

# The impact of anthropogenic air pollution from city to global health

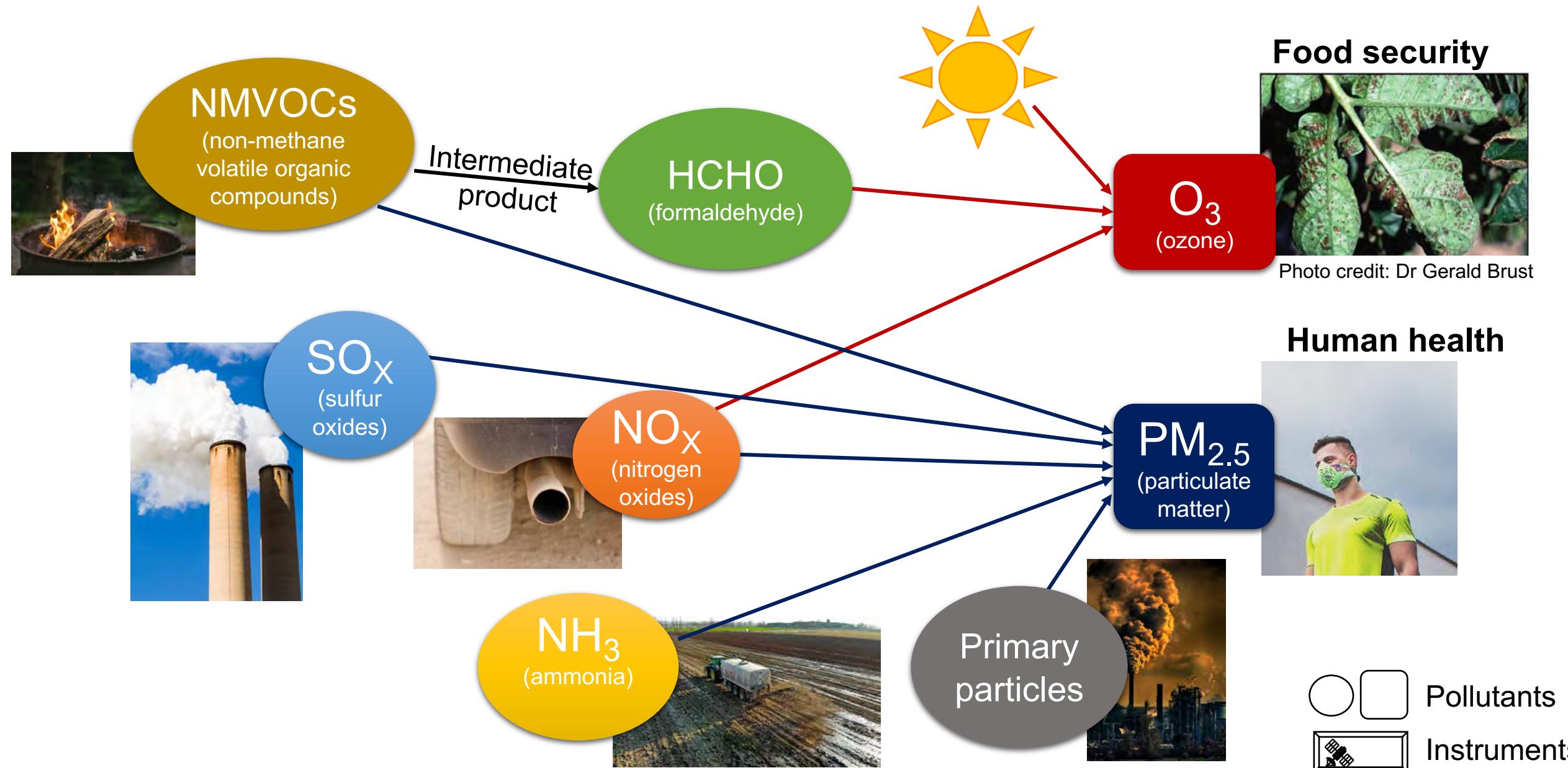


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Global Change Seminar  
University of Edinburgh

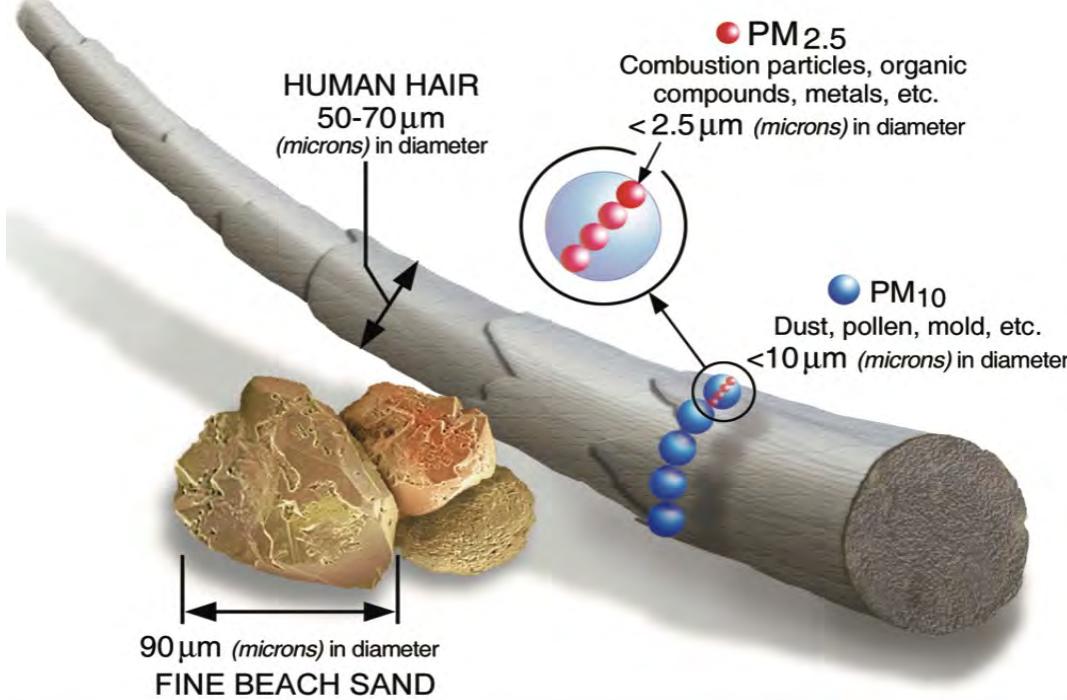
9 November 2022

# The cocktail of air pollutants we breathe



# PM is fine enough to be inhaled deep into the lungs

## Particulate Matter (PM)



Source – US EPA



**No safe level of exposure to PM**

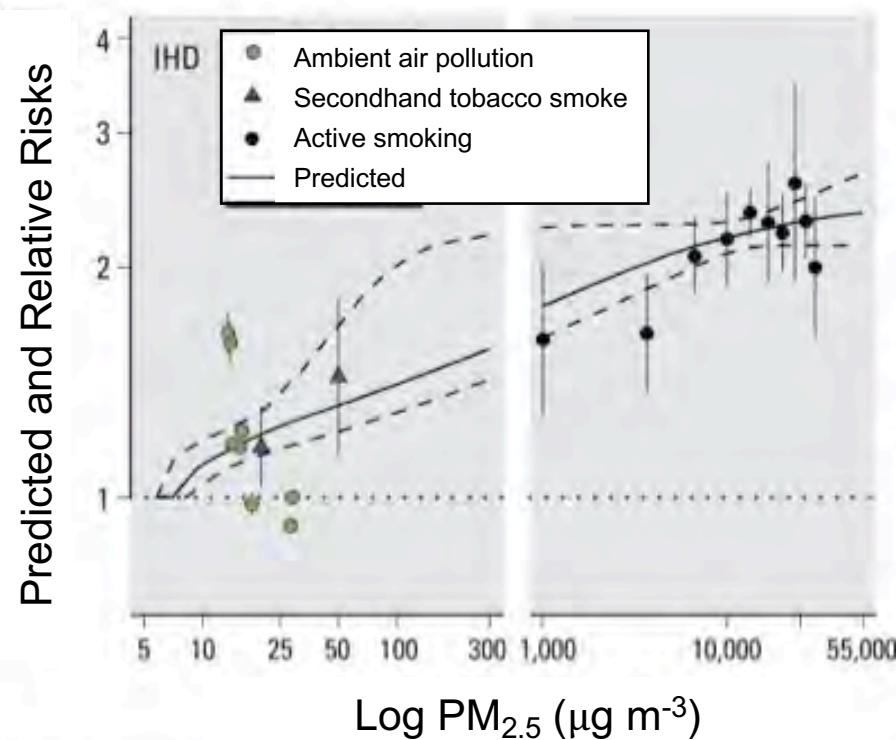
[WHO, 2021]

Air pollution may be damaging every organ of the body

# Standard and widely used risk assessment models

Relates PM<sub>2.5</sub> concentrations to the likelihood of adverse health outcomes

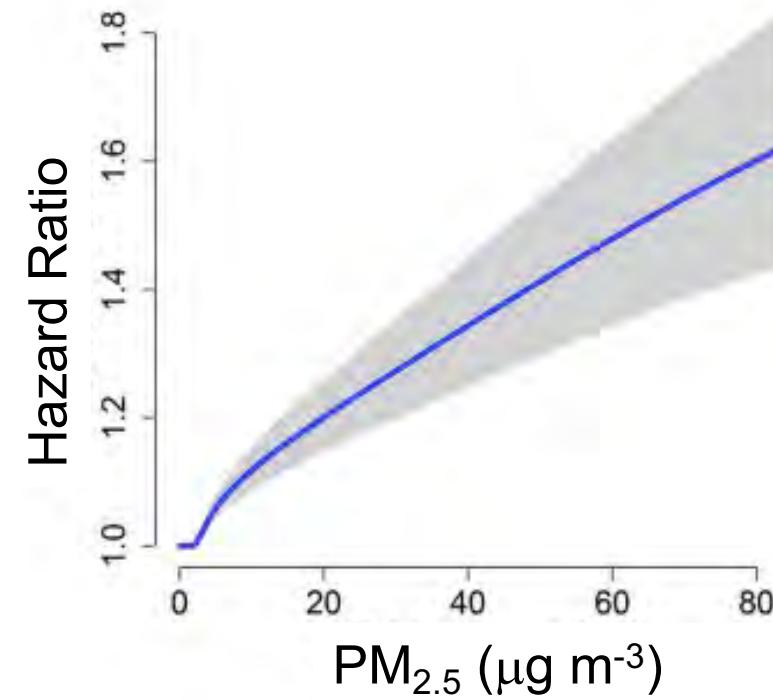
Integrated Exposure-Response (IER)



