
100
0
1 year
3 years
8 years
1 km²
5 km²
10 km²
Age
Employment
Urban/Rural

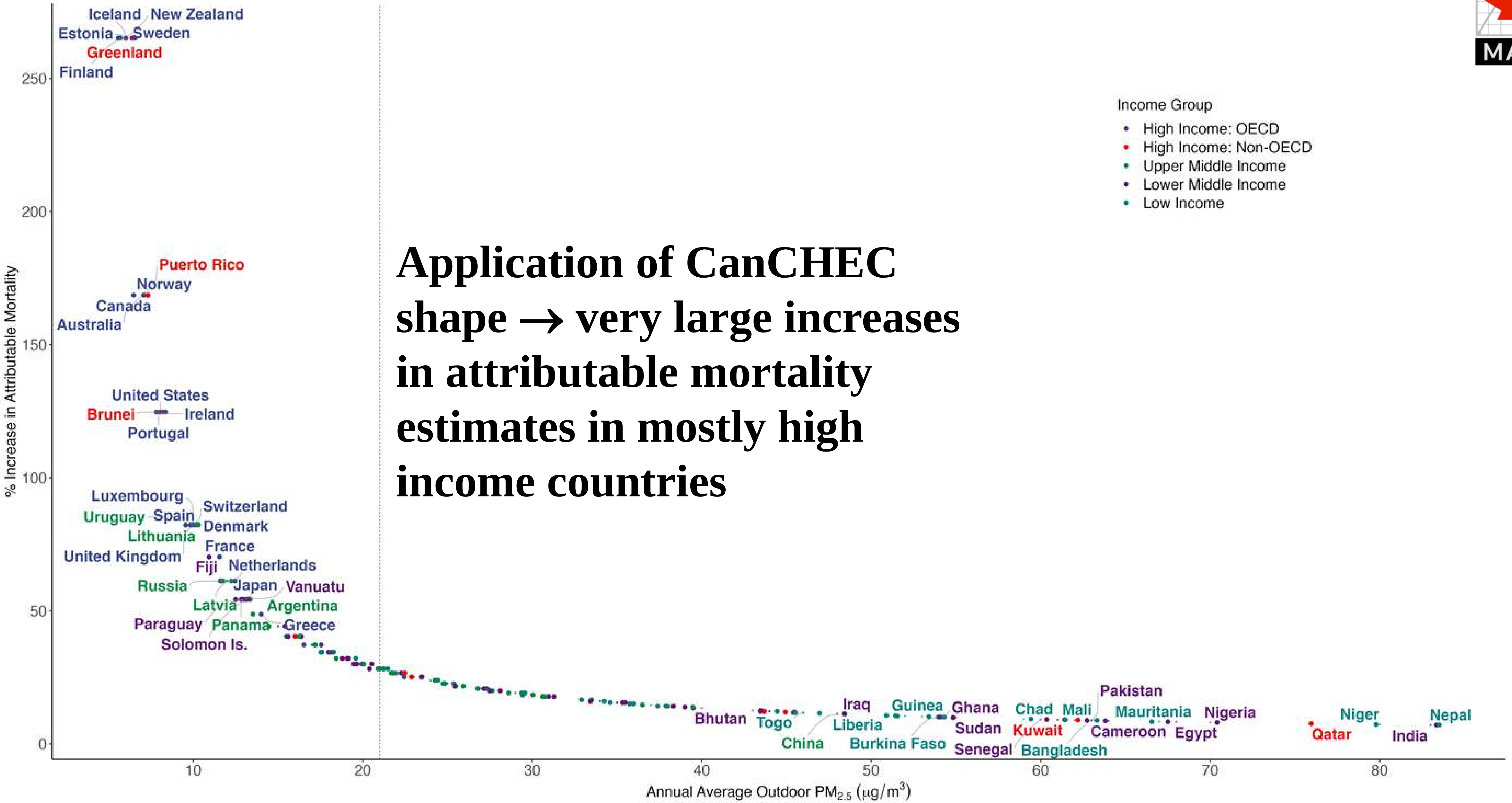
# Application of CanCHEC Shape → Additional 1.55 M (17% increase)




RCF Counterfactual: $\sim U(2.5\mu g/m^3, 5.0\mu g/m^3)$

CanCHEC: CanCHEC shape $2.5 - 5.0\mu g/m^3$ range

Weichenthal et al. Science Advances 20



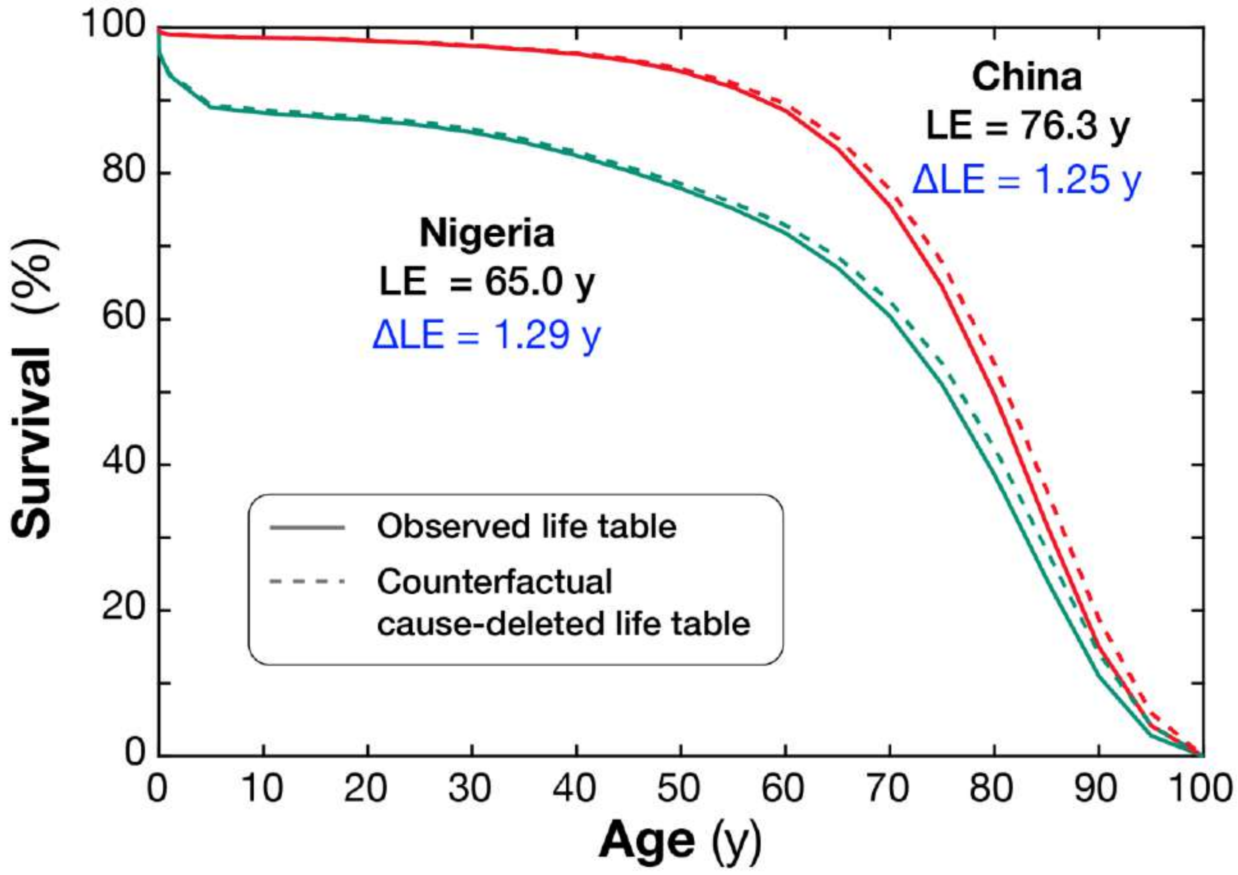

**Application of CanCHEC shape → very large increases in attributable mortality estimates in mostly high income countries**

Weichenthal et al. Science Advar

# Loss of life expectancy (ΔLE) from air pollution

What would the difference in life expectancy be if we were to:

- Eliminate <u>all</u> air pollution exposures
- Reduce it to different levels (for example, WHO guidelines or target levels)?




IHME GBD

STATE OF GLOBAL AIR /2019

# Good practice statements

For the management of certain types of particulate matter

## SAND AND DUST STORM

- Maintain suitable air quality management and **dust forecasting** programmes.
- Maintain air quality **monitoring** programmes and reporting procedures.
- Conduct epidemiological studies and **research** activities aimed at better understanding toxicity.
- Implement **wind erosion control** through the carefully planned expansion of green spaces.

