The health effects of air pollution: “Democratizing” tools to inform global policy decisions

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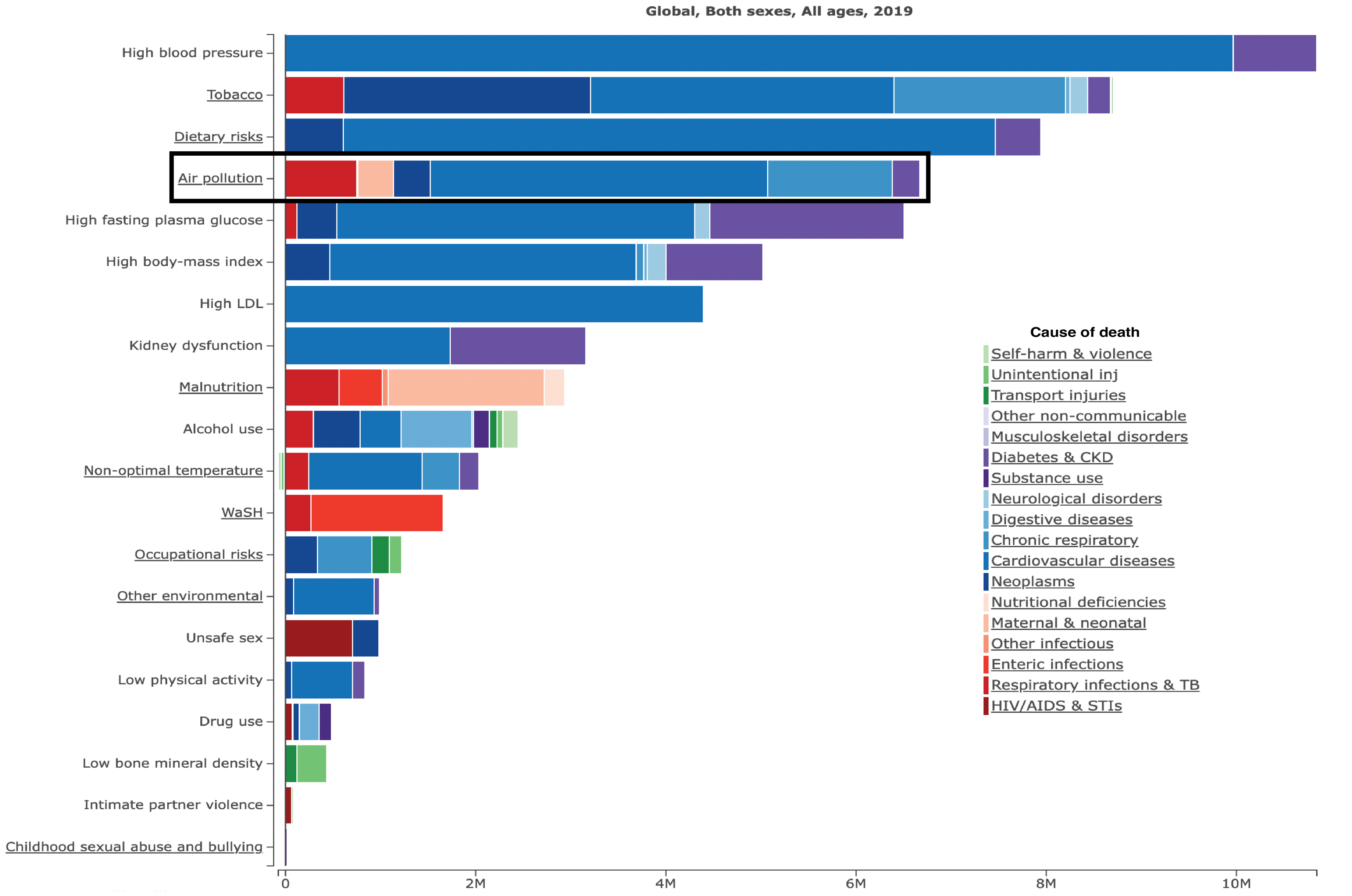
Overview

- **The people who suffer most from environmental issues often have the fewest tools & resources to address them**
  - Focus on air pollution and human health
    - Background: $PM_{2.5}$ and human health, exposure inequities
  - Overview of how science informs policy
    - Air quality health impact assessment, resource inequities
- **There are ongoing attempts to "democratize" tools & resources**
  - Focus on reduced-complexity air quality modeling
    - My work: Global InMAP
- **These often come with tradeoffs**
  - *e.g.*, losses in accuracy, extrapolating out of context

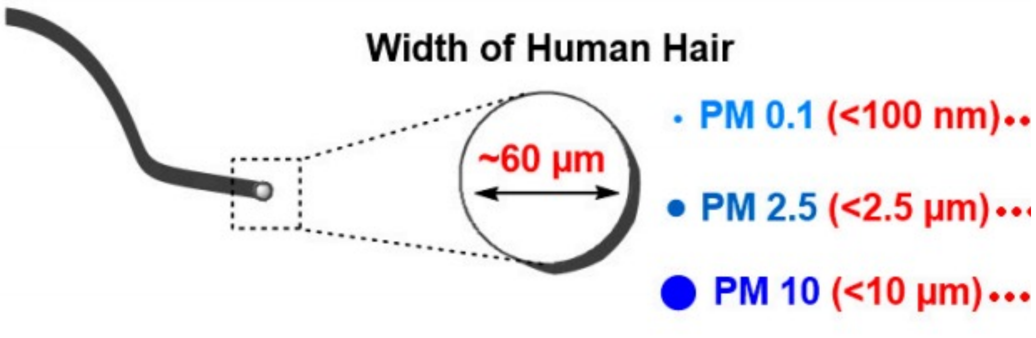

SUSTAINABLE DEVELOPMENT GOALS
17 GOALS TO TRANSFORM OUR WORLD
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

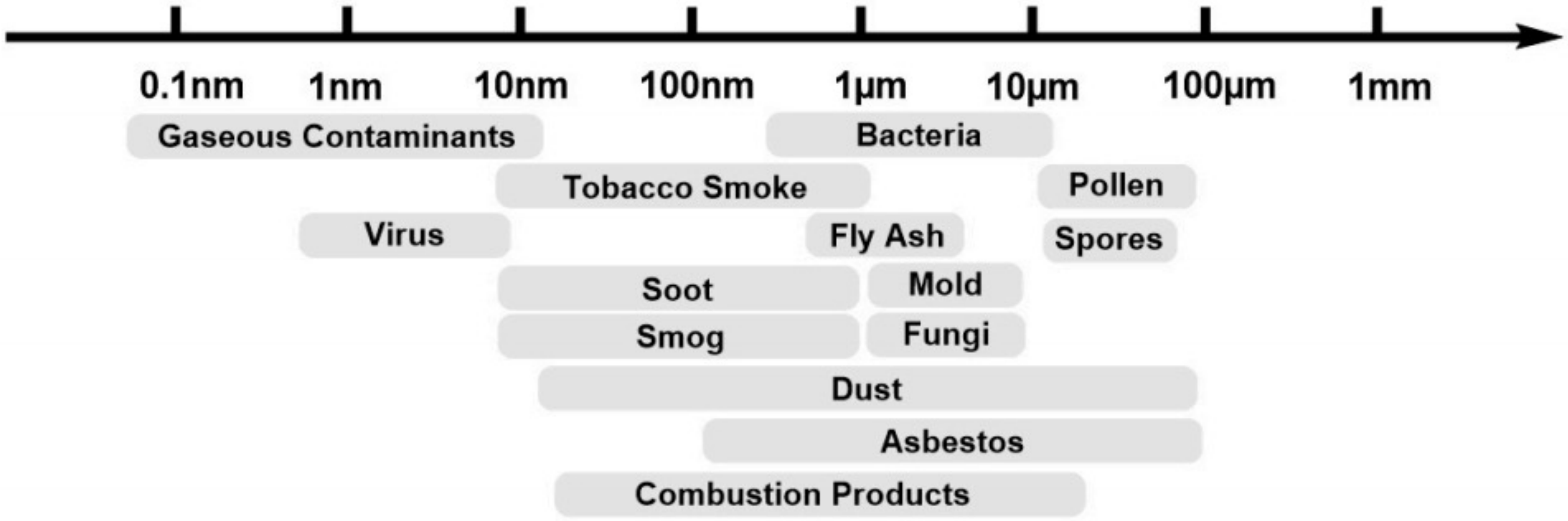
Air pollution: the most important environmental health risk



IHME (2020), *adapted from* Fouranzafar *et al.*, Lancet 386.10010 (2015). doi:10.1016/S0140-6736(16)31679-8

