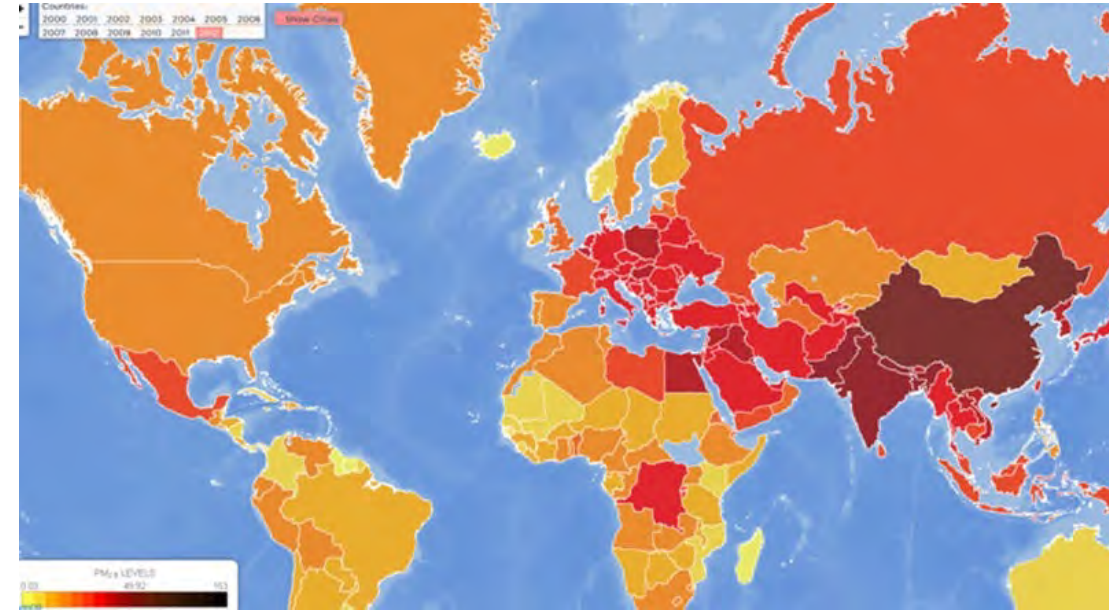
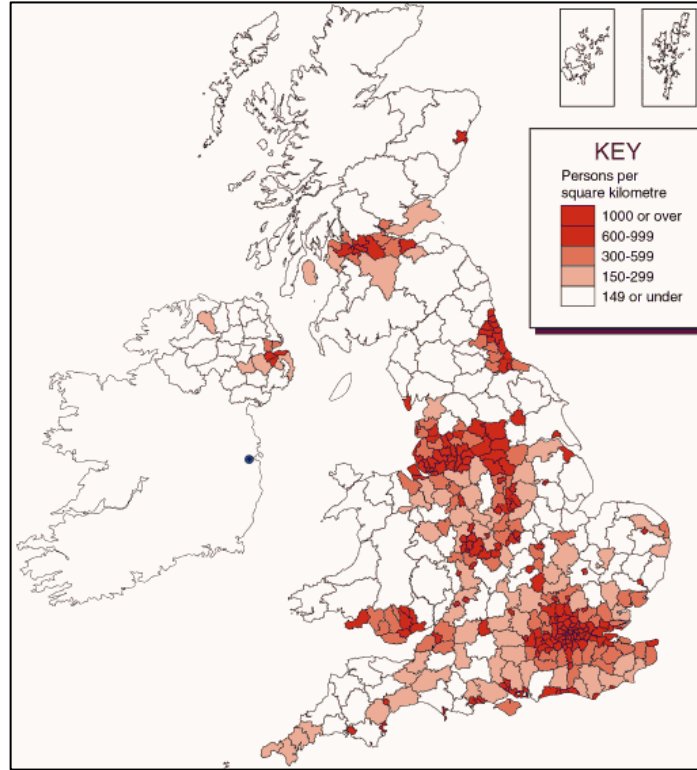


# Use of Chemical Transport Models to Motivate and Inform Air Quality Policies at Local, National and Global Scales



**Eloïse Marais**

**ERC HEAL Workshop**

**7 July 2022**

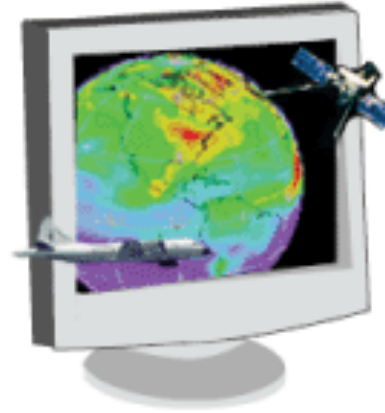
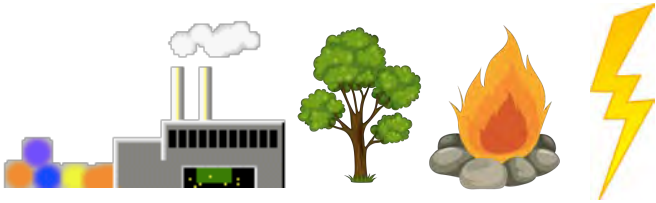
**[e.marais@ucl.ac.uk](mailto:e.marais@ucl.ac.uk)**

**Lab:** <https://maraisresearchgroup.co.uk/>; **Profile:** <https://www.geog.ucl.ac.uk/people/academic-staff/eloise-marais>

# The GEOS-Chem Chemical Transport Model

GEOS-Chem

Emissions  
(natural/human)



Offline meteorology  
(NASA GMAO)



Chemistry  
Transport  
Dry/wet deposition

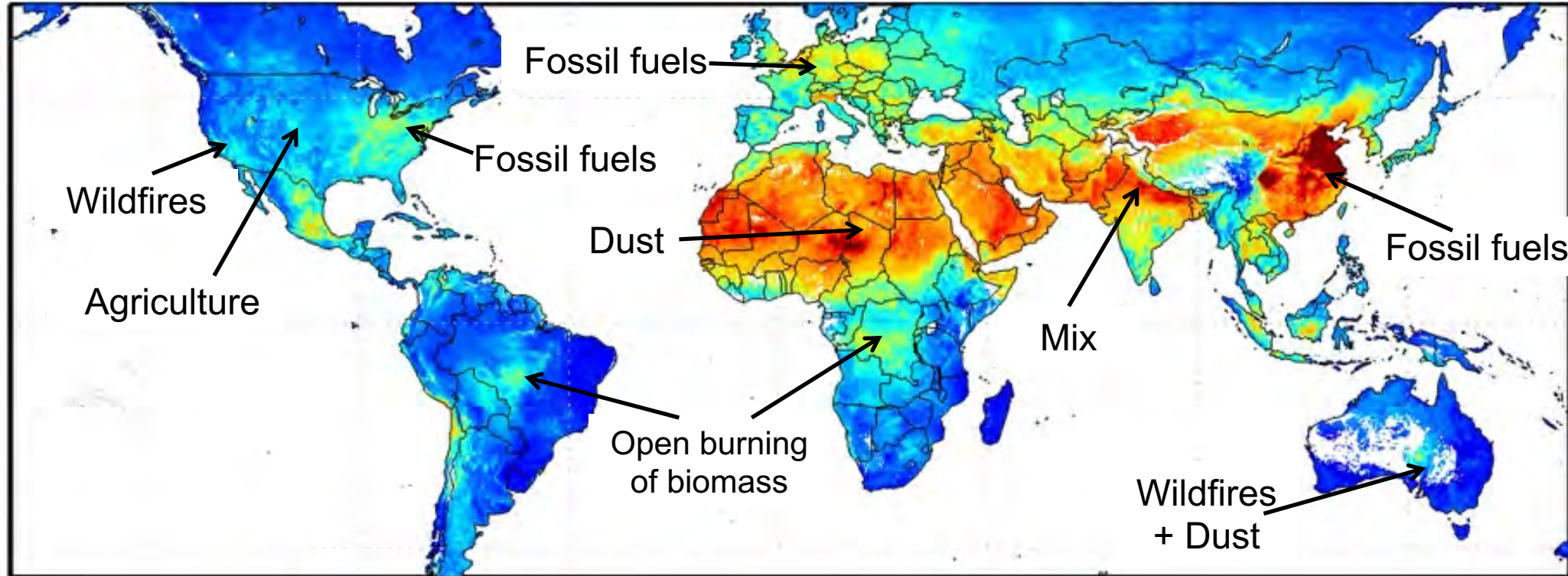


3D global/regional atmospheric concentrations

GEOS-Chem website home page: <https://geos-chem.seas.harvard.edu/>

# Global Distribution of Fine Particles (PM<sub>2.5</sub>)

PM<sub>2.5</sub> derived with satellite and surface observations and a model



Satellite-Derived PM<sub>2.5</sub> [ $\mu\text{g}/\text{m}^3$ ]

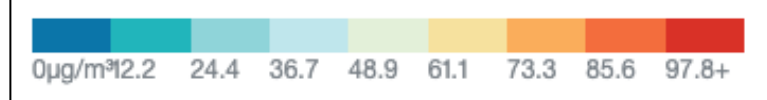
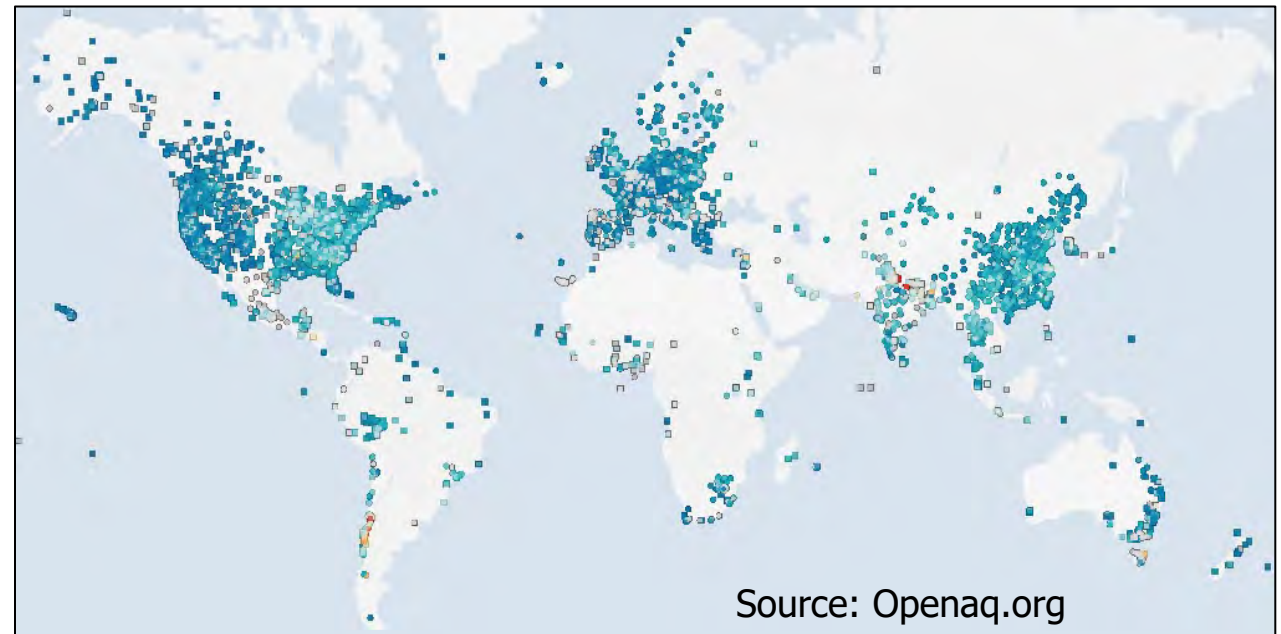
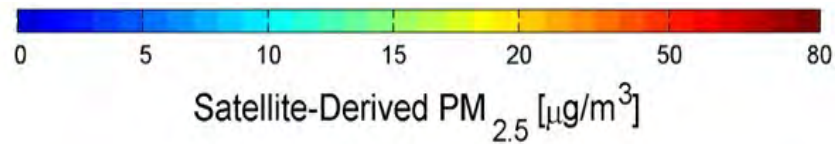
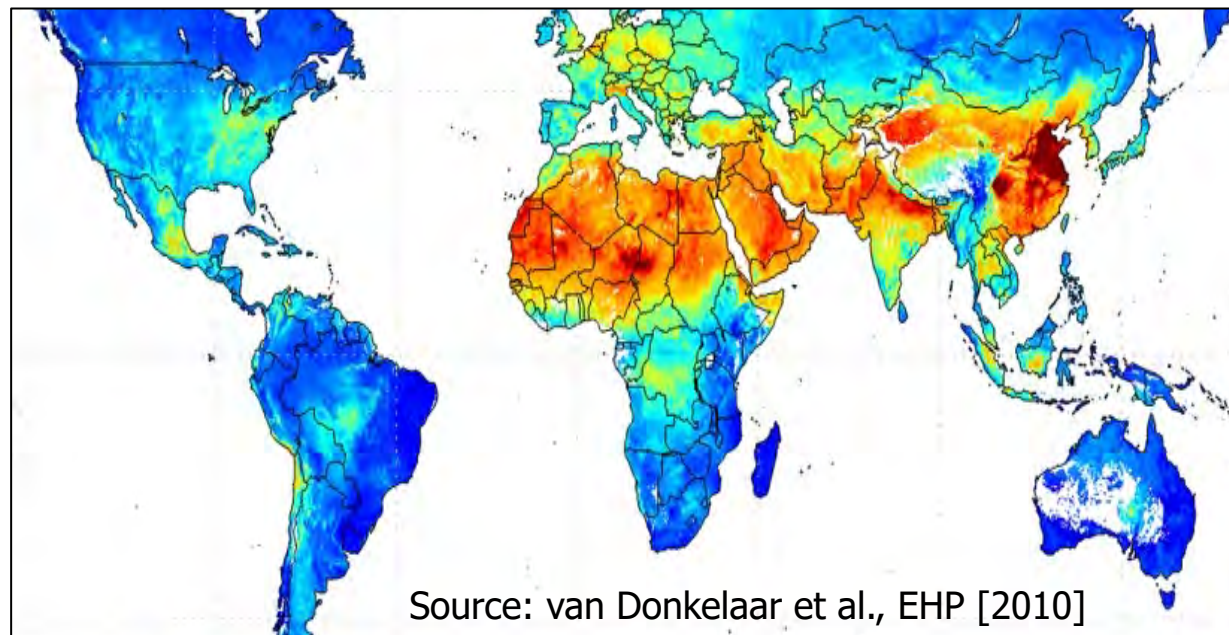
Source: van Donkelaar et al., EHP [2010]