[Burnett et al., 2014]

Data includes active and passive smoking to address outdoor PM<sub>2.5</sub> > 40  $\mu\text{g m}^{-3}$

Global Exposure Mortality Model (GEMM)



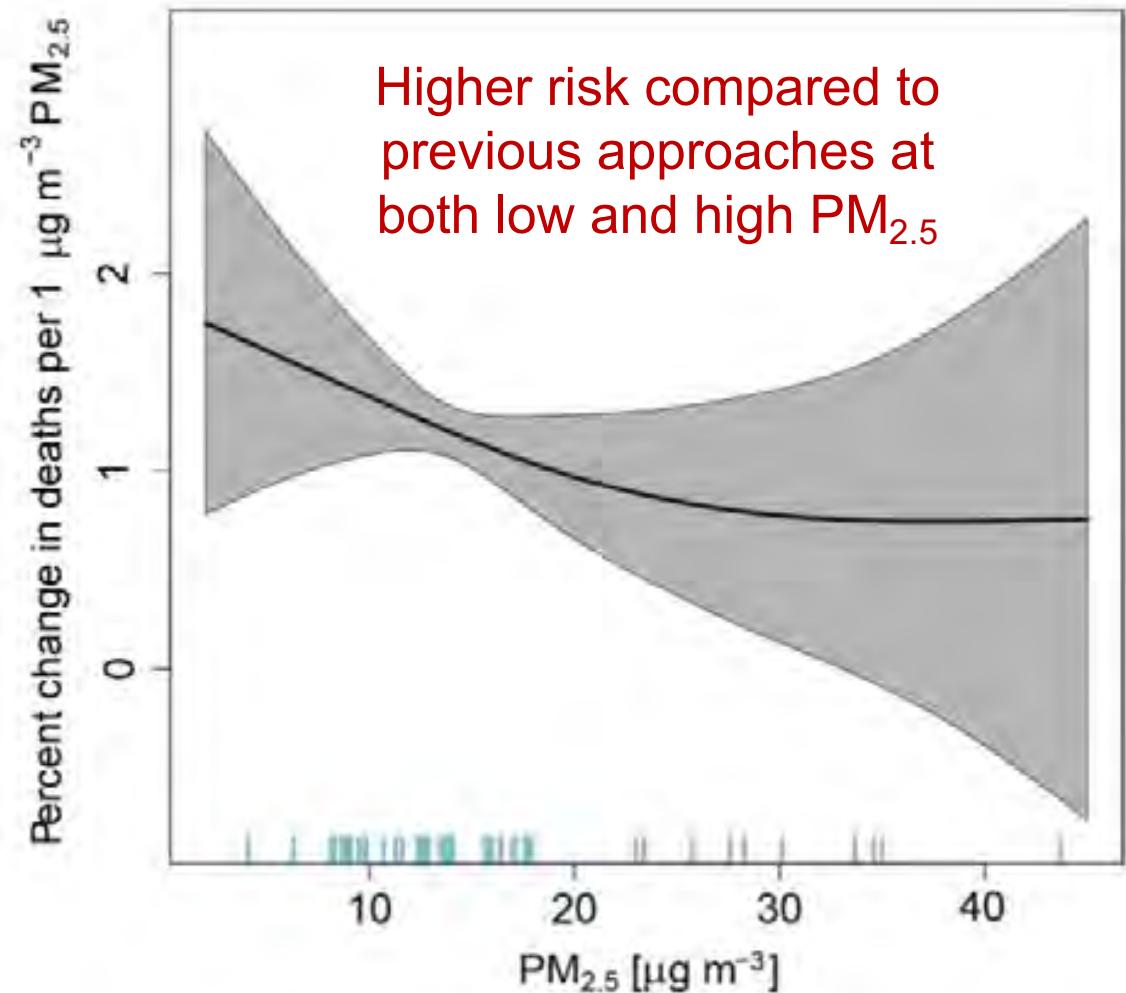
[Burnett et al., 2018]

41 cohort studies and model constrained using 4 parameters

**4-9 million premature deaths worldwide from long-term exposure to PM<sub>2.5</sub>**

# 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]

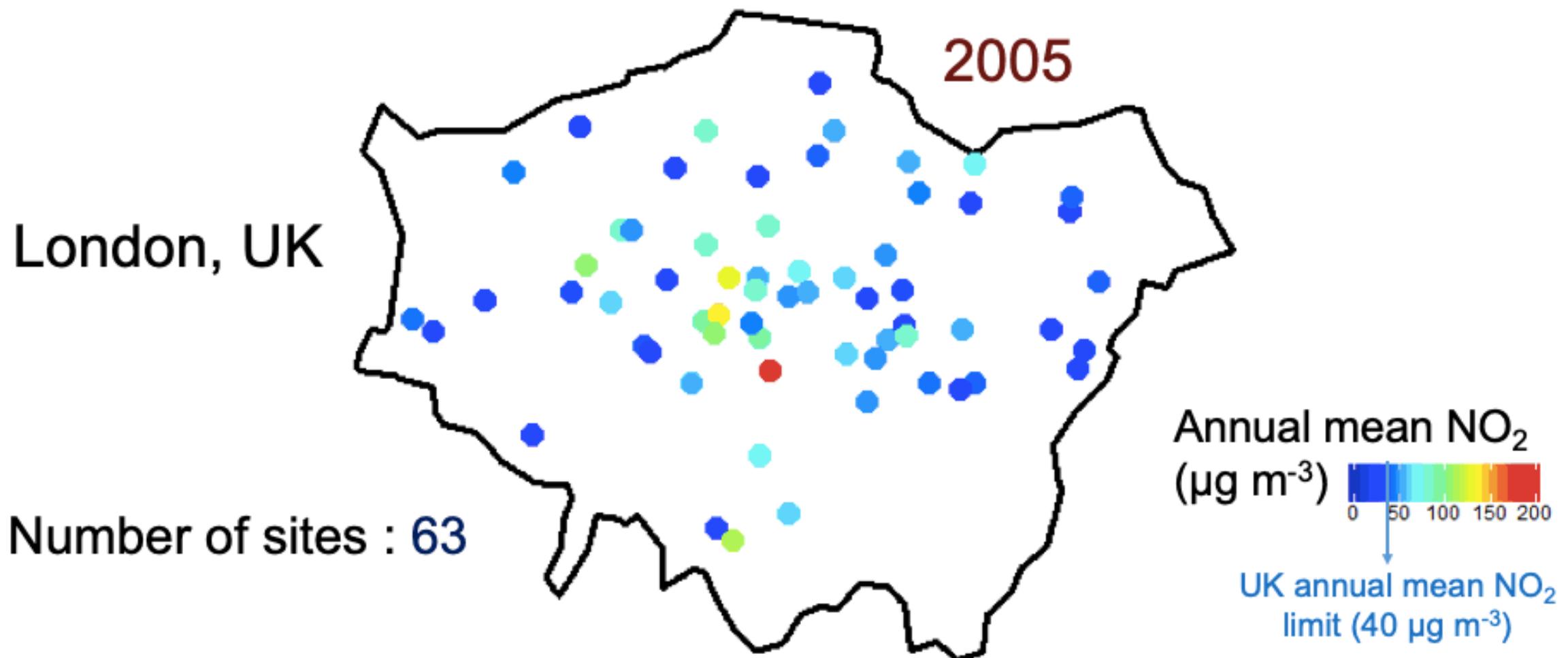
# Routine surface monitoring in cities is challenging

Important for assessing compliance but are expensive, inconsistent and have issues

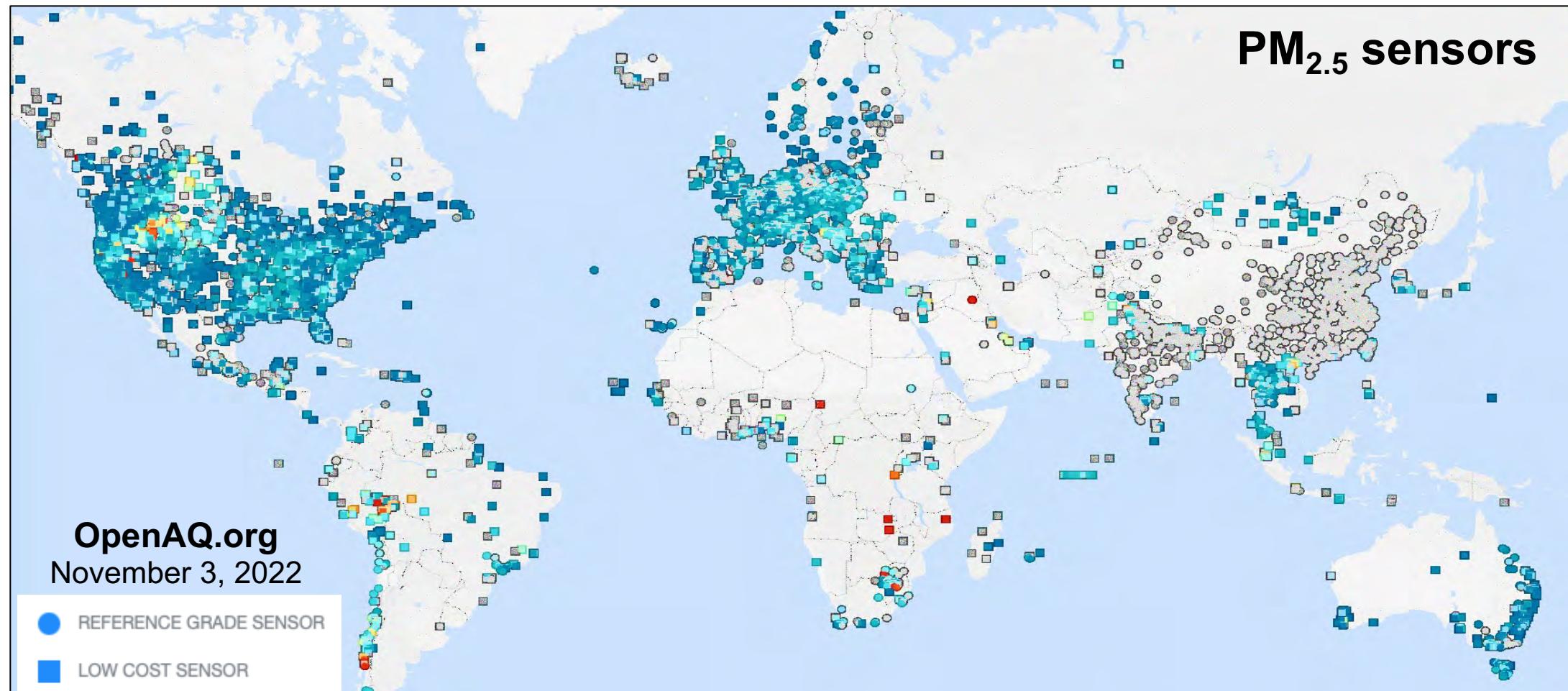


# Routine surface monitoring in cities is challenging

Important for assessing compliance but are expensive, inconsistent and have issues