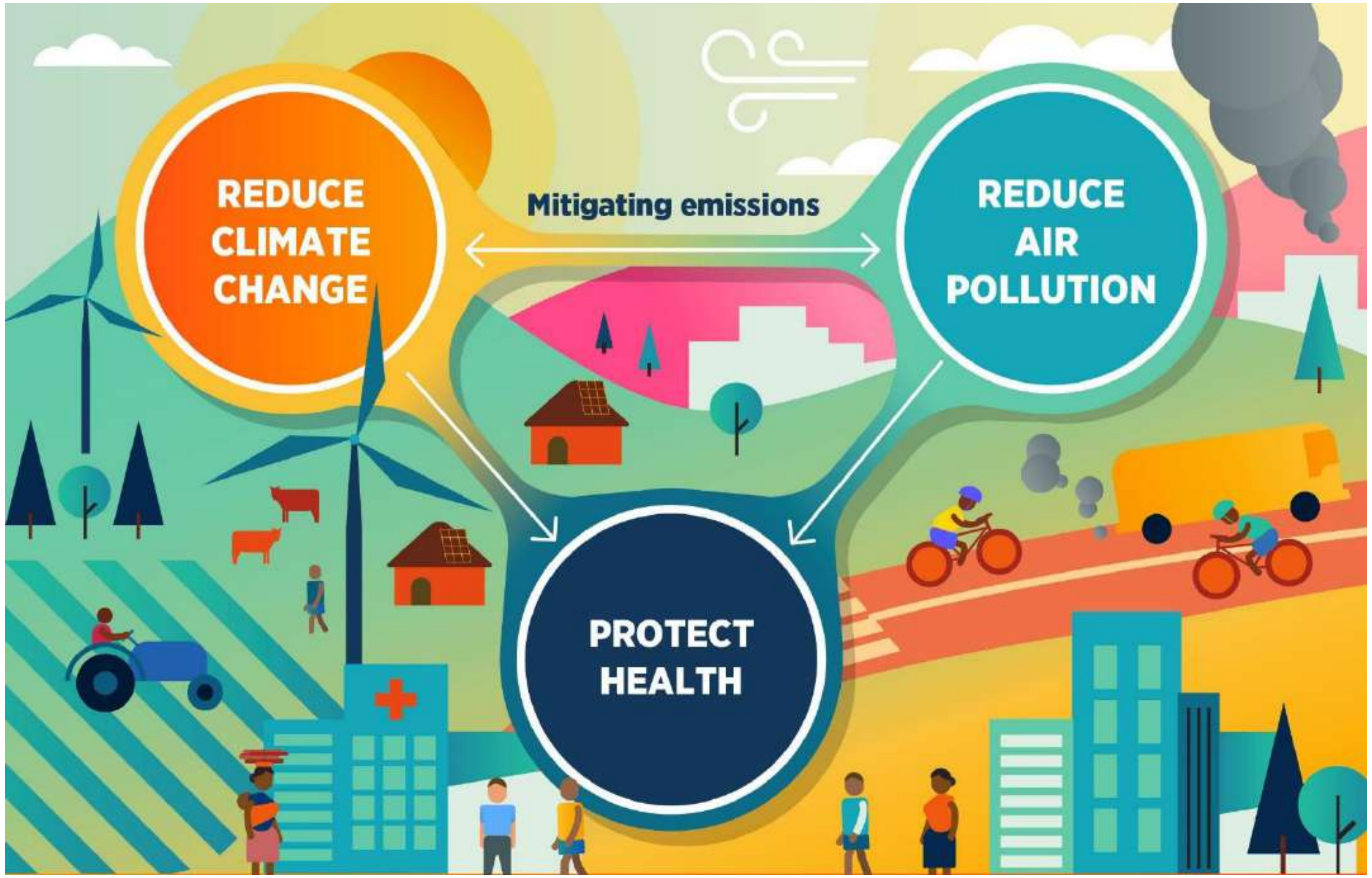
## BLACK/ELEMENTAL CARBON

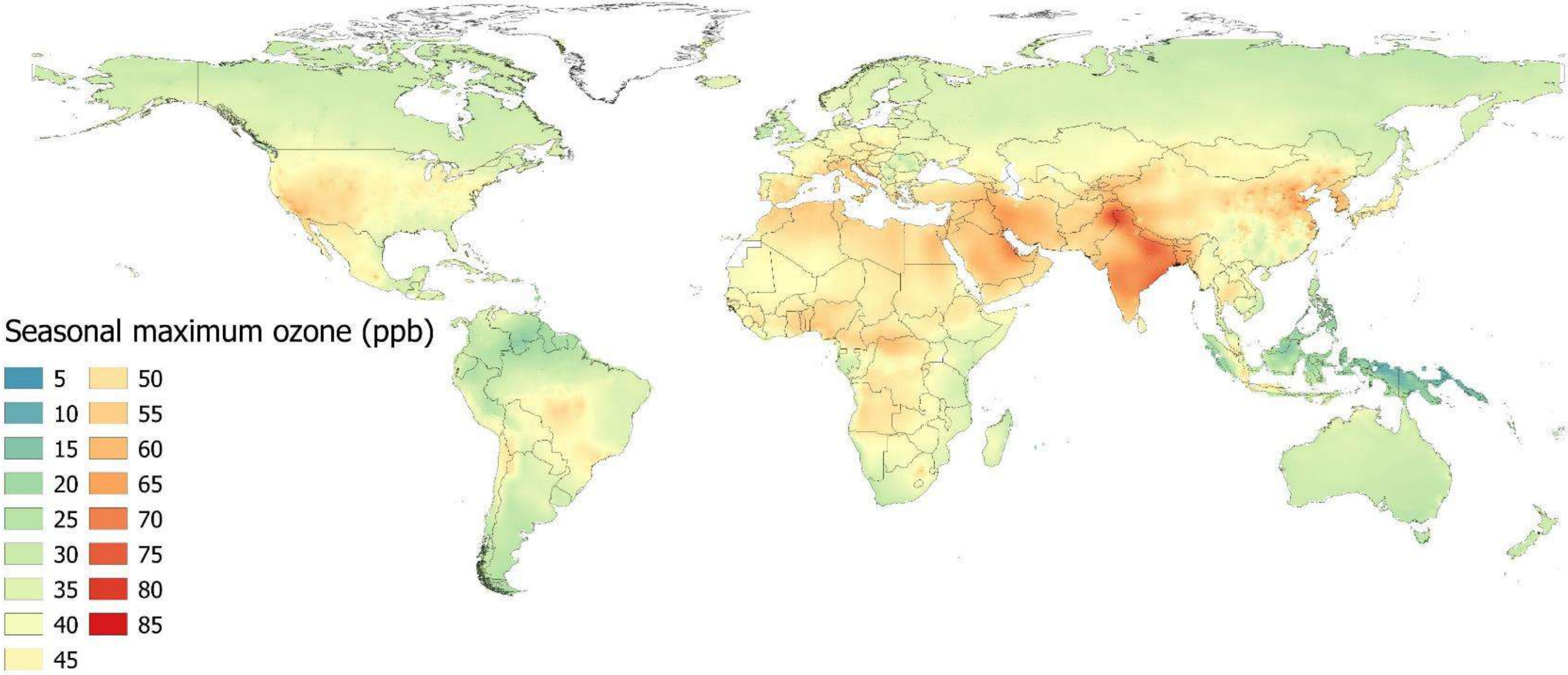
- Make systematic **measurements**.
- Undertake production of **emission inventories, exposure assessments and source apportionment**.
- Take measures to **reduce emissions and develop standards** (or targets).

## ULTRAFINE PARTICLES

- **Quantify ambient** UFP in terms of PNC for a size range with a lower limit of ≤ 10 nm and no restriction on the upper limit.
- Expand the common air quality **monitoring** strategy by integration of UFP monitoring.
- Distinguish between low and high PNC to guide decisions on the priorities of **UFP source emission control.**
- Utilize emerging science and technology for the **assessment of exposure.**

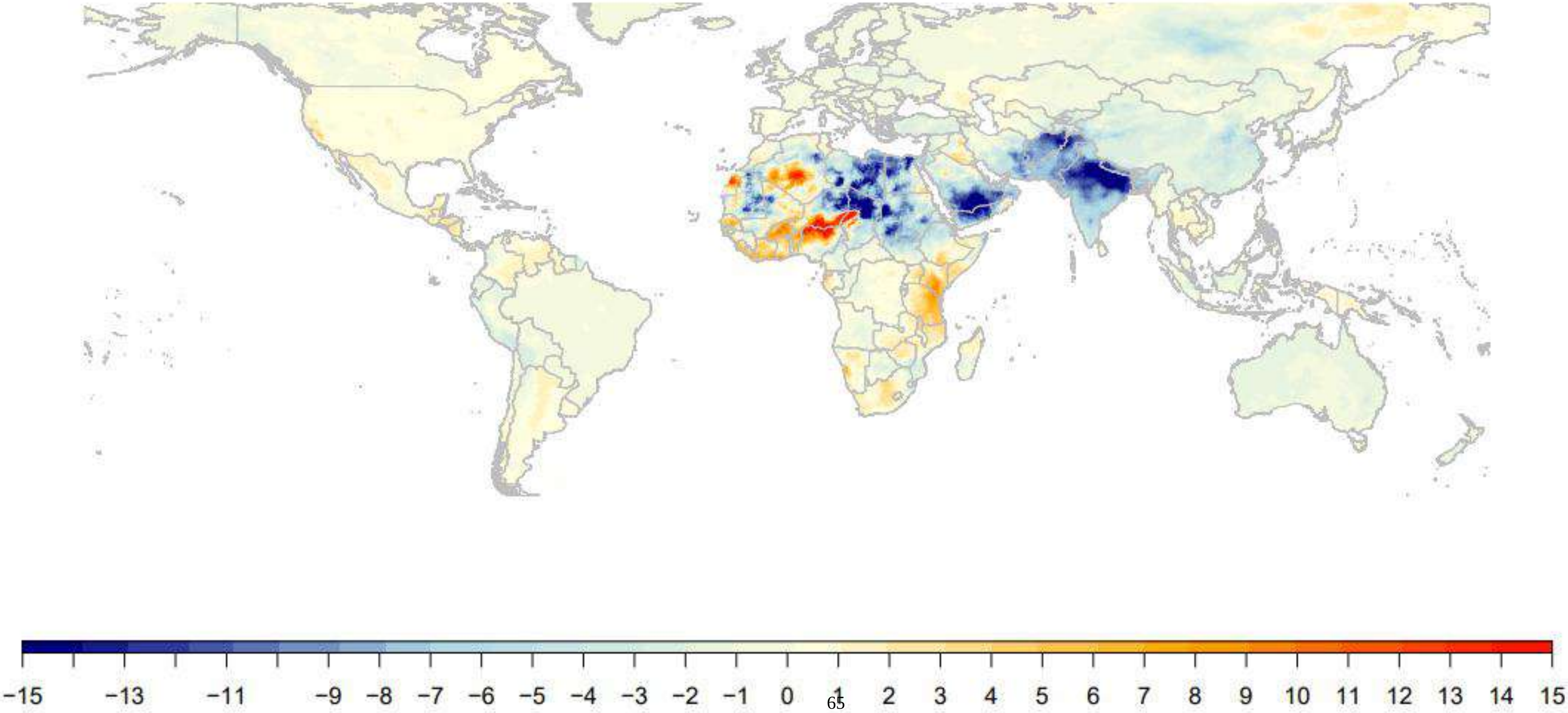
# Reducing air pollution and mitigating climate change



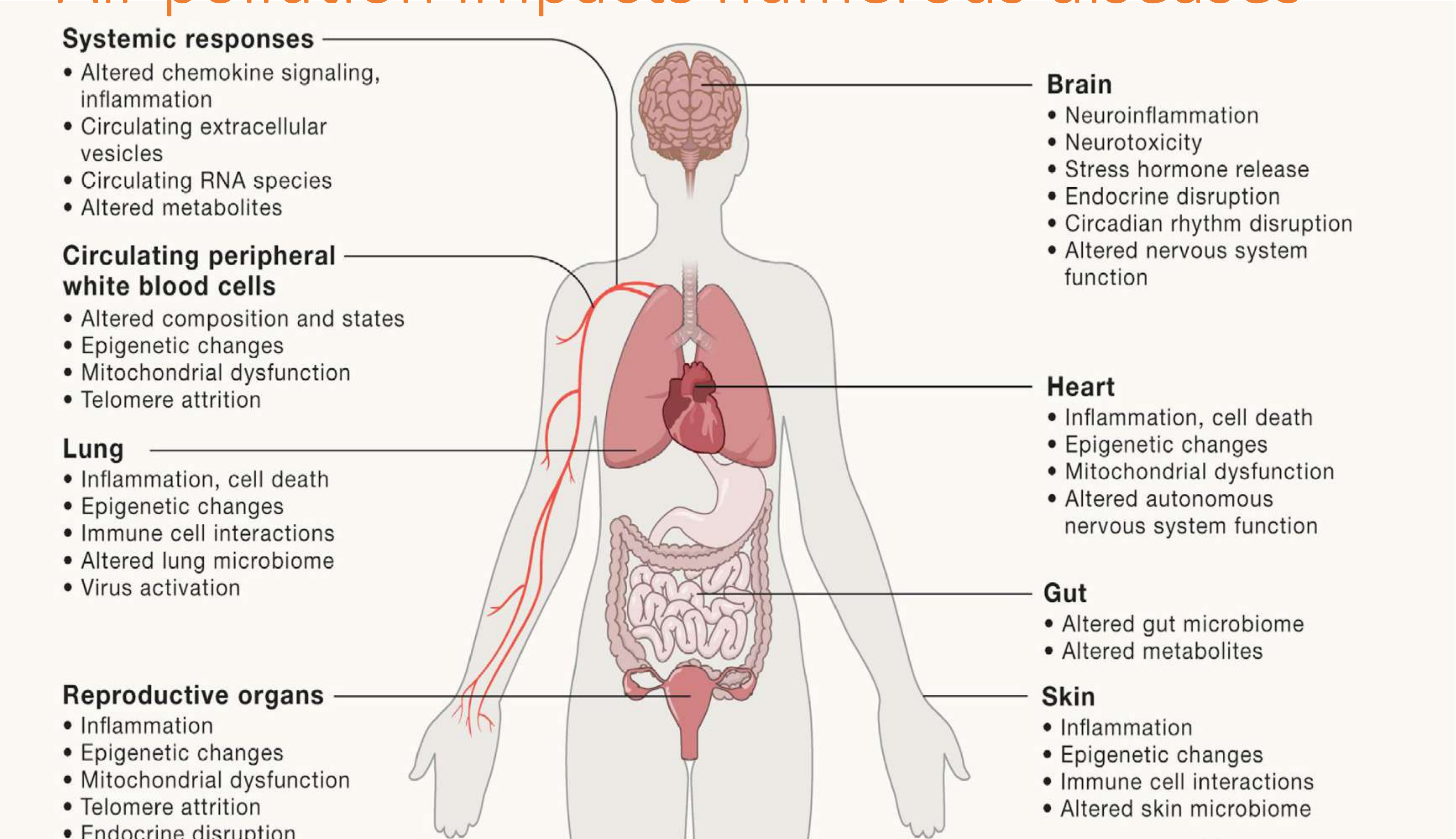

Seasonal maximum ozone (ppb)
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85