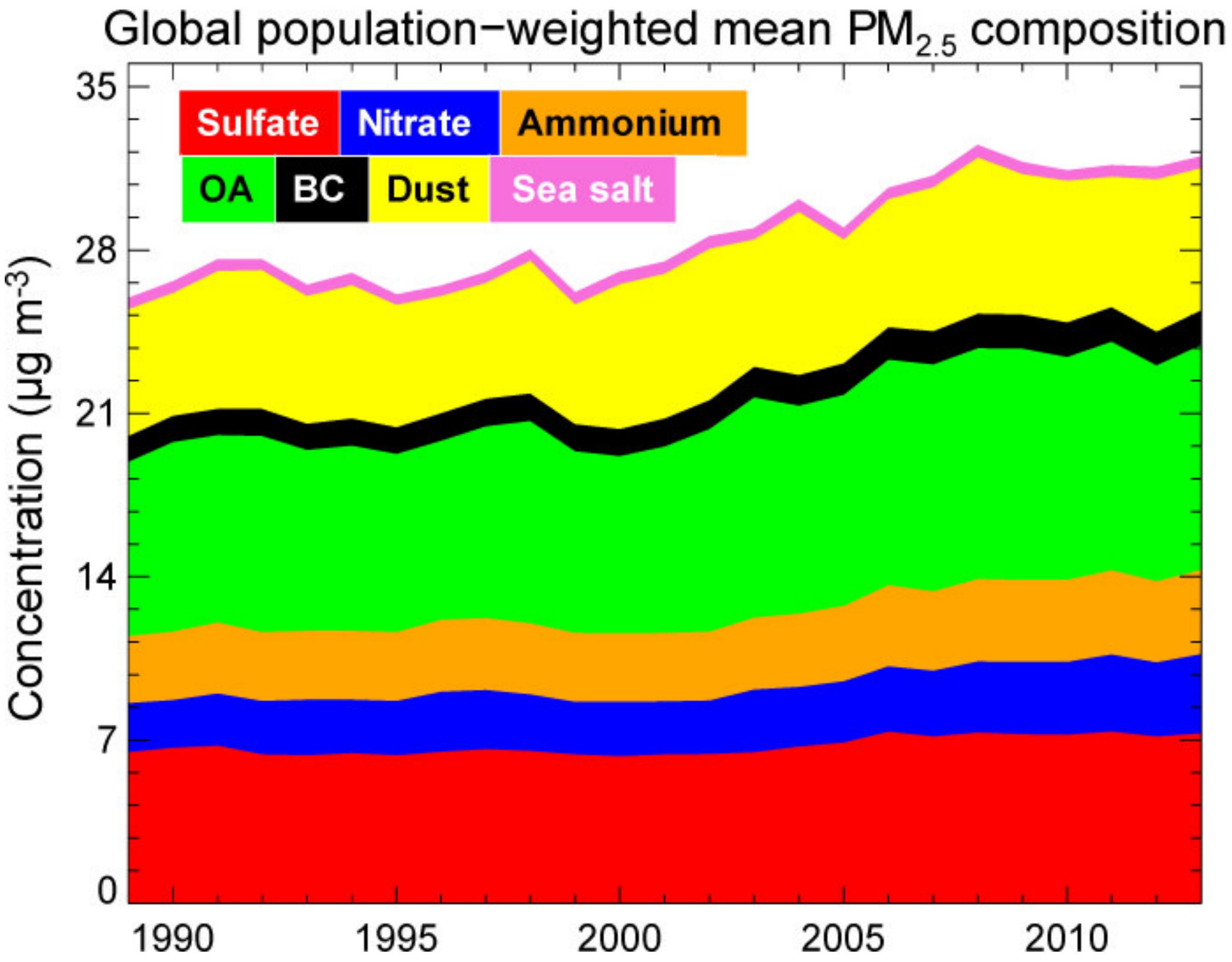
Most of the deaths are from exposure to fine particles ($PM_{2.5}$)





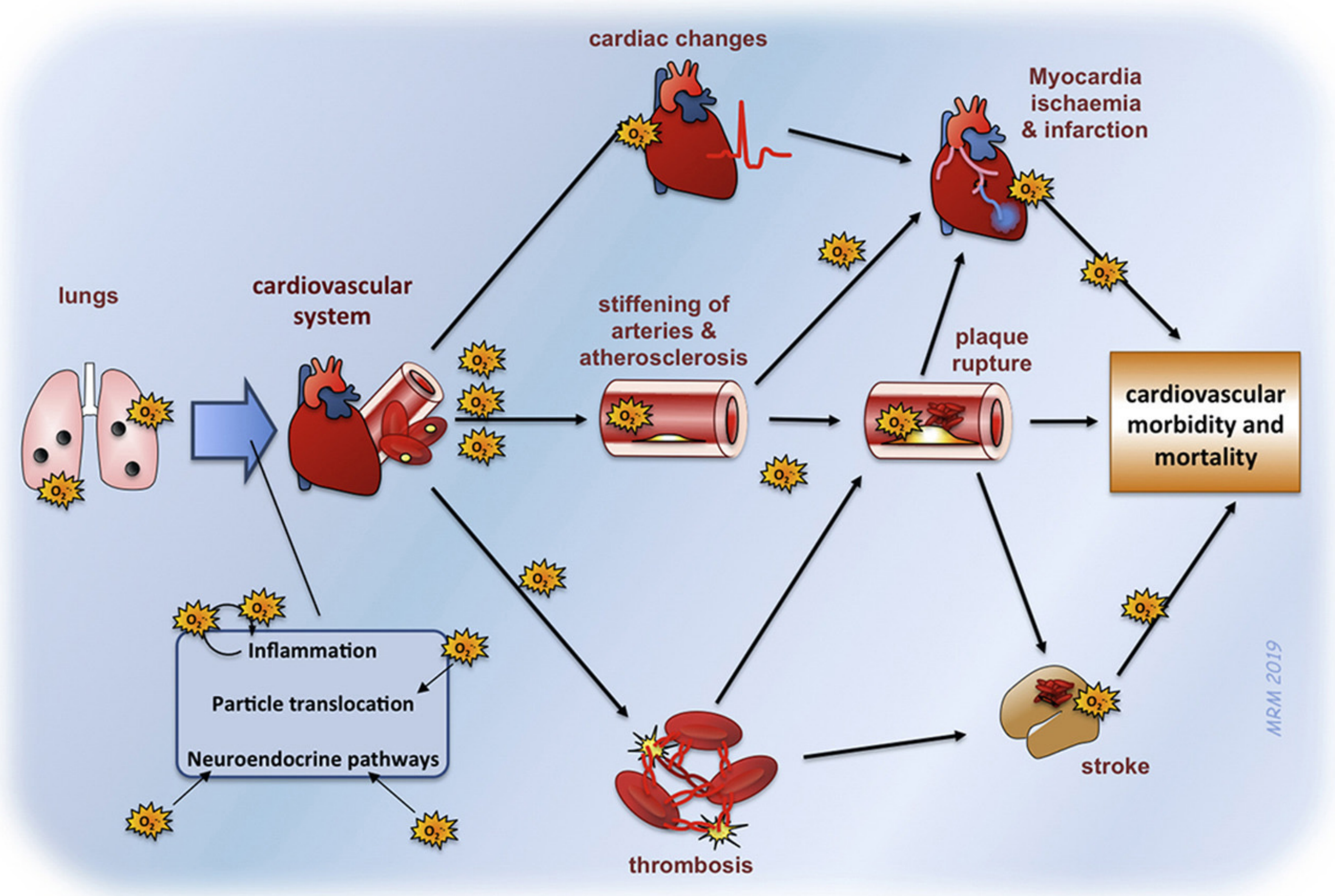
Schulze *et al.* Genes 8.10 (2017).
doi:10.3390/genes8100244

$PM_{2.5}$ are diverse (in source, shape, size, chemical composition …)



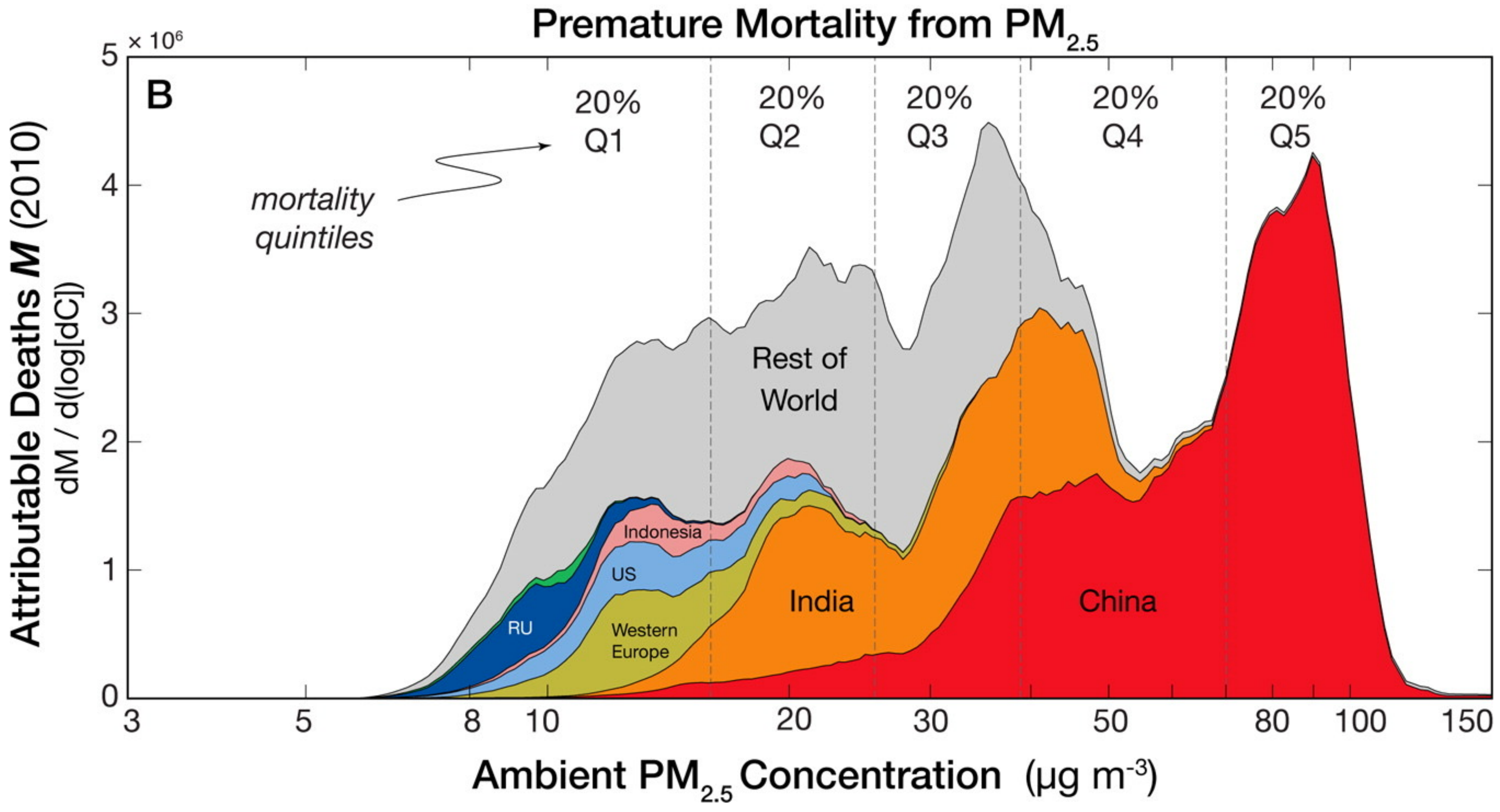
Li *et al*. Environ. Sci. Technol. 51.19 (2017). doi:10.1021/acs.est.7b02530

