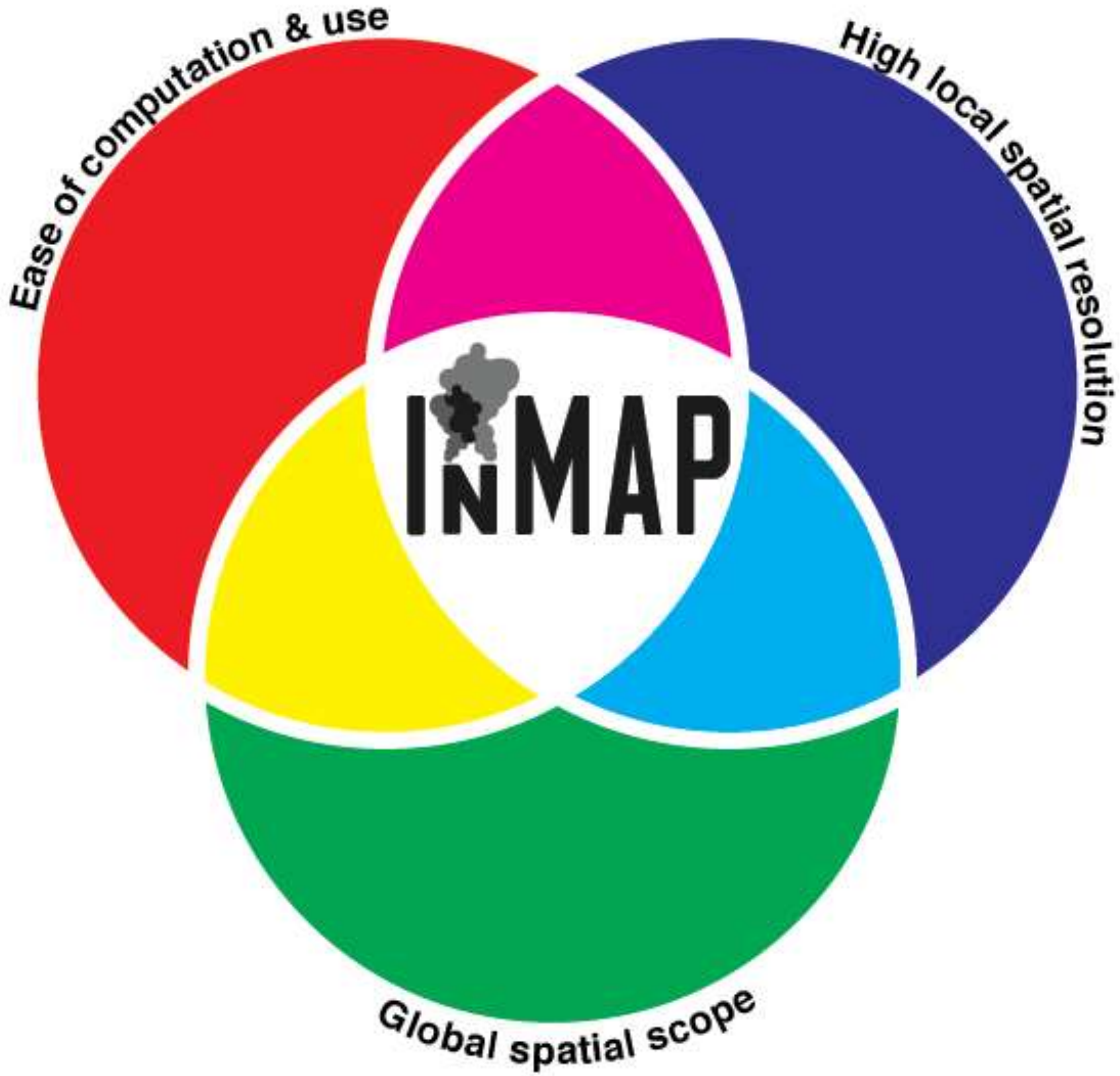

Global InMAP

A Global Reduced Complexity Air Quality Model

Sumil K. Thakrar

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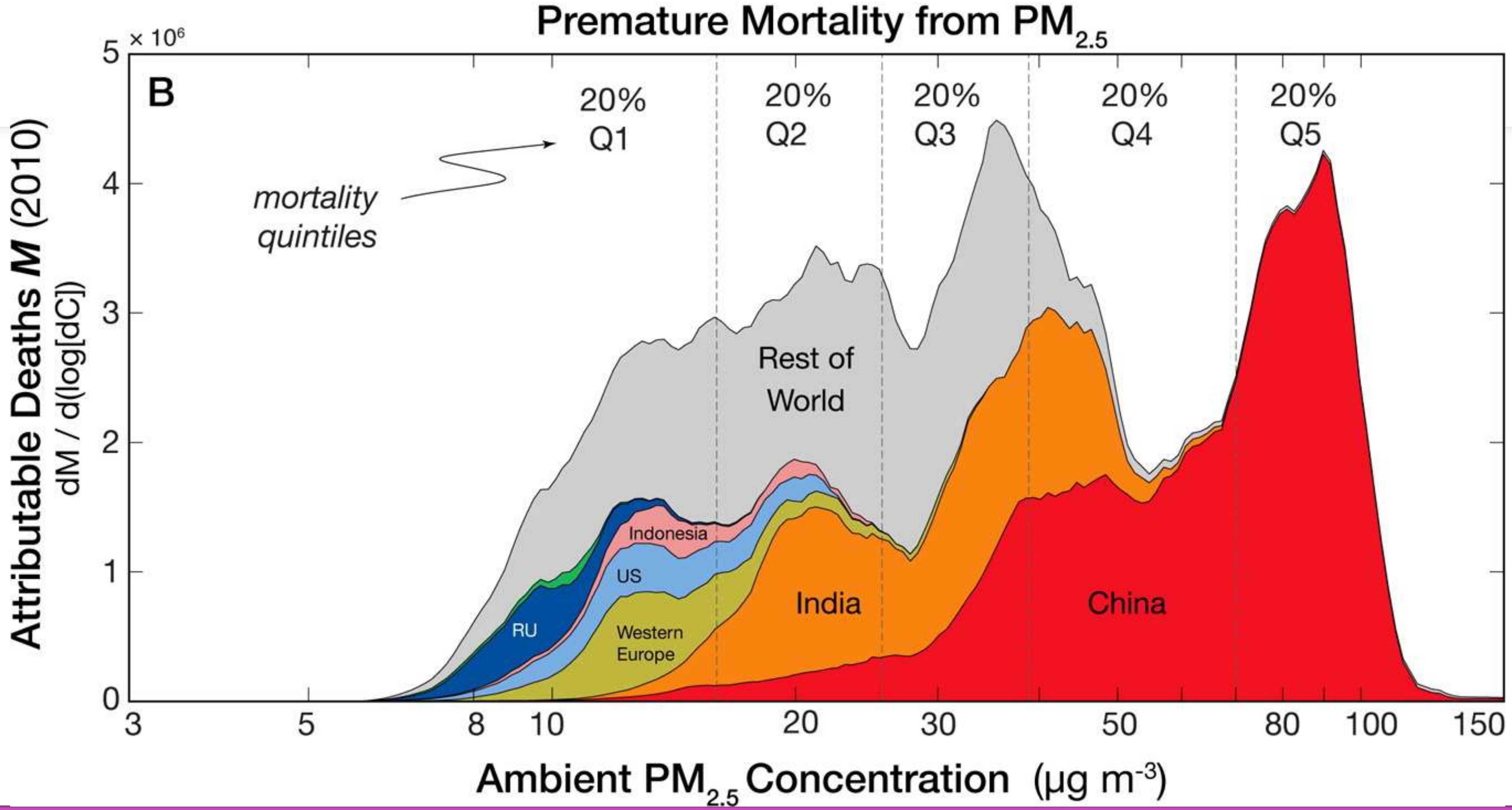
University of Minnesota