# Ambient PM2.5: Difference Between 2020 and 2019

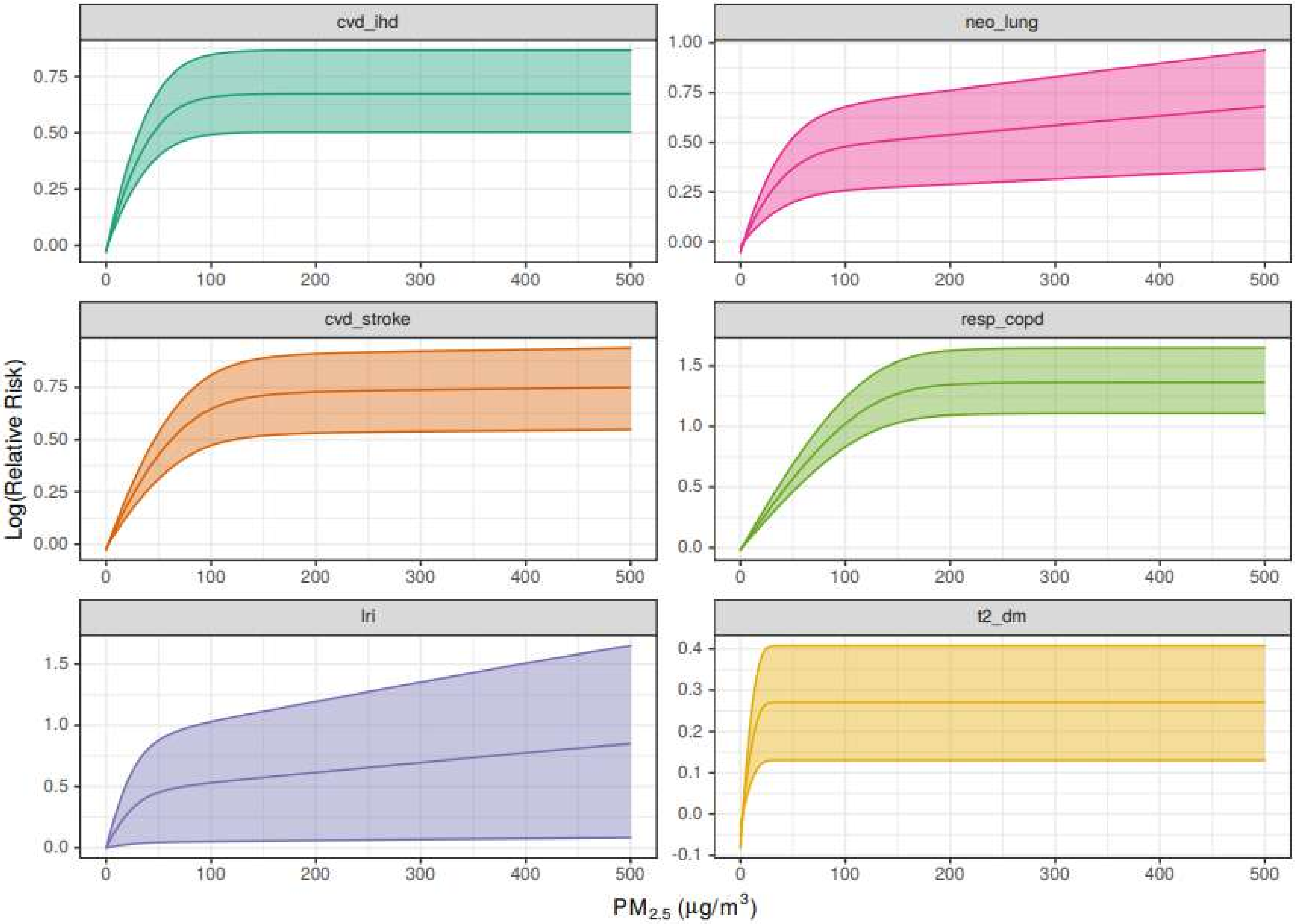
World Health Organization



# Air pollution impacts numerous diseases

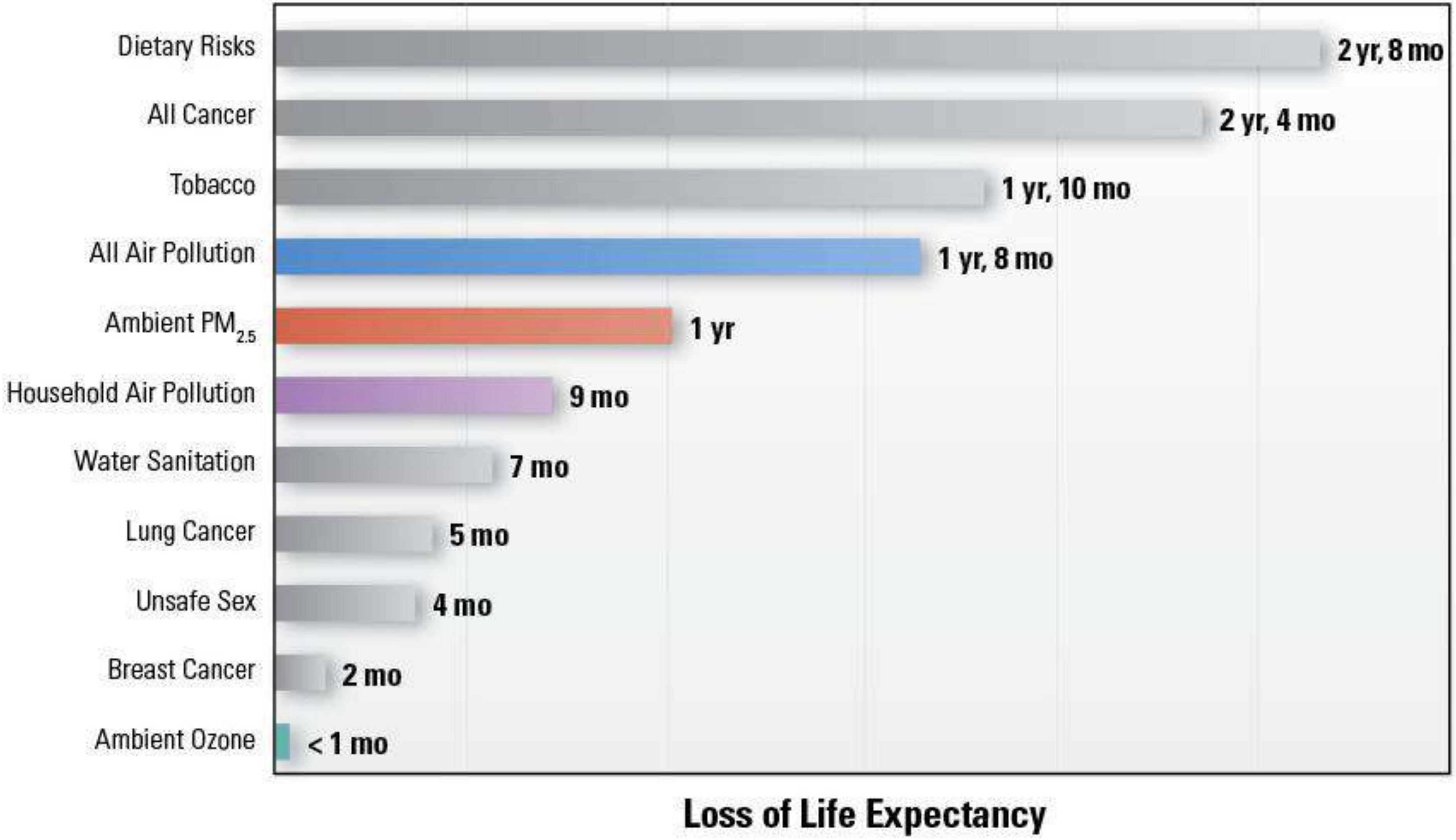



https://www.swisstph.ch/en/projects/ludok/healtheffects/

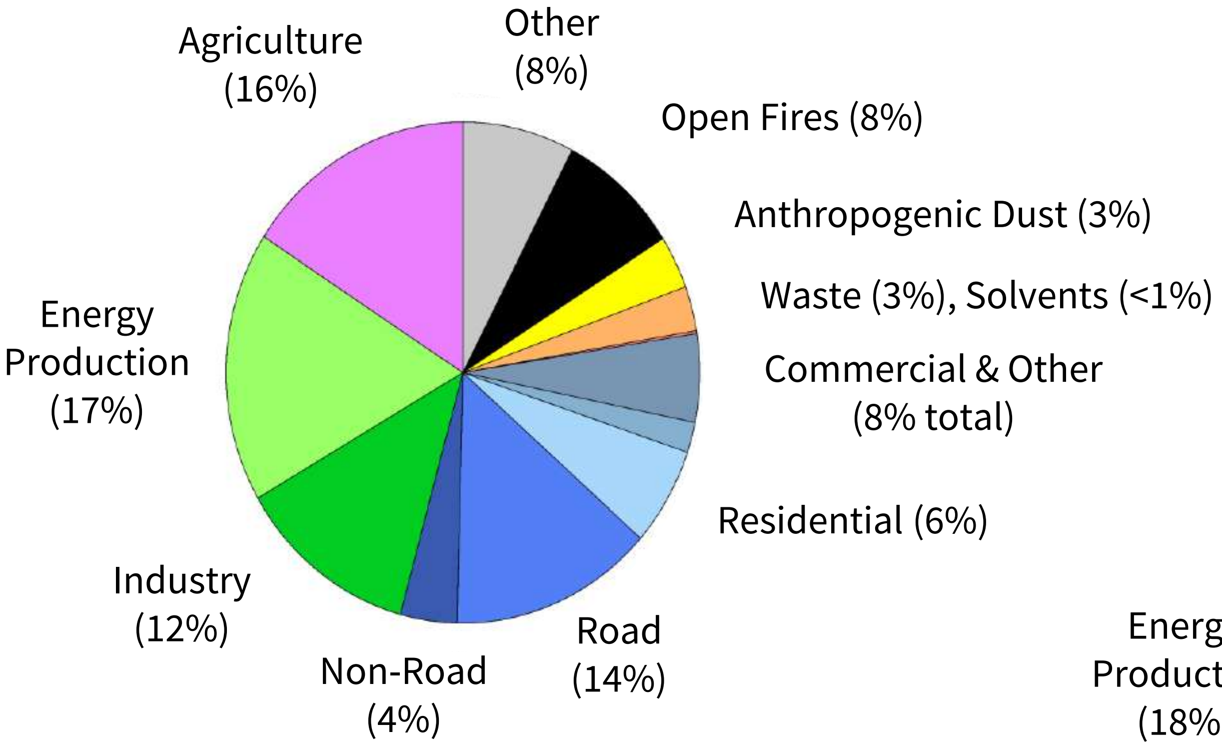


cvd_ihd
neo_lung
cvd_stroke
resp_copd
lri
t2_dm
Log(Relative Risk)
PM2.5 (μg/m3)
0.00
0.25
0.50
0.75
1.00
0.0
0.5
1.0
1.5
-0.1
0.1
0.2
0.3
0.4
0
100
200
300
400
500

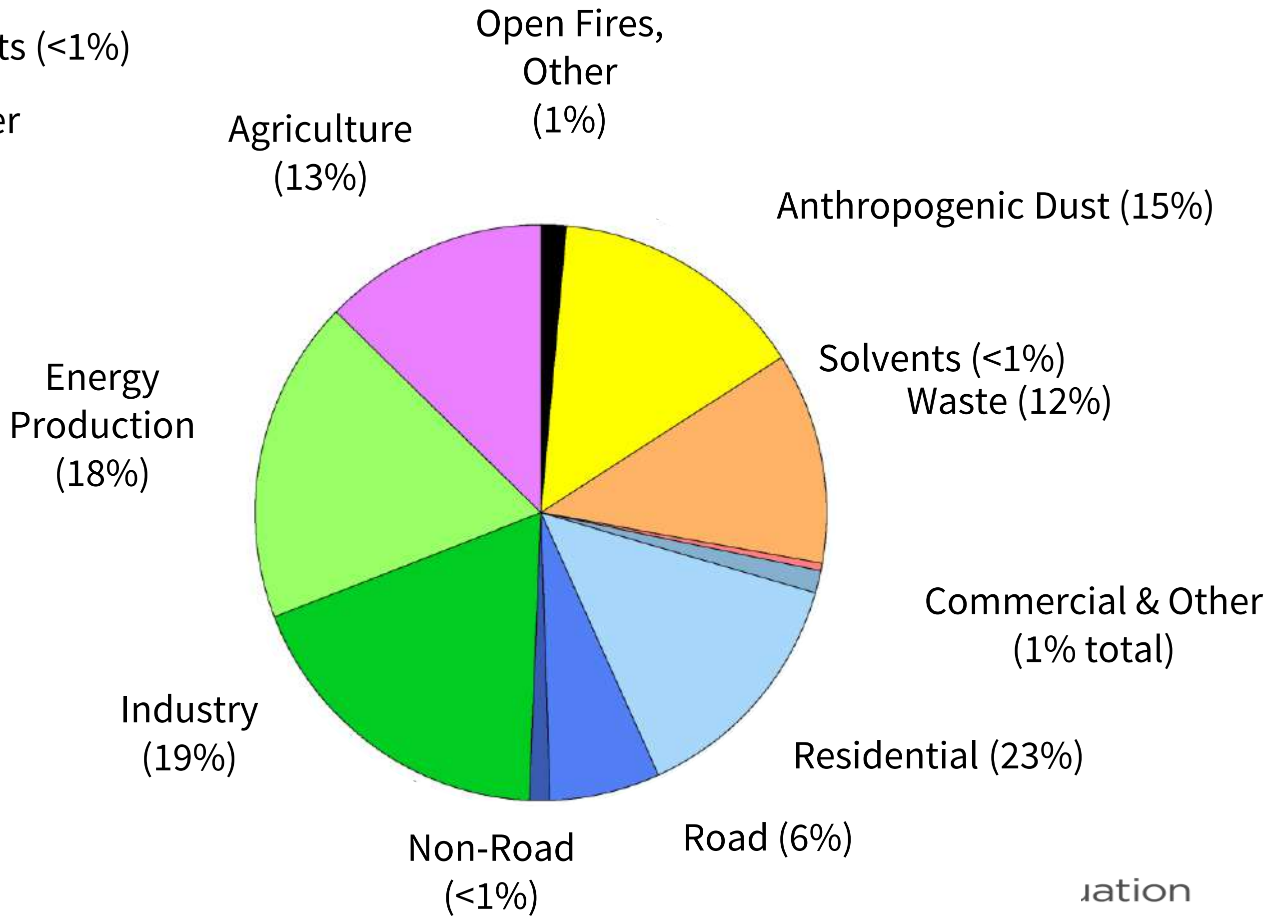
# Air pollution is a major contributor to lower life expectancy worldwide