Dominant sources include a range of natural and anthropogenic sources that vary spatially and seasonally



# Challenging to isolate sources using observations

Satellite products (left) and surface measurements (right) provide total PM<sub>2.5</sub>



Low-cost and reference  
monitor PM<sub>2.5</sub> [ $\mu\text{g}/\text{m}^3$ ]

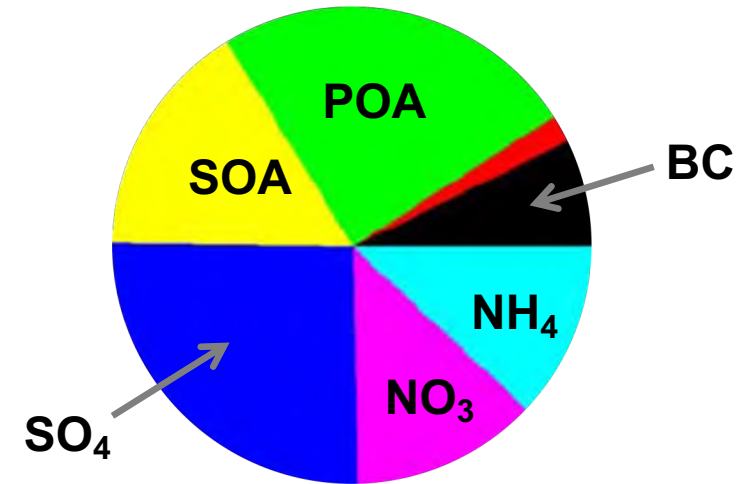
Even with measurements of individual PM<sub>2.5</sub> components, it is challenging to tease out the contribution from fossil fuels, **so we use a model.**

# Particles are a Mix of Components that Persist for Days

Direct emission  
of PM<sub>2.5</sub>  
(primary)

Emission of gas-phase  
precursors  
(secondary)

PM<sub>2.5</sub> includes a mix of components



Black carbon    **primary**

**Sulfate**

**Nitrate**

**Ammonium**

**secondary**

**Other inorganics**

**Organic aerosols**    **primary+secondary**

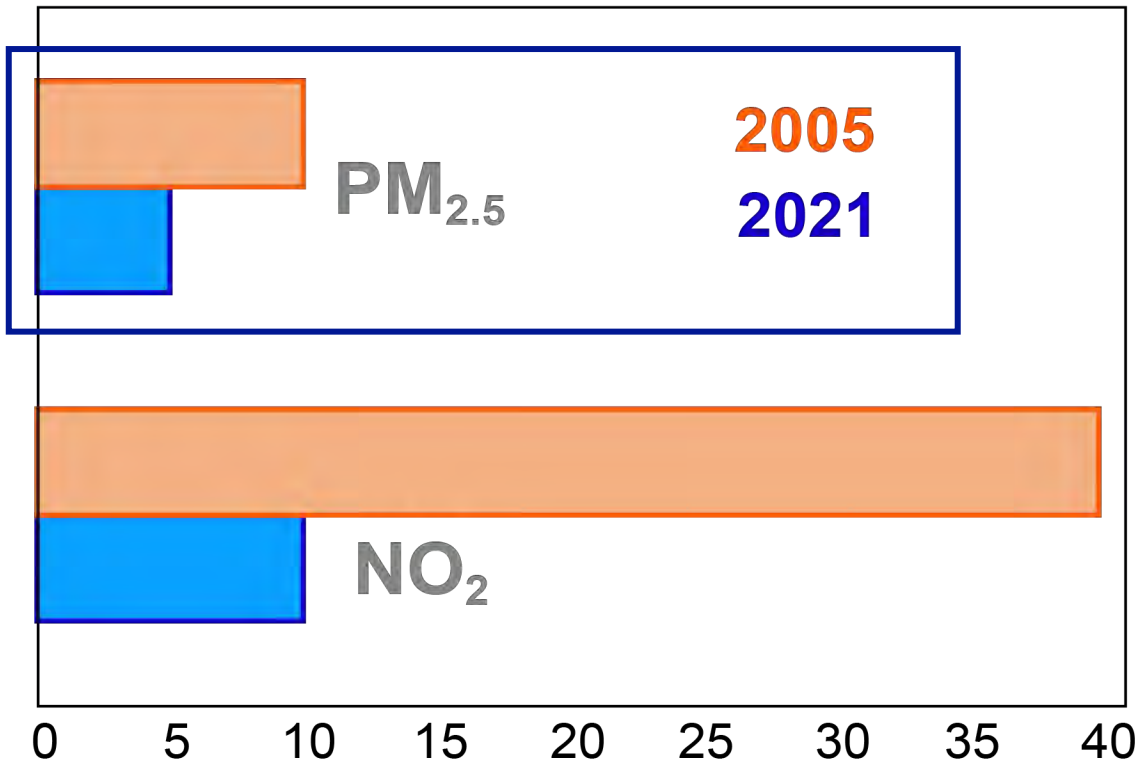
PM<sub>2.5</sub> includes local and distant sources (long atmospheric lifetime)



# Stricter World Health Organization (WHO) Guideline

(<https://apps.who.int/iris/handle/10665/345329>)

WHO Annual Air Quality Guidelines [ $\mu\text{g m}^{-3}$ ]



Source: WHO Facebook page

# Sources of Fine Particles (PM<sub>2.5</sub>) in UK Cities



Jamie Kelly  
(postdoc)