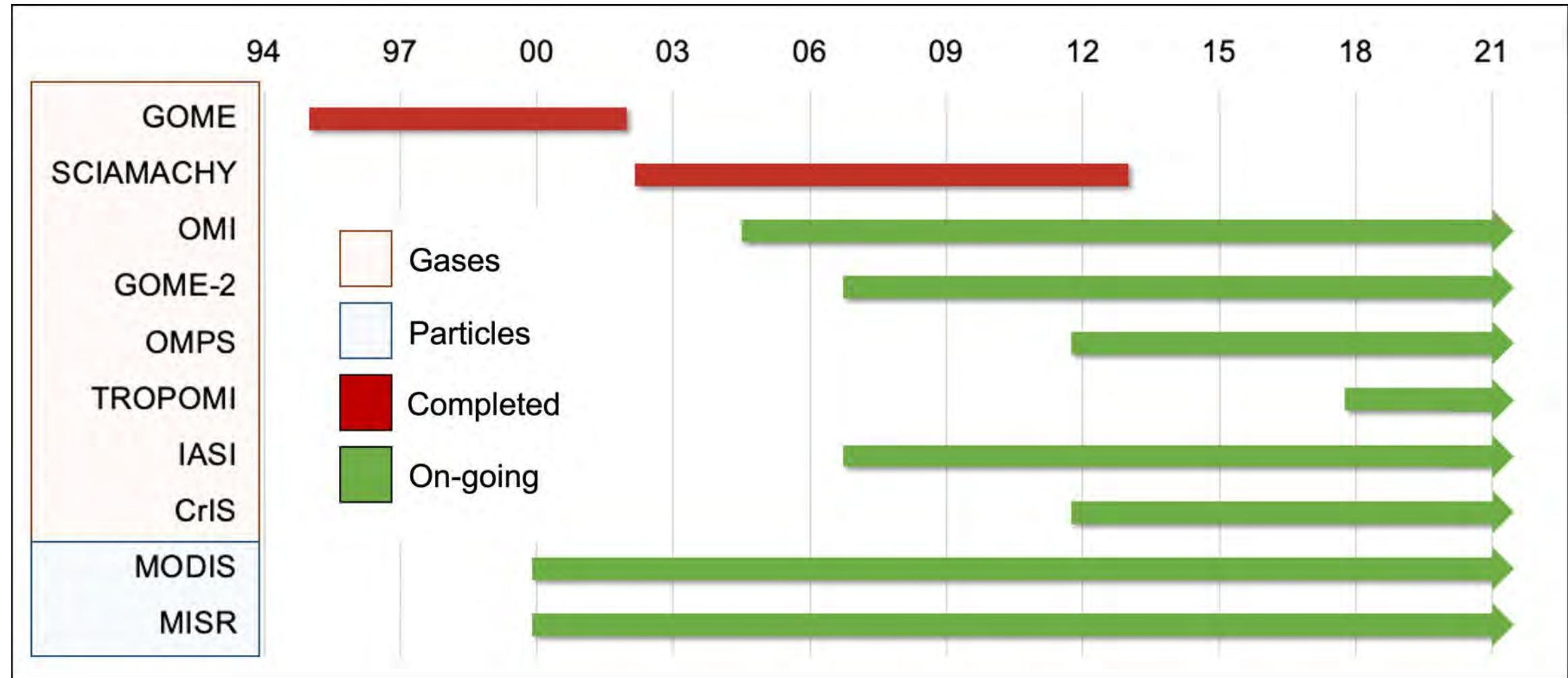
# Limited surface monitoring in the rapidly developing world



< 1 monitor per million people in the tropics

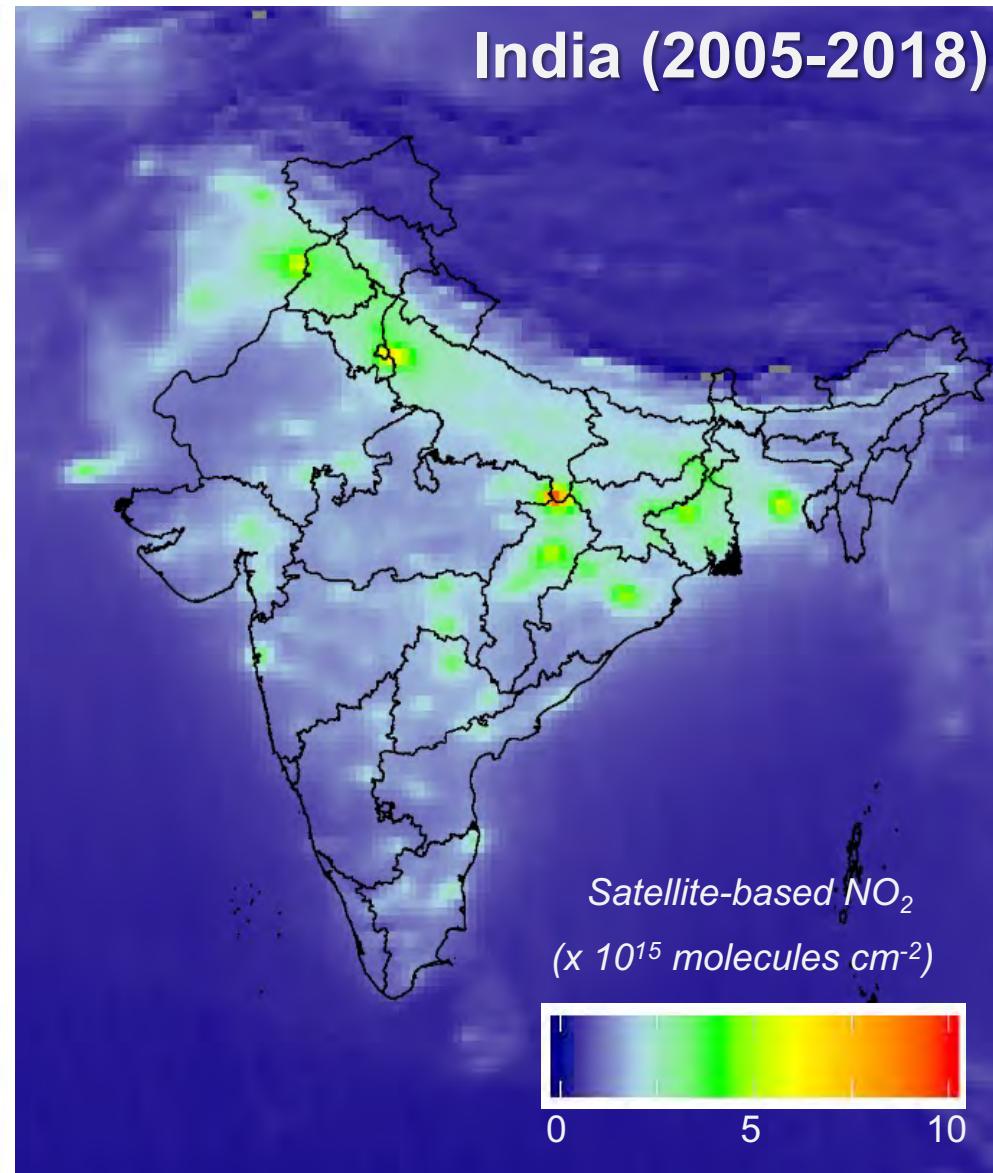
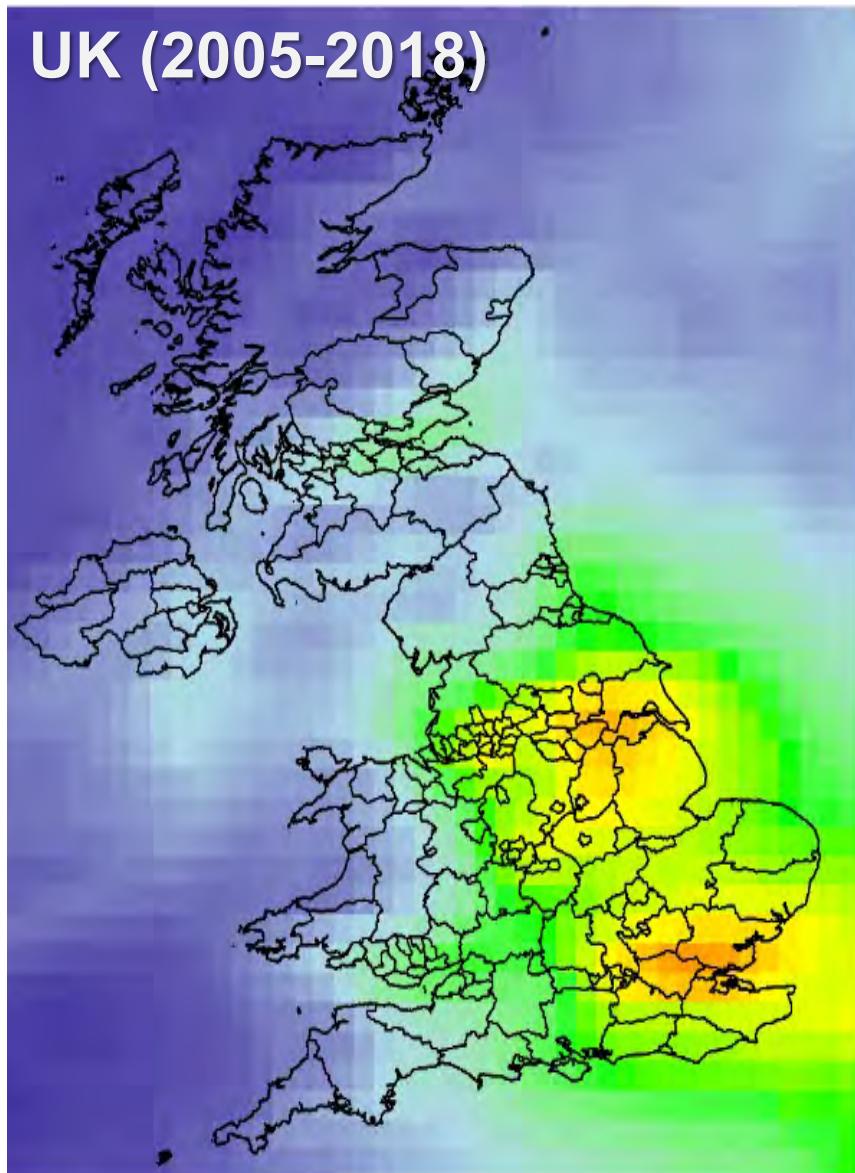
[Martin et al., 2019]