# United States: 7.4 μg $m^{-3}$

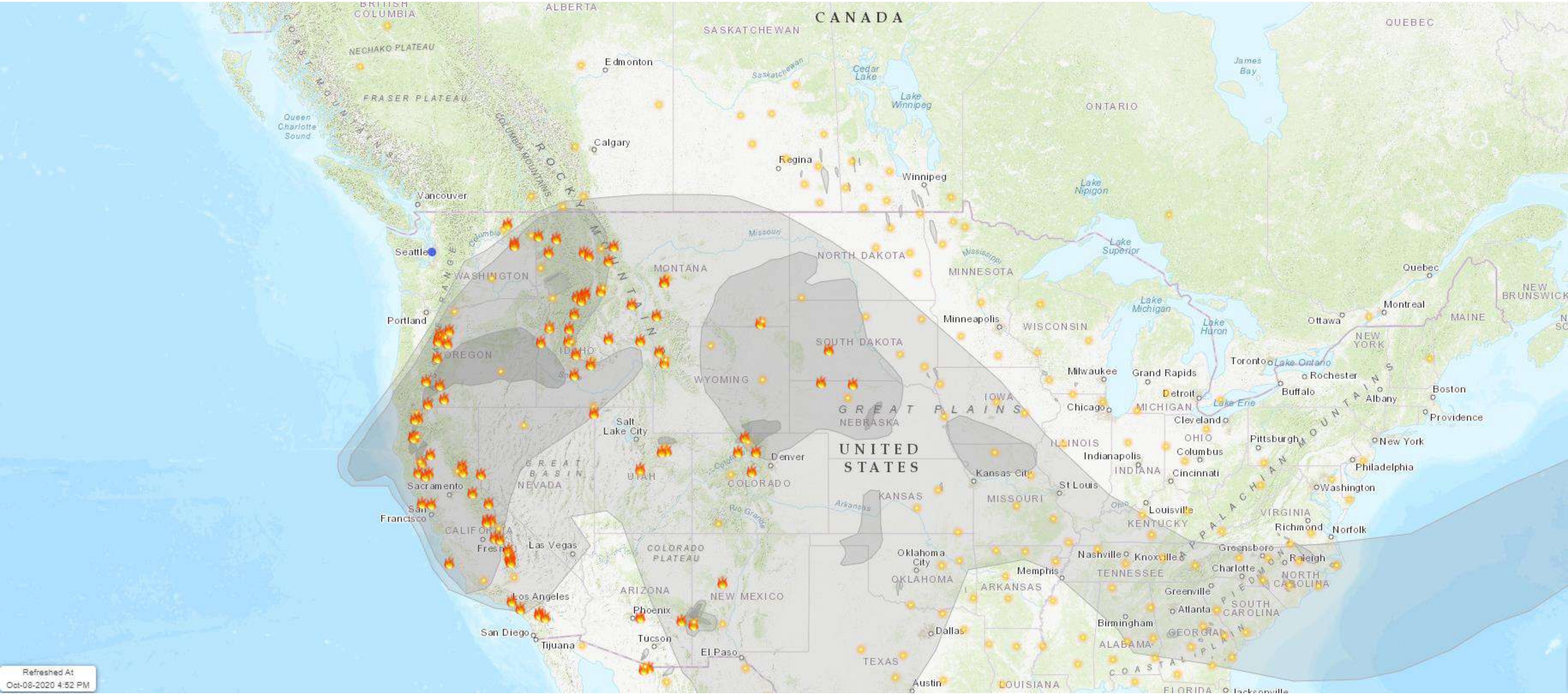



# China: 52.9 μg $m^{-3}$




Search by location...
Emissions Estimates
Particulate Matter
27 Gg
0 Gg
09/13/2021
Average Burned Area 2014
0.2% 0.5% 1% 2% 5% 10% 20% 50% 100%
Lng: -115.6641 Lat: 29.9930
Canada
Hudson Bay
United States
México
Colombia
Perú
Brazil
Bolivia
Paraguay
Ísland
Suomi / Finland
Sverige
United Kingdom
Deutschland
France
España
Italia
România
Україна
Беларусь
Ελλάς
Türkiye
Россия
Қазақстан
O'zbekiston
Türkmenistan
Монгол улс
中国
日本
India
Việt Nam
Philippines
Malaysia
Indonesia
Papua Niugini
Australia
Mali
Niger
Nigeria
Tchad
South Sudan
Soomaaliya
Kenya
Tanzania
Moçambique
Namibia
South Africa

# Fires and smoke all around us…

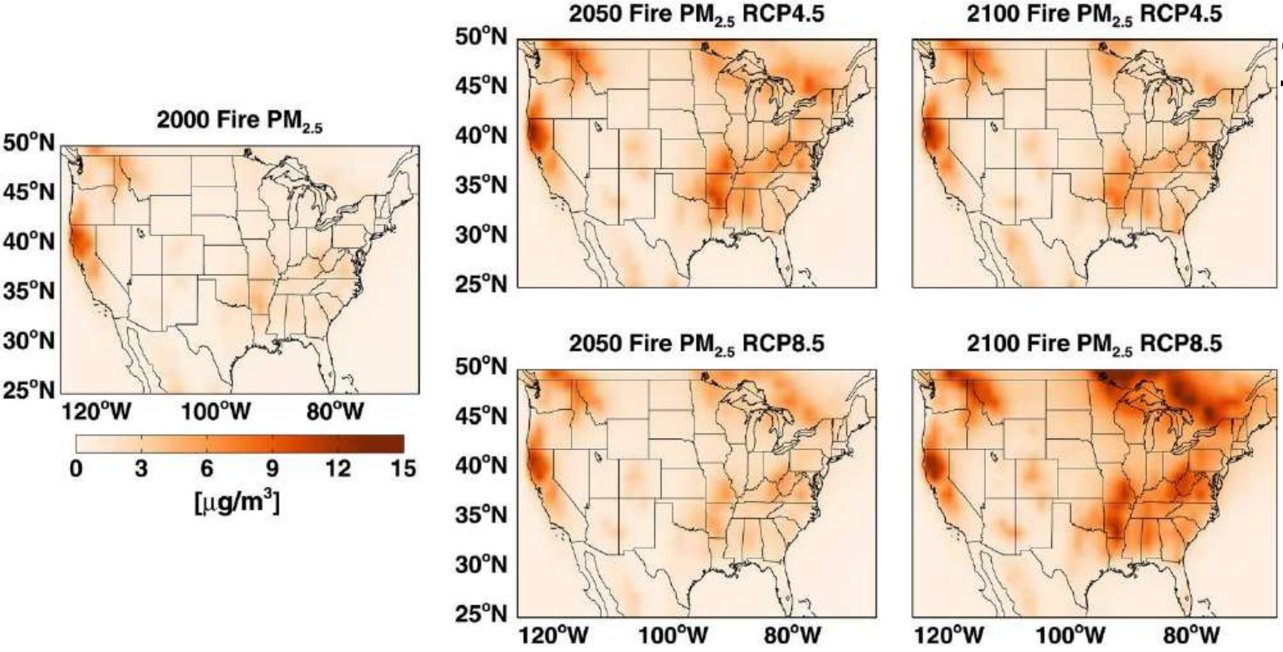


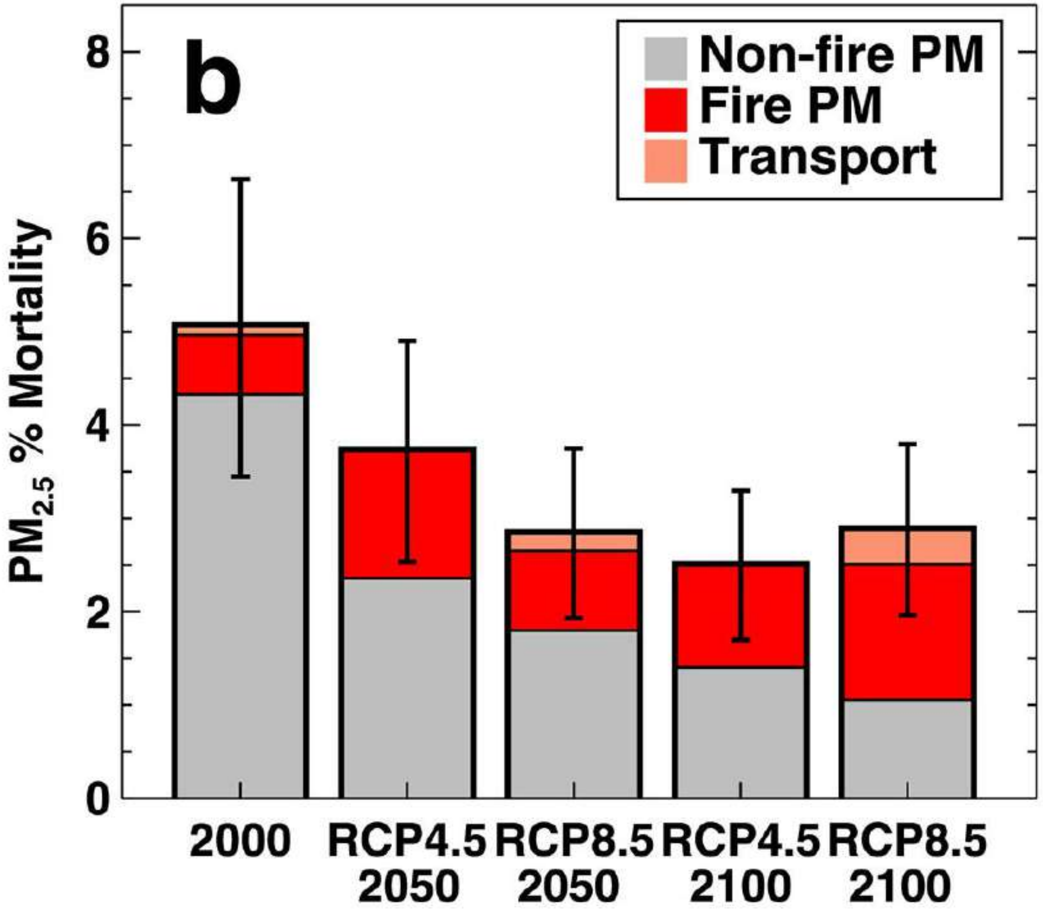

https://fire.airnow.gov/

# Future Fire Impacts on Smoke Concentrations, Visibility, and Health in the Contiguous United States

- Fire-related $PM_{2.5}$ increases 55% (RCP4.5, SSP1) - 190% (RCP8.5, SSP3) by 2100
- Current; 17,000 (0.7%) deaths attributable to fire-related $PM_{2.5}$

1.8%,






Ford, B., Val Martin, M., Zelasky, S. E., Fischer, E. V., Anenberg, S. C., Heald, C. L., & Pierce, J. R. (2018). Future fire impacts on smoke concentrations, visibility, and health in the contiguous United States. *GeoHealth*, 2, 229– 247. https://doi.org/10.1029/2018GH000144

# Particulate Air Pollution from Wildfires in the Western US under Climate Change

- ~57 million affected by ≥ 1 smoke wave (2004-2009).
- 82 million (44% increase) with climate change (A1B scenario) and population growth (2046-2051)
- Compared to 2004-2009:
  - 7 million more children (<18)
  - 5.7 million more seniors (>64)