Eloise A. Marais  
Jamie M. Kelly



Jordan White  
Roland J. Leigh



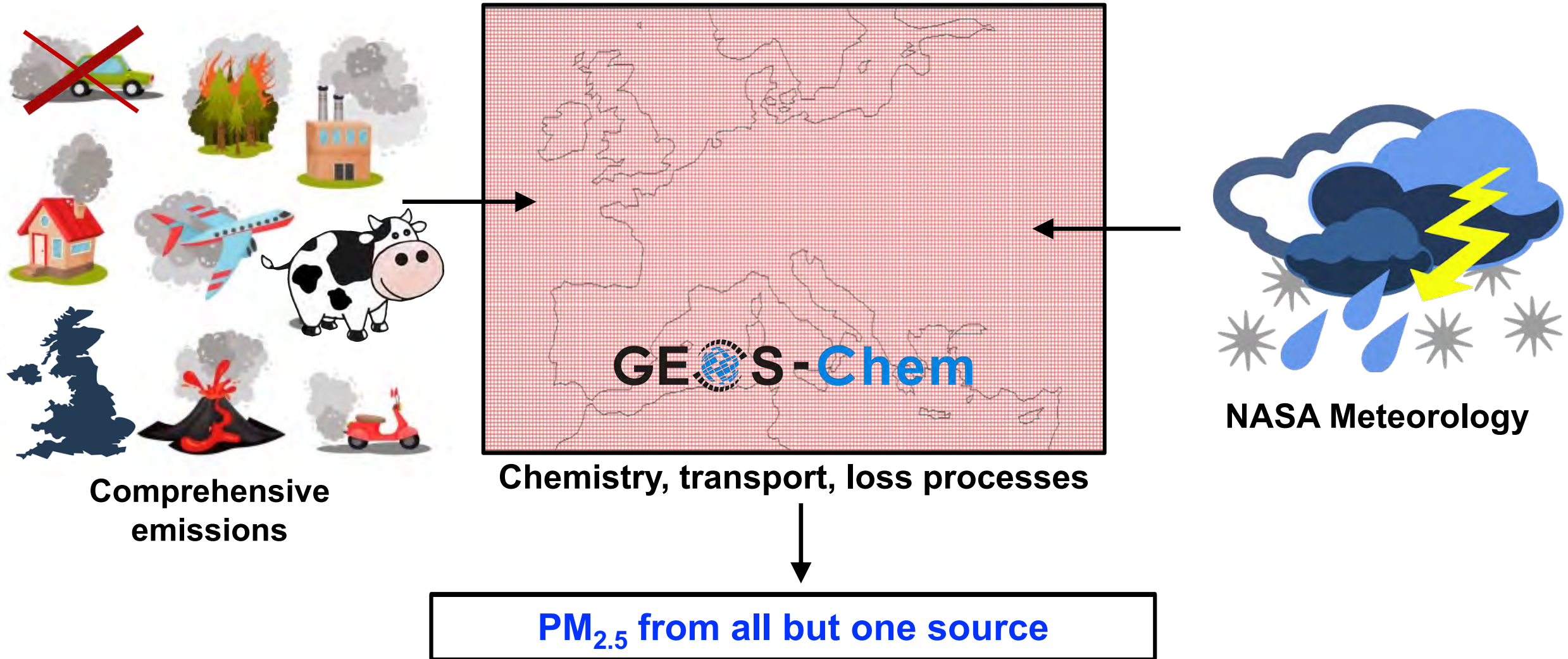
Leicester  
City Council

Jolanta Obszynska  
Matthew Mace



# Simulate PM<sub>2.5</sub> and Sources with GEOS-Chem

3D Atmospheric Chemistry Transport Model

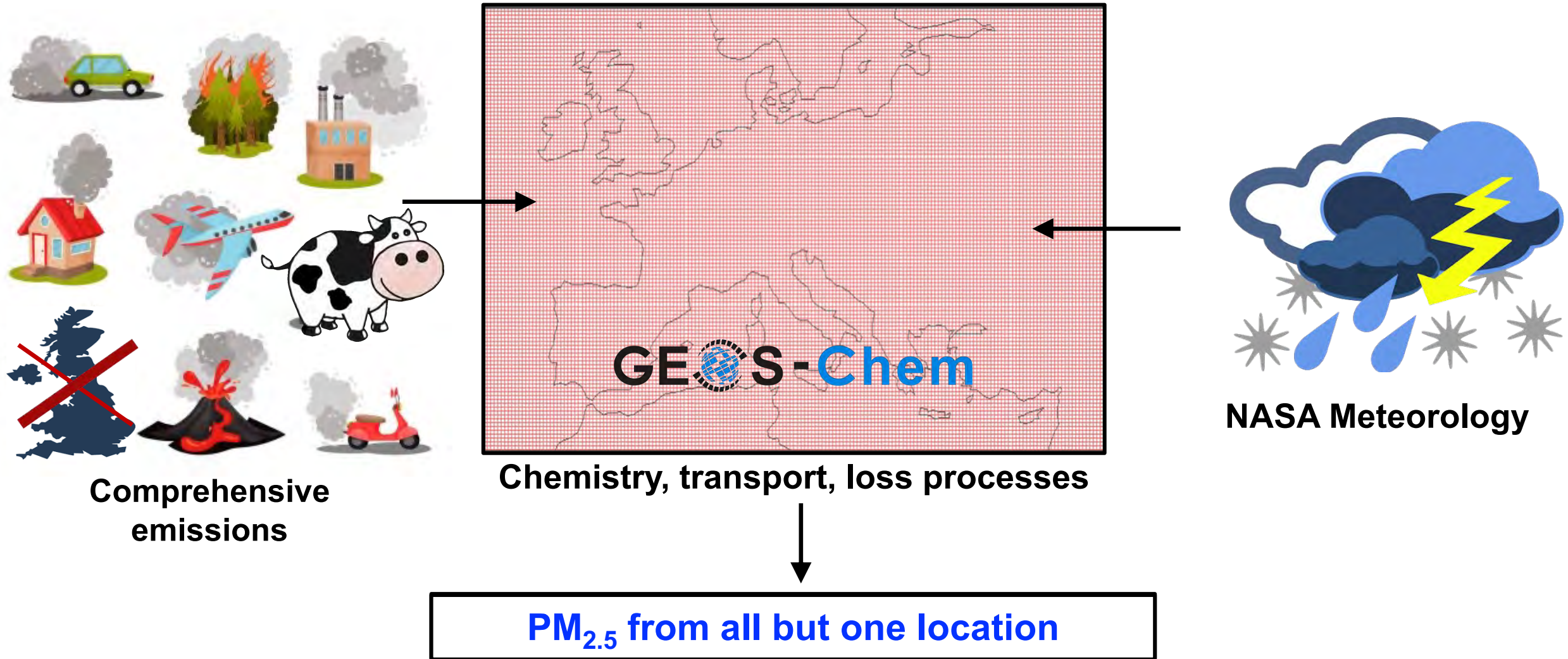


GEOS-Chem manual: <http://acmg.seas.harvard.edu/geos/>



# Simulate PM<sub>2.5</sub> and Sources with GEOS-Chem

3D Atmospheric Chemistry Transport Model



GEOS-Chem manual: <http://acmg.seas.harvard.edu/geos/>

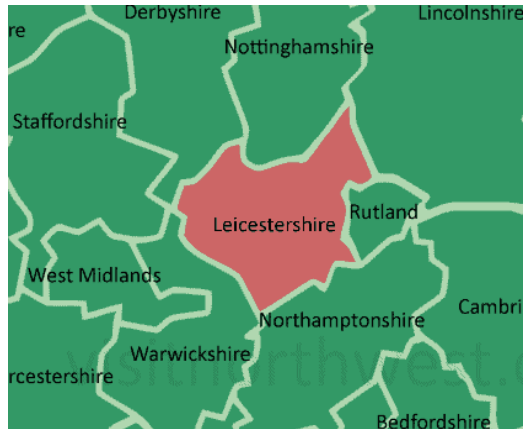


# Test Contribution of Potentially Influential Sources

## Local



**City**



**County**

## National



**Nearby large cities**

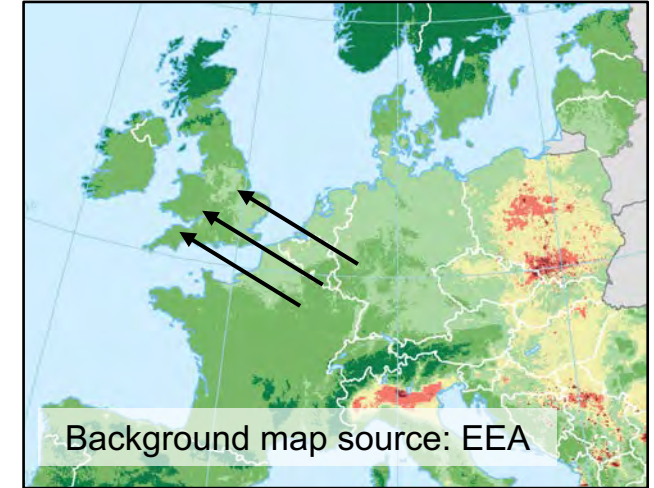


**Transport**



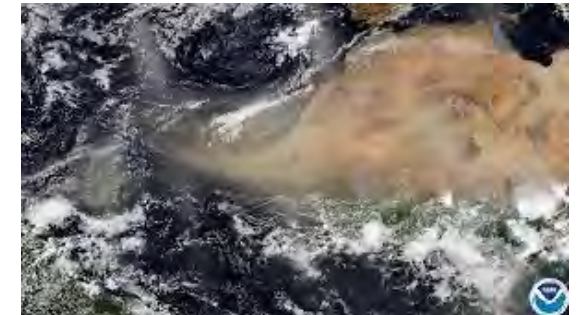
**Agriculture**

## Regional



**Mainland Europe**

## Global



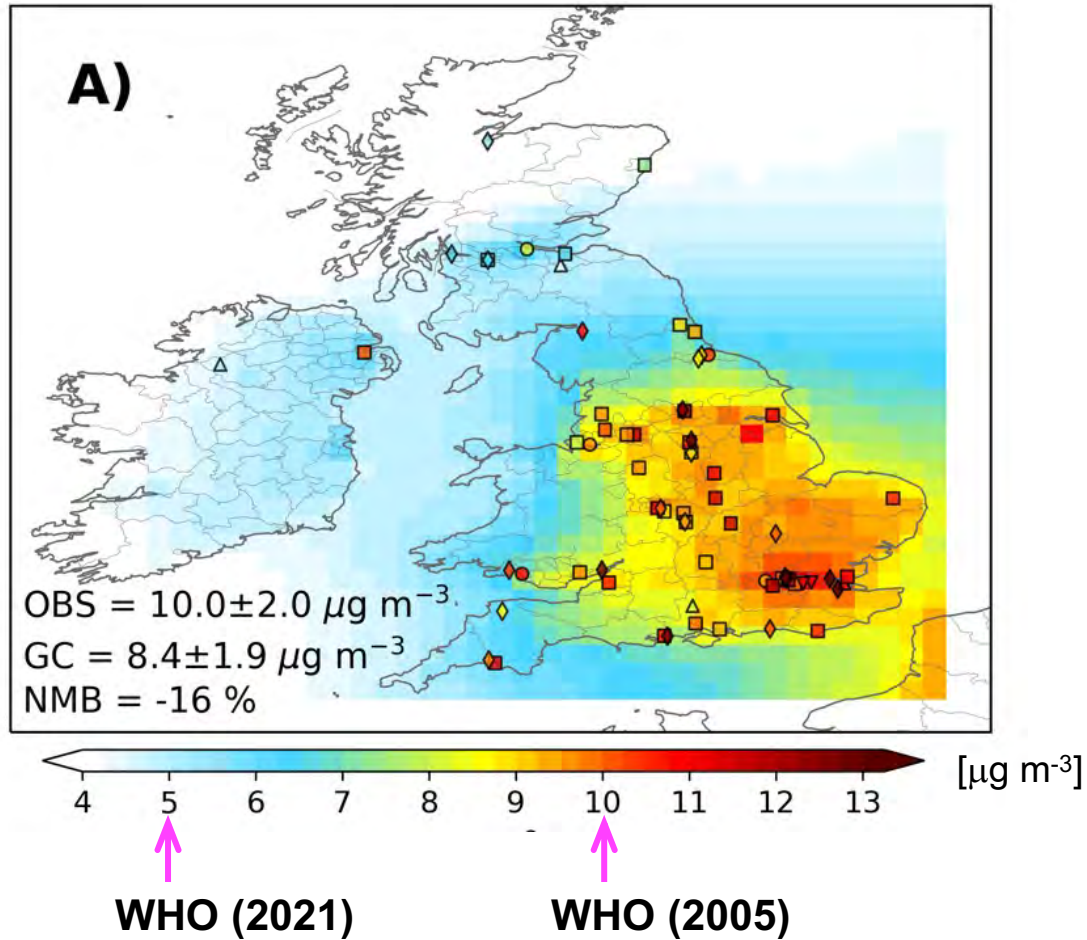
**Desert Dust**



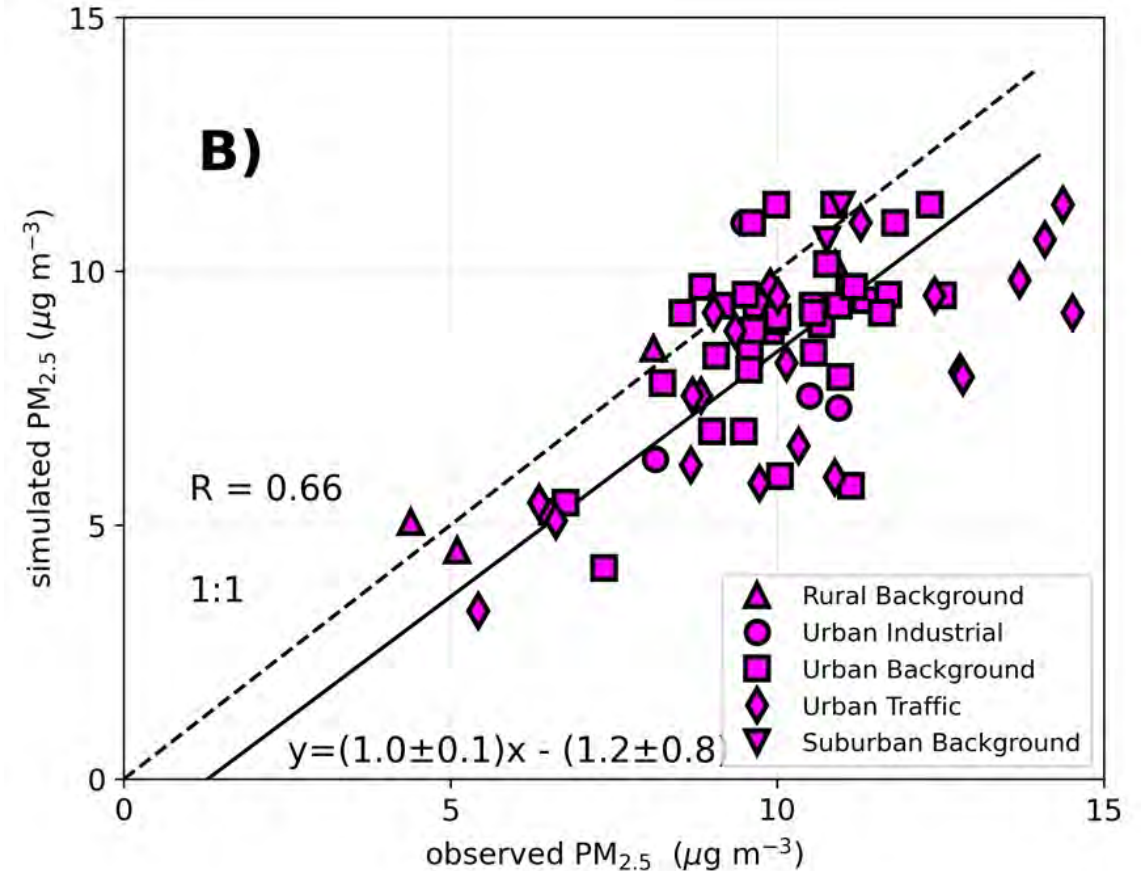
# Assess Model using Reference Monitors

Observations of total PM<sub>2.5</sub> from the Automatic Urban and Rural Network (AURN)

## Comparison of annual mean surface concentrations of PM<sub>2.5</sub> for 2019



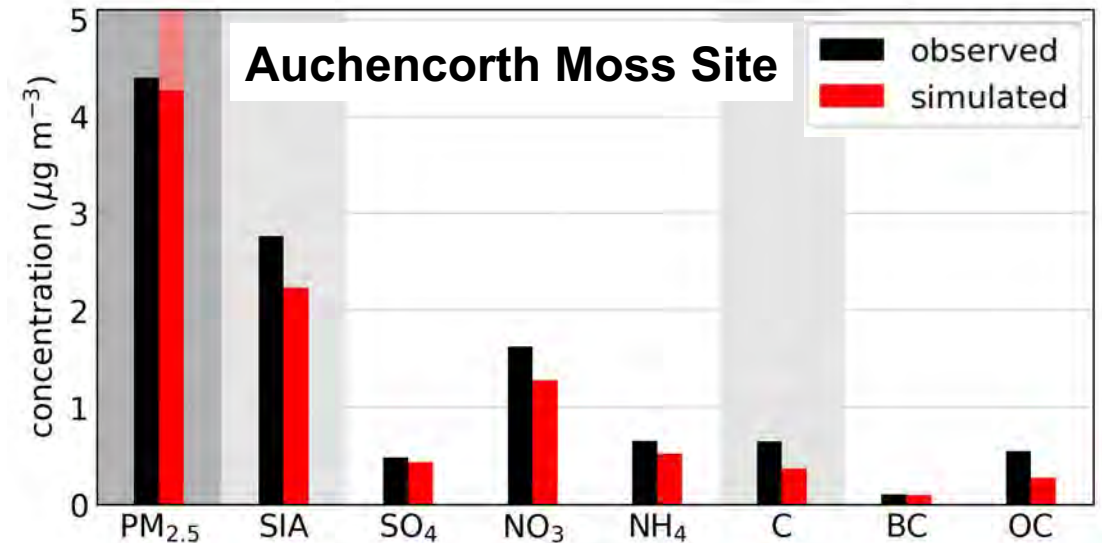
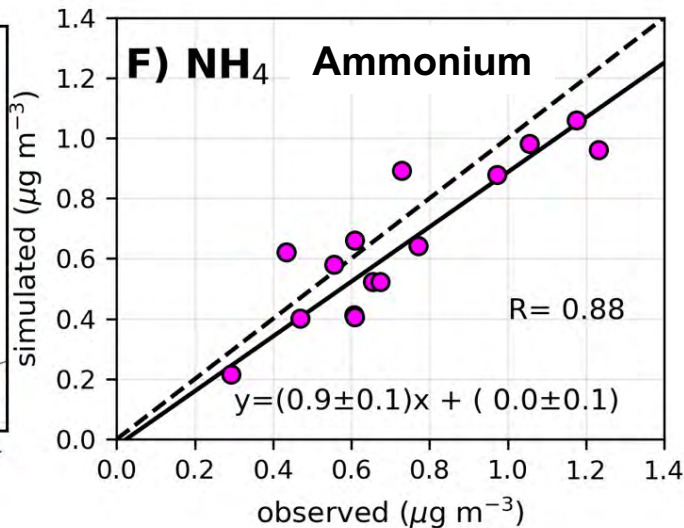
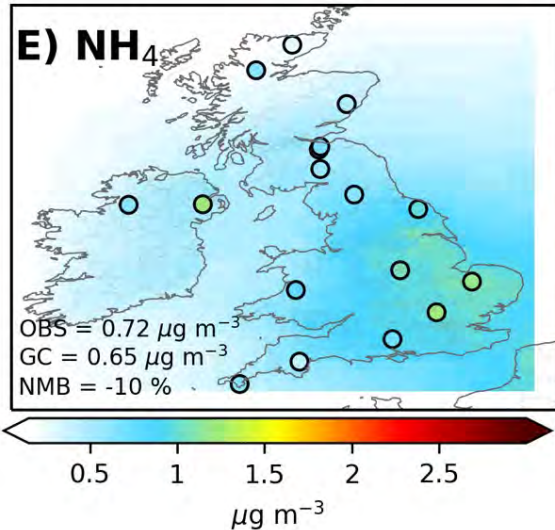
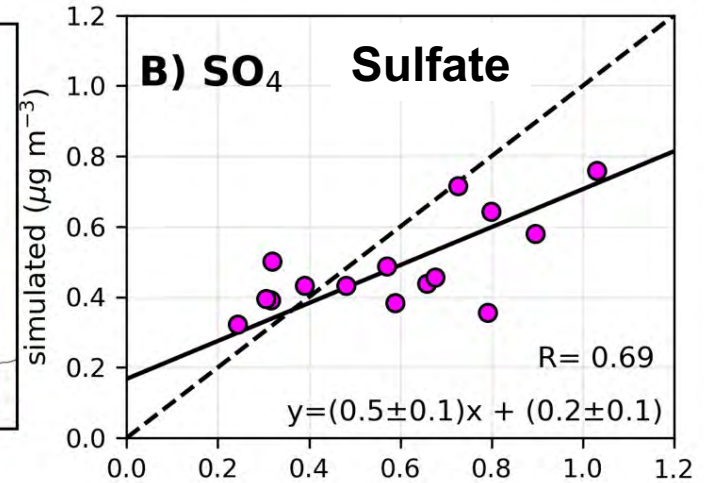
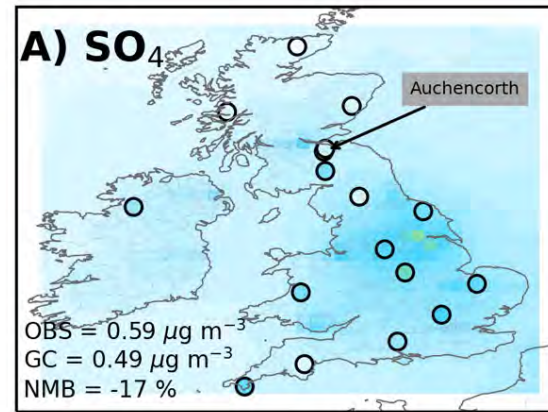
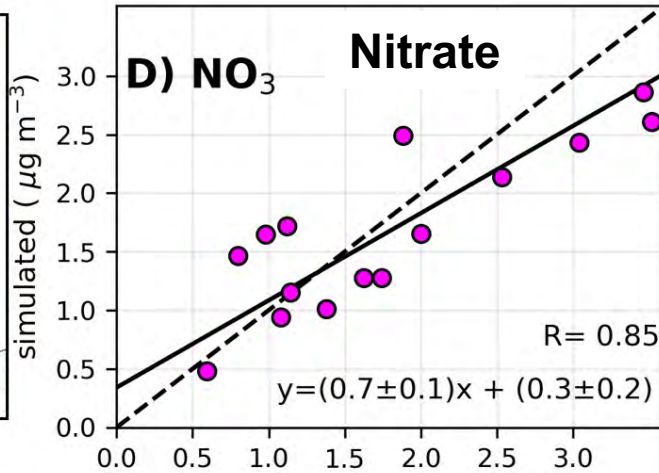
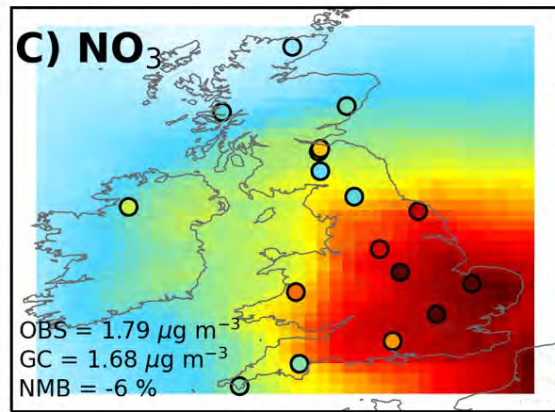
75% of UK exceeds updated WHO guideline