# Long and consistent record of atmospheric composition from space-based instruments

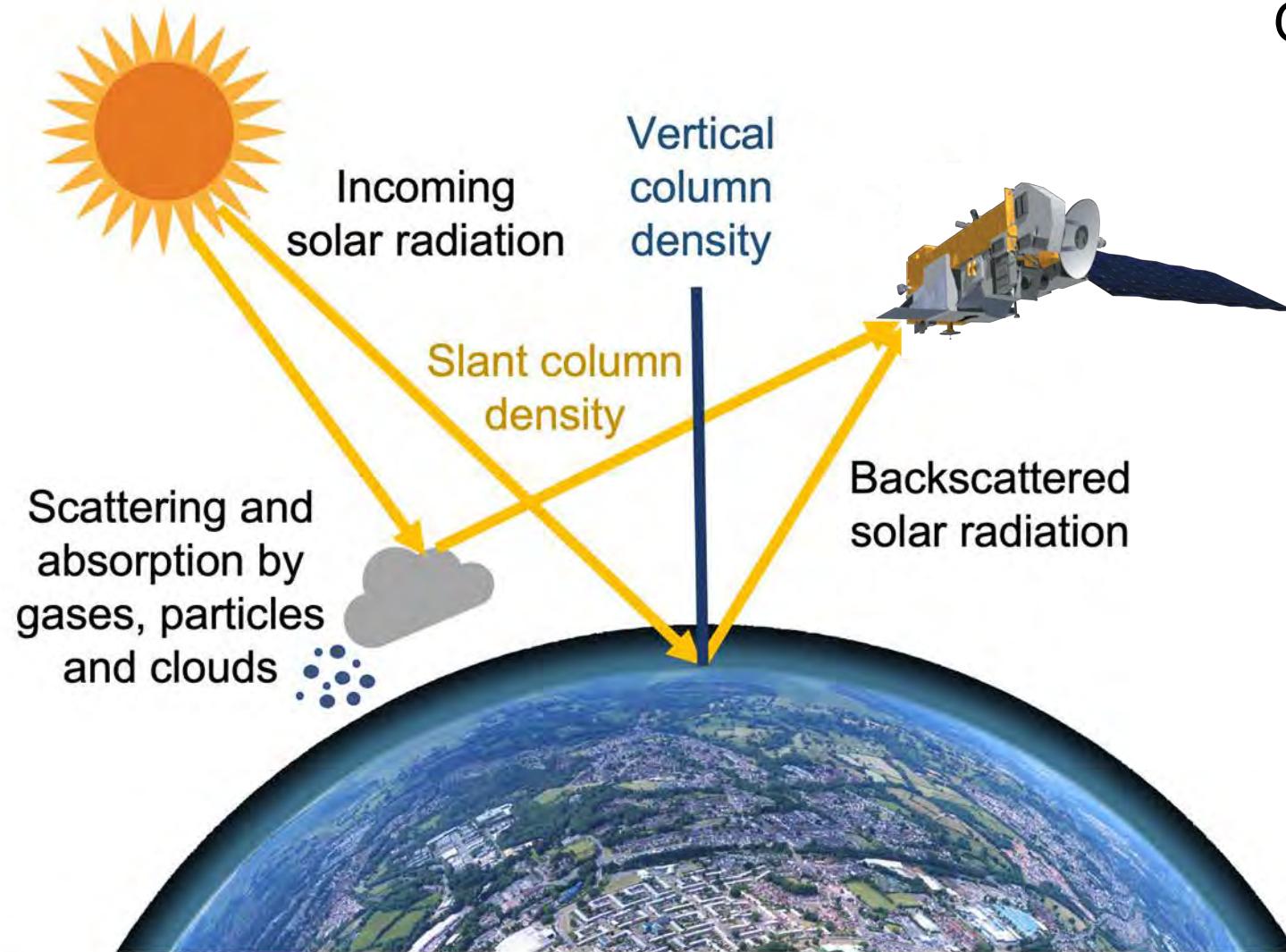


**OMI** for **NO<sub>2</sub>** and **HCHO** (proxy for NMVOCs); **IASI** for **NH<sub>3</sub>**; **MODIS** for **AOD** (proxy for PM<sub>2.5</sub>)

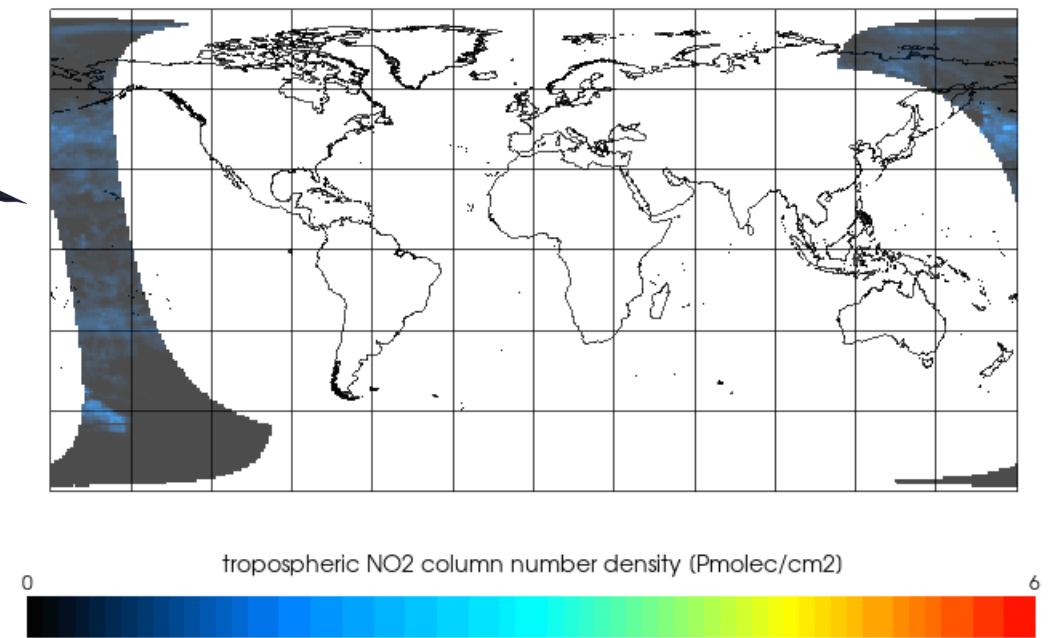
# Space-based instruments provide extensive data coverage