$PM_{2.5}$ exposure can lead to cardio-respiratory (and other) conditions



Miller *et al*. Free Radic Biol Med. (2020).
doi: 10.1016/j.freeradbiomed.2020.01.004

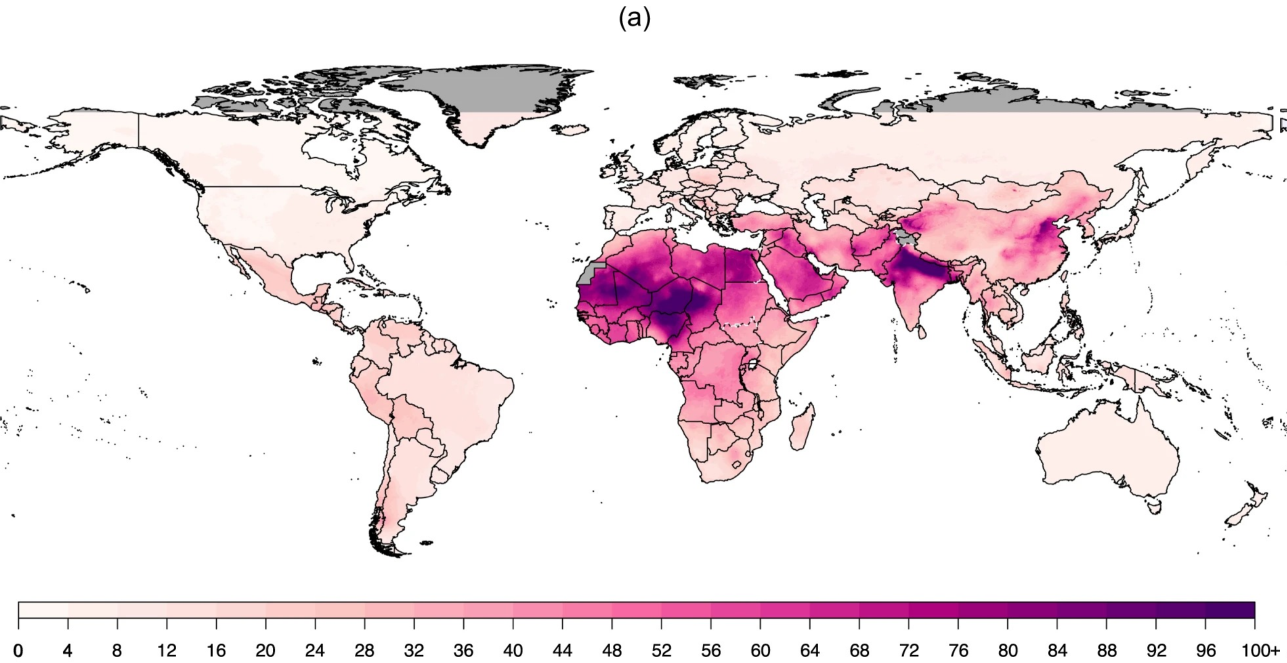
Millions of deaths—mostly in developing countries



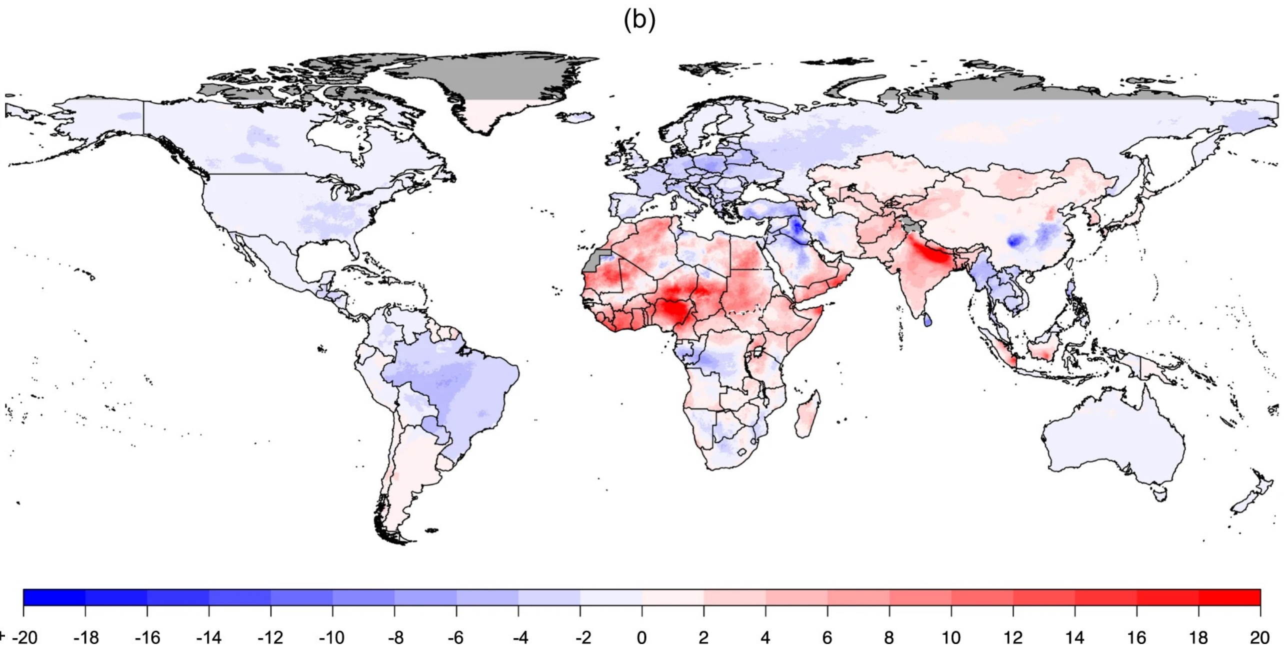
Apte, J. S., *et al*. Environ. Sci. Technol. (2015). doi: 10.1021/acs.est.5b01236

… and the inequality is getting worse

$PM_{2.5}$ concentrations in 2016

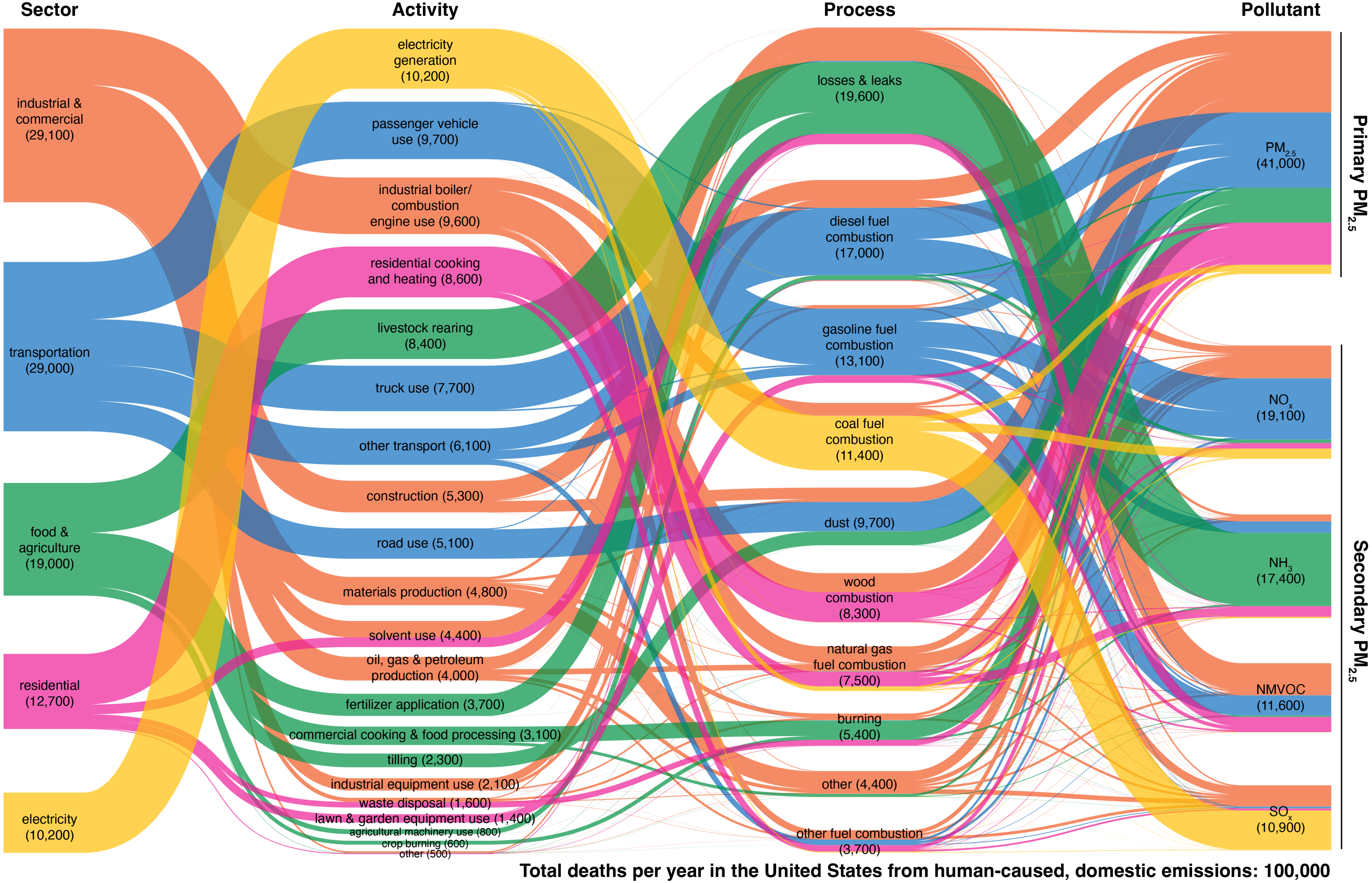


Change in $PM_{2.5}$ concentrations (2010 – 2016)



Shaddick, G., *et al.* NPJ Clim. Atmos. Sci. (2020). doi: 10.1038/s41612-020-0124-2

How do we fix it? A complex science & policy issue



- Deaths are caused by pollution from every sector of the economy
- We need to understand how a wide range of policy decisions affect human health

Thakrar, S. K., *et al.* Environ. Sci. Technol. Lett. (2020). doi:10.1021/acs.estlett.0c00424

Air quality health impact assessment: A basic overview

How do we estimate the air quality health impacts of a potential policy decision? (*e.g.*, reducing urban traffic)

5 steps:

1. emissions

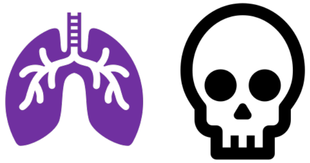
Understanding where, when, and how much pollution is emitted

→

2. concentrations

Modeling how, where, and when the pollution moves and reacts in the atmosphere

→



3. exposure & mortality

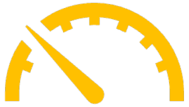
Estimating how many people breathe in more pollution, and how that contributes to health risks

→

4. valuation

Evaluating the economic costs of the policy decision, to aid cost-benefit analysis and holistic impact assessment

(→)



5. measurements

Performing measurements to assess impacts, evaluate models, understand baseline exposure, etc.