Consistent spatial pattern ( $R = 0.66$ ) and variance (slope = 1.0). Model 16% less than observations

# Assess Validity of Model using Reference Monitors

Use PM<sub>2.5</sub> composition measurements from UKEAP and EMEP sites to assess model



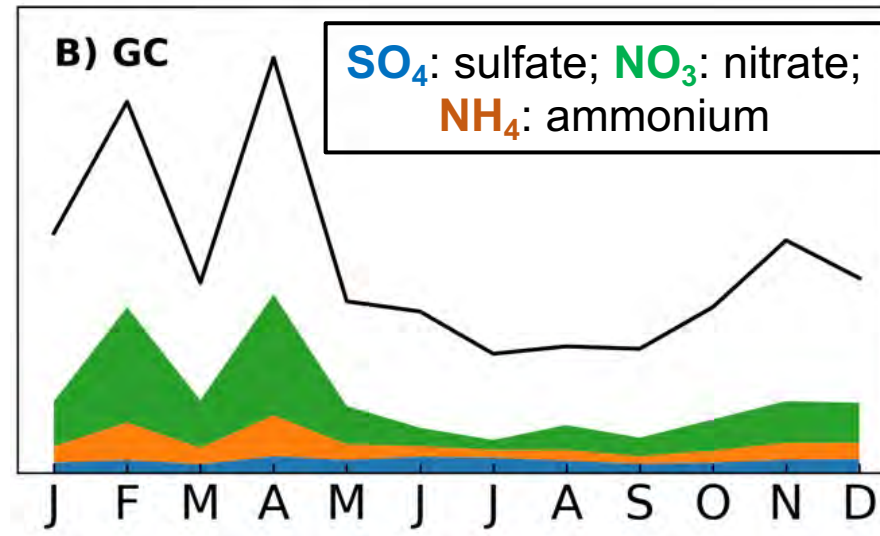
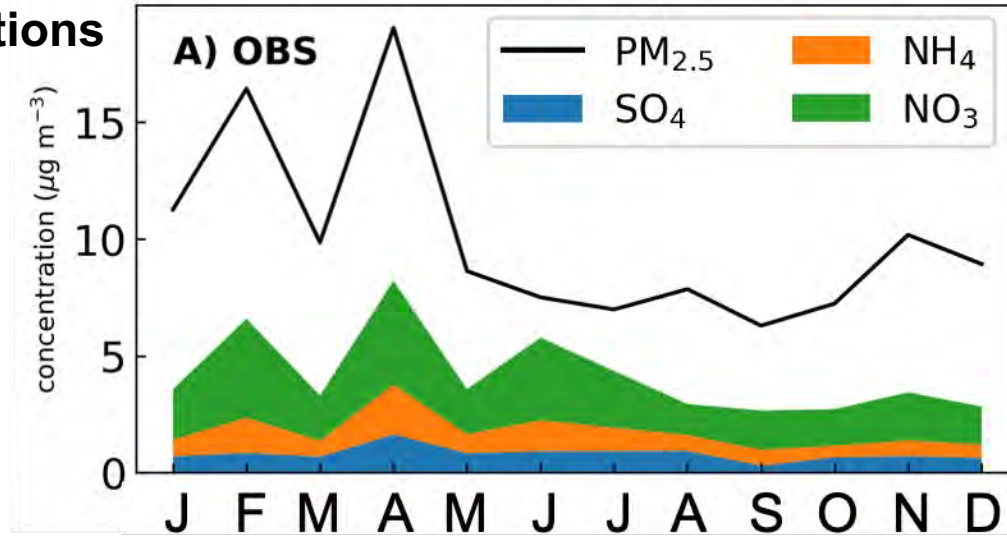
Model underpredicts observed (sulfate, nitrate, ammonium) and possibly overpredicts unobserved (dust) components. Model captures variance of components from NO<sub>x</sub> (nitrate) and ammonia (ammonium)



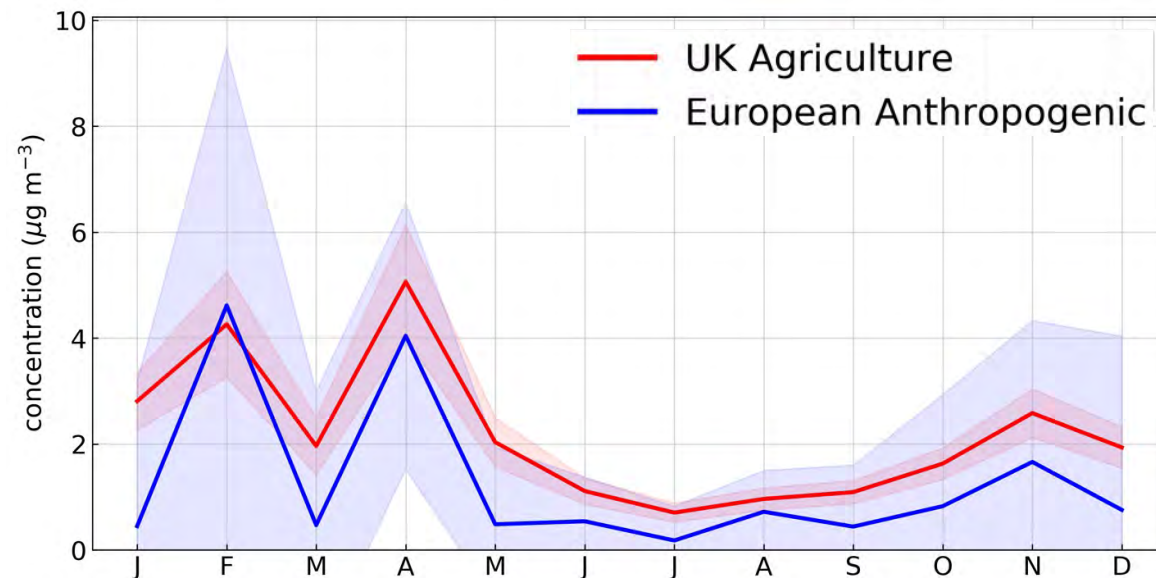
# Assess Validity of Model using Reference Monitors

Also evaluate model skill at reproducing observed seasonality in total and components PM<sub>2.5</sub>

Observations



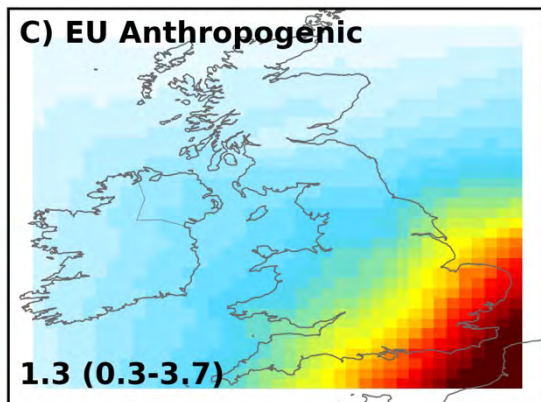
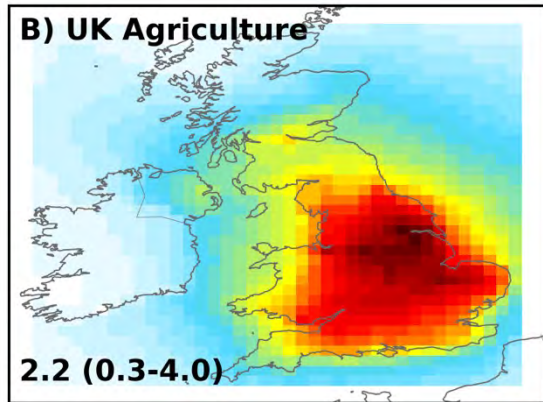
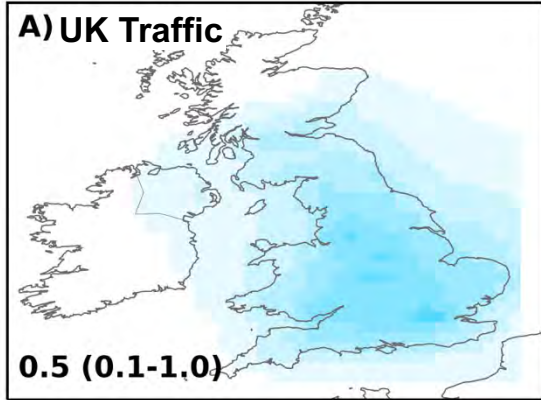
GEOS-Chem