# How do satellites measure atmospheric composition?



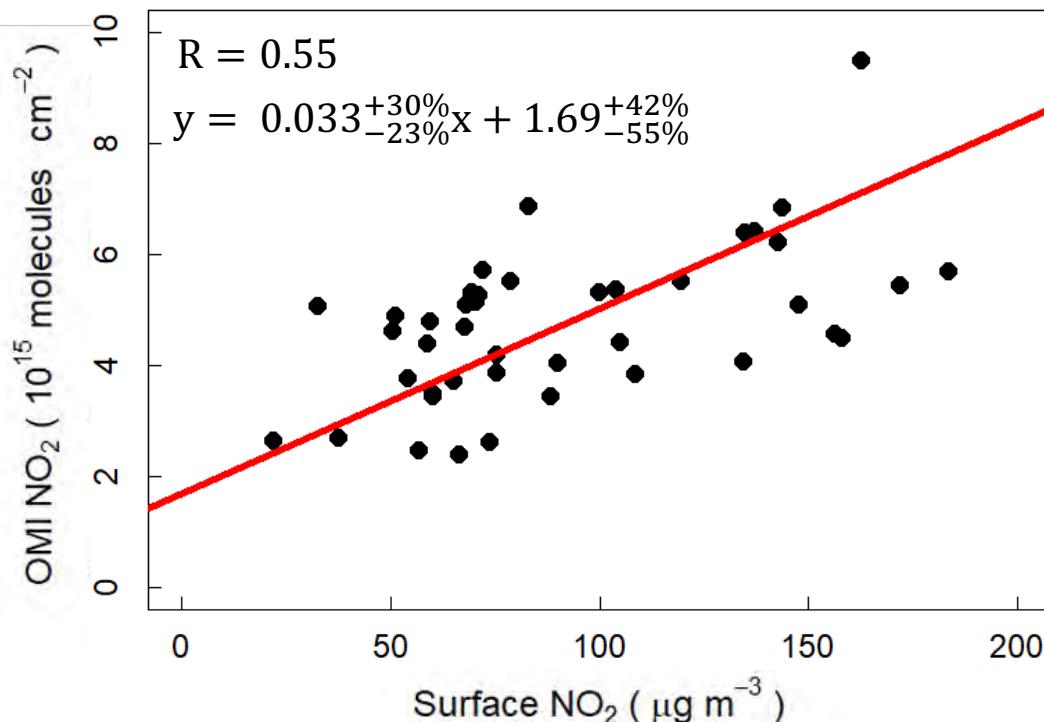
OMI overpass time : 13h30 local time



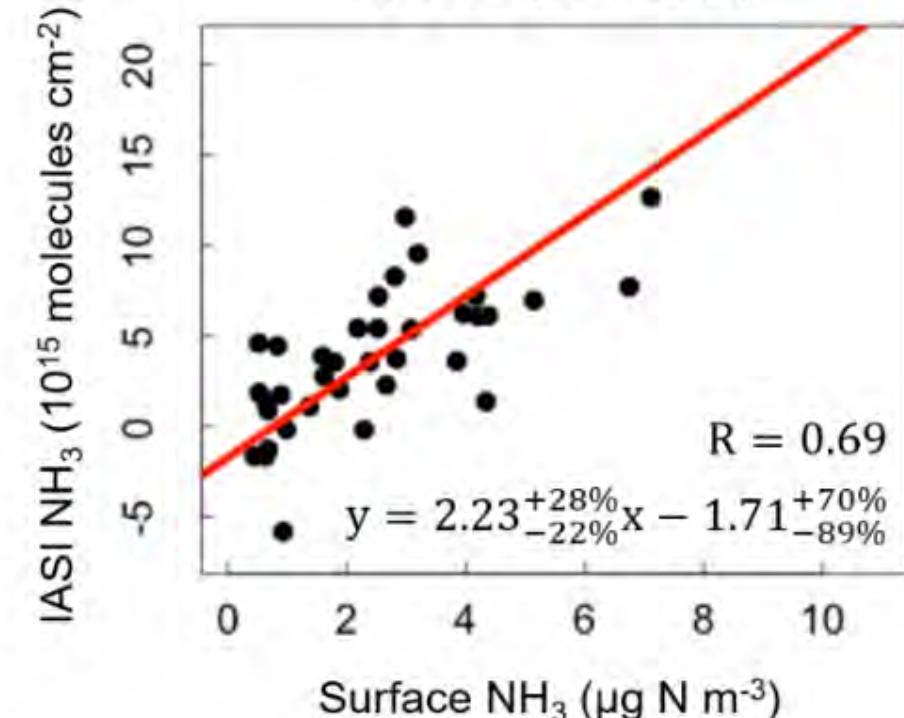
OMI NO<sub>2</sub> for each orbit

# Assessing the skill of satellite observations at reproducing variability in surface air quality

Satellite versus surface NO<sub>2</sub> in  
**Delhi, India (2011-2018)**



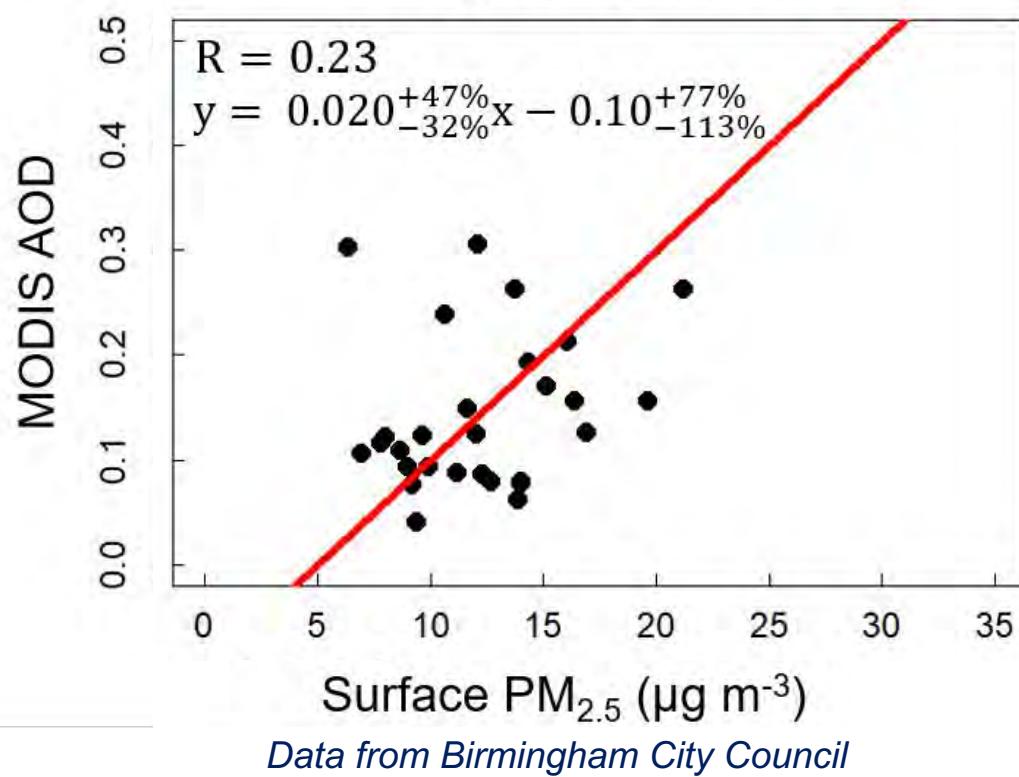
Satellite versus surface NH<sub>3</sub> at the  
background site **Harwell, UK (2011-2015)**



Temporal consistency between satellite and surface measurements of NO<sub>2</sub> and NH<sub>3</sub>

# Satellite observations of AOD reproduce long-term trends in PM<sub>2.5</sub>

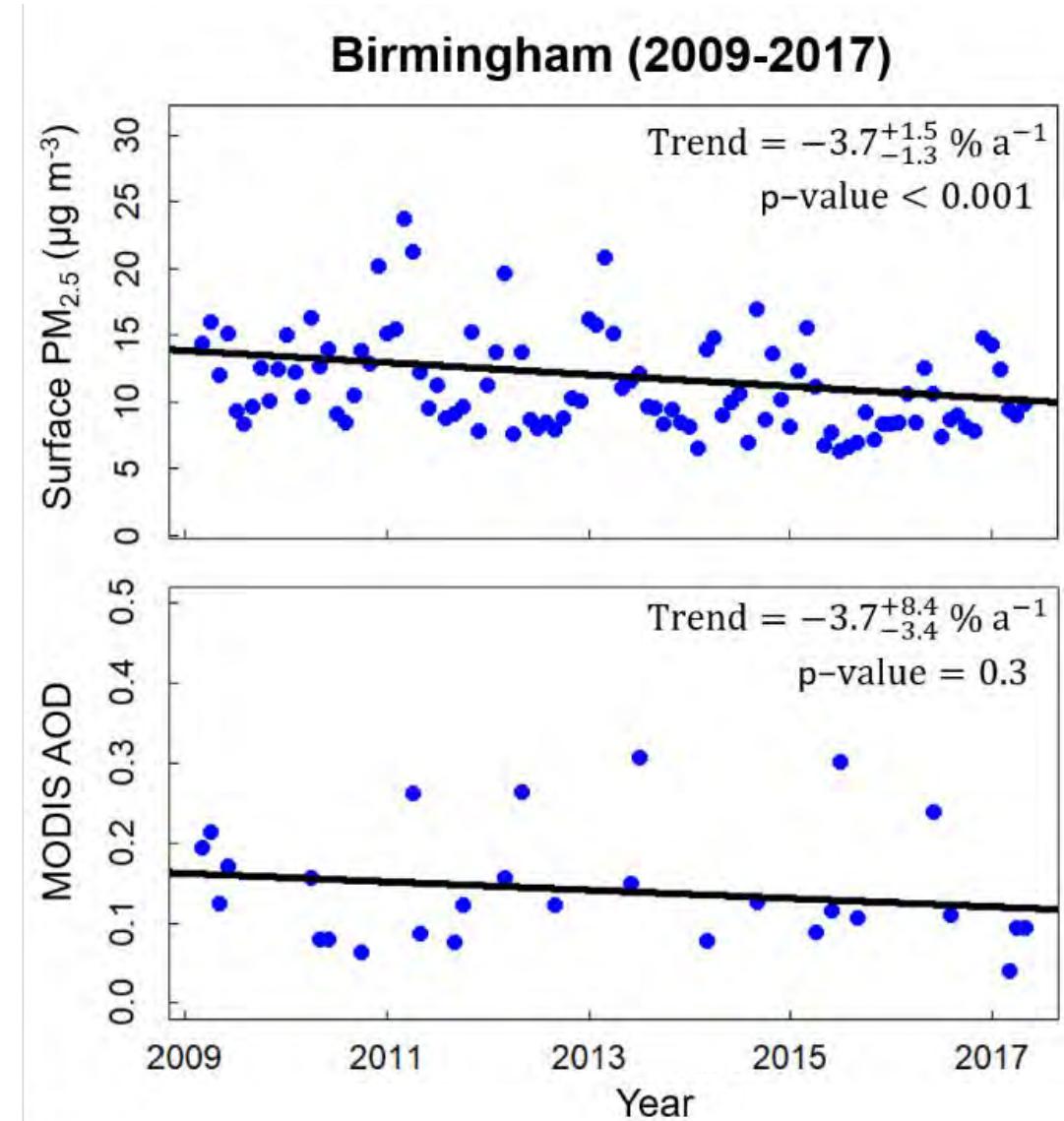
## Satellite AOD versus surface PM<sub>2.5</sub> in Birmingham, UK (2009-2017)



Complicated by meteorological conditions,  
aerosol composition & vertical distribution

[van Donkelaar et al., 2016; Shaddick et al., 2018]