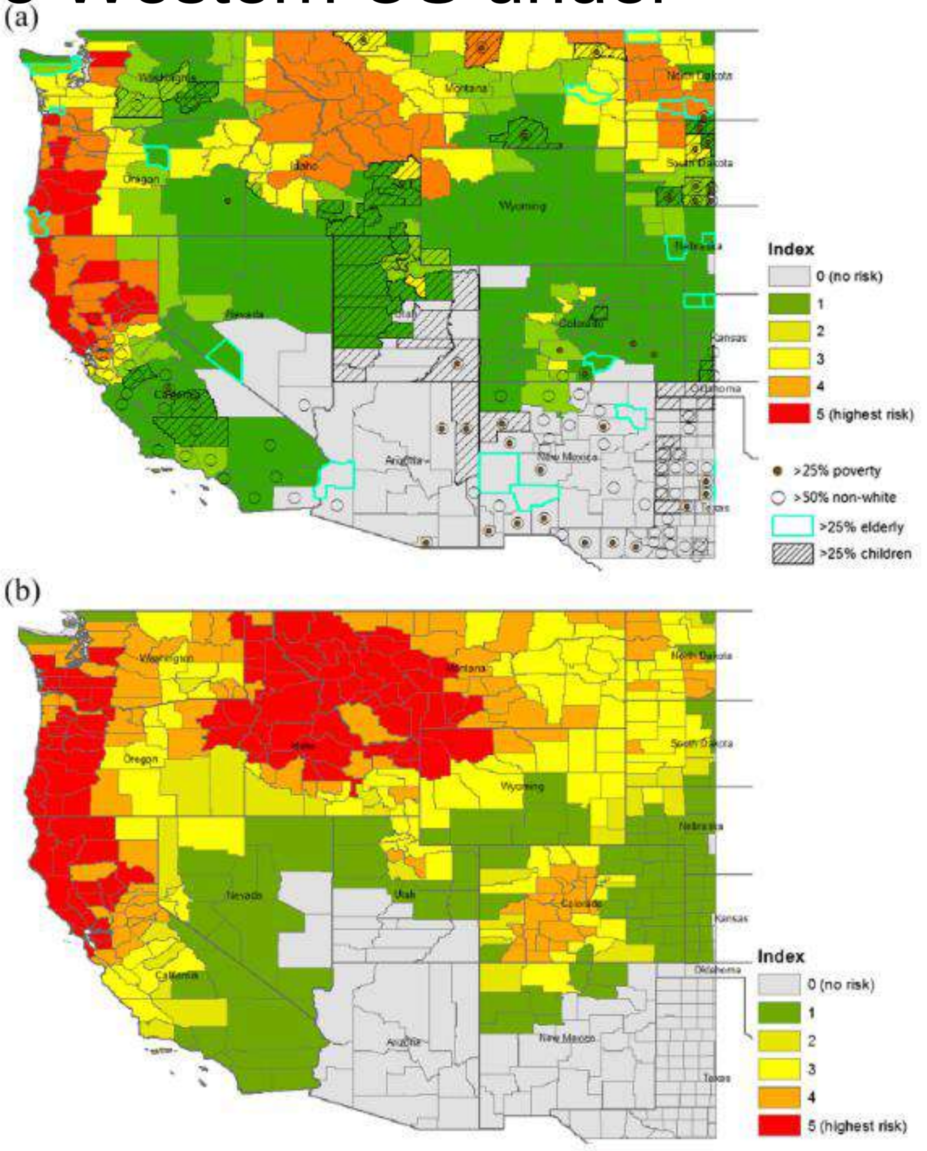



**Fig. 3** Fire Smoke Risk Index (FSRI) during fire seasons (May-October). Panel (**a**) is for present day (2004–2009) and panel (**b**) is for future (2046–2051) under climate change

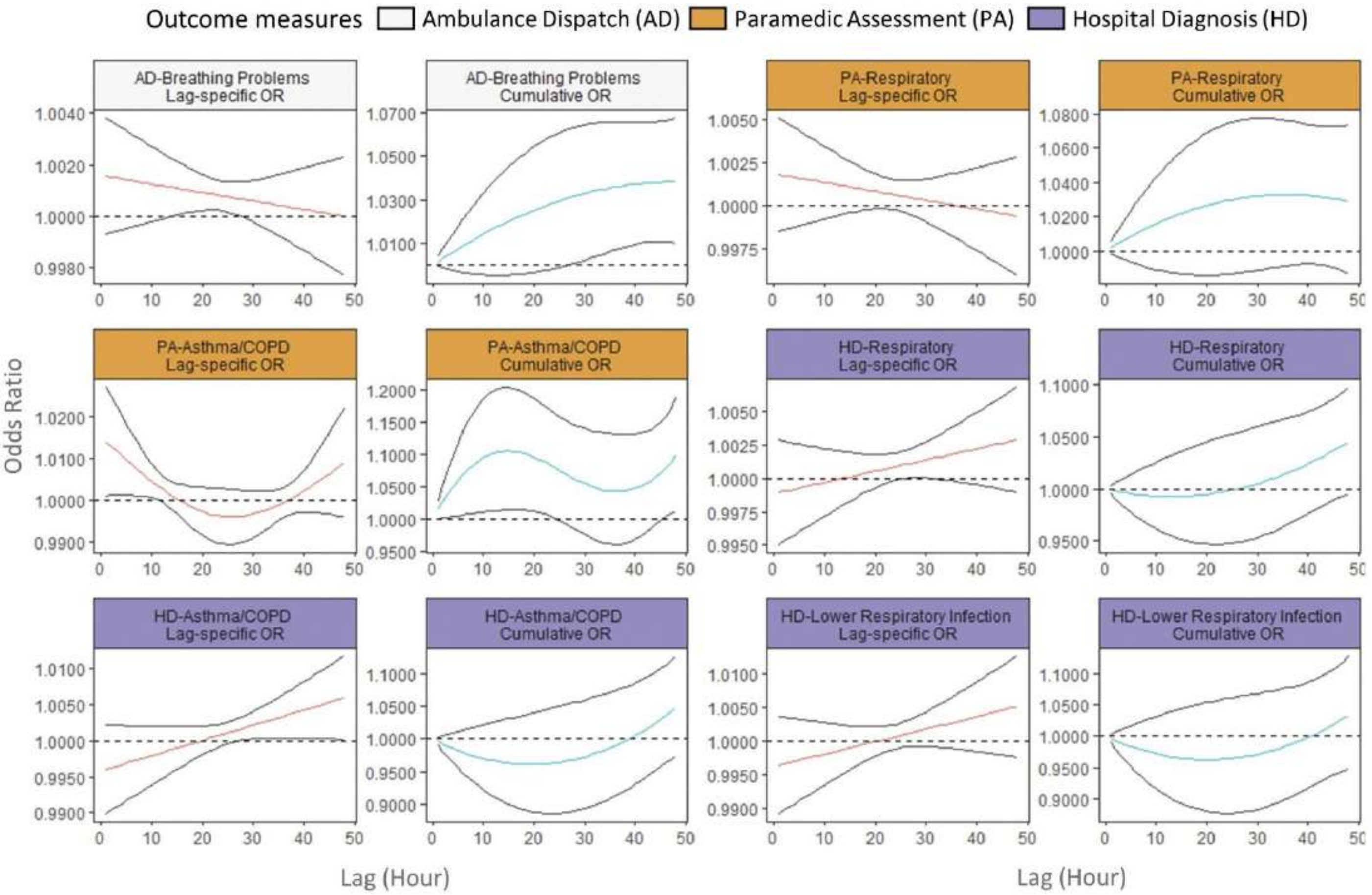


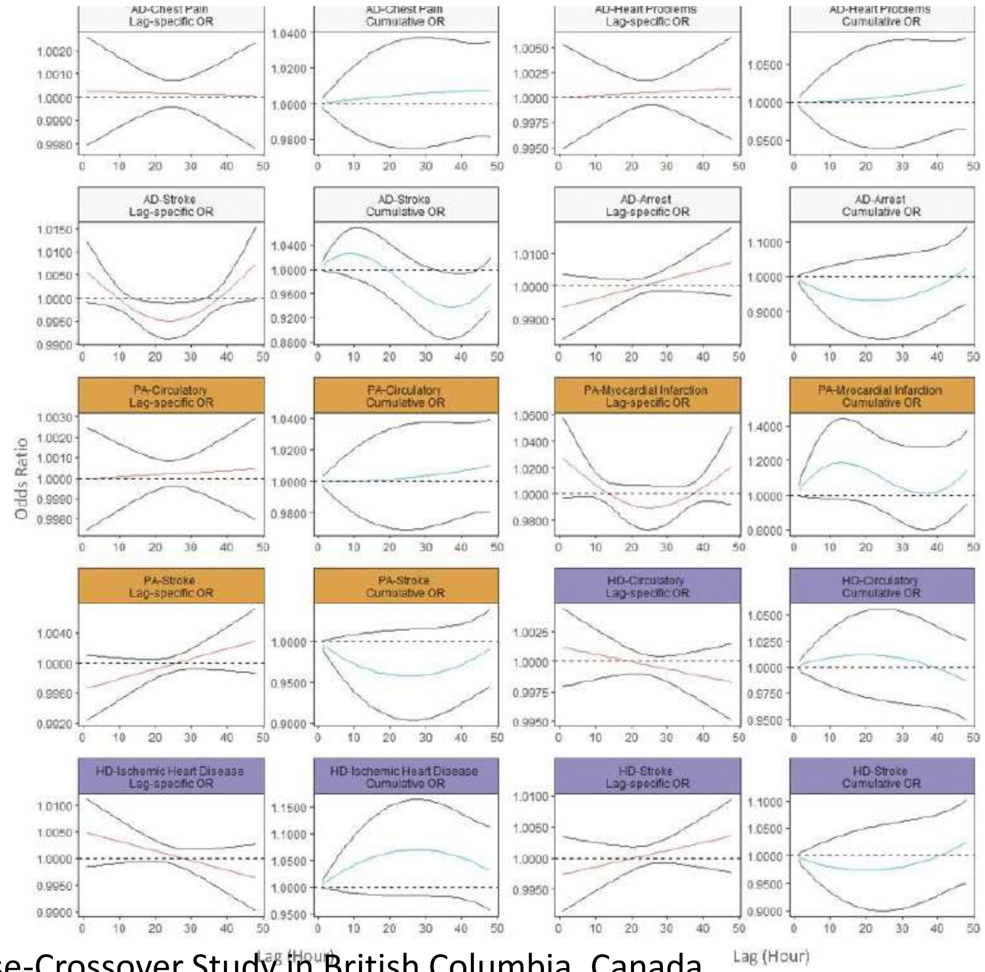
Liu JC, Mickley LJ, Sulprizio MP, et al. Particulate Air Pollution from Wildfires in the Western US under Climate Change. *Clim Change*. 2016;138(3):655-666. doi:10.1007/s10584-016-1762-6

# Timeframe of acute responses

Increased Rrespiratory and CVD (MI/IHD) impacts observed within 1 h of exposure

Indications of increased diabetes-related events

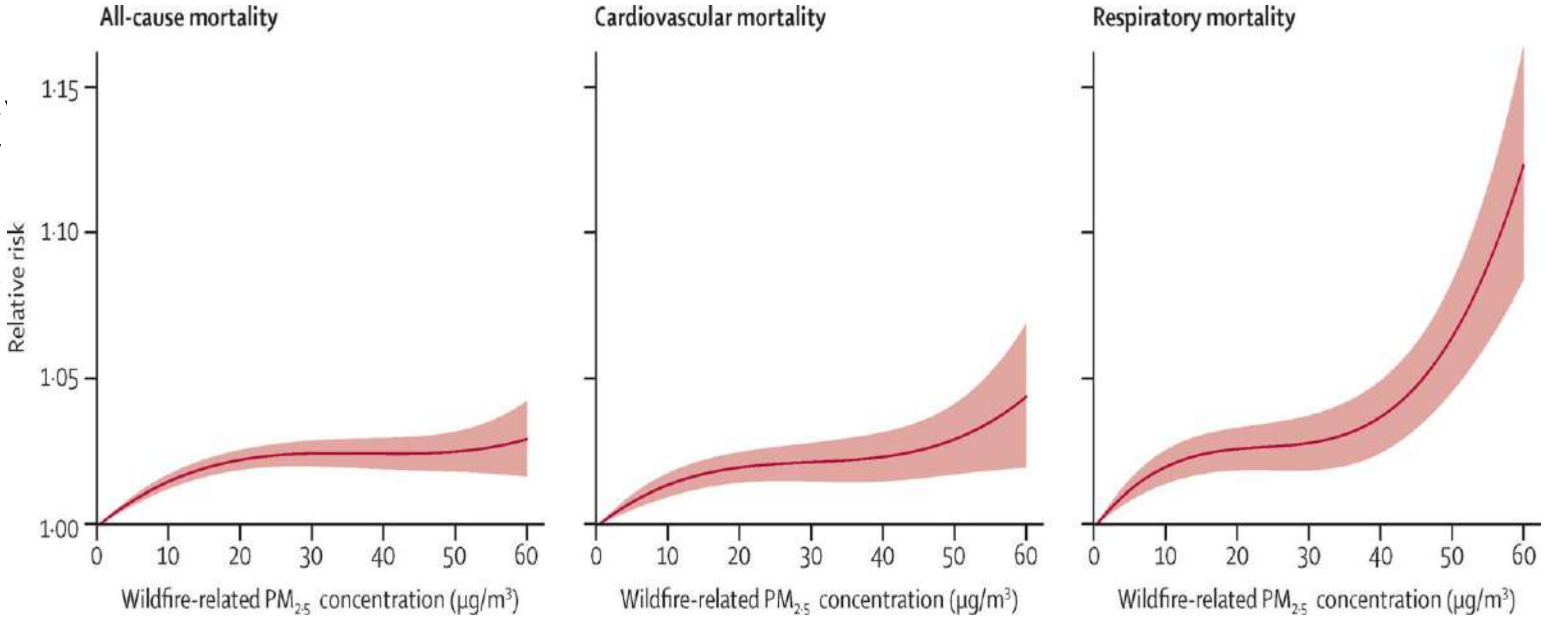



Yao et al. 2020. Particulate Matter and Ambulance Dispatches during Wildfire Seasons: A Case-Crossover Study in British Columbia, Canada.