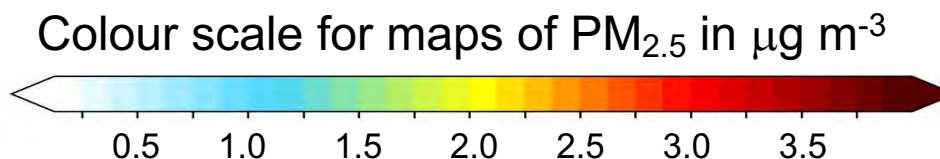
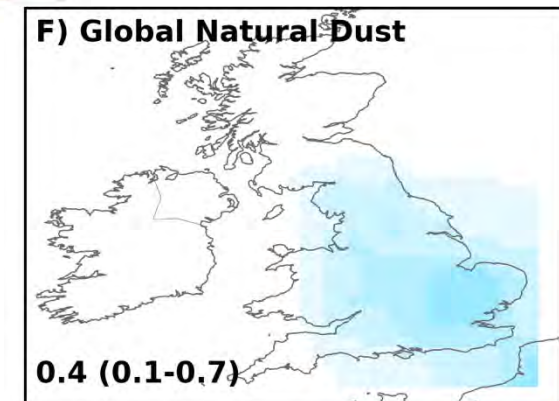
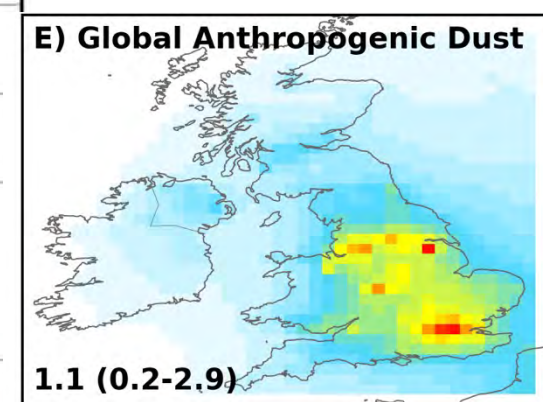
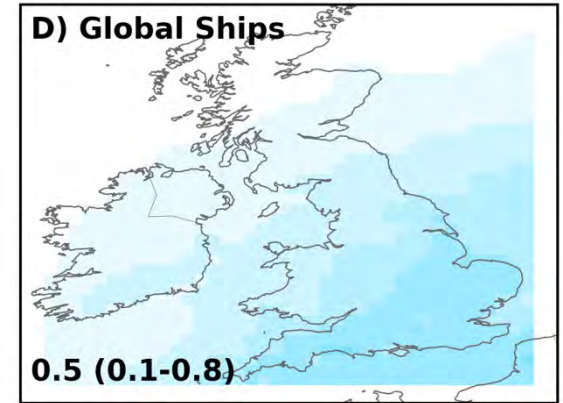
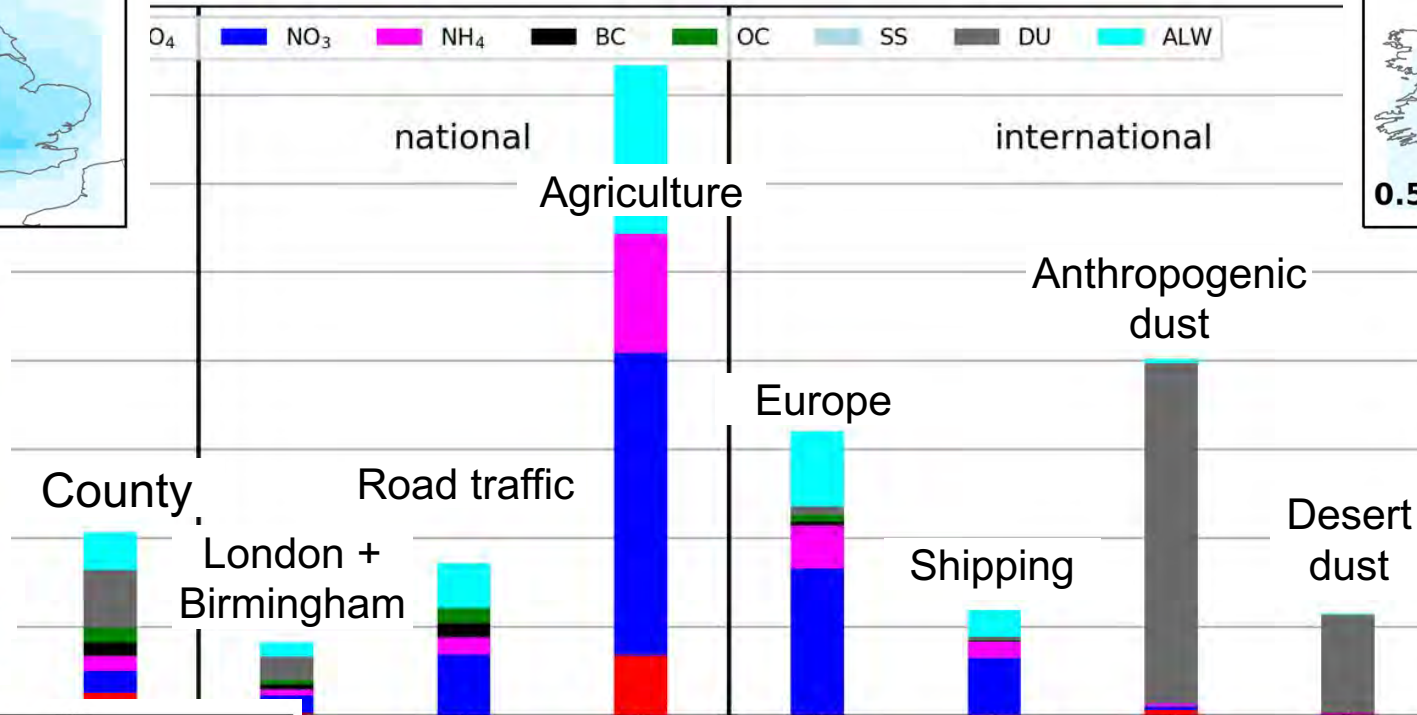
Interpret results with GEOS-Chem:

Cold season enhancements due to combined effect of pollution transport from Europe and agricultural emissions of ammonia

# Contribution of Sources to annual PM<sub>2.5</sub> in Leicester



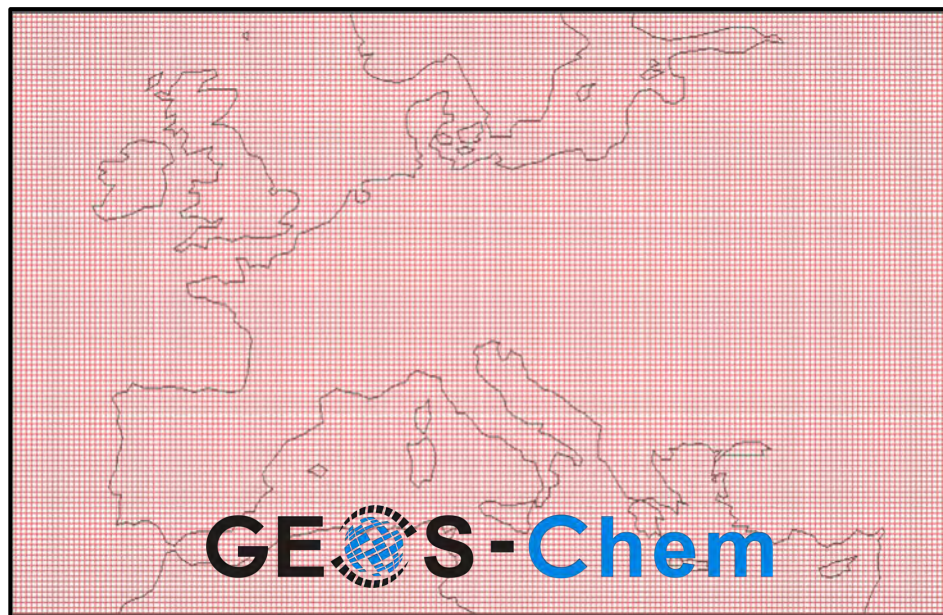
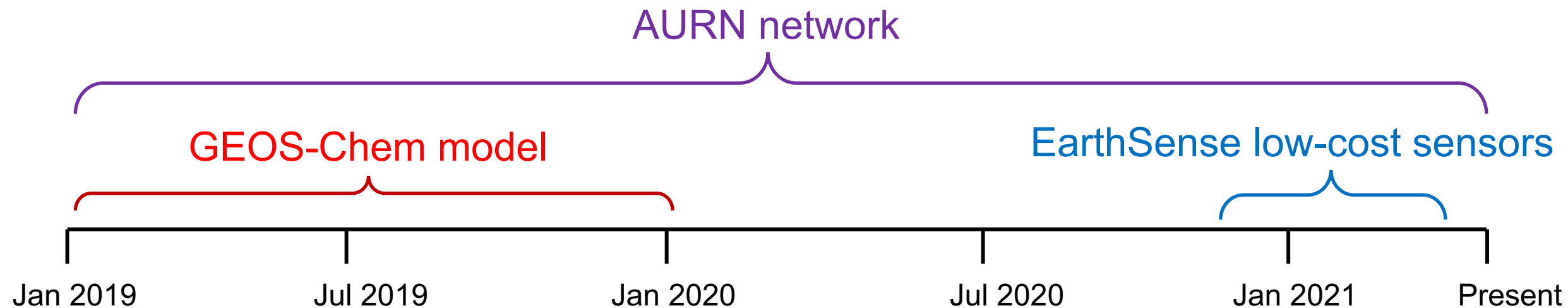
**SO<sub>4</sub>**: sulfate; **NO<sub>3</sub>**: nitrate; **NH<sub>4</sub>**: ammonium  
**BC**: black carbon; **OC**: organic carbon; **DU**: dust



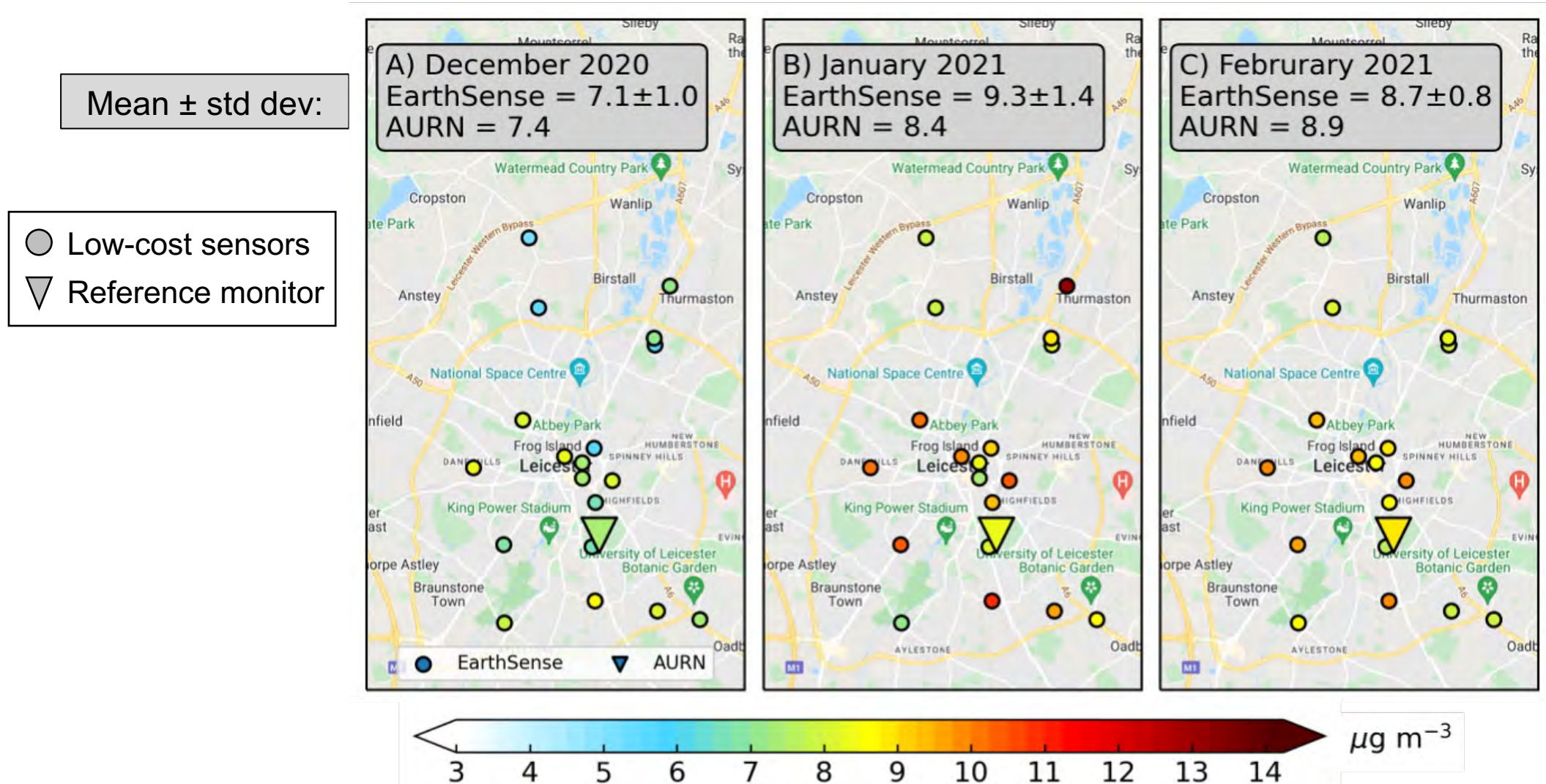


# Corroborating Evidence from Low-Cost Sensors

Low-cost network of sensors distributed throughout Leicester from Dec 2020 to Feb 2021



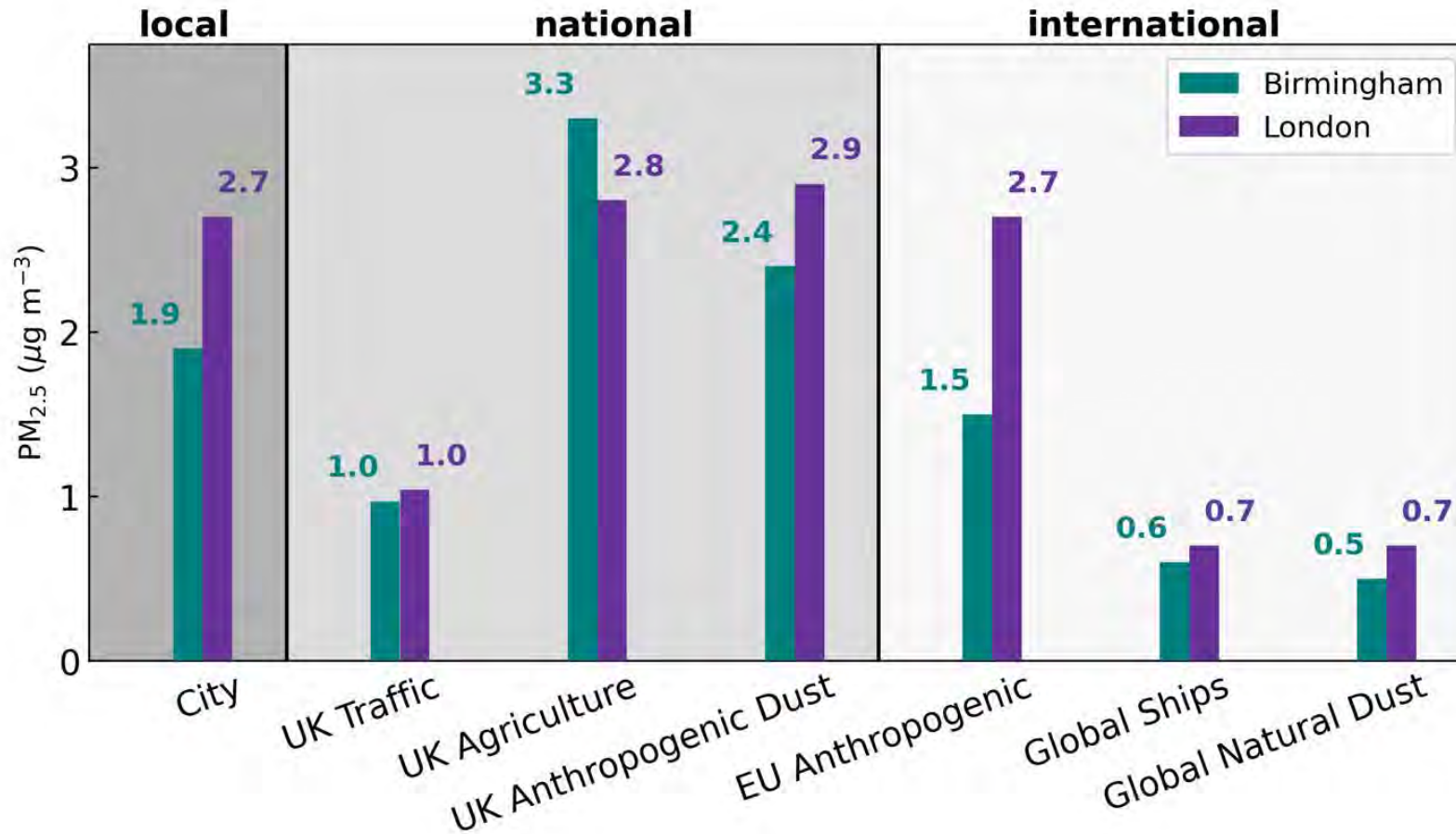
# Corroborating Evidence from Low-Cost Sensors