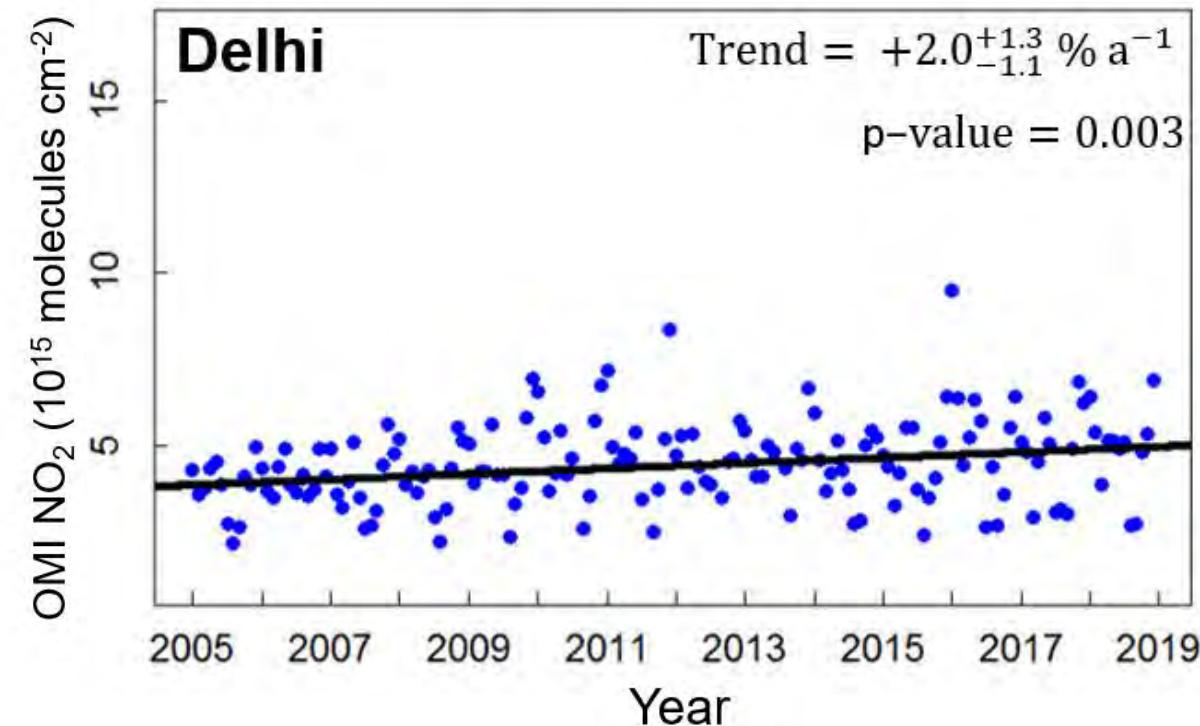
## Birmingham (2009-2017)



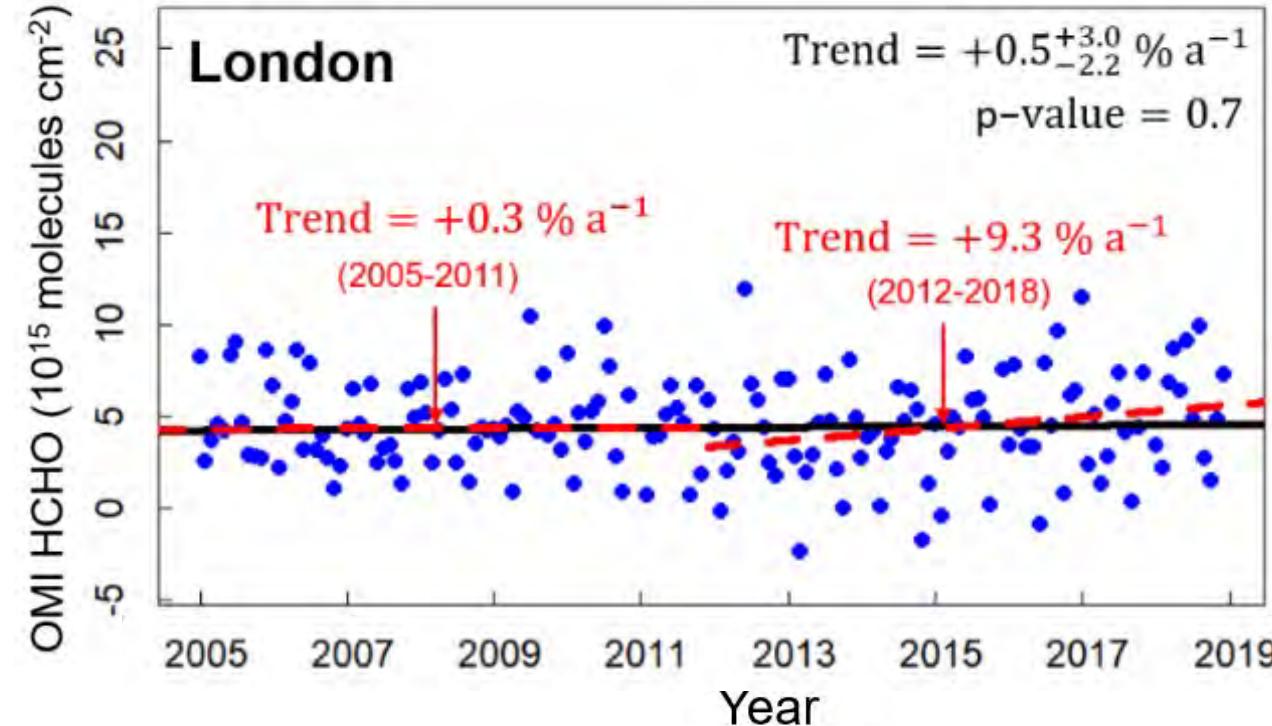
[Vohra et al., *Atmos. Chem. Phys.*, 2021]

# We apply trend analysis to long-term record of satellite observations

## Trends in Delhi NO<sub>2</sub>



## Trends in London NMVOCs



No evidence of efficacy of recent pollution control measures

Recent dramatic increase in reactive NMVOCs

# Long-term air pollutant trends for cities in the UK and India

(Arrow colour and size indicate trend direction and magnitude respectively)



# Summary

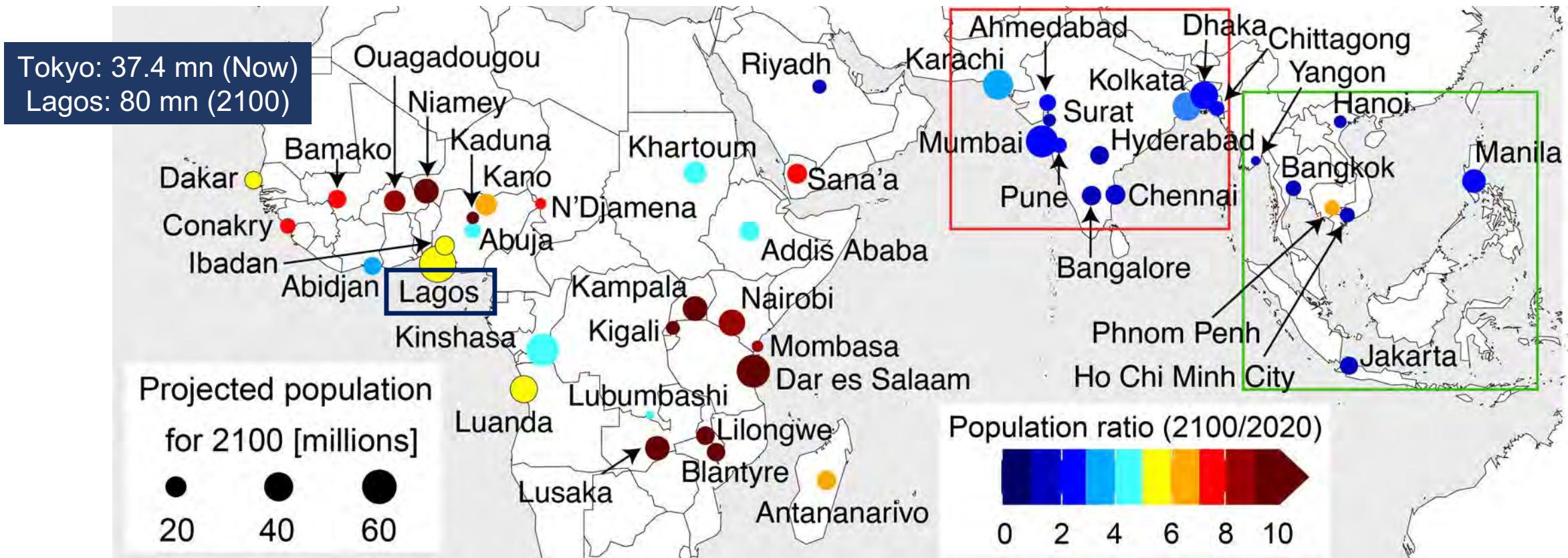
- Satellite observations of atmospheric composition assessed against available surface observations before quantifying trends in cities.
- In Indian cities, all pollutants (except NH<sub>3</sub> in Kanpur) on the rise. No improvements in air quality despite recent pollution control measures.
- In UK cities, declining trend in all pollutants due to successful control on vehicular emissions. Exception is **reactive NMVOCs in London** (**65%** rise in 2012-2018). Could be from household products, the food and beverage industry and residential combustion.

## Reference

K. Vohra, E. A. Marais, S. Suckra, L. Kramer, W. J. Bloss, R. Sahu, A. Gaur, S. N. Tripathi, M. Van Damme, L. Clarisse, P. F. Coheur, Long-term trends in air quality in major cities in the UK and India: A view from space, *Atmos. Chem. Phys.*, 21, 6275–6296, doi:10.5194/acp-21-6275-2021, 2021.