UNIVERSITY OF MINNESOTA

HEICCAM

Millions of deaths from air pollution, mostly in developing countries

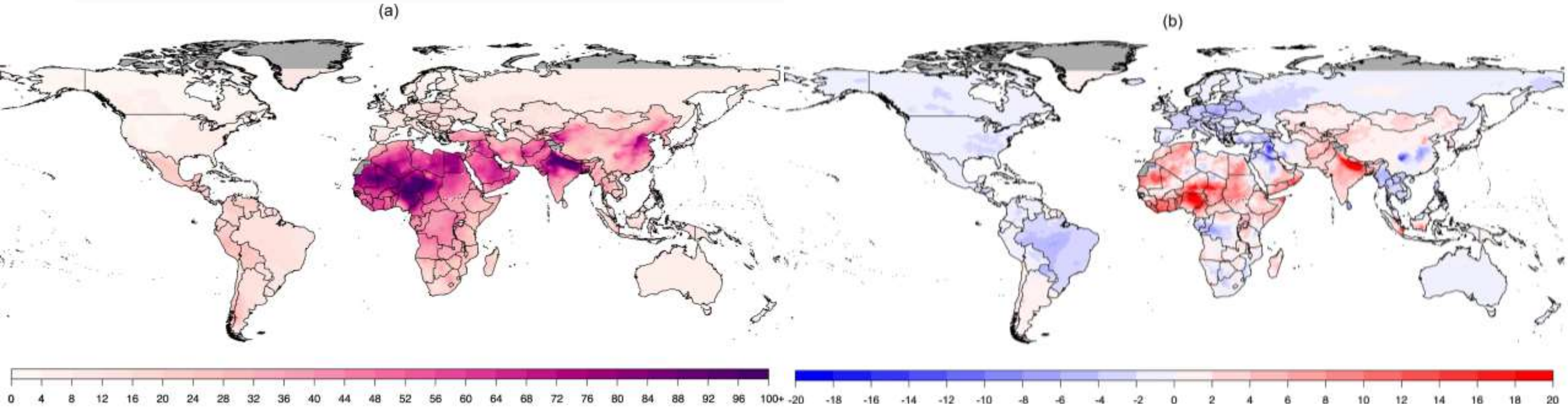


Apte, J. S., *et al*. Environ. Sci. Technol. (2015). doi: 10.1021/acs.est.5b01236

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 inform policies to improve air quality-related health? 5 steps:

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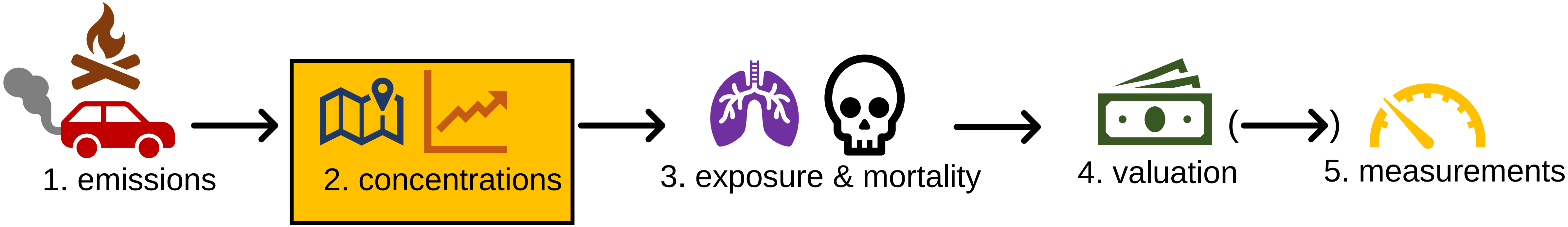


This step (air quality modeling) is the bottleneck, requiring **time**, **resources**, **expertise**, and **data**

- Air quality modelling is implausible for some use-cases and some policy-makers
- Developing countries typically have worse air quality, but also typically have:
  - **Less institutional and social capital** (collaboration networks with modelling teams, expertise in air quality modelling)
  - **Fewer resources and data** (*e.g.*, funding, access to supercomputers)
  - **More difficulty setting up models** (less data available, fewer models available!)

InMAP: A Reduced Complexity Model

- InMAP is designed to estimate **health impacts** from **changes in pollutant emissions** (*e.g.*, related to policy decisions) in a **low resource, expedient** manner.

- It directly estimates **annual average** changes in **$PM_{2.5}$ concentrations** (including secondary $PM_{2.5}$) across space, with a **variable resolution grid** (1–48 km for the United States).

- To do this, it uses **simplified physics and chemistry** that **leverage outputs from a more complex model** (WRF-Chem / GEOS-Chem).

Tessum *et al.*, *PLOS ONE* (2017).

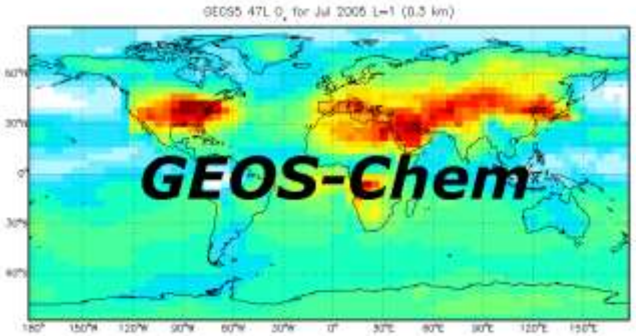
U.S. InMAP Resource Requirements

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

... but it was only available for the U.S. (**4%** of global population; **2%** of global air quality-related deaths)

Tessum *et al.*, *PLOS ONE* (2017).

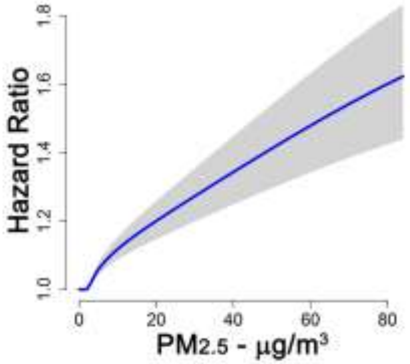
From U.S. to Global InMAP



(1) Parametrize InMAP chemistry and physics using a global, comprehensive chemical transport model

(2) Update InMAP to use global input parameters

(3) Develop a global, high resolution computational grid to run InMAP



(4) Estimate health impacts using globally appropriate concentration-response functions

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]*

https://doi.org/10.5281/zenodo.4641947

Each year, millions of premature deaths worldwide are caused by exposure to outdoor air pollution, especially fine particulate matter ($PM_{2.5}$). Designing policies to reduce these deaths relies on air quality modeling for estimating changes in $PM_{2.5}$ concentrations from many scenarios at high spatial resolution. However, air quality modeling typically has substantial requirements for computation and expertise, which limits policy design, especially in countries where most $PM_{2.5}$-related deaths occur. Lower requirement reduced-complexity models exist but are generally unavailable worldwide. Here, we adapt InMAP, a reduced-complexity model originally developed for the United States, to simulate annual-average primary and secondary $PM_{2.5}$ concentrations across a global-through-urban spatial domain: "Global InMAP". Global InMAP uses a variable resolution grid, with horizontal grid cell widths ranging from 500 km in remote locations to 4km in urban locations. We evaluate Global InMAP performance against both measurements and a state-of-the-science chemical transport model, GEOS-Chem. Against measurements, InMAP predicts total $PM_{2.5}$ concentrations with a normalized mean error of 62%, compared to 41% for GEOS-Chem. For the emission scenarios considered, Global InMAP reproduced GEOS-Chem pollutant concentrations with a normalized mean bias of 59%–121%, which is sufficient for initial policy assessment and scoping. Global InMAP can be run on a desktop computer; simulations here took 2.6–8.4 hours. This work presents a global, open-source, reduced-complexity air quality model to facilitate policy assessment worldwide, providing a screening tool for reducing air pollution-related deaths where they occur most.