According to low-cost sensors, local sources contribute **7%**. Model similarly low (**2%**)



# Results for Large Cities like London and Birmingham



**London:** 1,600 km<sup>2</sup>

**Birmingham:** 270 km<sup>2</sup>

**Leicester:** 70 km<sup>2</sup>

Local sources compete with rural agriculture in anomalously large London

Generalizable expression for estimating PM<sub>2.5</sub> from local sources and agriculture:

$$\text{PM}_{2.5,\text{local}} = +0.8 \times \ln(\text{Area}) - 2.6 \quad (R^2 = 0.89)$$

$$\text{PM}_{2.5,\text{agriculture}} = -0.3 \times \ln(\text{Area}) + 4.9; \quad (R^2 \sim 1)$$

# Conclusions and Acknowledgements

- Under-regulated agricultural sector dominates PM<sub>2.5</sub> year-round
- Mainland Europe makes large cold-season contribution to PM<sub>2.5</sub>
- Policies targeting local sources only likely to have an effect in large cities
- Results reinforce the need for continued and strengthened international agreements and measures to control ammonia emissions from agriculture
- Agriculture also a prominent source of greenhouse gases (methane, nitrous oxide), so potential for climate and air quality co-benefits

Support provided by Leicester City Council from a Defra-funded Air Quality Grant



Department  
for Environment  
Food & Rural Affairs



# Global premature mortality due to exposure to air pollution from fossil fuels

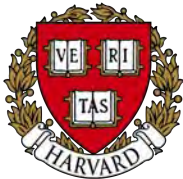
K. Vohra, A. Vodonos, J. Schwartz, E. A. Marais, M. P. Sulprizio,  
L. J. Mickley, <https://doi.org/10.1016/j.envres.2021.110754>



**Karn Vohra**

(postdoc)

 @kohra\_thefog



UNIVERSITY OF  
BIRMINGHAM

WALLACE  
GLOBAL FUND

# PM<sub>2.5</sub> from Burning Fossil Fuels

PM<sub>2.5</sub> precursors emitted from a range of activities that combust fossil fuels

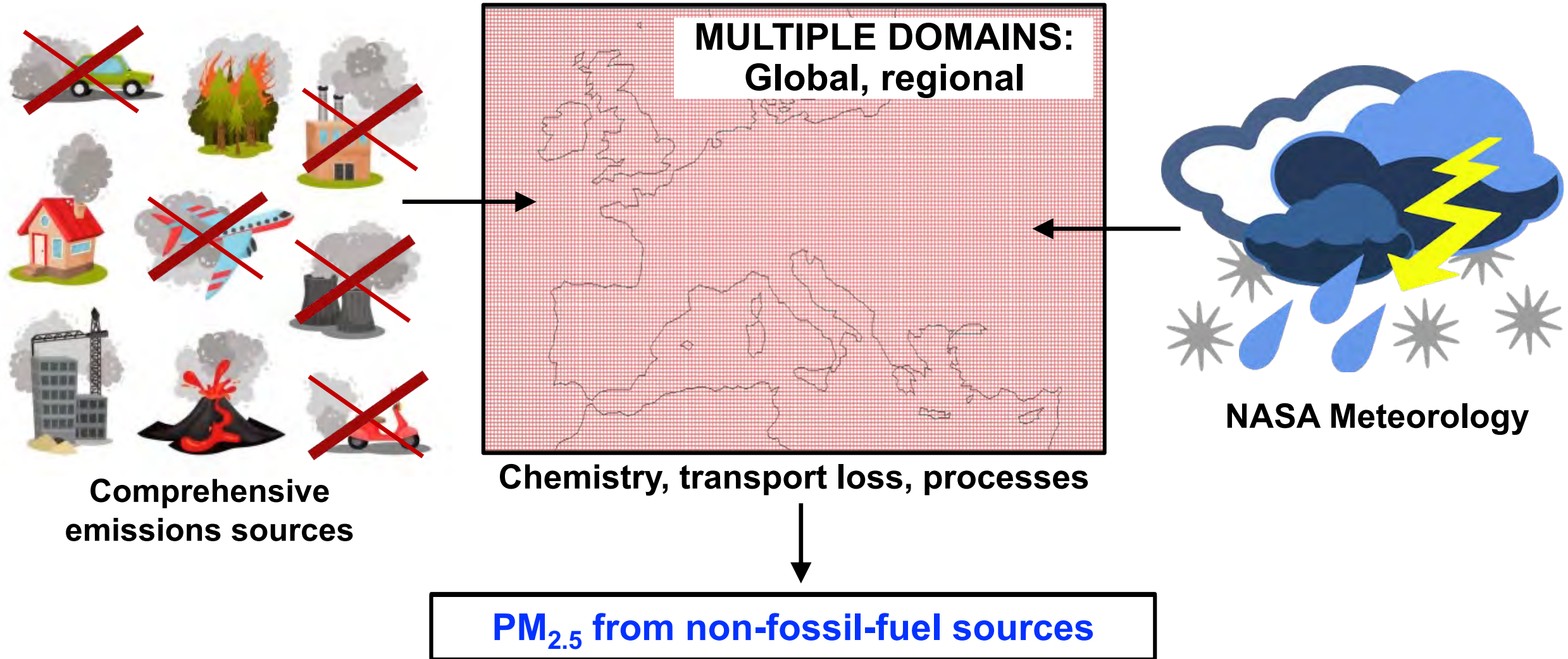
Combustion for transport, industry, energy generation, and domestic heating, lighting and cooking





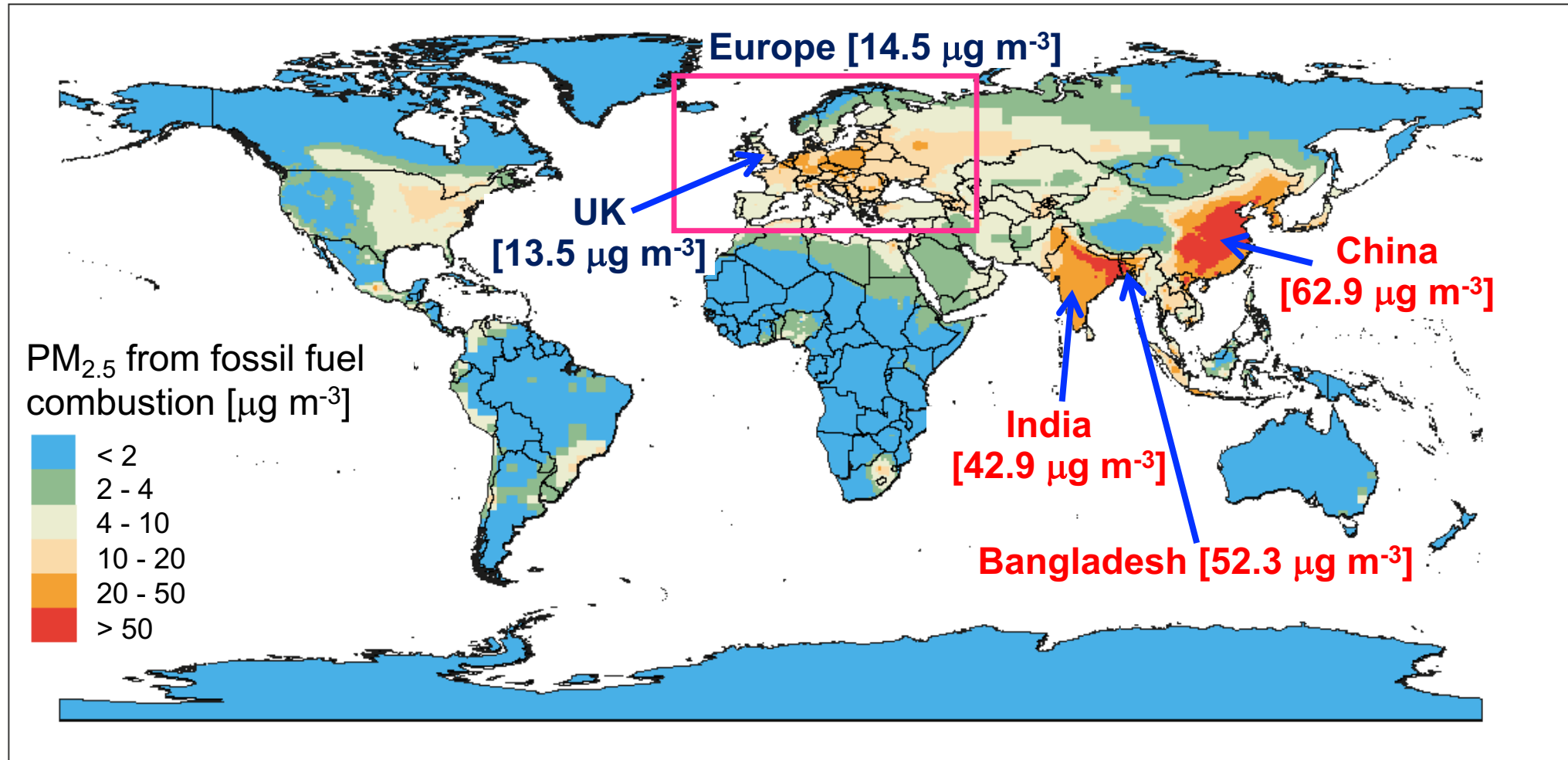
# Simulate Surface PM<sub>2.5</sub> with GEOS-Chem

3D Atmospheric Chemistry Transport Model



# GEOS-Chem Estimate of Fossil Fuel PM<sub>2.5</sub>

Difference between model simulations with and without fossil fuel PM<sub>2.5</sub>

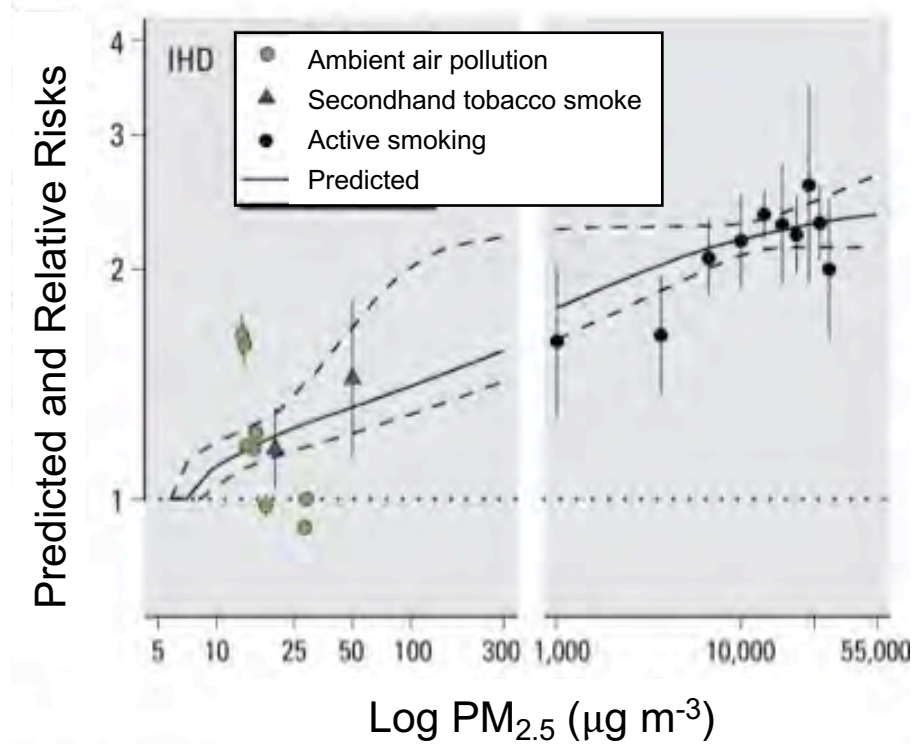


Hotspots are in China, Bangladesh, India, and central Europe



# Standard and Widely used Risk Assessment Models

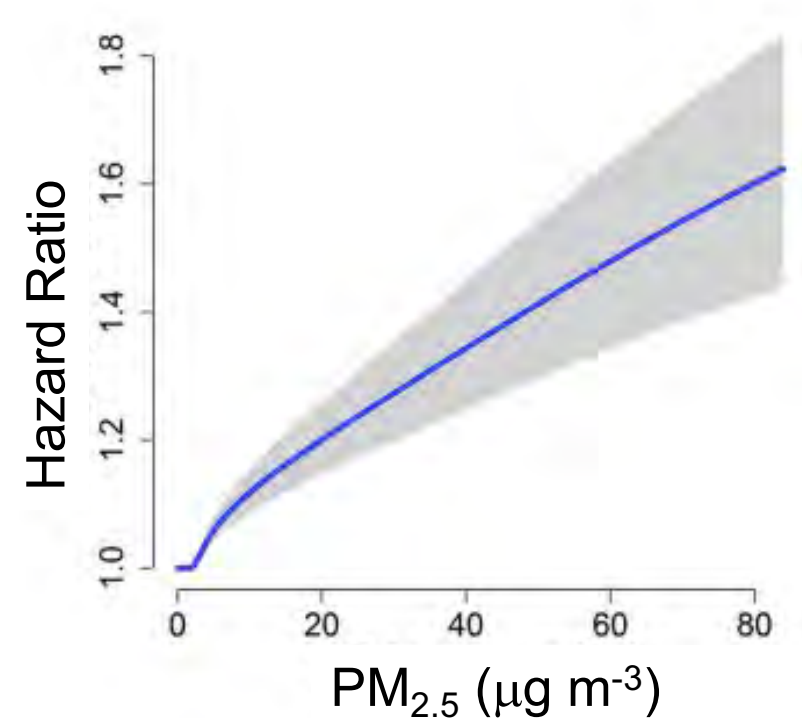
## Integrated Exposure-Response (IER)