# Mortality risk attributable to wildfire-related $PM_{2·5}$ pollution: a global time series study in 749 locations

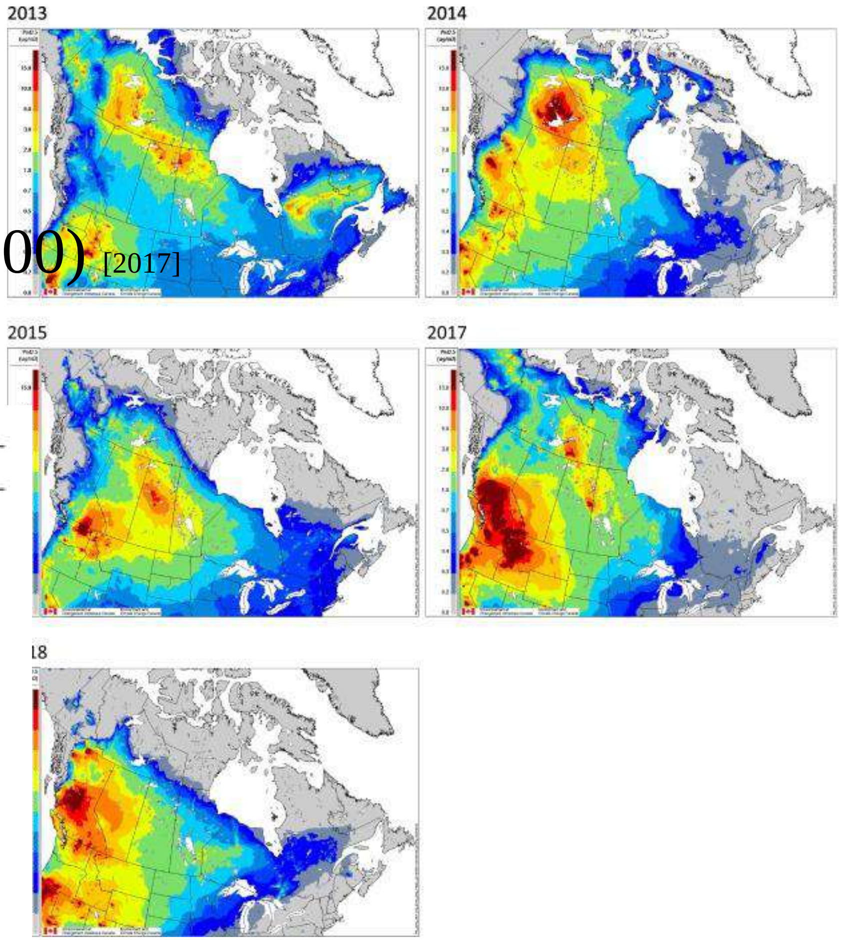
- 749 cities (43 countries), 2000–16
- 0.62% (0.48–0.75) of all-cause deaths attributable to acute exposure impacts of wildfire-related $PM_{2·5}$ during study period
- 0.55% (0.43–0.67) C
- 0.64% (0.50–0.78) R




[Mortality risk attributable to wildfire-related $PM_{2·5}$ pollution: a global time series study in 749 locations.]Chen G et al. Lancet Planet Health. 2021 Sep;5(9):e579-e587. doi: 10.1016/S2542-5196(21)00200-X.

# Health impact analysis of $PM_{2.5}$ from wildfire smoke in Canada (2013–2015, 2017–2018)

- Acute exposure mortality: 54 (22-87) [2013] - 240 (95-389) [2017]
- Chronic exposure mortality: 570 (290-840) [2013] – 2500 (1300-3600) [2017]

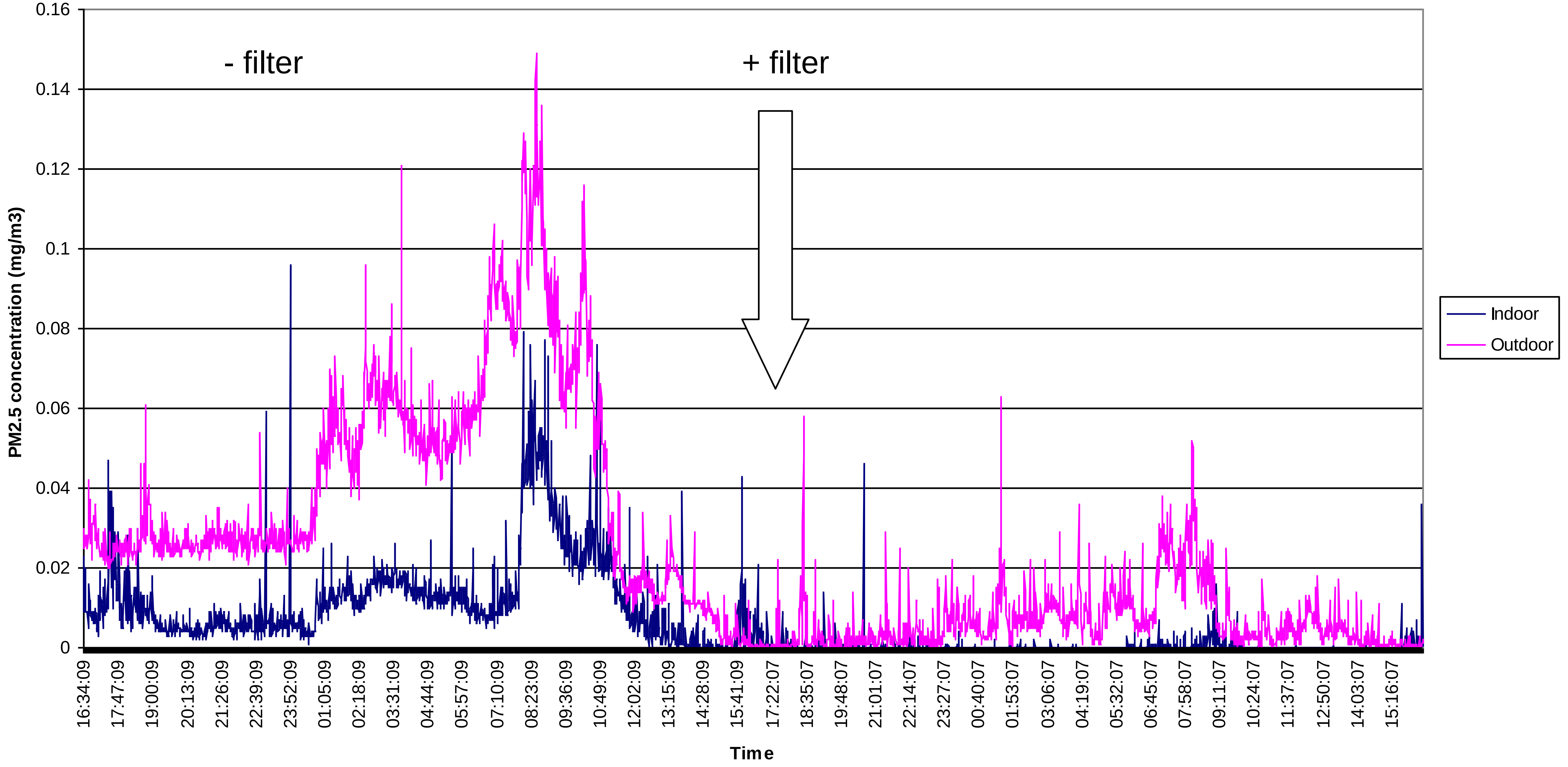



Acute health impacts and economic valuation[a] from wildfire $PM_{2.5}$, for 2013–2015 and 2017–2018 [95% confidence intervals].

| | 2013 | 2014 | 2015 | 2017 | 2018 |
|---|---|---|---|---|---|
| Acute mortalities | 54<br>[22–87] | 70<br>[26–113] | 97<br>[39–156] | 240<br>[95–389] | 131<br>[50–210] |
| Acute mortality valuation[b] | **$410M**<br>[$120M–830M] | **$520M**<br>[$160M–$1.1B] | **$730M**<br>[$220M–$1.5B] | **$1.8B**<br>[$530M–$3.7B] | **$980M**<br>[$280M–$2.0B] |
| Acute respiratory symptom days | 1,400,000<br>[0–2,850,000] | 1,900,000<br>[0–3,740,000] | 2,500,000<br>[0–5,100,000] | 6,100,000<br>[0–12,200,000] | 3,400,000<br>[0–6,760,000] |
| Asthma symptom days[c] | 100,000<br>[21,000–185,000] | 140,000<br>[29,000–248,000] | 190,000<br>[40,000–336,000] | 420,000<br>[91,000–739,000] | 240,000<br>[52,000–431,000] |
| Child acute bronchitis episodes | 2600<br>[0–5700] | 3400<br>[0–7700] | 4600<br>[0–10,200] | 10,000<br>[0–22,200] | 6000<br>[0–13,000] |
| Respiratory emergency room visits | 170<br>[114–230] | 230<br>[150–300] | 310<br>[200–410] | 710<br>[470–950] | 420<br>[280–570] |
| Respiratory hospital admissions | 34<br>[23–46] | 45<br>[29–61] | 61<br>[40–83] | 140<br>[90–190] | 83<br>[54–112] |
| Cardiac emergency room visits | 60<br>[32–88] | 75<br>[41–110] | 110<br>[56–155] | 250<br>[130–380] | 140<br>[75–210] |
| Cardiac hospital admissions | 46<br>[24–67] | 57<br>[31–84] | 80<br>[43–117] | 190<br>[102–283] | 110<br>[58–160] |
| Restricted activity days | 750,000<br>[439,000–1,057,000] | 1,000,000<br>[579,000–1,419,000] | 1,400,000<br>[791,000–1,899,000] | 3,200,000<br>[1,910,000–4,520,000] | 1,800,000<br>[1,074,000–2,543,000] |
| Acute morbidity valuation[b] | **$73M**<br>[$13M–$177M] | **$97M**<br>[$17M–$240M] | **$131M**<br>[$24M–$320M] | **$310M**<br>[$58M–$750M] | **$170M**<br>[$33M–$420M] |

[a] The dollar values are socio-economic values associated with small changes in the risk of various health outcomes. AQBAT provides economic valuation estimates of those health impacts, considering the potential social welfare consequences, including medical costs, reduced workplace productivity, pain and suffering, and the impacts of increased mortality risk.
[b] Values represent mean valuation of multiple iterations; [2.5th–97.5th percentiles].
[c] Asthma symptom days are only estimated for children (5–19 years of age).

Health impact analysis of $PM_{2.5}$ from wildfire smoke in Canada (2013-2015, 2017-2018). Matz CJ, Egyed M, Xi G, Racine J, Pavlovic R, Rittmaster R, Henderson SB, Stieb DM. Sci Total Environ. 2020 Jul 10;725:138506. doi: 10.1016/j.scitotenv.2020.138506




Summer 2004, William's Lake, BC Age:20 years, Size:1060ft$^2$ (7 rooms), open windows during morning, no air conditioning

Barn P, Larson T, Noullett M, Kennedy S, Copes R, Brauer M. Infiltration of forest fire and residential wood smoke: an evaluation of air cleaner effectiveness. J Expo Sci Environ Epidemiol. 2008 Sep;18(5):503-11.