Global InMAP Resource Requirements

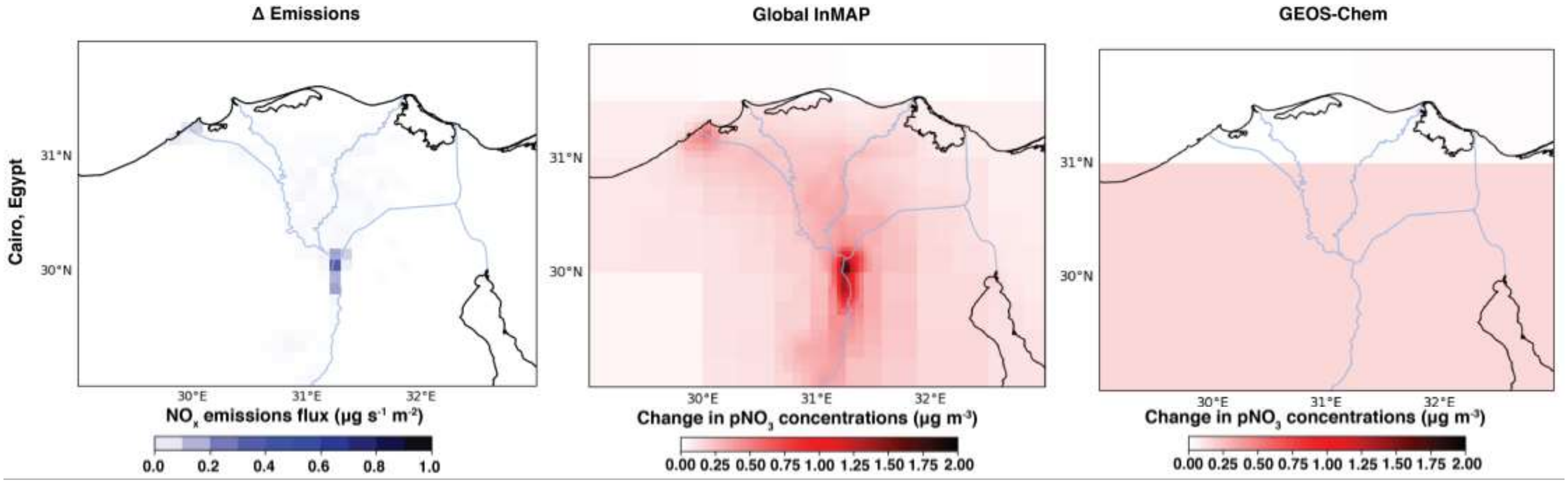
requirement	Reduced complexity model (Global InMAP)	traditional global model (GEOS Chem)
time	4 hours	100 hours
resources	desktop computer	supercomputer
expertise	Undergrad/M.S. level	Ph.D. level
data	Just a shapefile	Emissions, meteorology, *etc.*
spatial resolution	4km in urban areas	12 × 12 km
pop-wtd.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

96% faster

13x ground-level grid cells

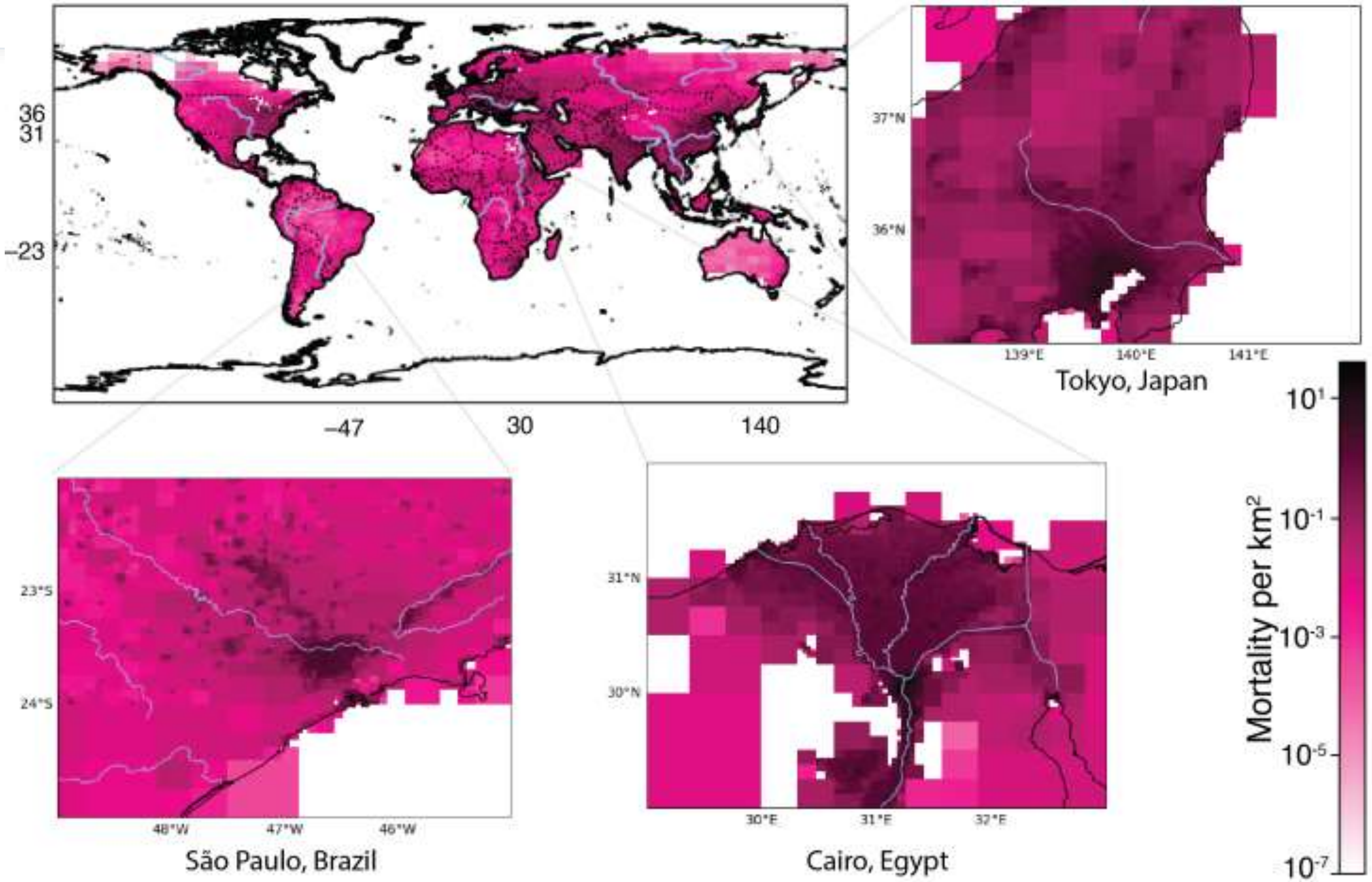
Thakrar *et al.*, *PLOS ONE* (2022).

Global InMAP can resolve urban-scale changes in pollutant concentrations worldwide