[Burnett et al., 2014]

Data includes active and passive smoking  
to address outdoor PM<sub>2.5</sub> > 40 μg m<sup>-3</sup>

## Global Exposure Mortality Model (GEMM)

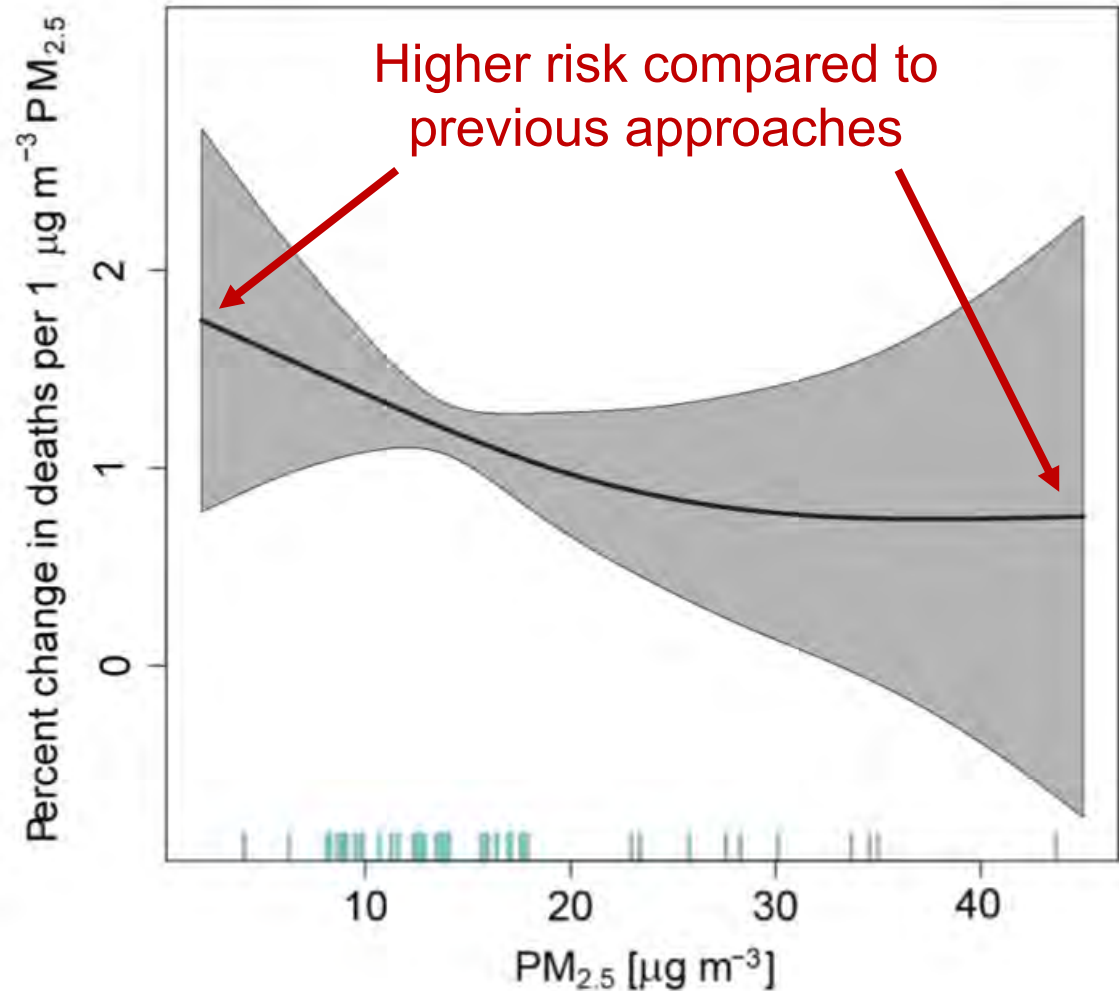


[Burnett et al., 2018]

41 cohort studies and model  
constrained using 4 parameters

# Updated Risk Assessment Model used in our Study

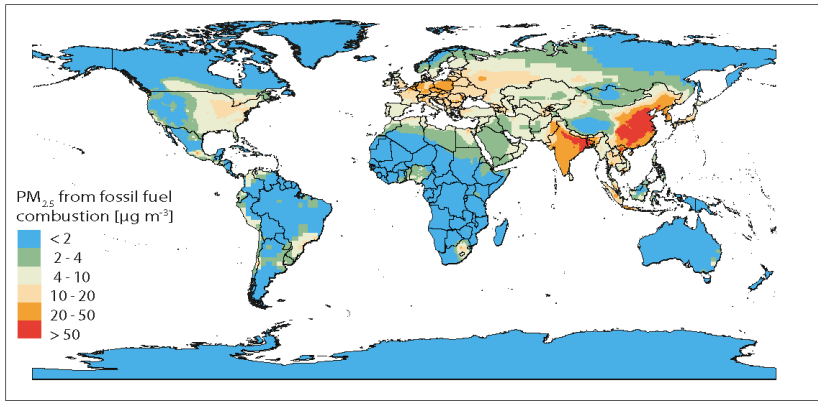
- Flexible shape of concentration-response function
- More cohort studies, and wider concentration and age range than previous approaches
- Includes death from all-causes



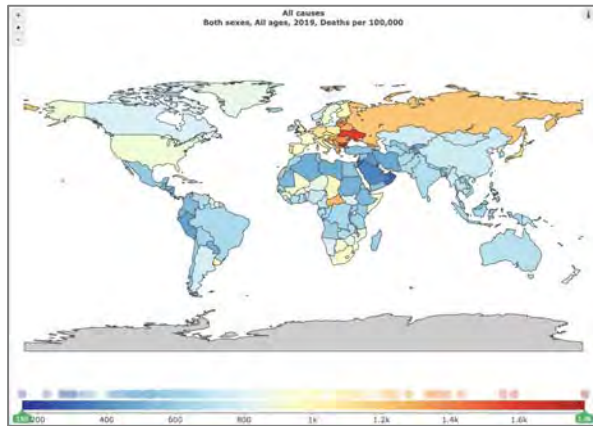
[Vodonos et al., 2018]



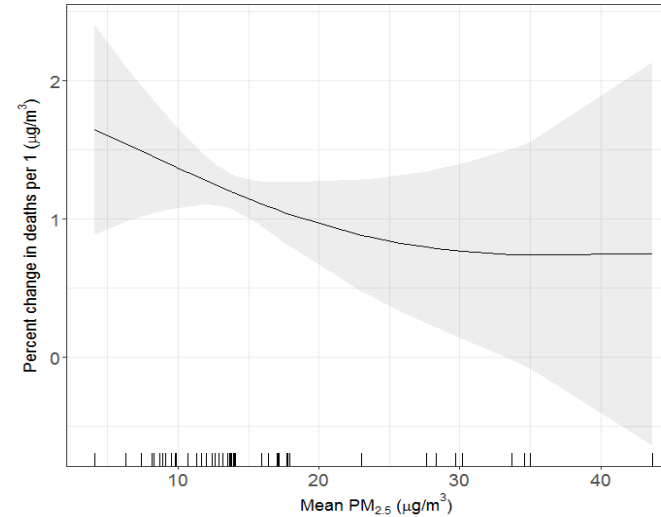
# Approach used to Calculate Health Impact



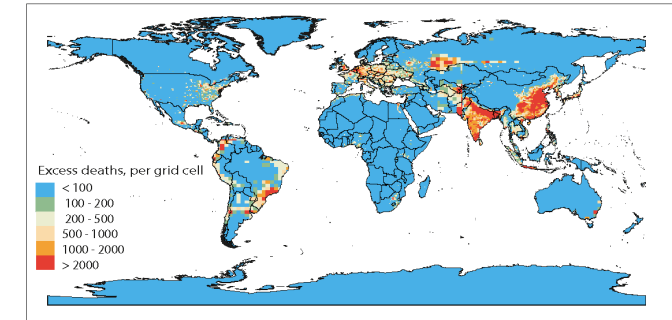
Fossil-fuel PM<sub>2.5</sub> from GEOS-Chem



Baseline mortality from Global Burden of Disease



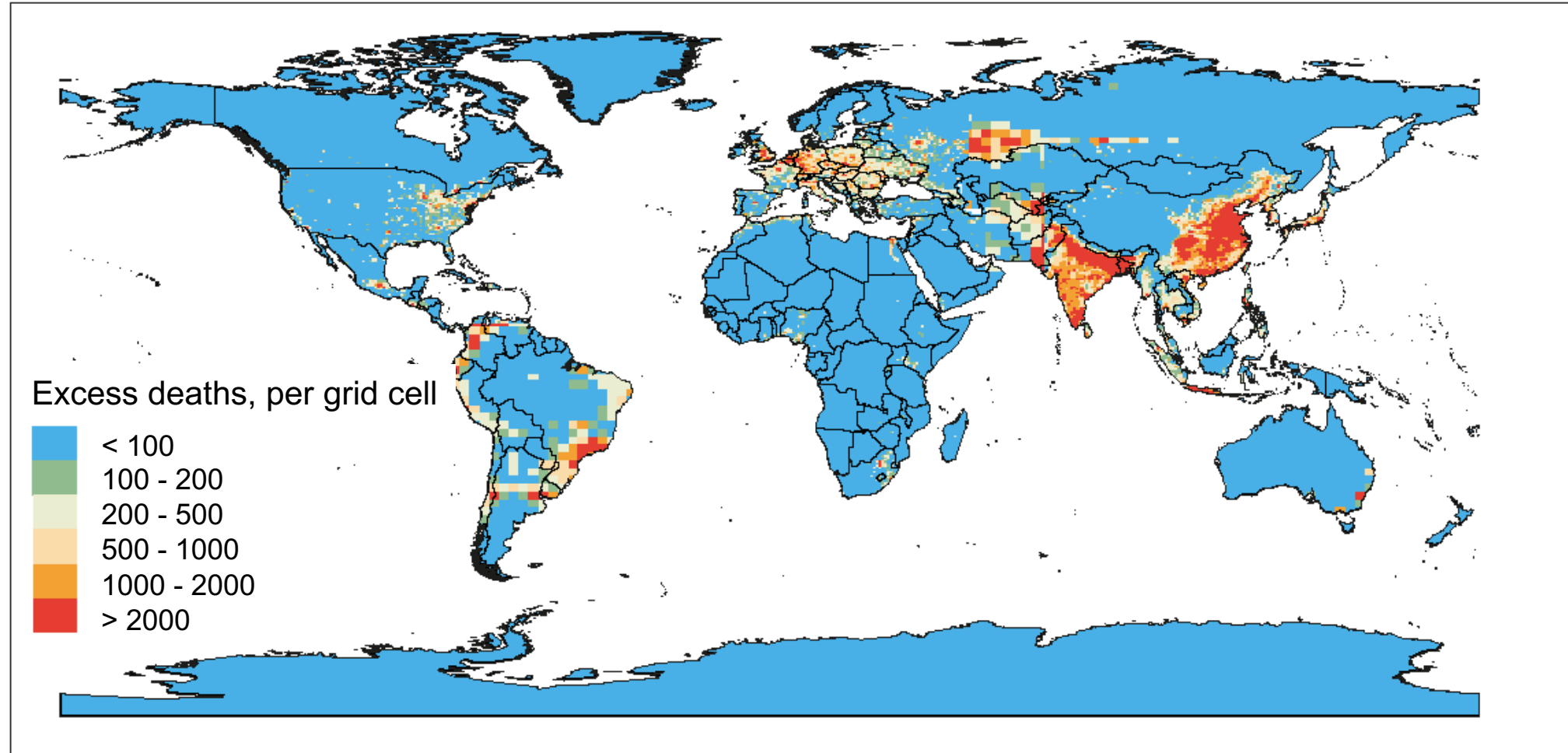
Meta-analysis concentration-response function from cohort studies



Global premature mortality

We use the derived fossil-fuel PM<sub>2.5</sub> with baseline mortality in the meta-analysis concentration-response function to estimate global premature mortality