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5 steps:

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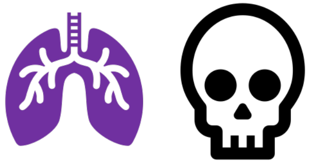
Modeling how, where, and when the pollution moves and reacts in the atmosphere

This step (air quality modeling) is the bottleneck

→



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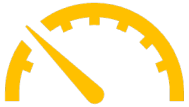

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Traditional air quality modeling is difficult …

You are simulating the atmosphere!

Annual simulations can take:
Time: often weeks for annual simulations,
Resources: typically require supercomputer use, GB of memory and TB of storage
Expertise: often require teams of scientists, Ph.D. level
Data: often requires substantial set-up (emission inventories, boundary conditions, surface characteristics, *etc.*

This is implausible for some use-cases and some policy-makers. For example,

- What if you wanted to do optimal policy?
- What if you wanted to assess 10,000 different policy scenarios?

GEOS-Chem

Bey *et al.* J Geophys.l Res.: Atmos. 106.D19 (2001). doi:10.1029/2001JD000807

Linux   Slurm, PBS   NetCDF, bpch

Fortran, compilers   … and some science!

Traditional air quality modeling is difficult … especially in places where it is needed the most

Developing countries typically have worse air quality, but also typically have:

- **Less institutional and social capital** (collaboration networks with modelling teams)

- **Fewer resources** (*e.g.*, funding, access to supercomputers)

- **More difficulty setting up models** (less data available, fewer models available!)

60% of air quality related deaths occur in countries where there is no known GEOS-Chem user

Support Team, Steering Committee, & Users of GEOS-Chem

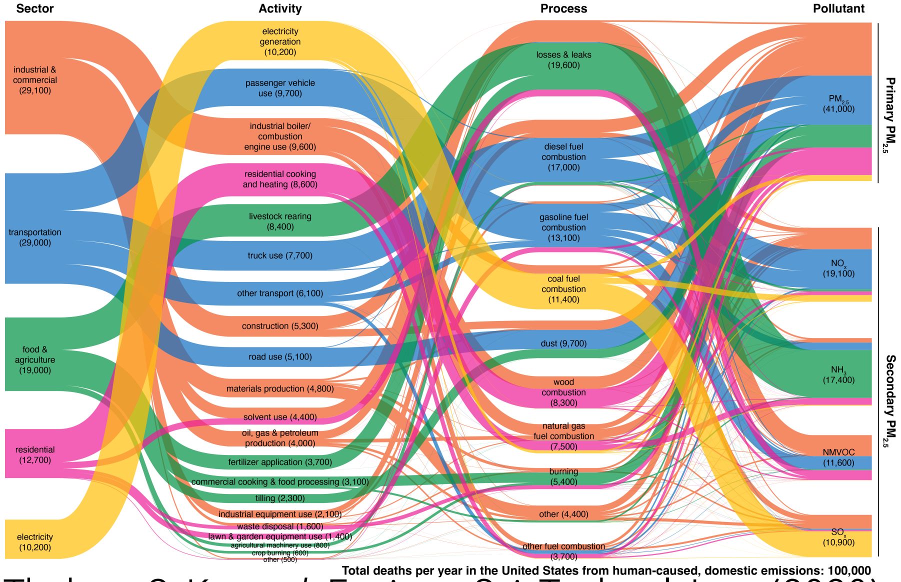
“Reduced-complexity” air quality models (RCMs) are a “democratizing” tool

Reduced complexity models (e.g., InMAP, AP2, EASIUR, COBRA) estimate $PM_{2.5}$ exposure and health impacts more expediently than traditional models, typically using simplifying assumptions

requirement	traditional regional model (WRF-Chem)	Reduced complexity model (InMAP)
time	weeks	hours
resources	supercomputer	laptop computer
expertise	Ph.D. level	Undergrad/M.S. level
data	Emissions, meteorology, *etc.*	Just a shapefile
spatial resolution	12 × 12 km	1km in urban areas

InMAP

Tessum *et al.*, PloS One 12.4 (2017). doi:10.1371/journal.pone.0176131



Thakrar, S. K., *et al.* Environ. Sci. Technol. Lett. (2020). doi:10.1021/acs.estlett.0c00424

… but they are generally unavailable outside the United States (4% of the world’s population; 2% of its air quality-related deaths)

My work: a global, reduced-complexity air quality model to bridge the gap for policy assessment worldwide

- Global InMAP uses the same underlying mechanism as InMAP (a United States RCM), but can be used across a global spatial domain
- Global InMAP leverages outputs from GEOS Chem, a traditional air quality model

requirement	traditional global model (GEOS Chem)	Reduced complexity model (Global InMAP)
time	100 hours	4 hours
resources	supercomputer	desktop computer
expertise	Ph.D. level	Undergrad/M.S. level
data	Emissions, meteorology, *etc.*	Just a shapefile
spatial resolution	12 × 12 km	4km in urban areas
pop-wtd. avg. grid cell area	39,000 km^2	1,000 km^2

96% faster

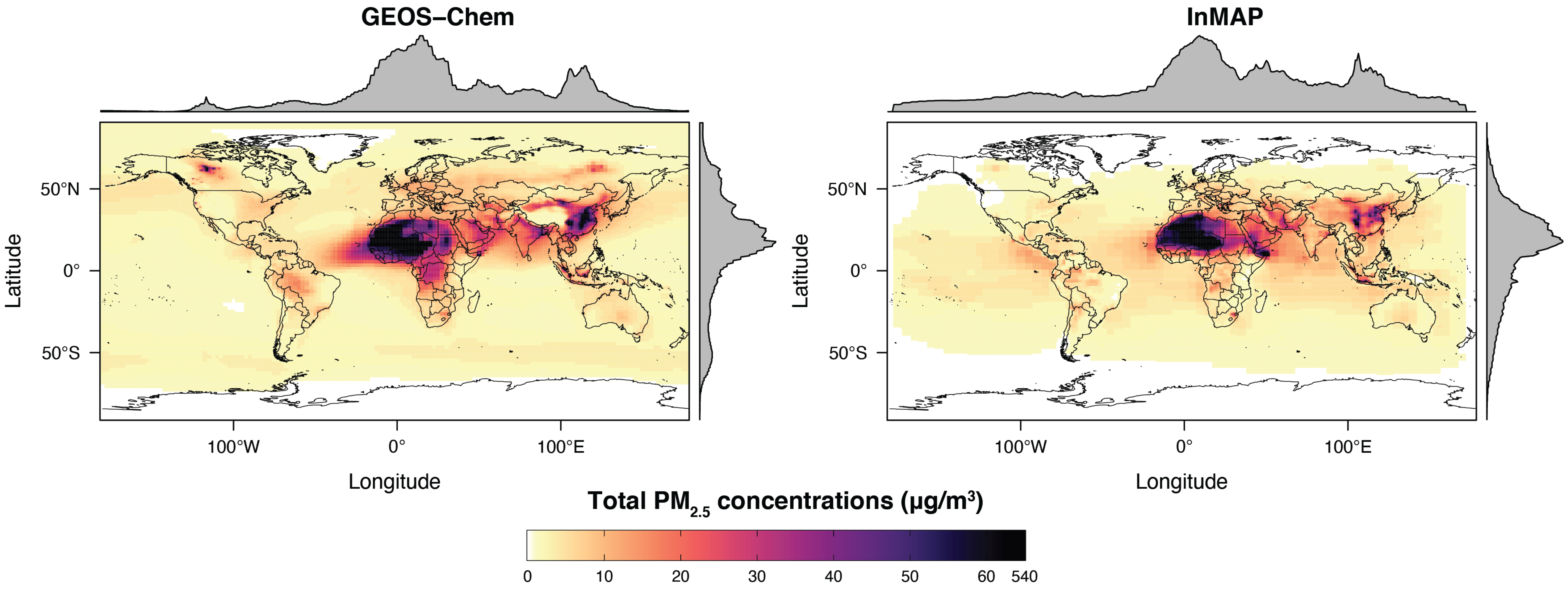
13× ground-level grid cells

Tahiti (1,000 km^2)

Taiwan (39,000 km^2)

Thakrar, S. K., *et al.* PLoS One. (2022). doi:10.1371/journal.pone.0268714

Global InMAP predicts pollutant concentrations fairly accurately ...