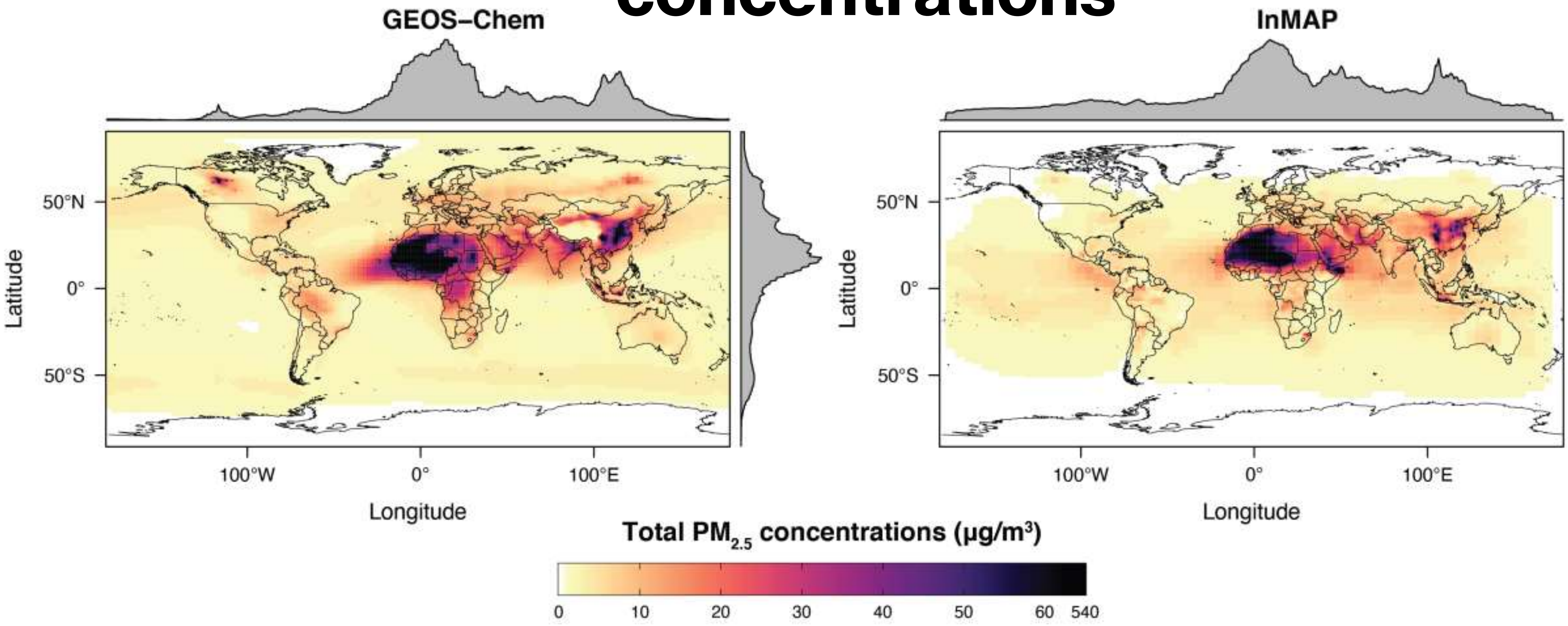
Thakrar *et al.*, *PLOS ONE* (2022).

Global InMAP can estimate high-resolution changes in mortality



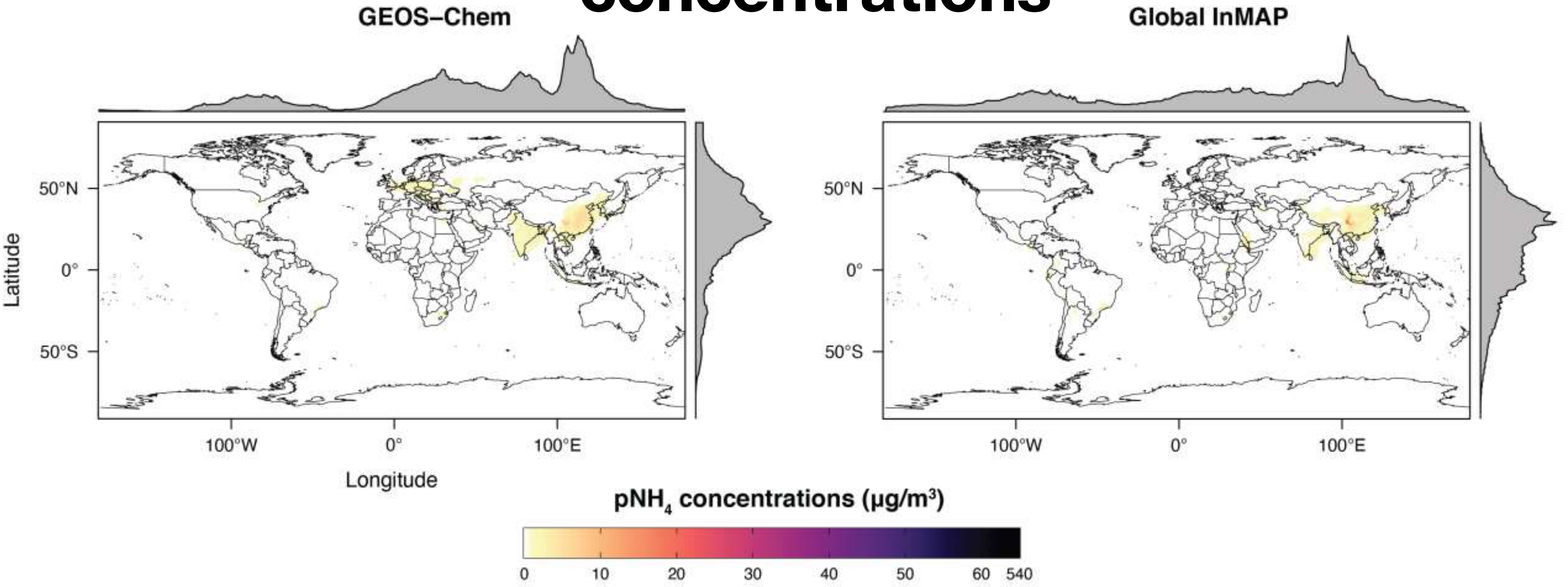
Thakrar *et al.*, *In Preparation*

Global InMAP can predict total pollutant concentrations



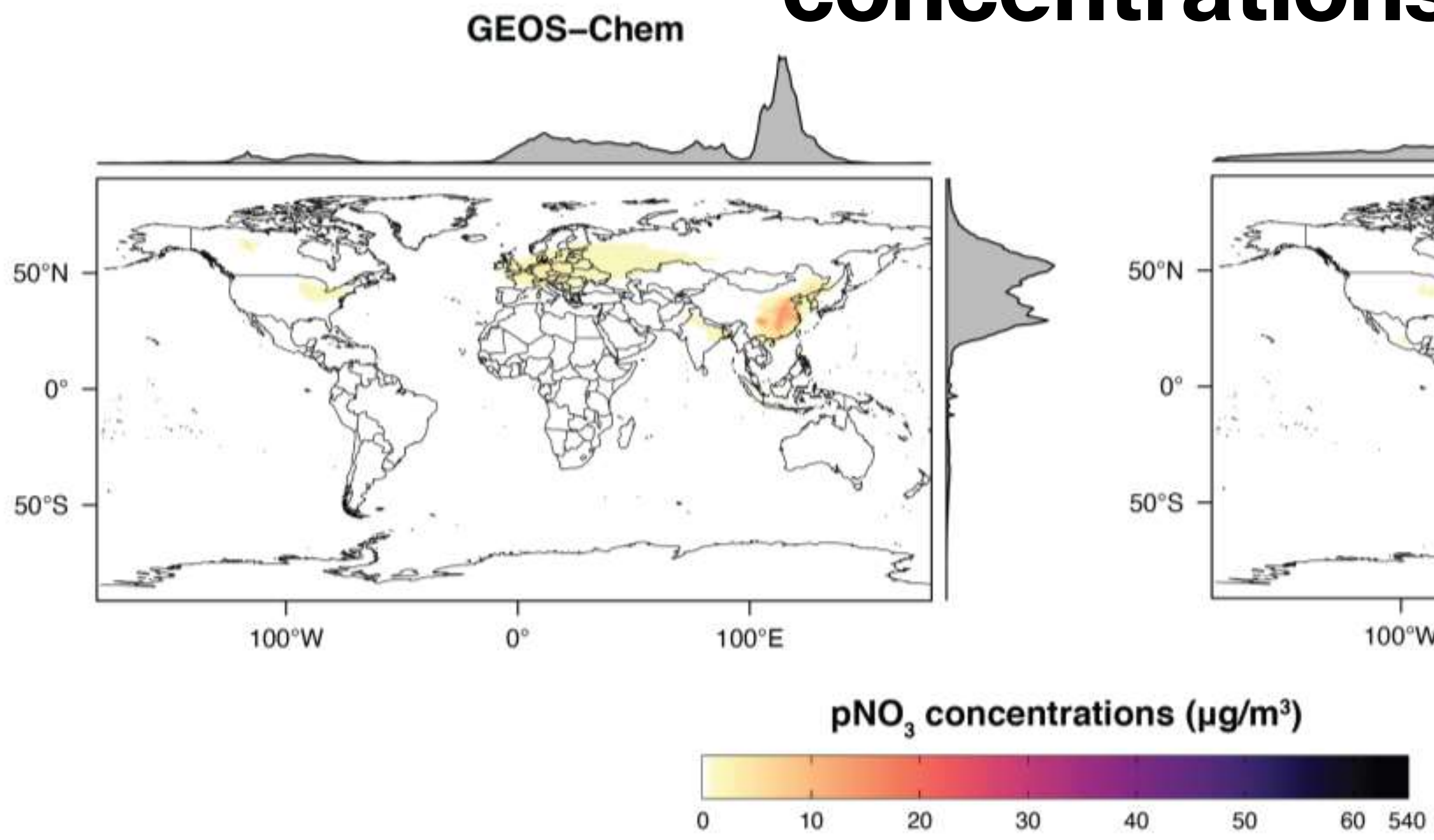
Thakrar *et al.*, *PLOS ONE* (2022).