# Tropical cities are experiencing unprecedented growth

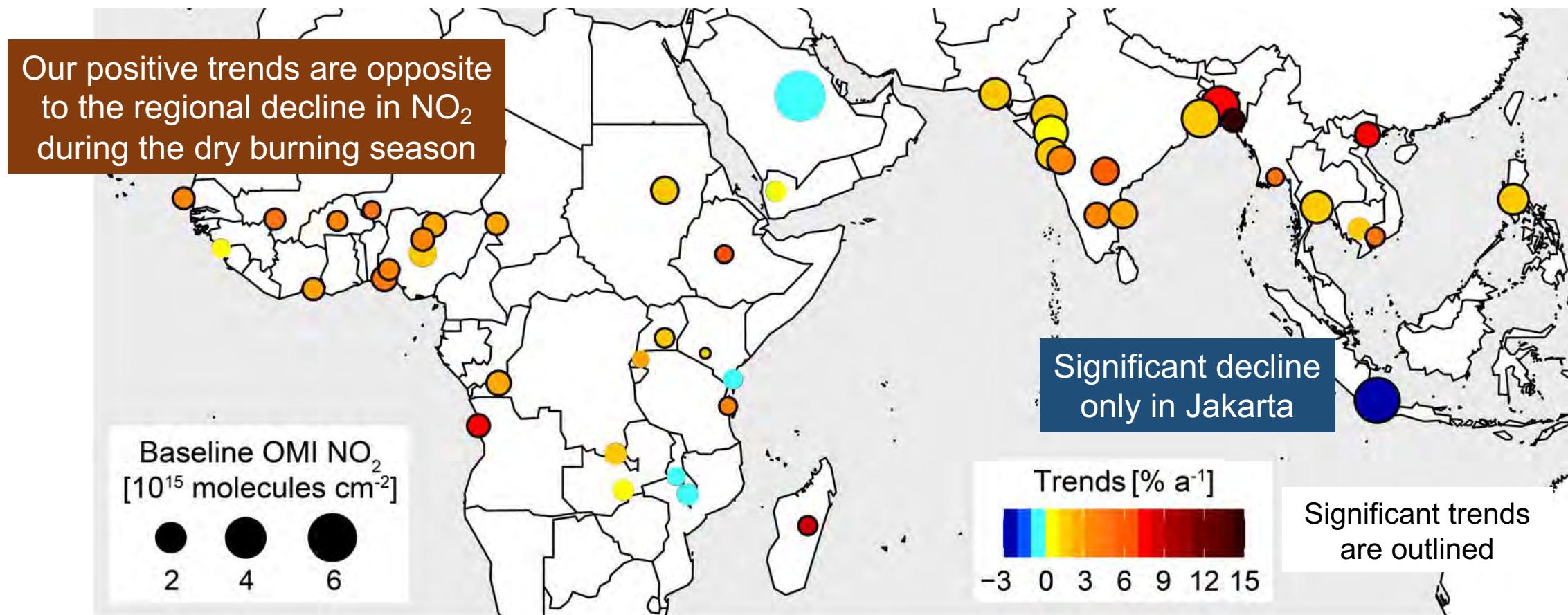
46 cities in tropical Asia, Africa and the Middle East will be megacities by 2100



Forecast annual growth rates for 2020-2100: 3-31% in Africa, 0.8-3% in **South Asia** and 0.5-7% in **Southeast Asia** [Hoornweg & Pope, 2017]

# Trends in NO<sub>2</sub> in tropical future megacities in 2005-2018

NO<sub>2</sub> increases in 41 cities by 0.1-14.1 % a<sup>-1</sup>

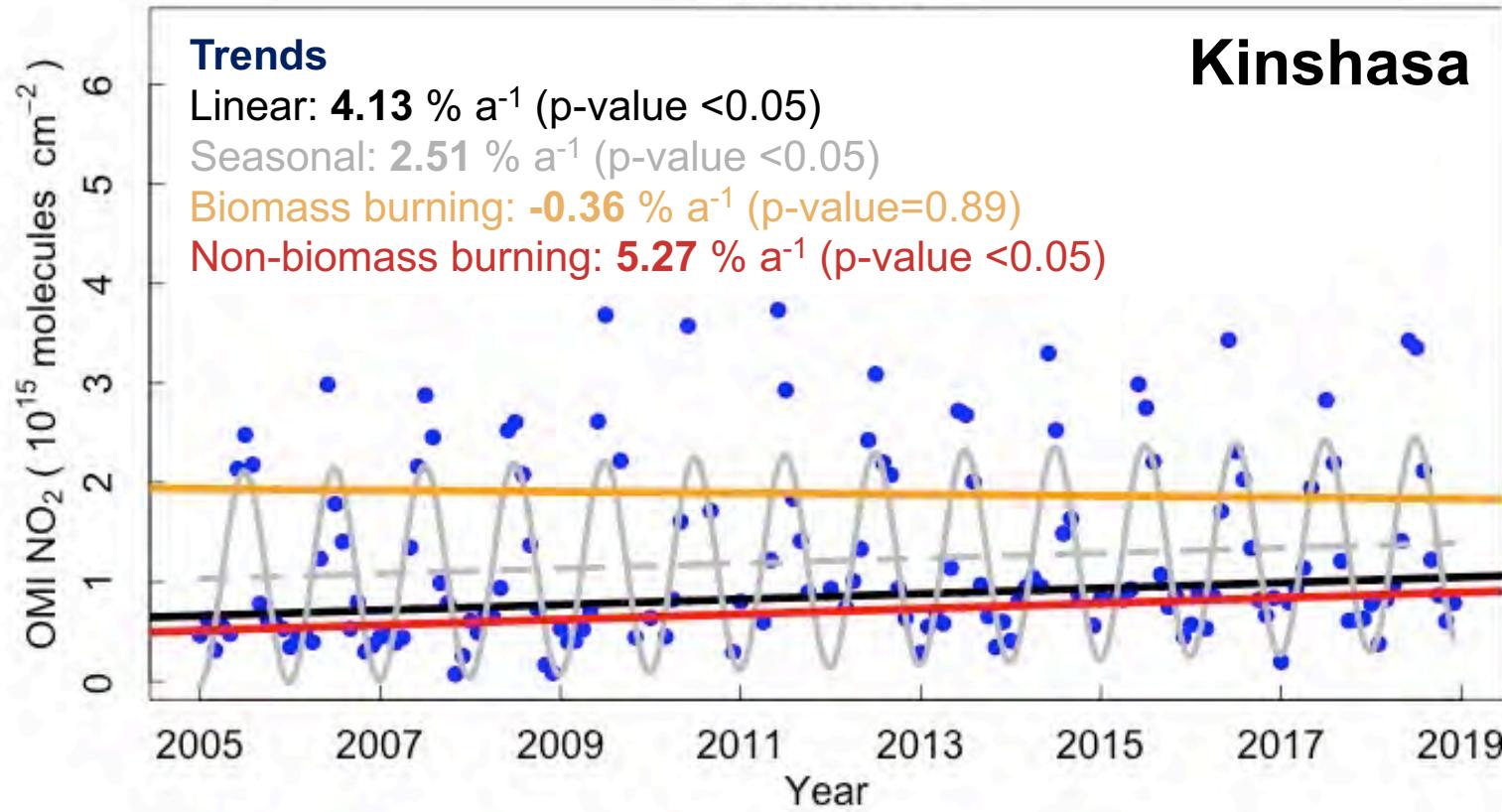


Steep increases in NO<sub>2</sub> with implications for ozone and PM<sub>2.5</sub> formation

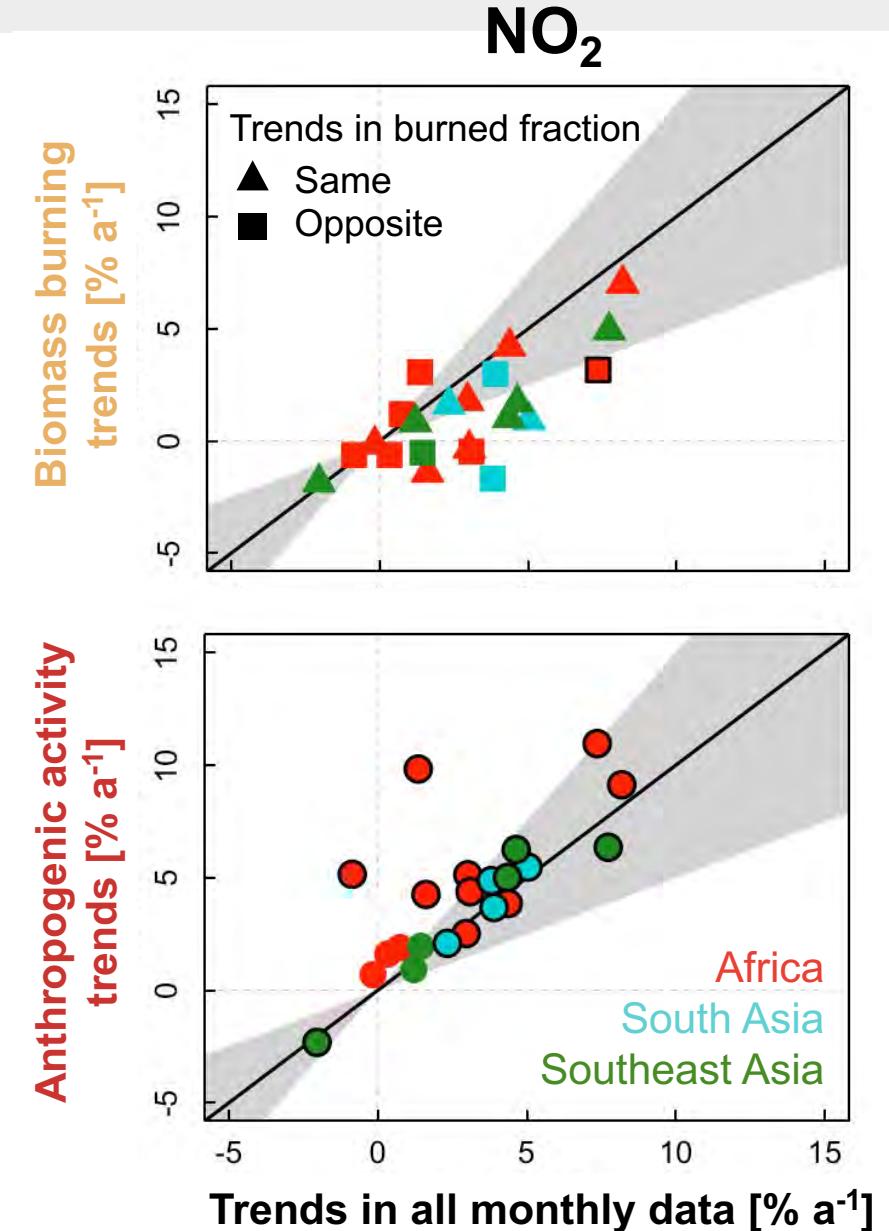
[Vohra et al., *Sci. Adv.*, 2022]