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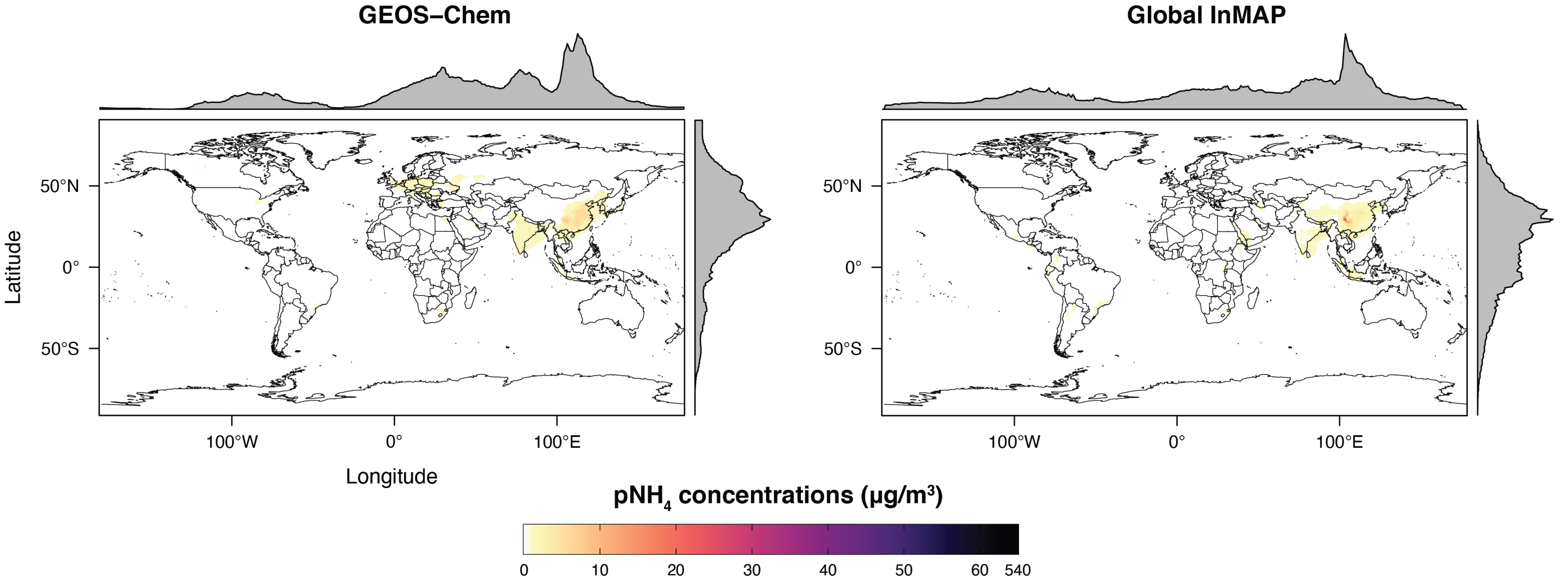

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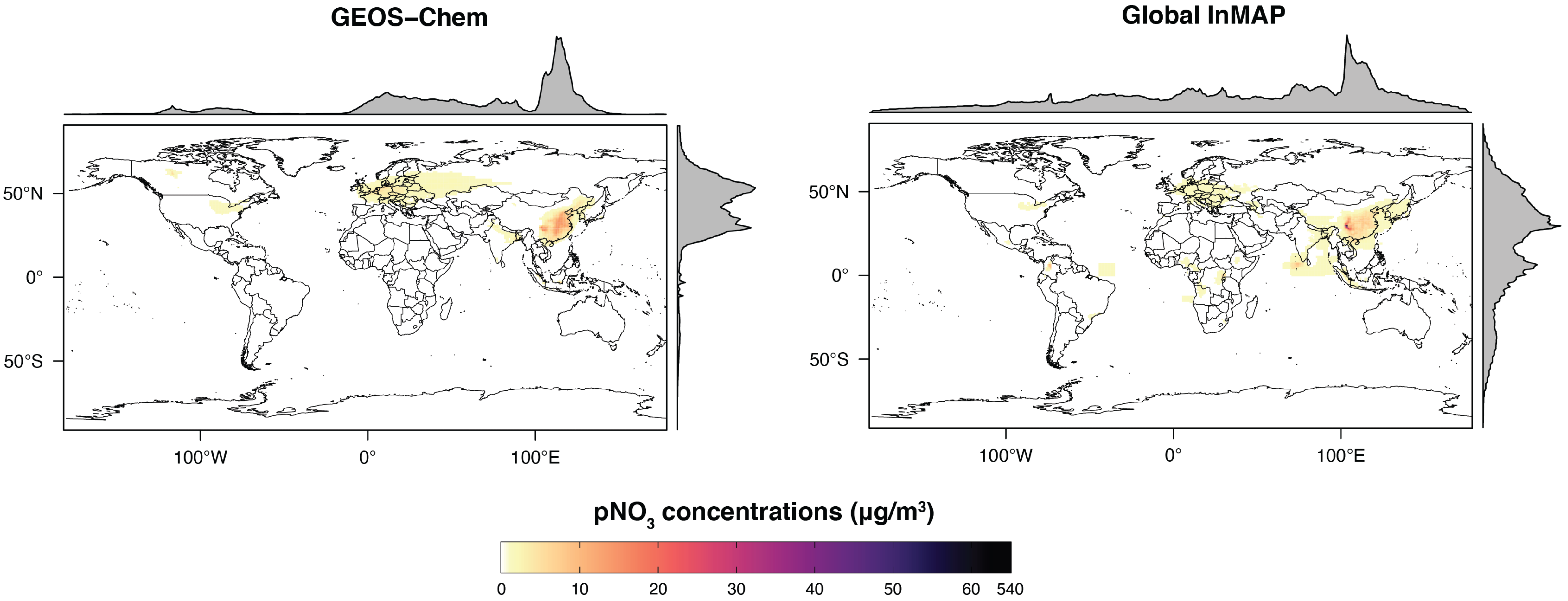

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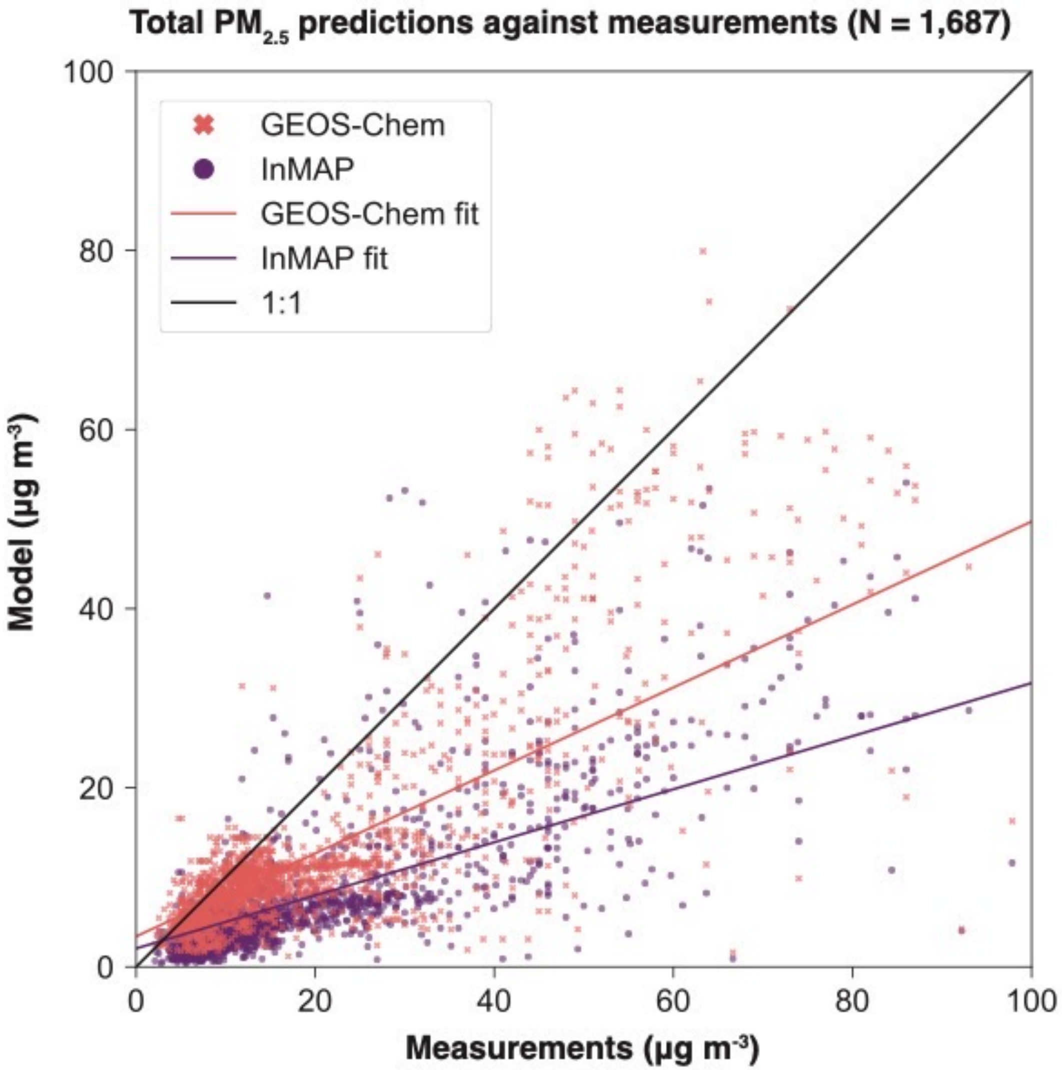
... but (of course) not as accurately as a traditional model