Global InMAP can predict total pollutant concentrations



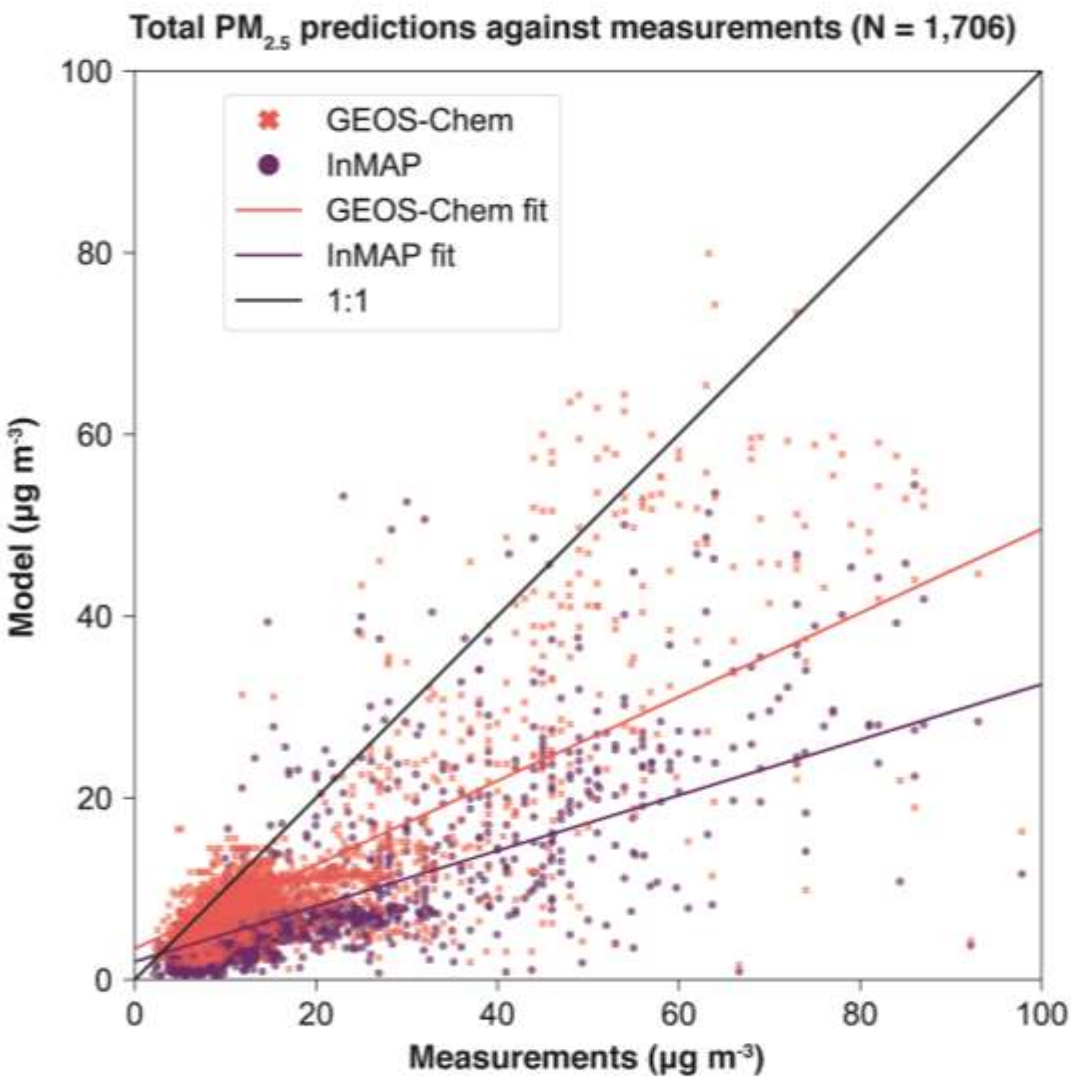
Thakrar *et al.*, *PLOS ONE* (2022).

Global InMAP can predict total pollutant concentrations



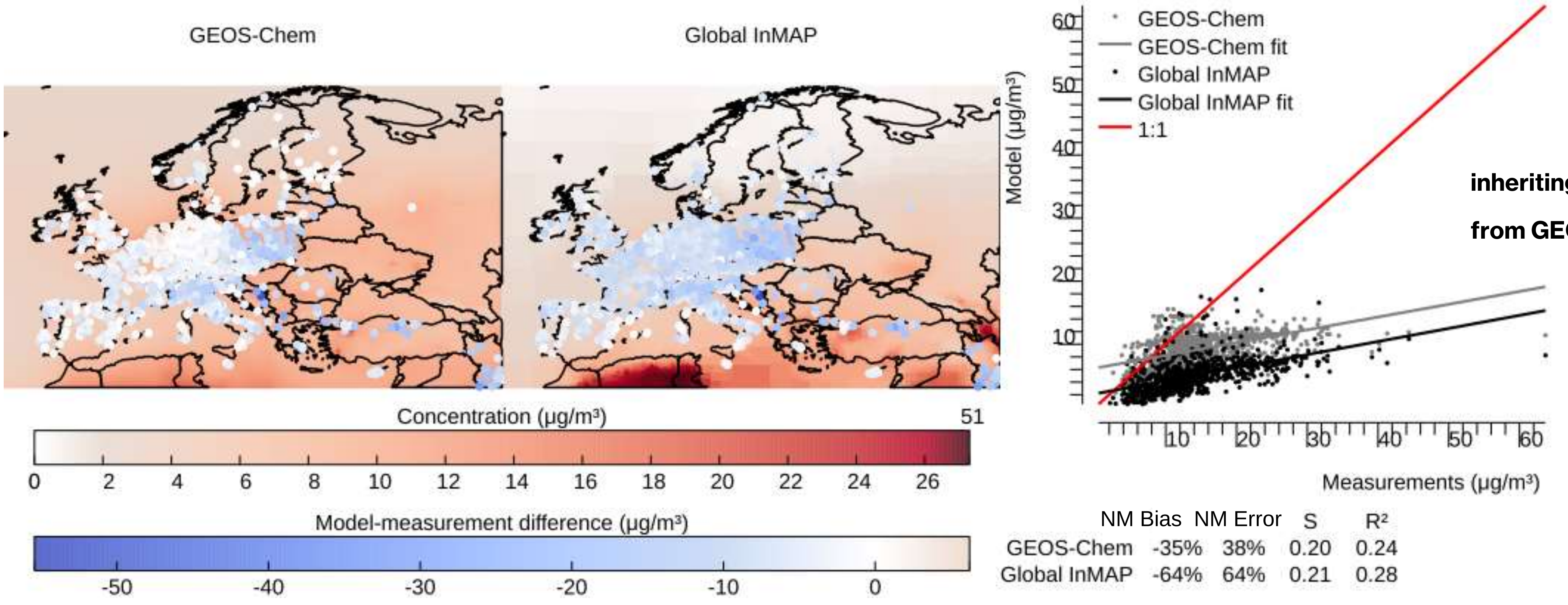
Thakrar *et al.*, *PLOS ONE* (2022).