# Global Premature Mortality from Fossil Fuel combustion



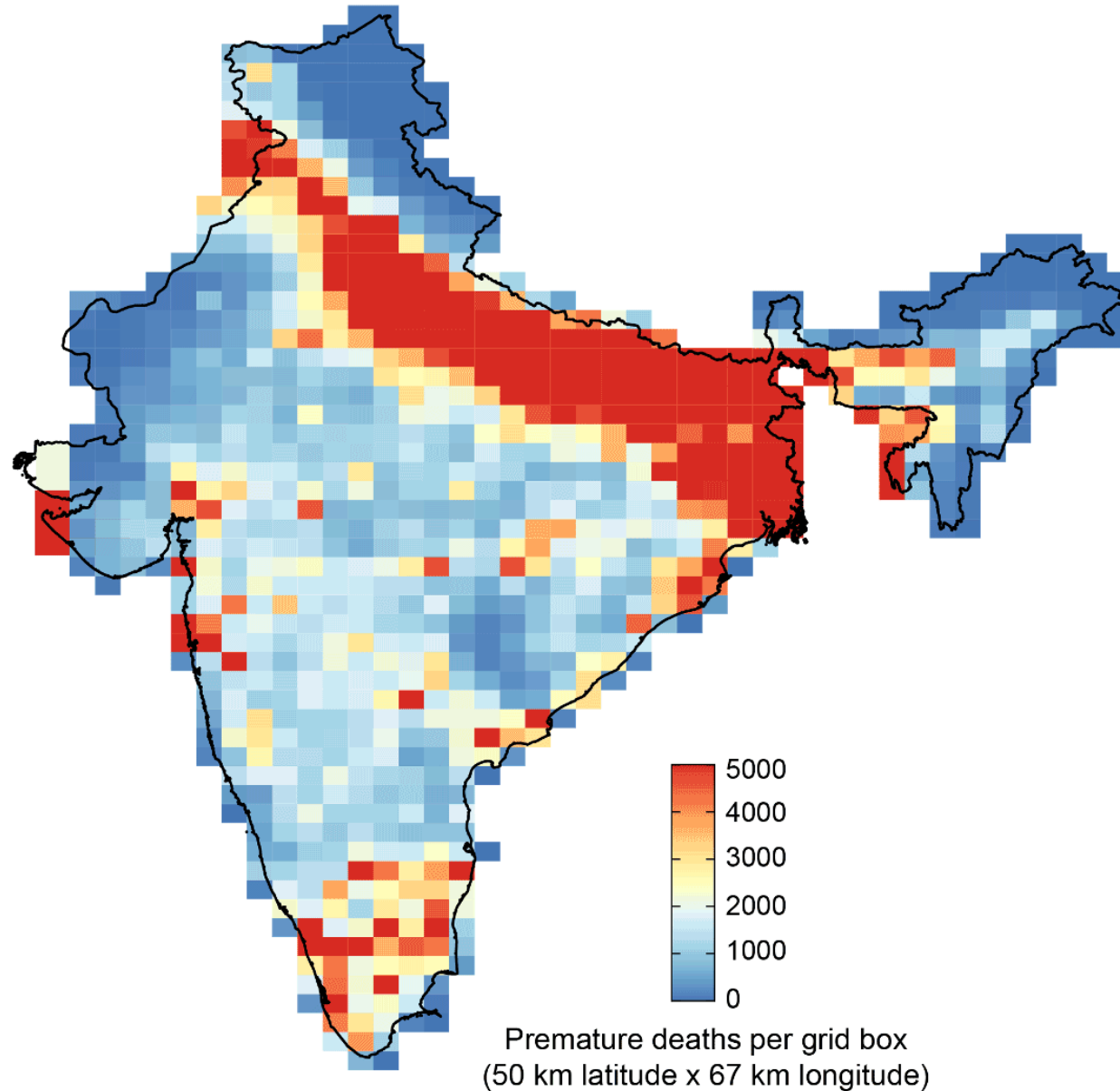
**10.2 million** premature deaths attributed to fossil-fuel PM<sub>2.5</sub> in 2012  
[-47 million, 17 million]

[Vohra et al., 2021]



# Regional Premature Mortality from Fossil Fuel Combustion

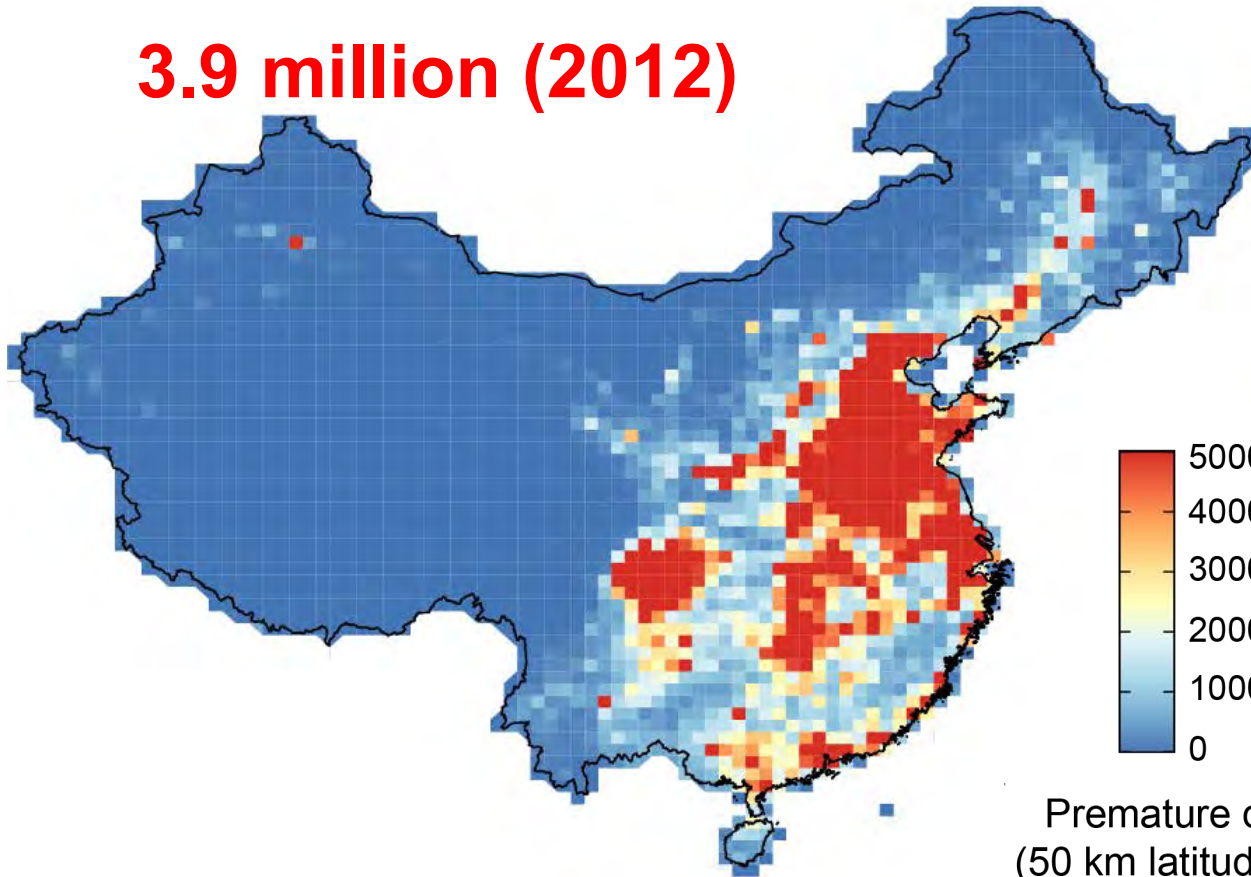
**India**  
**2,500,000**



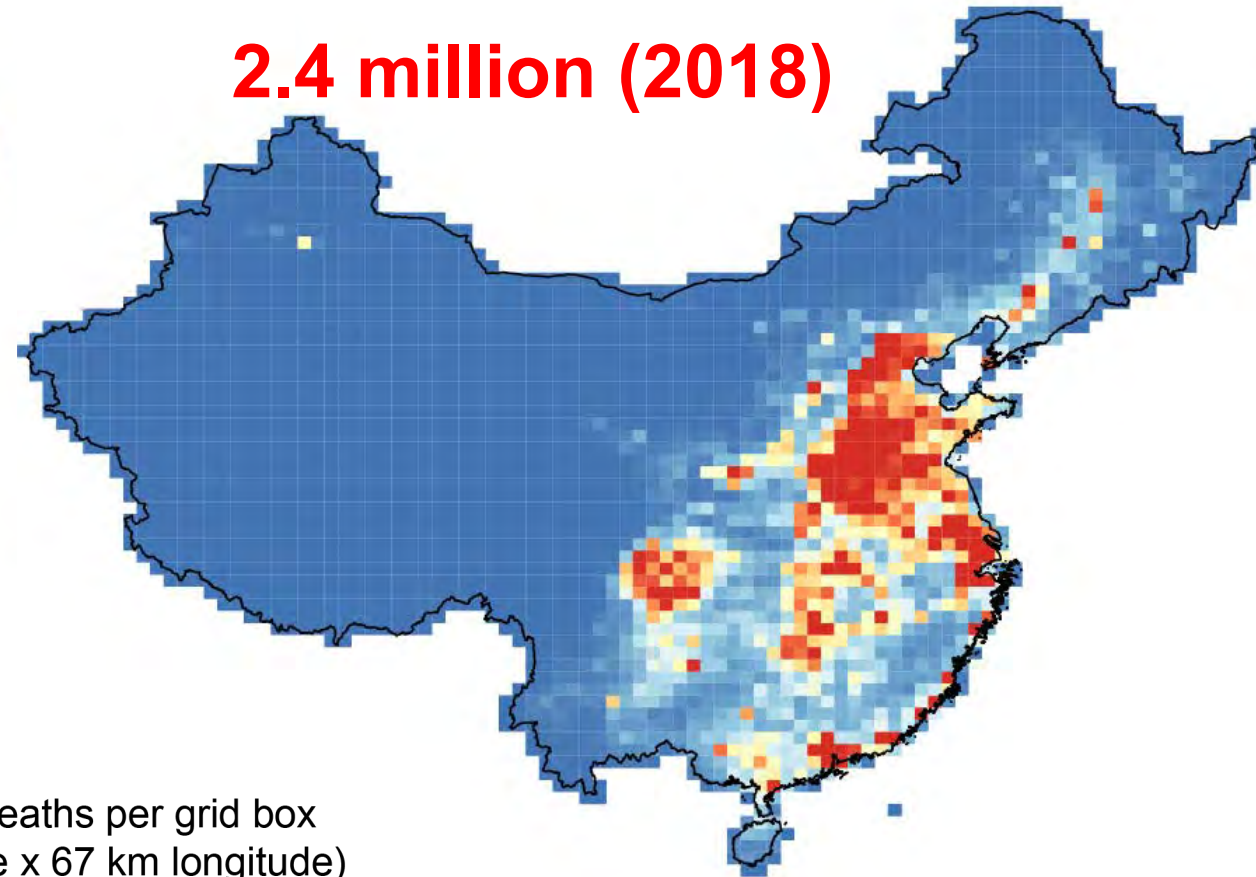
# Policies Help Mitigate Premature Deaths

**China**

**3.9 million (2012)**



**2.4 million (2018)**



Premature deaths per grid box  
(50 km latitude x 67 km longitude)

**1.5 million fewer deaths in 2018 than 2012 due to policy-driven  
decline in PM<sub>2.5</sub> pollution in China**



# Response to Findings

We calculate global premature mortality that is much greater than previous estimates (updated risk assessment model, higher spatial resolution PM<sub>2.5</sub>)

**Swell of media attention from leading news agencies and advocacy groups**



Translated into **many languages** for audiences in France, Spain, India, Canada, China, Central and South America

<https://www.theguardian.com/environment/2021/feb/09/fossil-fuels-pollution-deaths-research>

# General Comments and Conclusions

Central to success of using models is ability validate with reliable and representative observations.

Persistent uncertainties in relative risk at extreme low and high concentrations of PM<sub>2.5</sub>.

Controls on agriculture would be most effective at addressing PM<sub>2.5</sub> pollution in the UK, Europe and likely also other parts of the world that have already implemented successful measures targeting point sources.

Enhanced success of our projects resulted from working directly with policy- and decision-makers at local and national scales.

Greater synergies needed between air quality and climate agencies, due to co-benefits of targeting sources that emit air pollutants and precursors and greenhouse gases.



# Additional Resources

## **The Conversation pieces on health and air quality:**

<https://theconversation.com/ditching-fossil-fuels-will-have-immediate-health-benefits-for-millions-world-leaders-must-seize-the-chance-171015>

<https://theconversation.com/air-pollution-in-fast-growing-african-cities-presents-a-risk-of-premature-death-183944>

## **Datasets derived using GEOS-Chem:**

Global premature mortality from fossil fuel air pollution: <https://doi.org/10.5522/04/14595714>

## **Visualization of results on Tableau dashboard:**

[https://public.tableau.com/app/profile/karn.vohra/viz/Globalmortalitylinkedtoairpollutionfromfossilfuelcombustion/Global\\_mortality\\_fossil-fuelPM2\\_5](https://public.tableau.com/app/profile/karn.vohra/viz/Globalmortalitylinkedtoairpollutionfromfossilfuelcombustion/Global_mortality_fossil-fuelPM2_5)

<https://public.tableau.com/app/profile/karn.vohra/viz/Trendsinairqualityinfast-growingtropicalcities/Dashboard1>

## **Research group website:**

<https://maraisresearchgroup.co.uk/>