Athens, Winter 2012-13

# Biomass combustion (heat, energy)

**Energy policy**

EU Primary $PM_{2.5}$ emissions (residential woodstoves)

25% (1990) -> 38% (2020)

Sigsgaard et al. Eur Respir J 2015;46:1577-1588

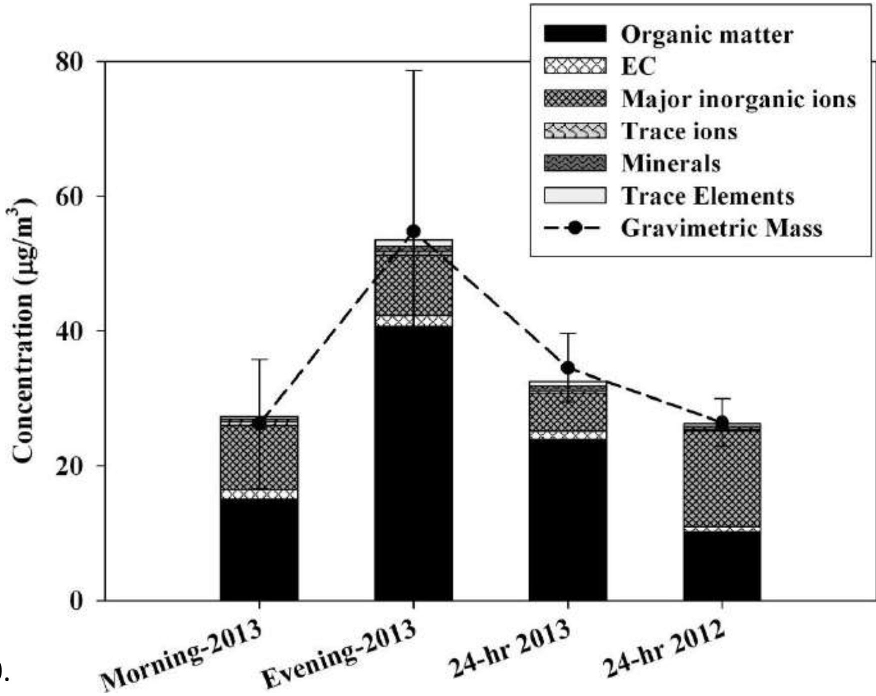
**Economy**

30% increase (2012-13) $PM_{2.5}$

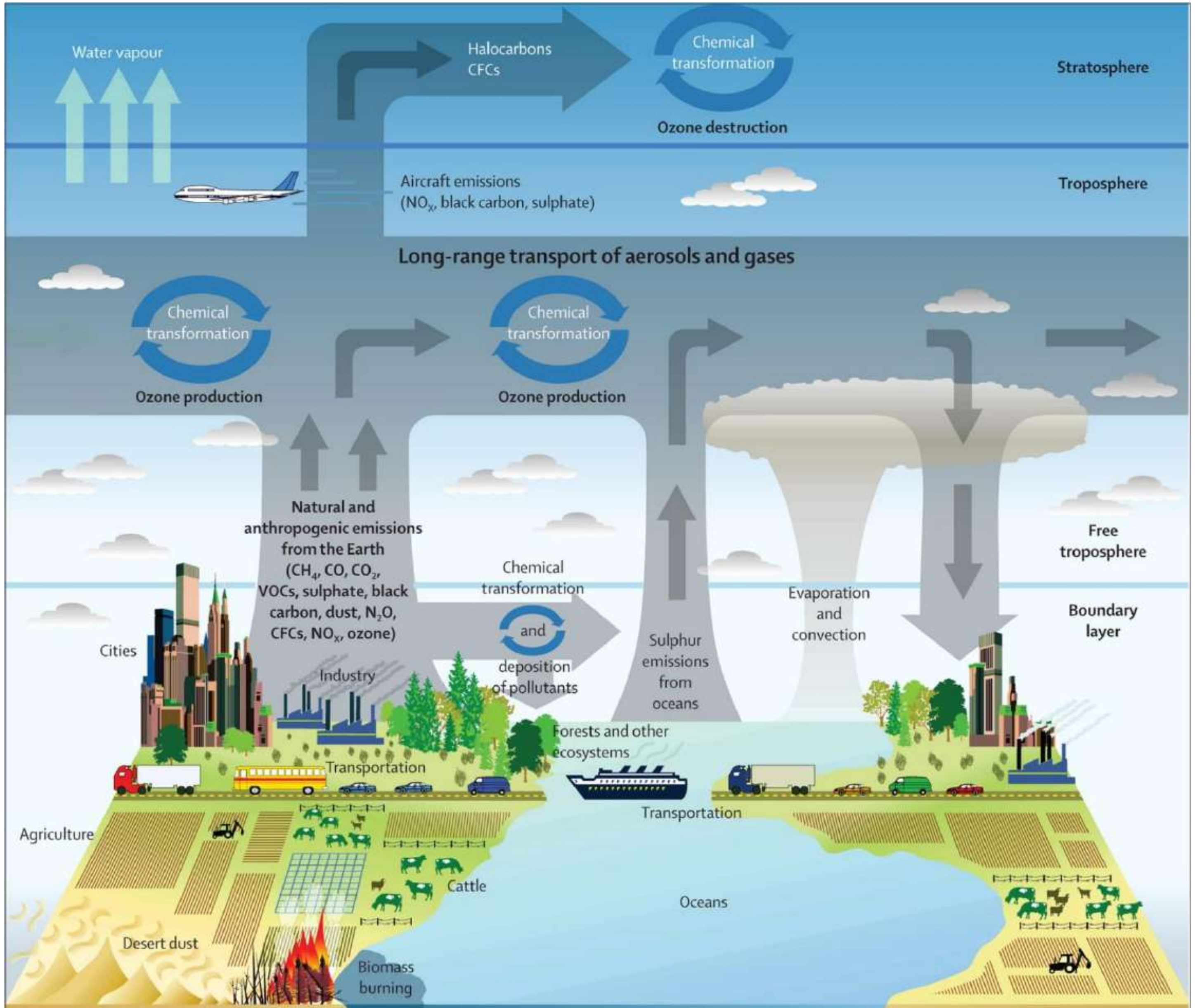
2.5X increase wood smoke tracers.

20-30% decrease in fuel oil tracers (e.g., Ni and V)

Saffari et al. *Environ. Sci. Technol.* **2013,** 47, 13313-13320.

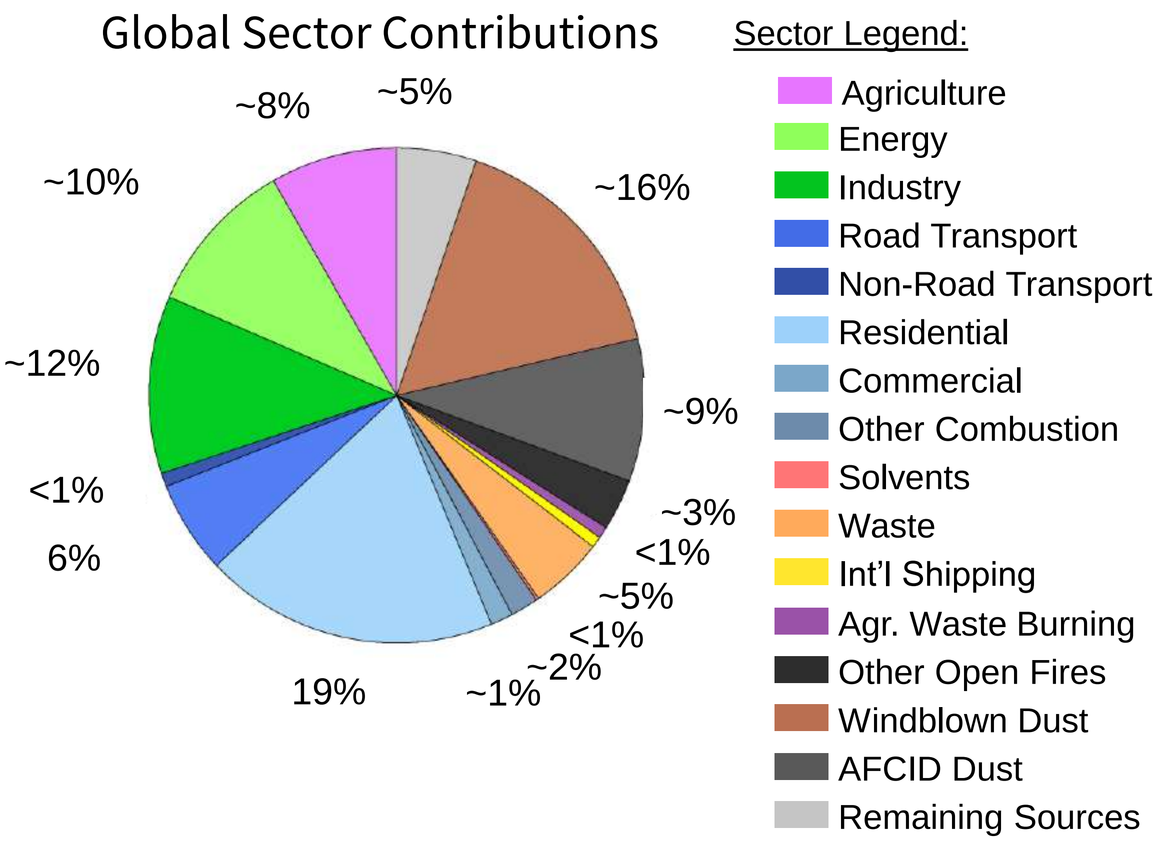


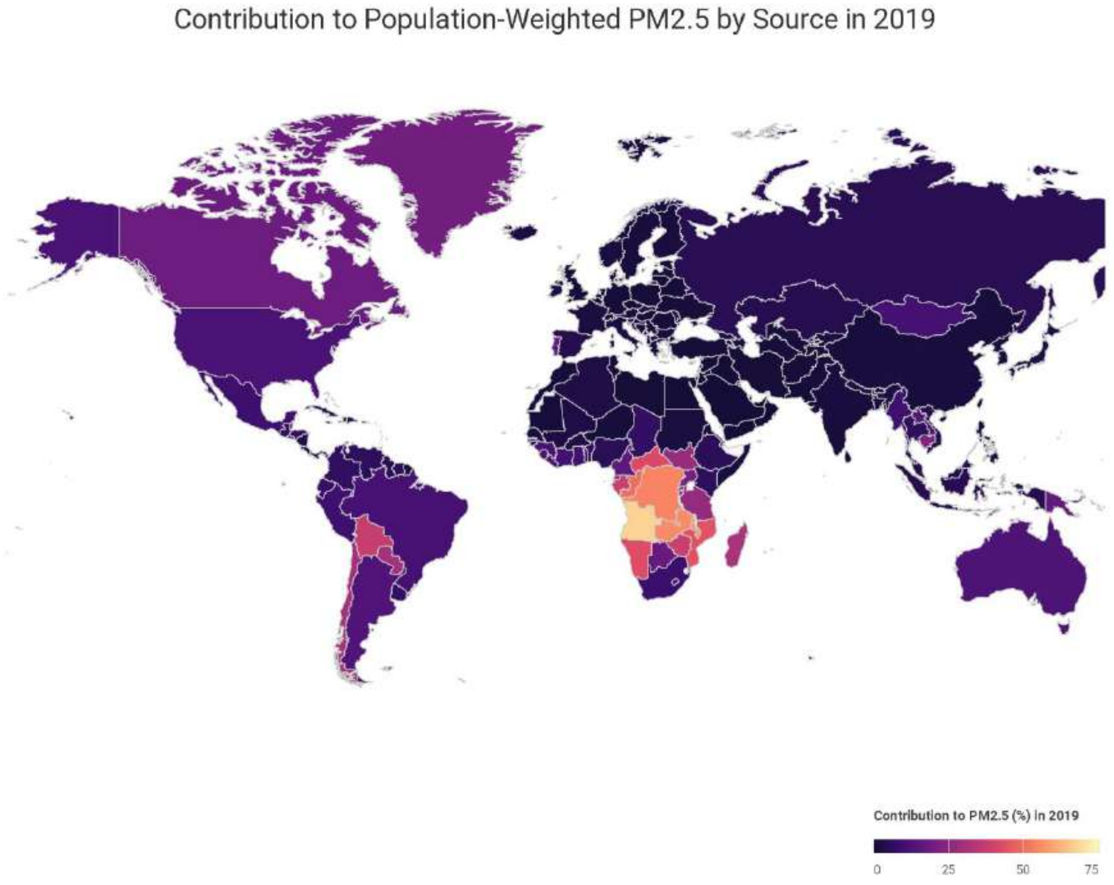
# Atmospheric processing




Guarnieri and Balmes. Lancet, 2014. 383(9928): 1581 – 1592 doi:10.1016/S0140-6736(14)60617-6