But (of course) not as accurately as a traditional chemical transport model



	NM Bias	NM Error	Slope	R^2
GEOS-Chem	-37%	41%	0.46	0.55
- *pop-wtd*	-37%	40%	0.47	0.75
Global InMAP	-60%	62%	0.31	0.33
- *pop-wtd*	-58%	62%	0.34	0.57

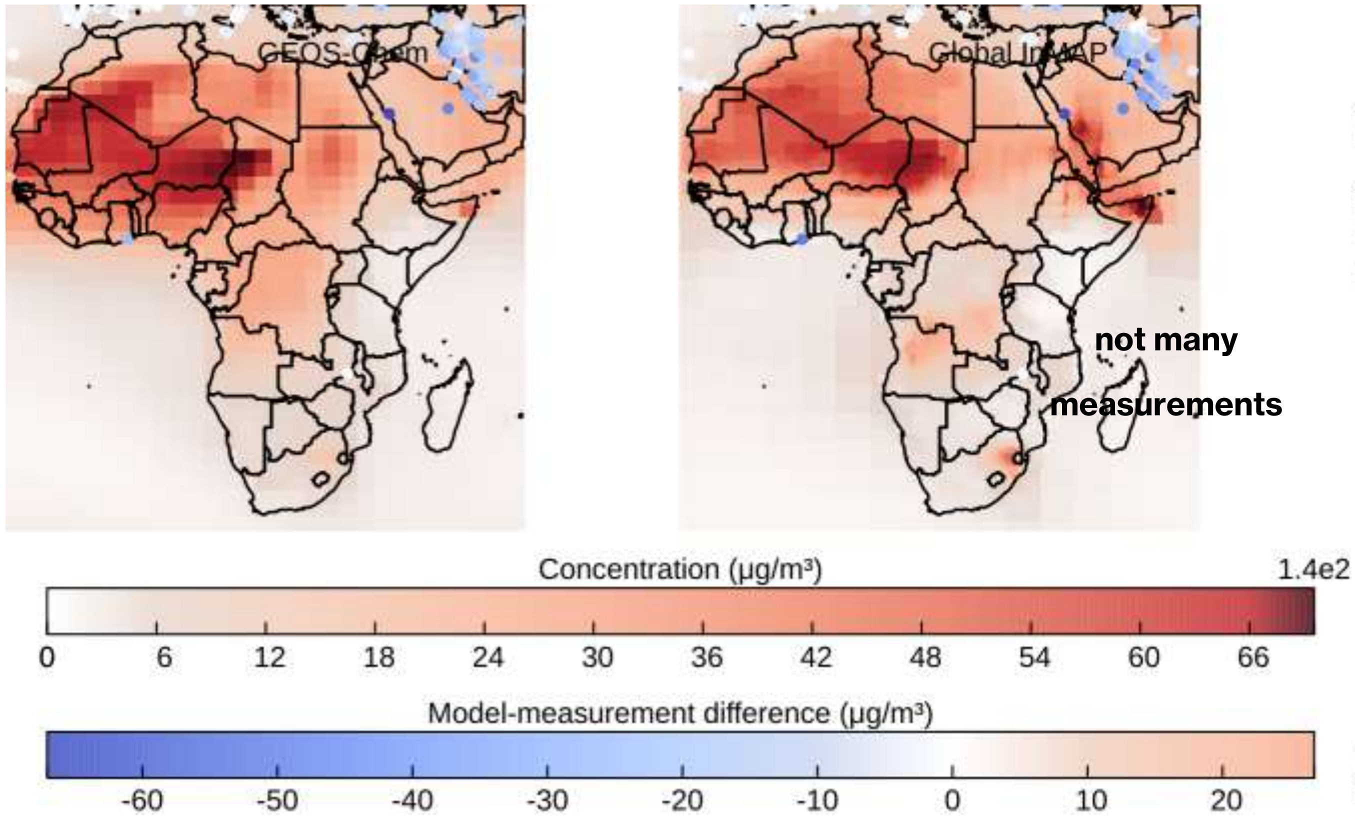
Global InMAP performance varies by region

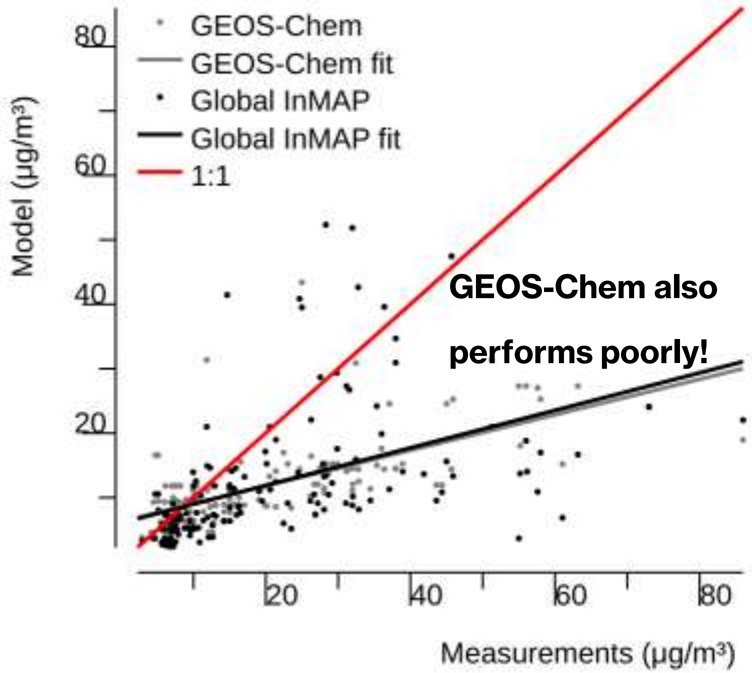


	NM Bias	NM Error	S	R^2
GEOS-Chem	-35%	38%	0.20	0.24
Global InMAP	-64%	64%	0.21	0.28