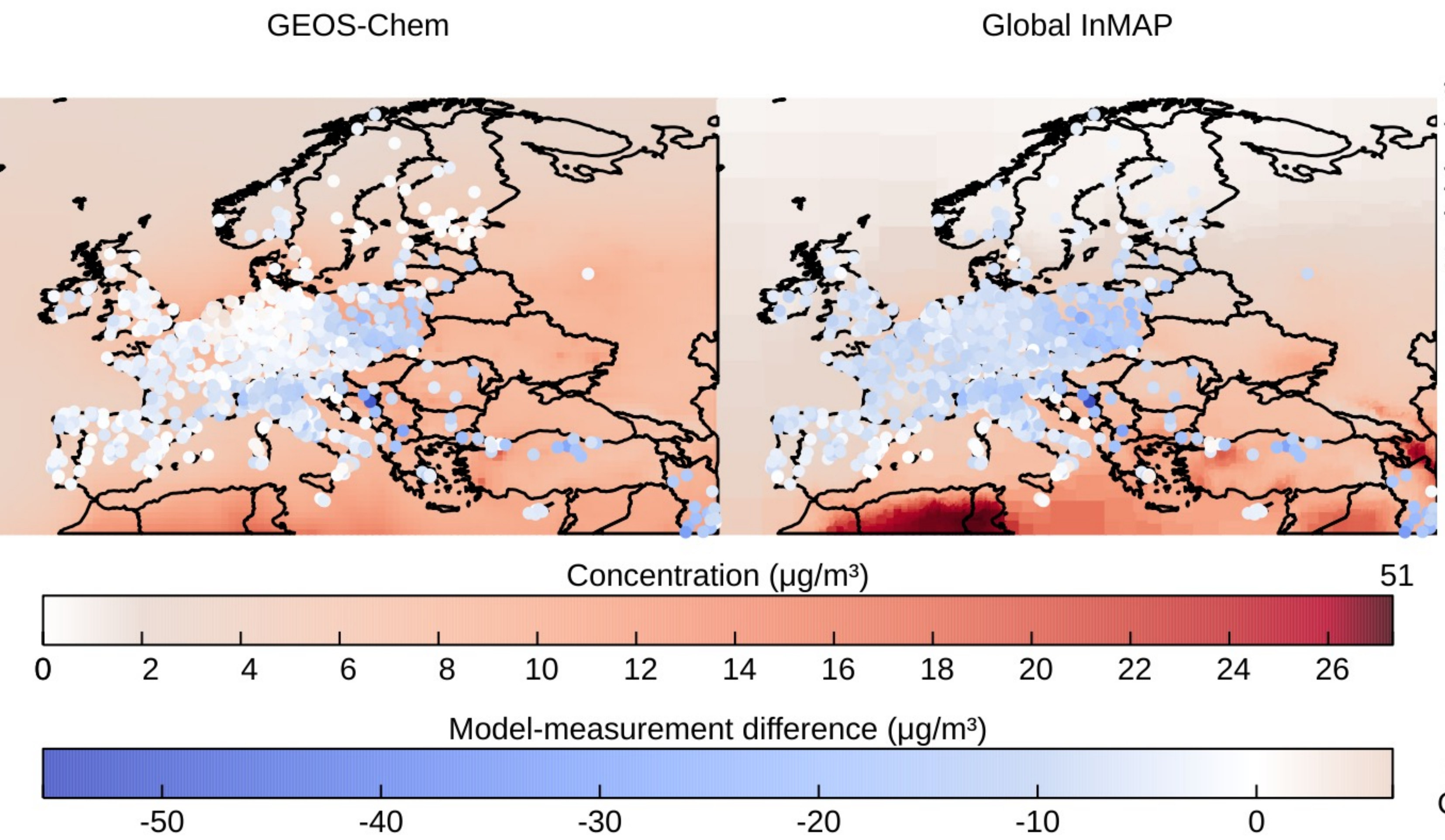


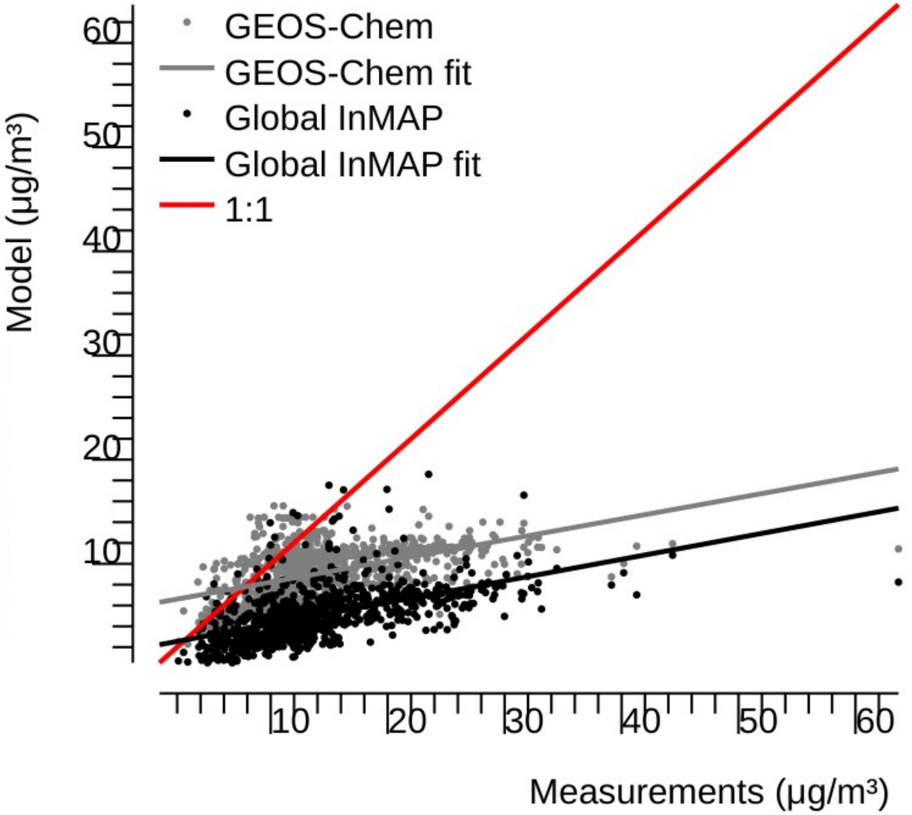
	NMB	NME	Slope	R^2
GEOS-Chem	-37%	41%	0.46	0.55
Global InMAP	-60%	63%	0.30	0.35

Thakrar, S. K., *et al.* PLoS One. (2022). doi:10.1371/journal.pone.0268714

Global InMAP performance varies by region

- Global InMAP inherits biases from GEOS Chem (which it uses to parameterize its physics and chemistry)
- This suggests better inputs can improve Global InMAP