# Source sector contributions (GBD 2019)

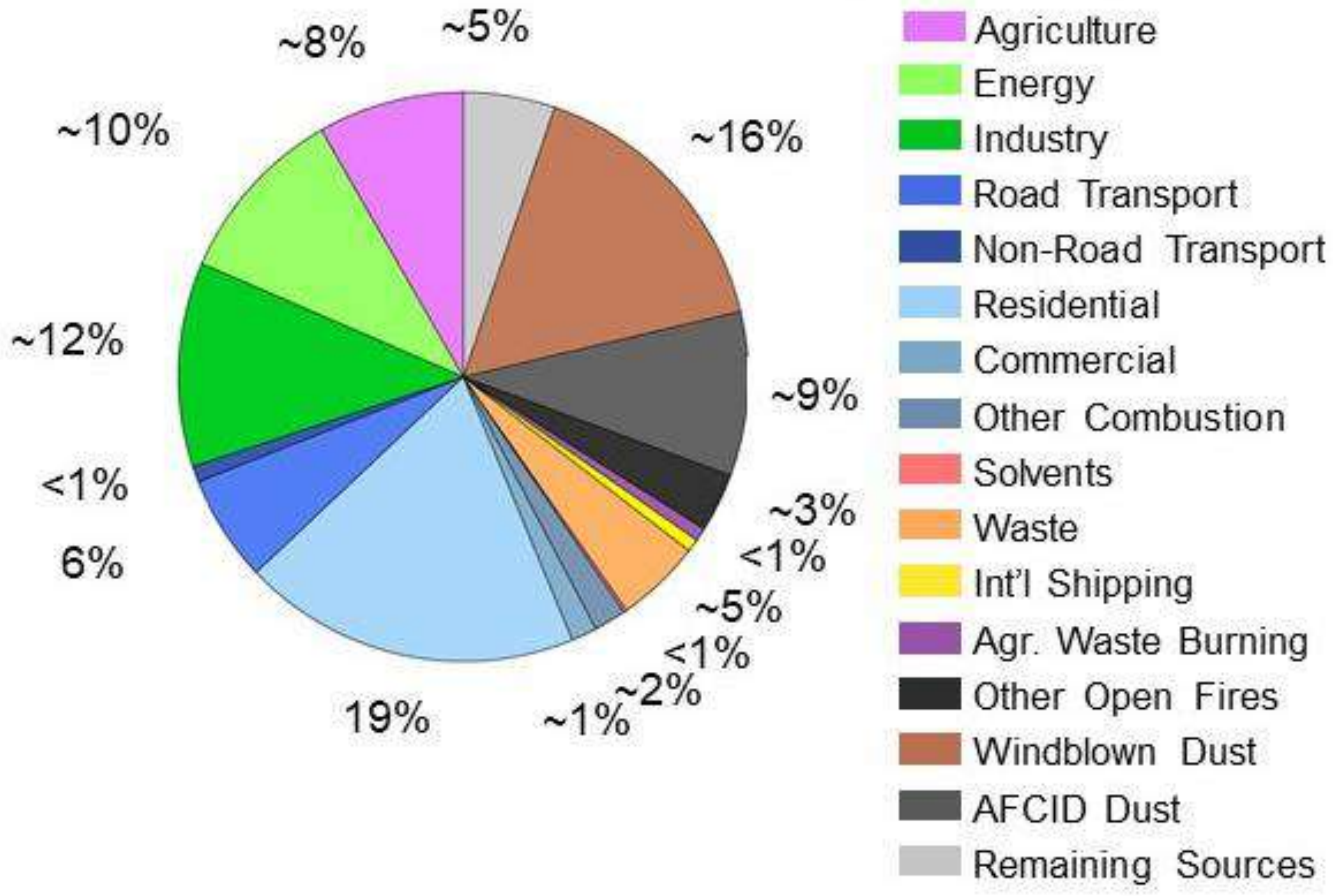


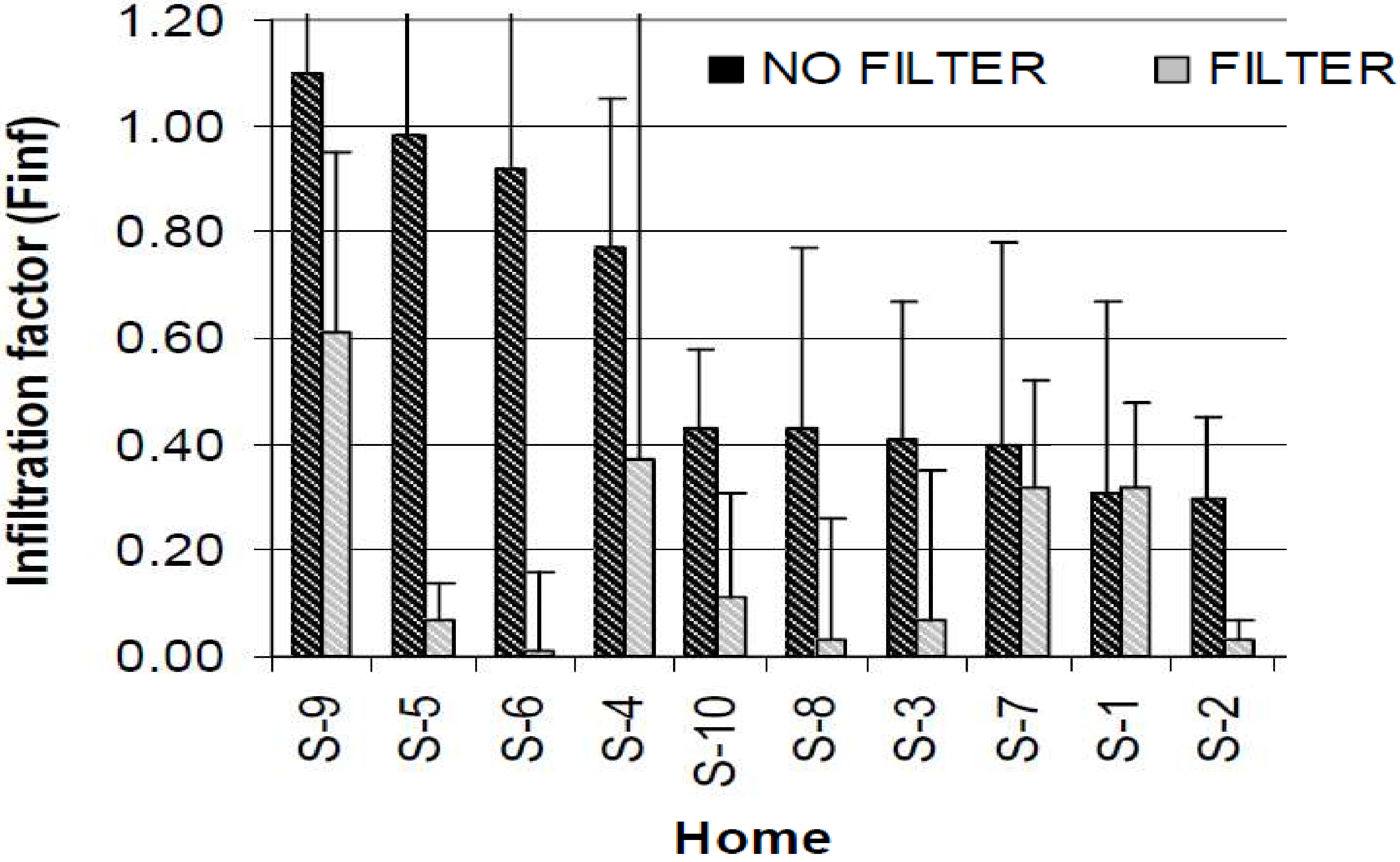

https://gbdmaps.med.ubc.ca/

Source sector and fuel contributions to ambient $PM_{2.5}$ and attributable mortality across multiple spatial scales. Nat Commun. 2021 Jun 14

# Global sources of ambient ($PM_{2.5}$) air pollution



# Room HEPA filter air cleaners

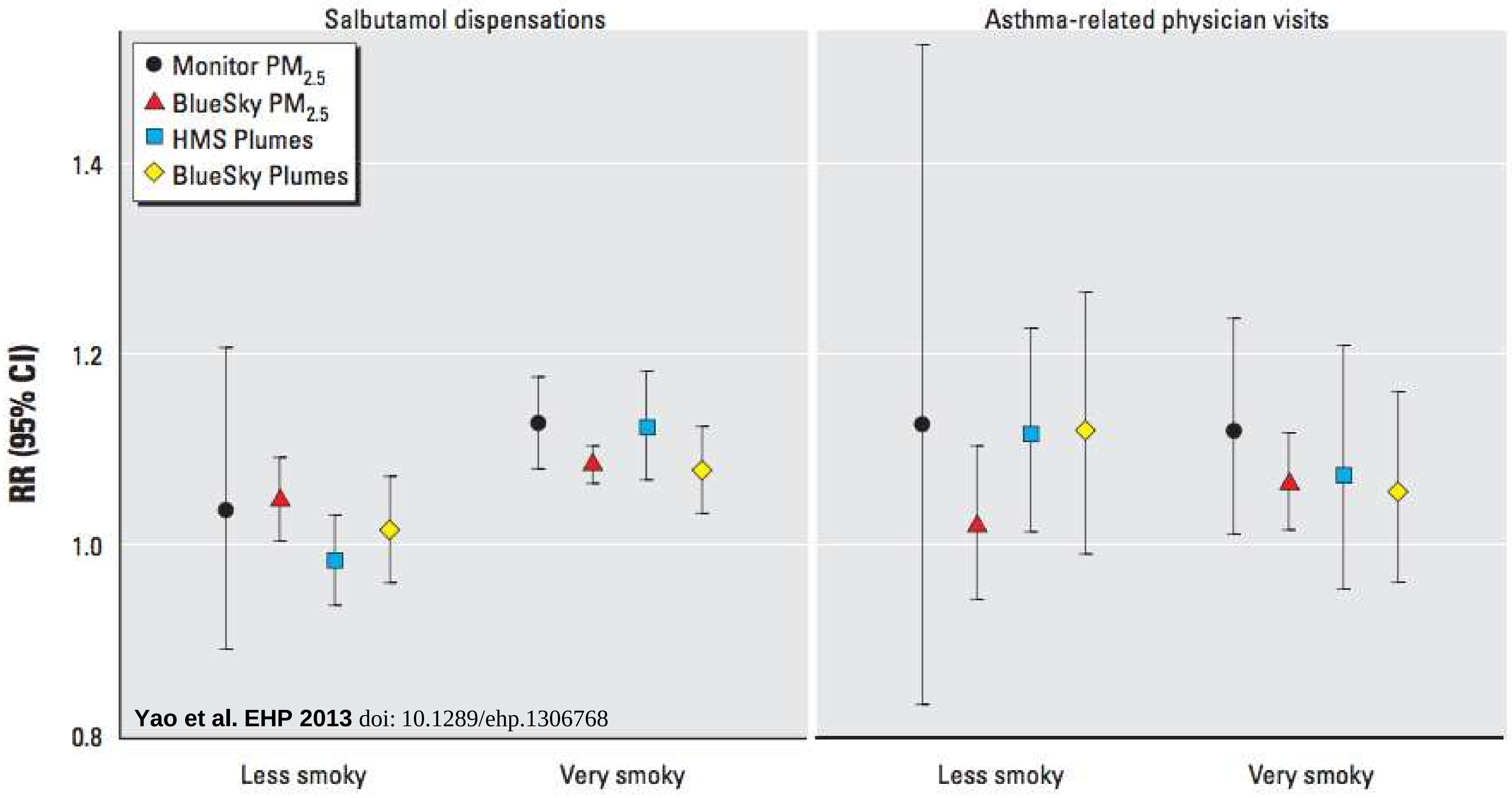



**65% decrease in indoor fire smoke**



Barn P, Larson T, Noullett M, Kennedy S, Copes R, Brauer M. Infiltration of forest fire and residential wood smoke: an evaluation of air cleaner effectiveness. J Expo Sci Environ Epidemiol. 2008 Sep;18(5):503-11.

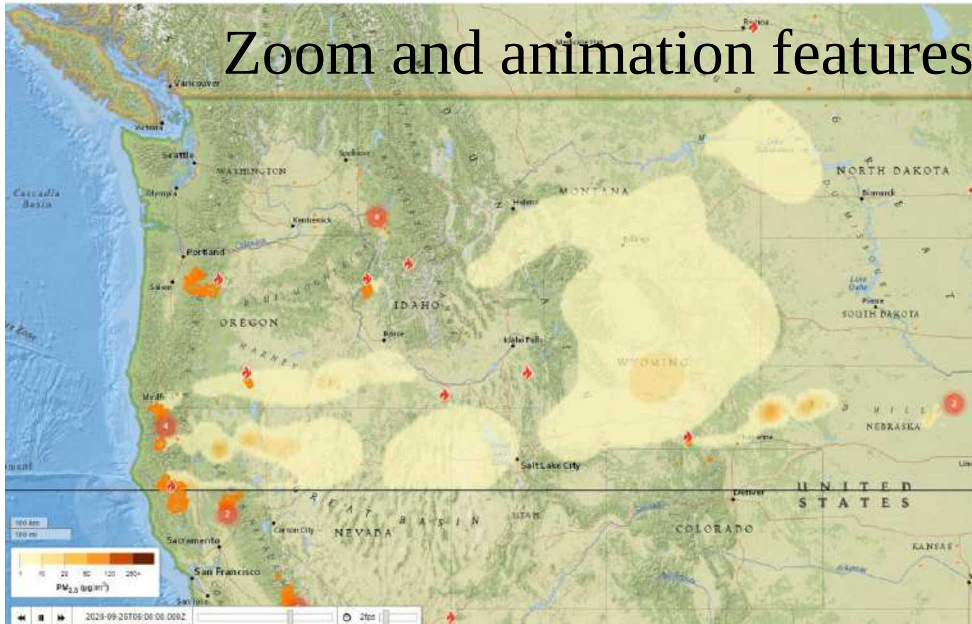
# Effects of **forecasted** smoke consistent with effects of **observed** smoke for asthma outcomes




**Yao et al. EHP 2013** doi: 10.1289/ehp.1306768

# Smoke forecasts for health protection

- Temporal and spatial specificity > accuracy or complexity
- Integrate into existing weather tools
- Extend current tools to 7-day smoke forecast




Bowman, D.M.J.S.; Daniels, L.D.; Johnston, F.H.; Williamson, G.J.; Jolly, W.M.; Magzamen, S.; Rappold, A.G.; Brauer, M.; Henderson, S.B. Can Air Quality Management Drive Sustainable Fuels Management at the Temperate Wildland–Urban Interface? *Fire* **2018**, *1*, 27