inheriting biases from GEOS-Chem

Global InMAP performance varies by region

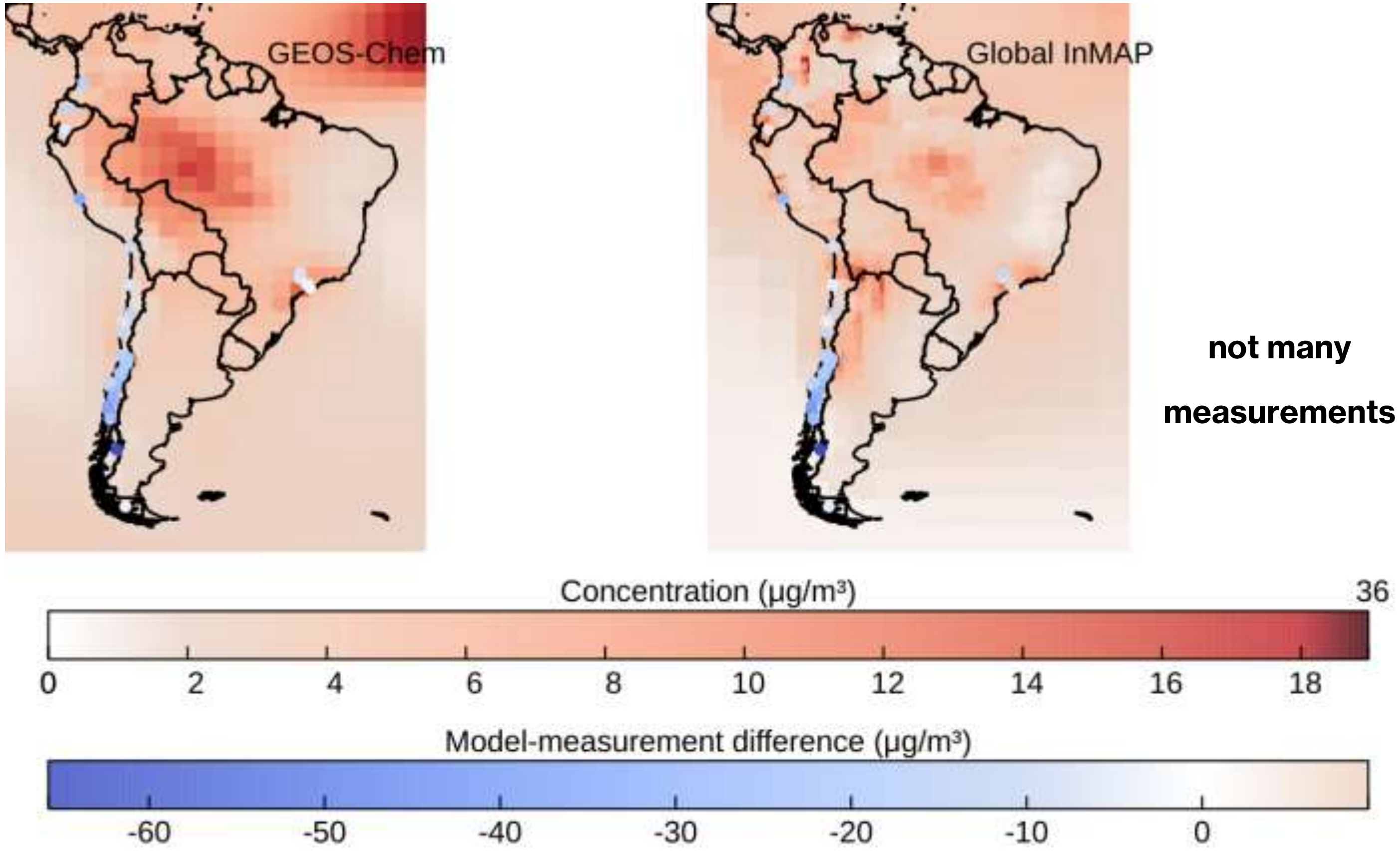




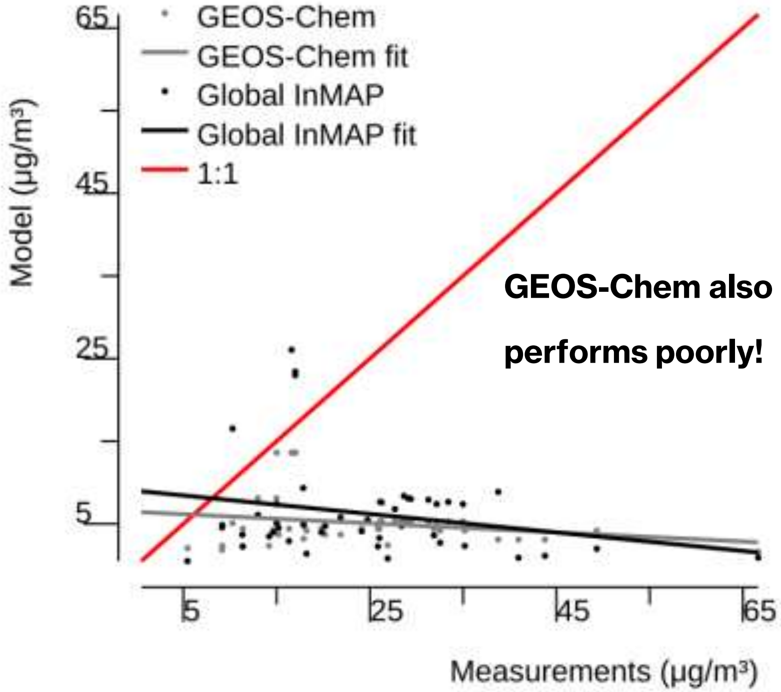
	NM Bias	NM Error	S	R^2
GEOS-Chem	-42%	50%	0.28	0.47
Global InMAP	-41%	52%	0.29	0.22

Thakrar *et al.*, *PLOS ONE* (2022).

Global InMAP performance varies by region



not many measurements



GEOS-Chem also performs poorly!

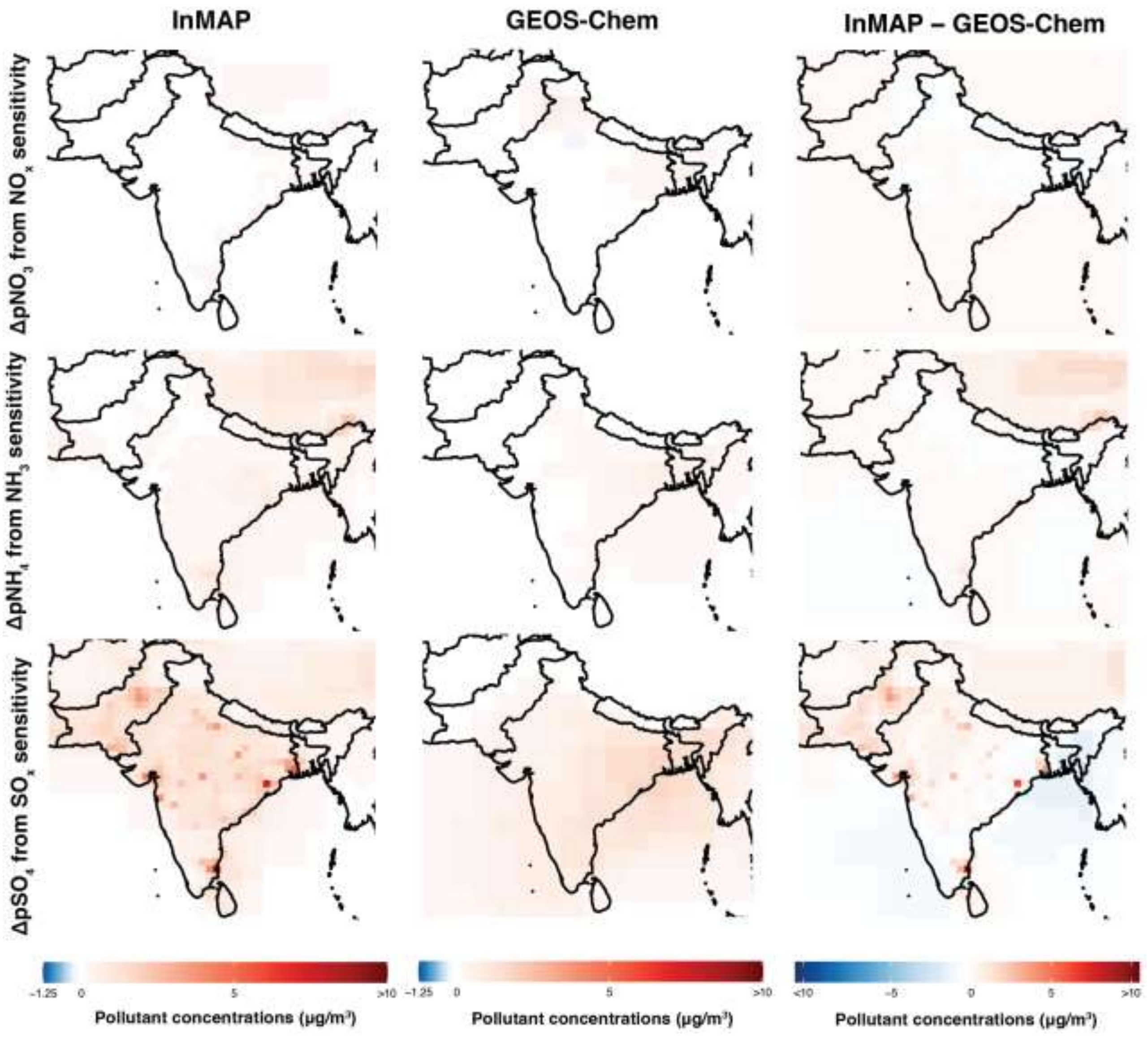
	NM Bias	NM Error	S	R^2
GEOS-Chem	-79%	79%	-0.06	0.05
Global InMAP	-74%	79%	-0.11	0.05

Thakrar *et al.*, *PLOS ONE* (2022).