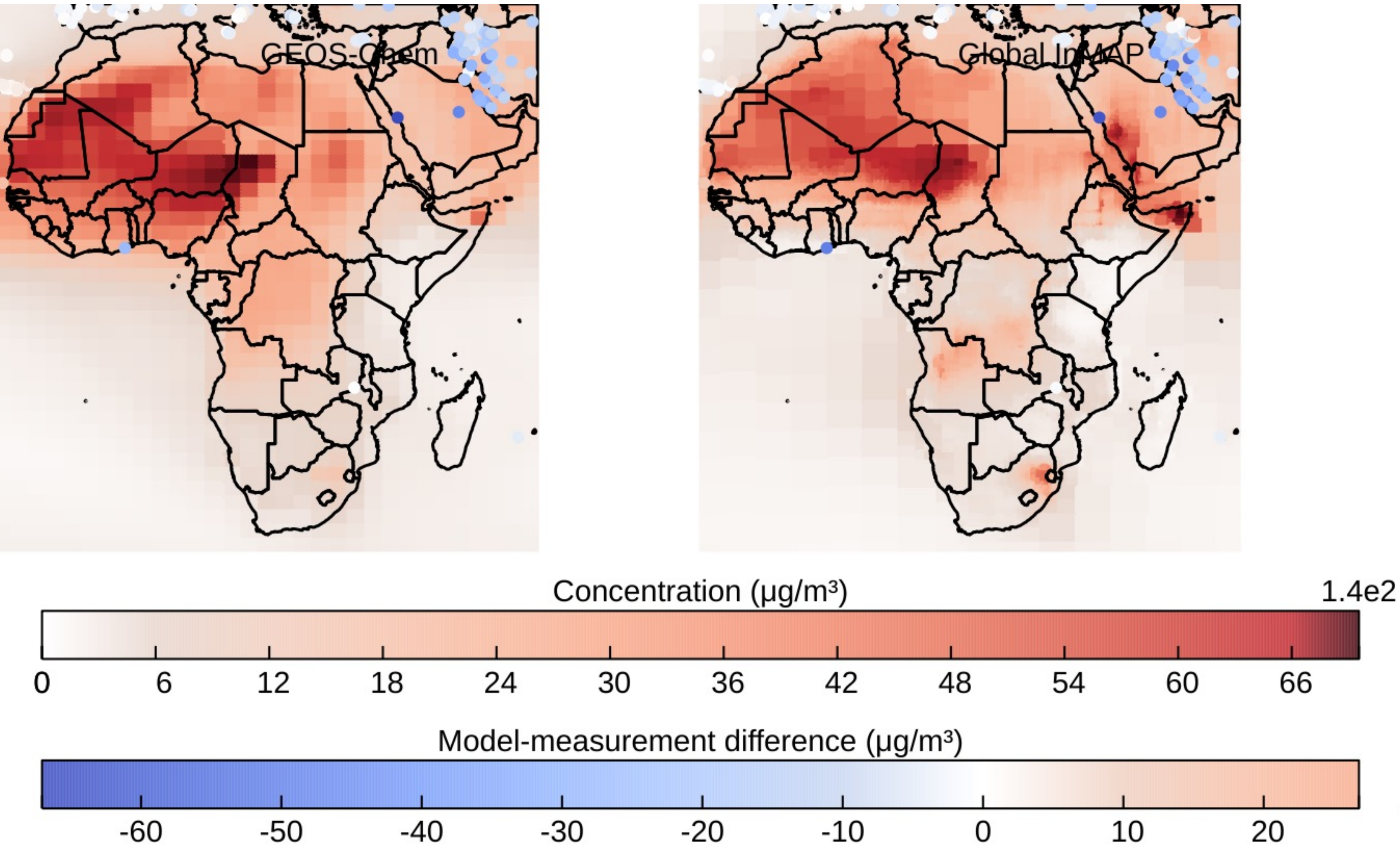


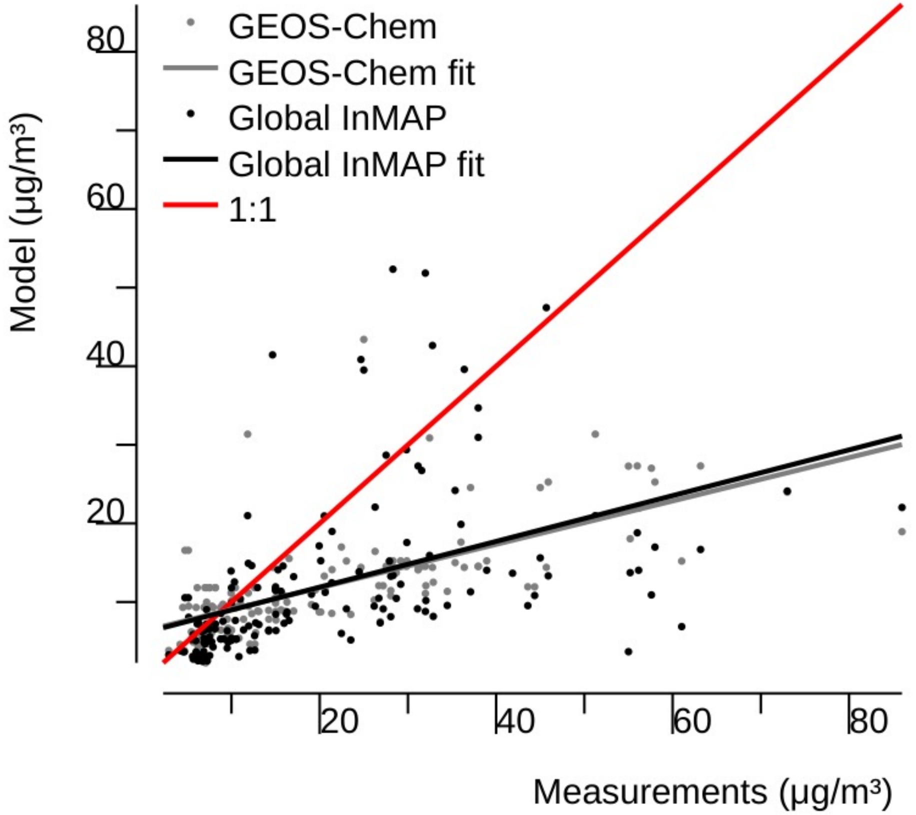
	NMB	NME	S	R^2
GEOS-Chem	-35%	38%	0.20	0.24
Global InMAP	-64%	64%	0.21	0.28

Thakrar, S. K., *et al.* PLoS One. (2022). doi:10.1371/journal.pone.0268714

For some regions, Global InMAP performance is inaccurate—but …

- Not much more inaccurate than traditional models!
- There are often not enough measurements to properly evaluate …





	NMB	NME	S	R^2
GEOS-Chem	-42%	50%	0.28	0.47
Global InMAP	-41%	52%	0.29	0.22

Thakrar, S. K., *et al.* PLoS One. (2022). doi:10.1371/journal.pone.0268714

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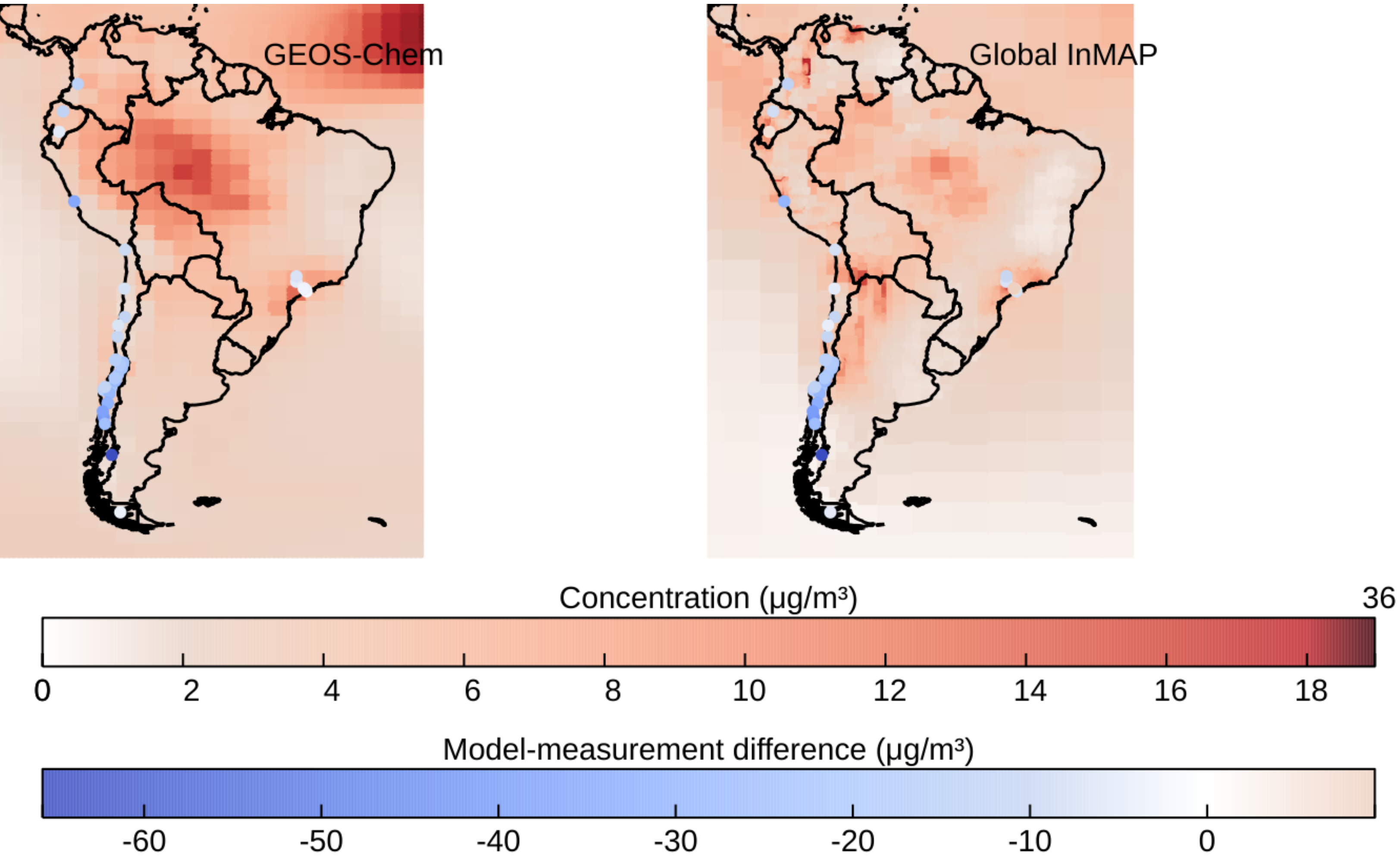
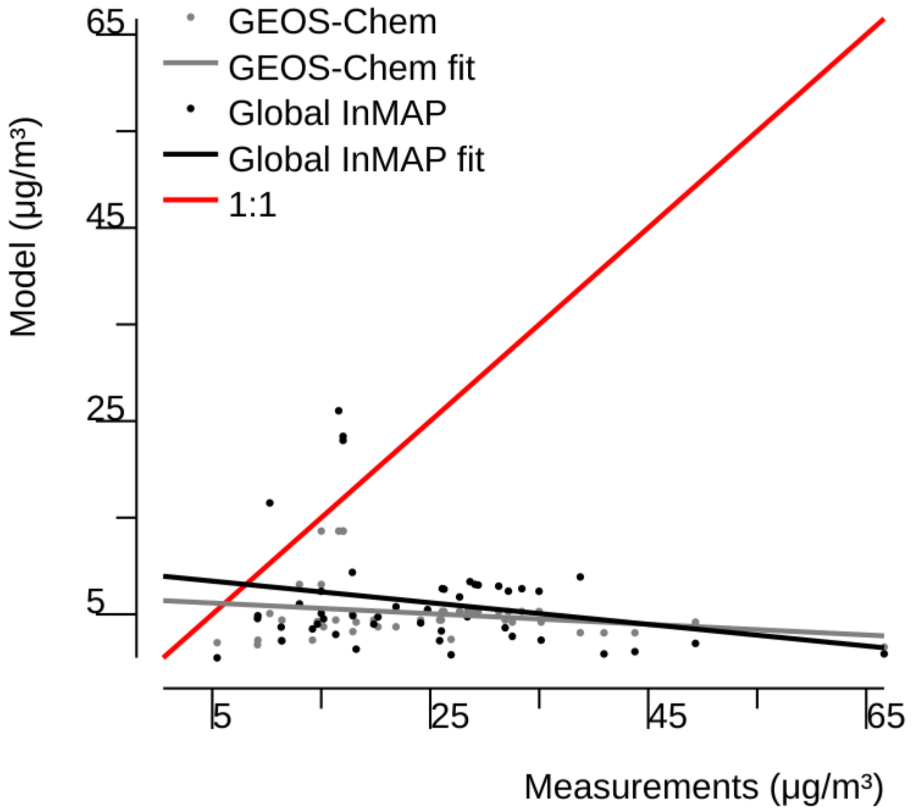
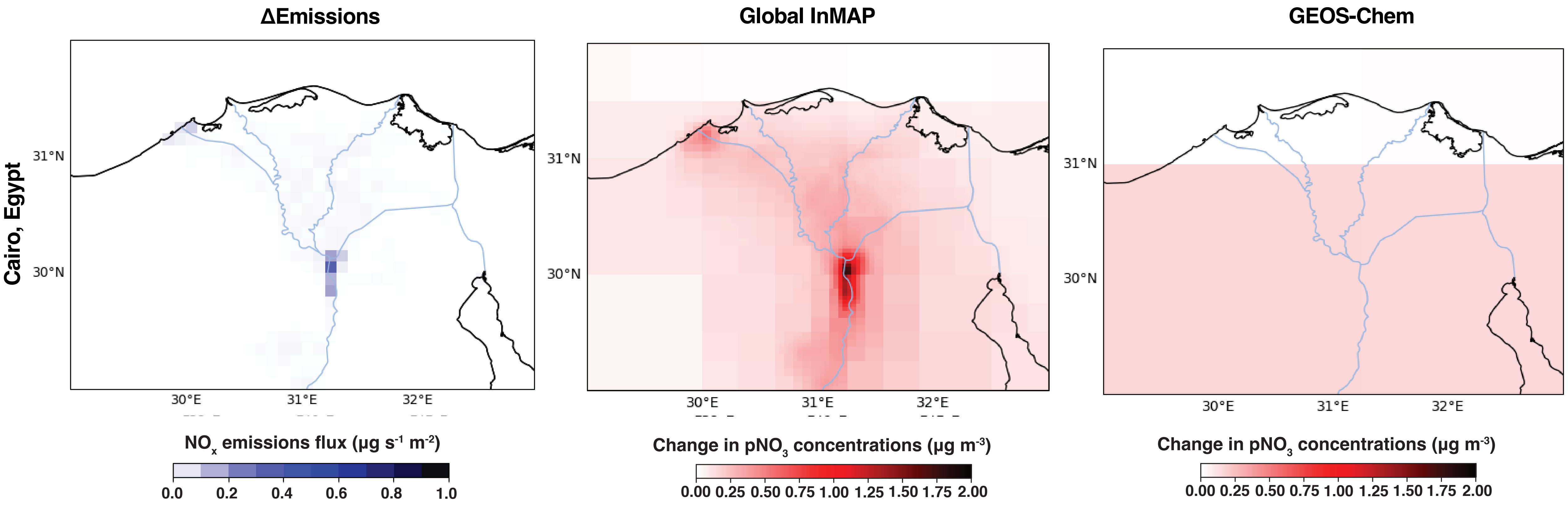




	NMB	NME	S	R^2
GEOS-Chem	-79%	79%	-0.06	0.05
Global InMAP	-74%	79%	-0.11	0.05

Thakrar, S. K., *et al.* PLoS One. (2022). doi:10.1371/journal.pone.0268714

Global InMAP can predict global pollutant concentrations at the urban scale



Thakrar, S. K., *et al.* PLoS One. (2022). doi:10.1371/journal.pone.0268714

RESEARCH ARTICLE

Global, high-resolution, reduced-complexity air quality modeling for PM2.5 using InMAP (Intervention Model for Air Pollution)

Sumil K. Thakrar[1,2]*, Christopher W. Tessum[3], Joshua S. Apte[4,5], Srinidhi Balasubramanian[1¤], Dylan B. Millet[6], Spyros N. Pandis[7,8], Julian D. Marshall[9], Jason D. Hill[1]*

1 Department of Bioproducts & Biosystems Engineering, University of Minnesota, St Paul, Minnesota, United States of America, **2** Department of Applied Economics, University of Minnesota, St Paul, Minnesota, United States of America, **3** Department of Civil and Environmental Engineering, University of Illinois at Urbana −Champaign, Urbana, Illinois, United States of America, **4** Department of Civil and Environmental Engineering, University of California, Berkeley, Berkeley, California, United States of America, **5** School of Public Health, University of California, Berkeley, California, United States of America, **6** Department of Soil, Water, and Climate, University of Minnesota, St Paul, Minnesota, United States of America, **7** Department of Chemical Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania, United States of America, **8** Department of Chemical Engineering, University of Patras, Patras, Greece, **9** Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington, United States of America

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Advanced Energy Partnership for Asia

Quantifying Impacts of Renewable Electricity Deployment on Air Quality and Human Health in Southeast Asia Based on AIMS III Scenarios

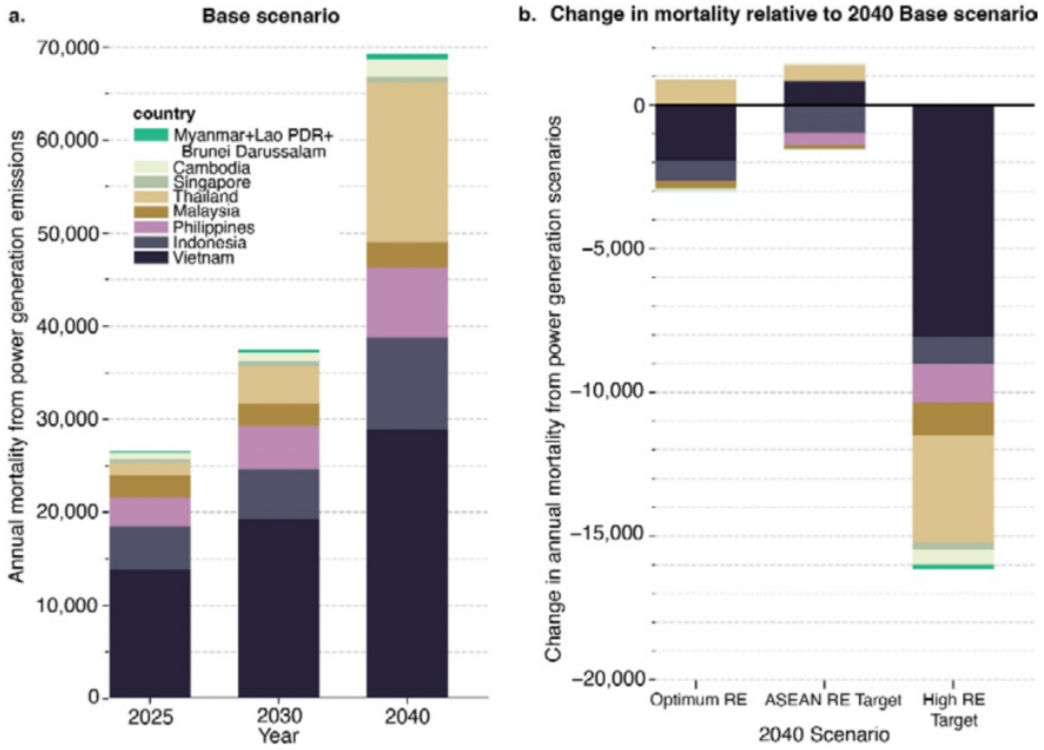
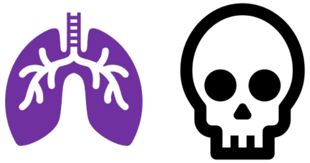
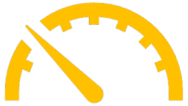


Figure 4. (a) Annual excess mortality attributable to total projected power generation emissions in the Base scenario, broken down by ASEAN member country in which mortality occurs. (b) Change in excess mortality in 2040 (relative to the Base scenario) for the ASEAN RE Target, High RE Target, and Optimum RE scenarios, broken down by ASEAN member country in which mortality occurs

Thakrar, S. K., *et al.* PLoS One. (2022). doi:10.1371/journal.pone.0268714

Ravi, V., Thakrar, S. K., *et al.* (2022). NREL/TP-6A20-83832

Every step of air quality health impact assessment is more difficult in a developing country

	Typical developed country	Typical developing country
 1. emissions	• A nationally compiled emission inventory • Appropriate emission factors and data	• Often have to use global emission inventories • Emission factors are often old or inappropriate
 2. concentrations	• A wide variety of models available (global, regional, urban-scale, policy tools)	• Often hard to use regional models (so one resorts to global models)
 3. exposure & mortality	• Good cohort studies • Good demographic data, underlying mortality risks are well-characterized	• Risk curves may be extrapolated out of range • Poor demographic data
 4. valuation	• Use the Value of Statistical Life, • Easy to estimate social costs,	• It's not always clear how to value mortality risk appropriately
 5. measurements	• Dense and distributed monitoring network	• Often there are no high quality ground measurements

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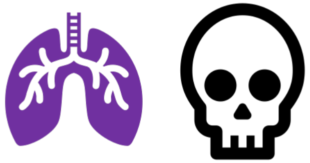 3. exposure & mortality	• Good cohort studies • Good demographic data, underlying mortality risks are well-characterized	• Risk curves may be extrapolated out of range • Poor demographic data
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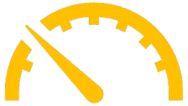
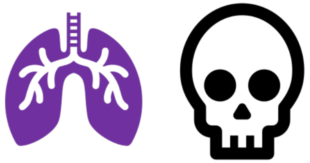
 5. measurements	• Dense and distributed monitoring network	• Often there are no high quality ground measurements

A Tale of Two Cities

Minneapolis, USA (8.4 μg/m^3)

Cairo, Egypt (87 μg/m^3)

Democratizing tools can help bridge the gap, but often have tradeoffs

	Typical developed country	Typical developing country	Democratizing tools?
 1. emissions	• A nationally compiled emission inventory • Appropriate emission factors and data	• Often have to use global emission inventories • Emission factors are often old or inappropriate	• Satellite data can constrain emission inventories or identify hot spots
 2. concentrations	• A wide variety of models available (global, regional, urban-scale, policy tools)	• Often hard to use regional models (so one resorts to global models)	• Reduced-complexity tools like Global InMAP
 3. exposure & mortality	• Good cohort studies • Good demographic data, underlying mortality risks are well-characterized	• Risk curves may be extrapolated out of range • Poor demographic data	
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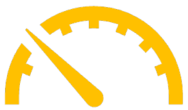 5. measurements	• Dense and distributed monitoring network	• Often there are no high-quality ground measurements	• Low-cost sensors

Conclusions

- Exposure to air pollution is associated with millions of deaths each year, mostly in developing countries
- Designing policy solutions to reduce air quality-related deaths relies on scientific tools (*e.g.*, models, measurements)
- The countries with the worst air quality also are the least equipped with the scientific tools needed to inform policy
- “Democratizing” tools (such as my work in building global, reduced complexity air quality models) can help bridge the gap between available tools and policy needs, especially in countries where expertise, resources, or existing tools are in short supply

Potential discussion questions

There are clear environmental inequities: the world’s poorest face the largest environmental burdens.

1. Are policy makers in developing nations also generally less equipped with resources, tools, and knowledge to reduce their burdens? Should we as a community think more about how environmental science is produced, and whether it is unequally applied?

2. What is the potential for “democratizing” tools (low-cost devices, data, models, etc.)? What is their role in sustainable development? What are the tradeoffs? What are the opportunities?