Global InMAP can estimate changes in pollutant concentrations comparably to a traditional model

Scenarios involve increasing:

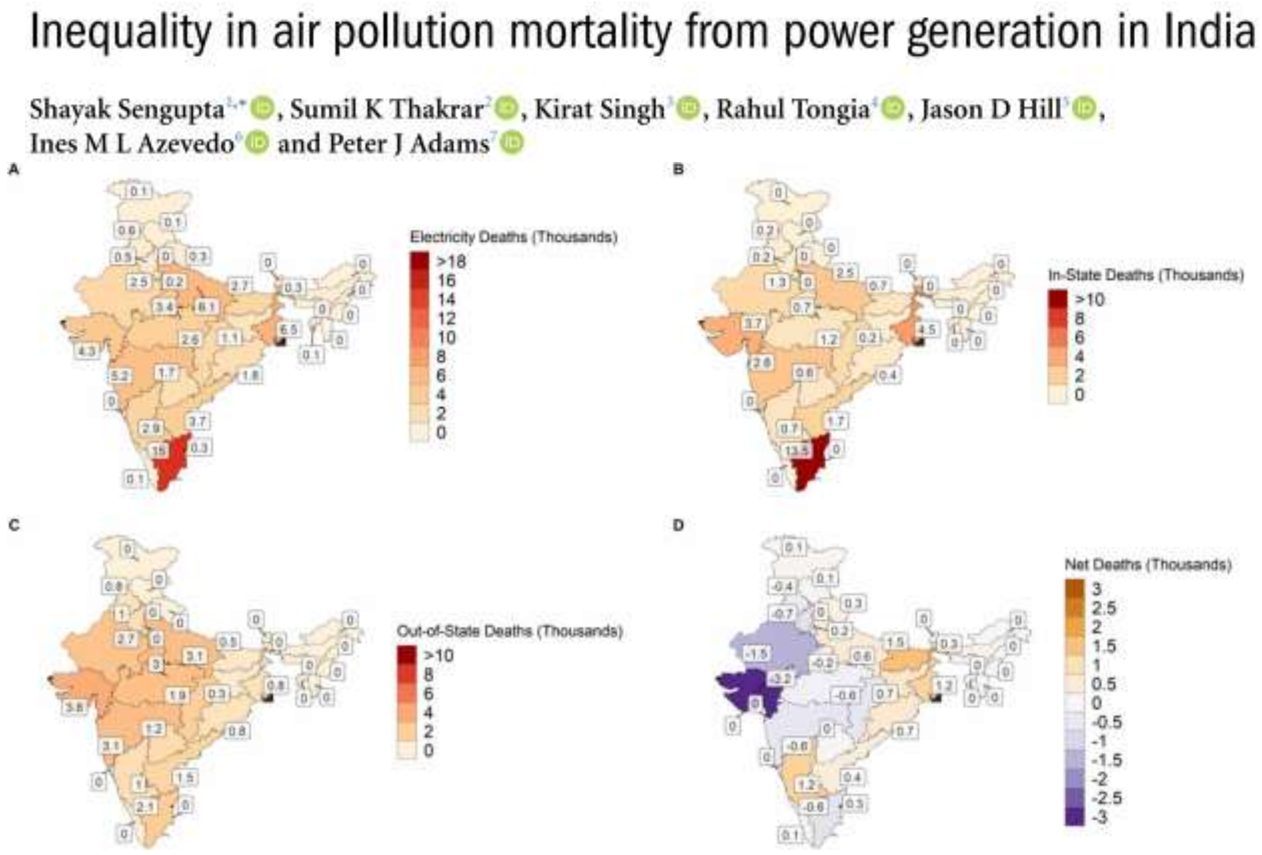
- NO_x emissions from transportation
- NH_3 emissions from agriculture
- SO_x emissions from power generation



Thakrar *et al.*, *PLOS ONE* (2022).

Some Uses & Developments: South & Southeast Asia

Global InMAP has been used to estimate air quality-related health impacts of energy and transportation scenarios across India (Sengupta *et al.*, 2022; Peshin *et al.*, *In Preparation*; Singh *et al.*, *In Review*)



Sengupta, *et al.* (2022).

Some Uses & Developments: South & Southeast Asia

Global InMAP is also being used to estimate the individual health harms of all 7,000+ brick kilns in Bangladesh (Thakrar *et al.*, *In Preparation*).

Thakrar, Boyd, & Mattsson (*In Preparation*).

Some Uses & Developments: South & Southeast Asia

University of Minnesota · USAID · NREL · ASEAN Centre for Energy

Advanced Energy Partnership for Asia

Quantifying the Impacts of Renewables Deployment on Air Quality and Human Health in Southeast Asia

Basic Training on the Global InMAP Model

Introduction

This basic training on the Global InMAP model is designed to apply University of Minnesota's (UM) Global Intervention Model for Air Pollution (Global InMAP) air quality model to Southeast Asian context to demonstrate for planners and government staff a publicly available, user-friendly tool that can quantify the air-quality benefits of renewables deployment scenarios. Generally, this training aims to improve technical capacity and knowledge of the linkages between air quality, human health outcomes, and renewables deployment in Southeast Asian countries. Audiences for this effort is specified to members of Heads of ASEAN Power Utilities (HAPUA) who specialize in environmental impacts of the electricity system.

To meet the learning objective, the course is structured in 2 modules:

- Module 1: Introduction to Global InMAP and model set-up
- Module 2: Applying Global InMAP in the region using a test case

Each module will have the following basic structure:

- A presentation giving an overview of how to use the model,
- A software tutorial class and interactive online session,
- Time for questions and support.

USAID · NREL · University of Minnesota Driven to Discover · ASEAN Centre for Energy

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

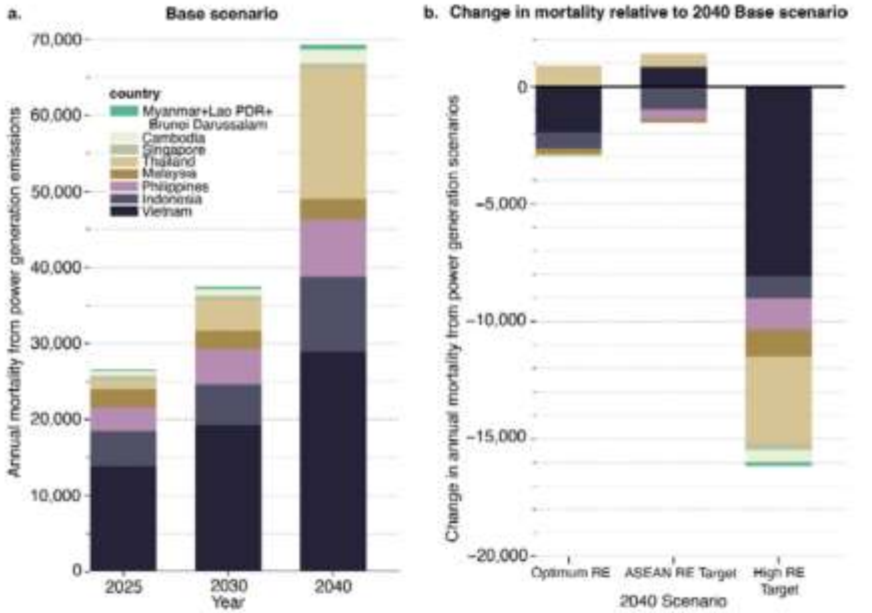
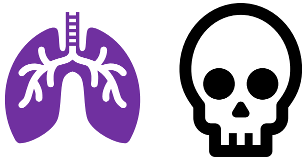
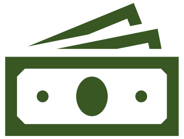
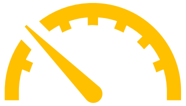


Figure 4. (a) Annual excess mortality attributable to total projected power generation emissions in the Base scenario, broken down by ASEAN member country in which mortality occurs. (b) Change in excess mortality in 2040 (relative to the Base scenario) for the ASEAN RE Target, High RE Target, and Optimum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

Ravi & Thakrar, *et al.*, ASEAN (2022).

Air quality health impact assessment is more difficult in a developing country

	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	
 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	• 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 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

Thank you