# What's driving these trends?

Separate observations into **biomass burning** and **non-biomass burning**

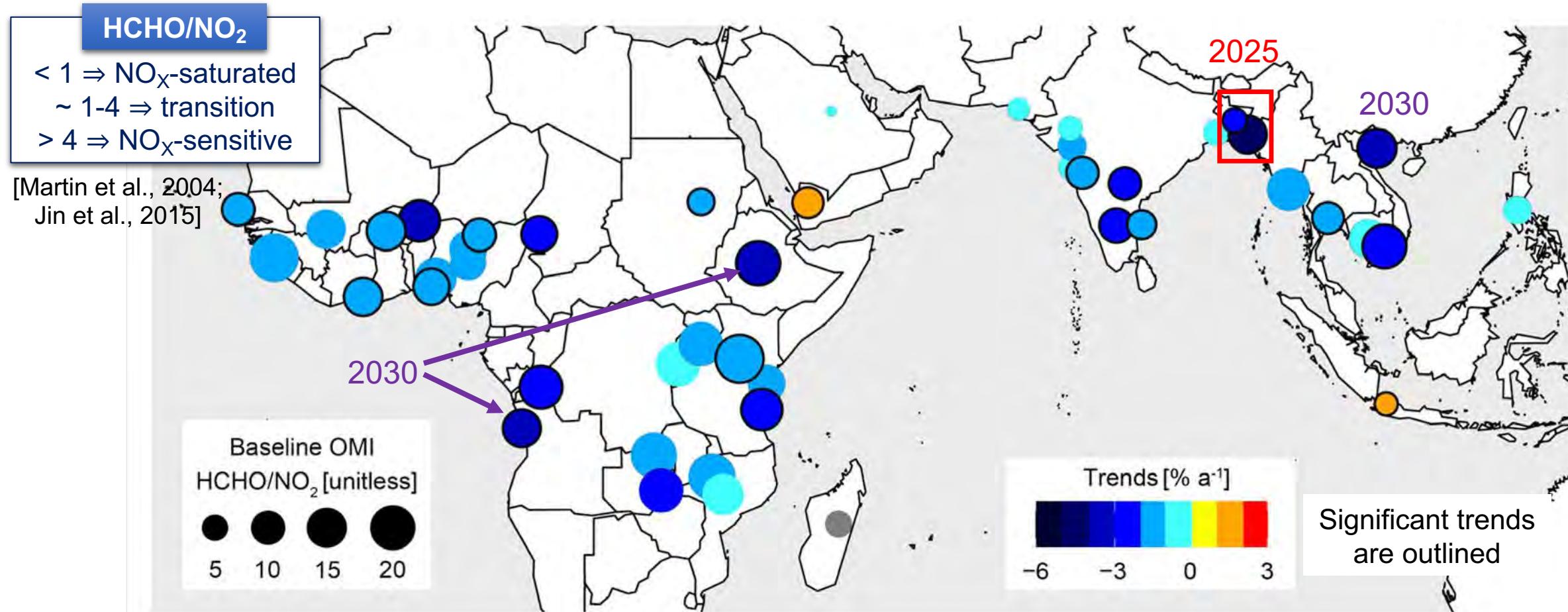


Almost exclusively driven by anthropogenic activity,  
rather than traditional biomass burning



# Trends in ozone production regimes in 2005-2018

Satellite observations of HCHO/NO<sub>2</sub> are used as proxy for ozone production regimes

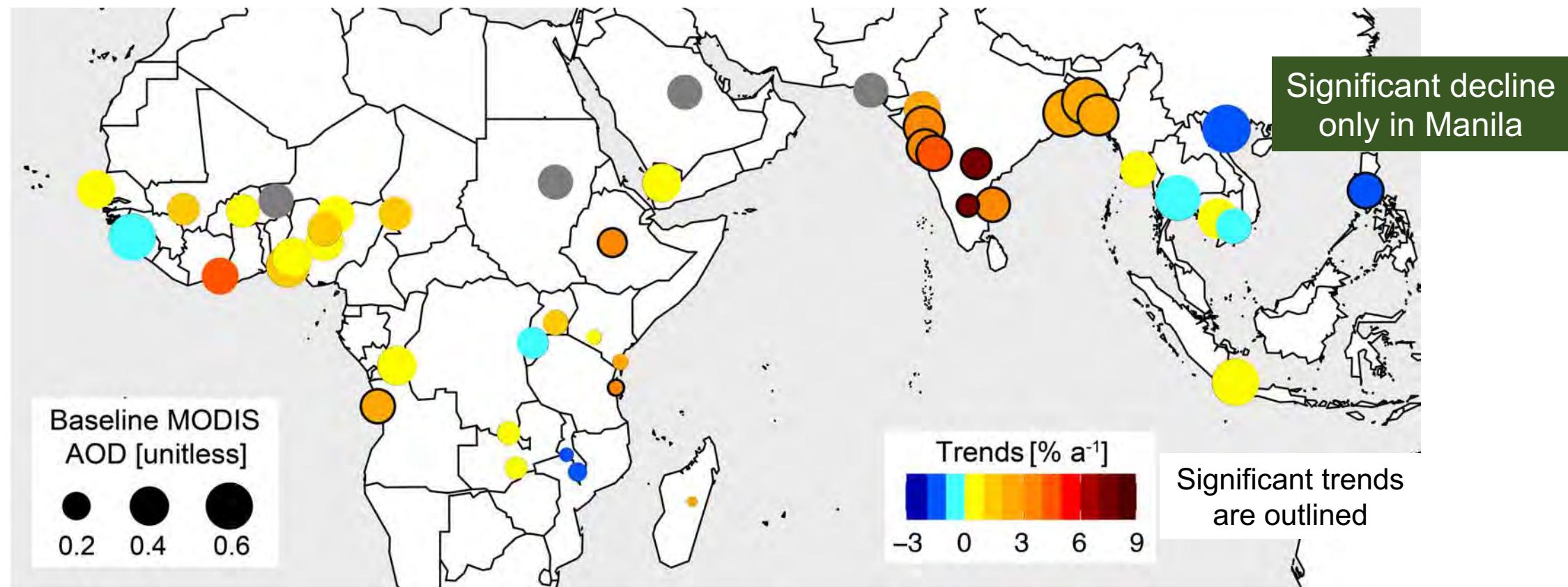


All cities except Riyadh are in NO<sub>x</sub>-sensitive regime; Jakarta and Sana'a will remain in NO<sub>x</sub>-sensitive regime; Gradual transition to NO<sub>x</sub>-saturated regime may occur as early as 2025

[Vohra et al., Sci. Adv., 2022]

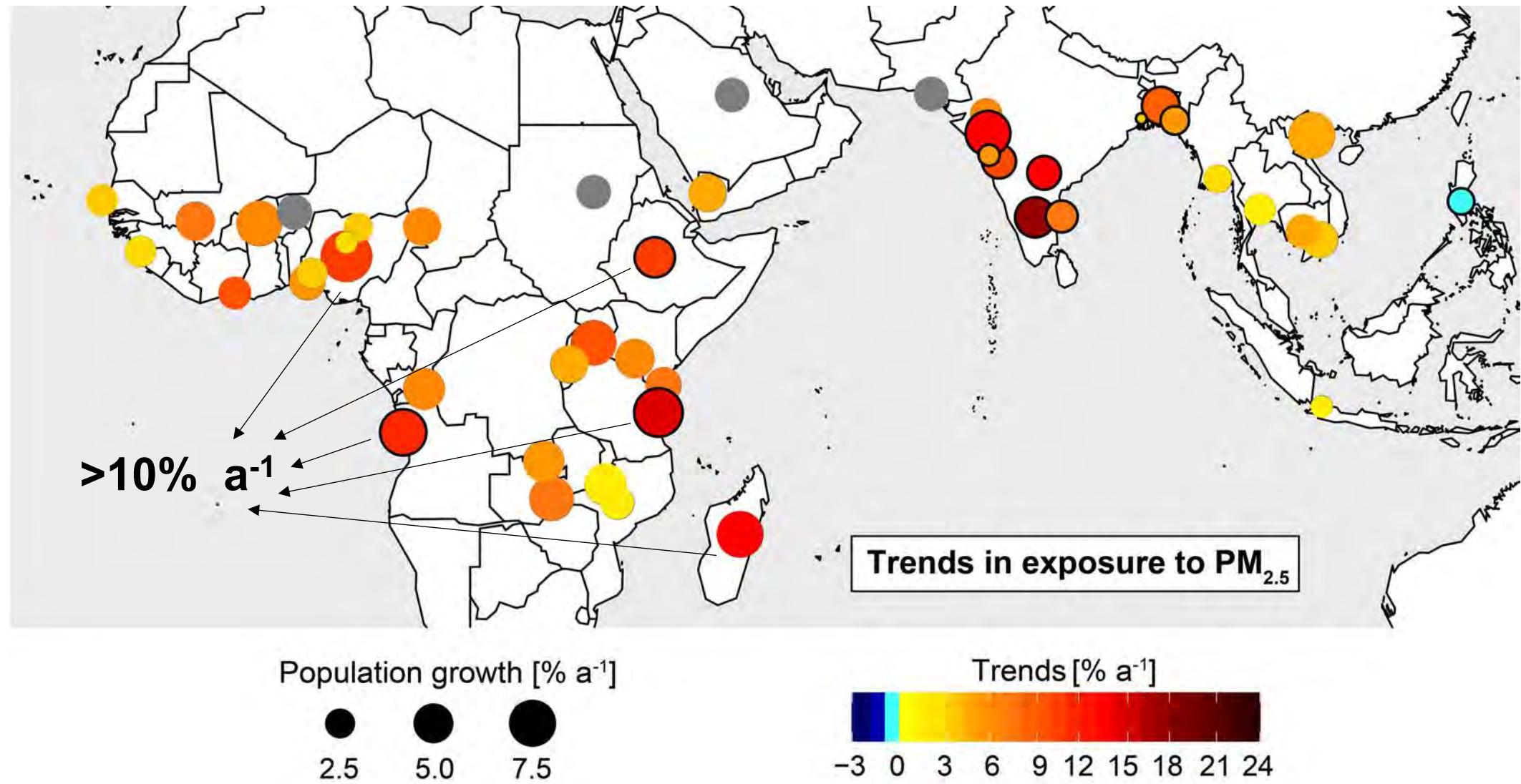
# Trends in PM<sub>2.5</sub> in tropical future megacities in 2005-2018

Large and significant increases of 3-8 % a<sup>-1</sup> in PM<sub>2.5</sub> over Indian subcontinent



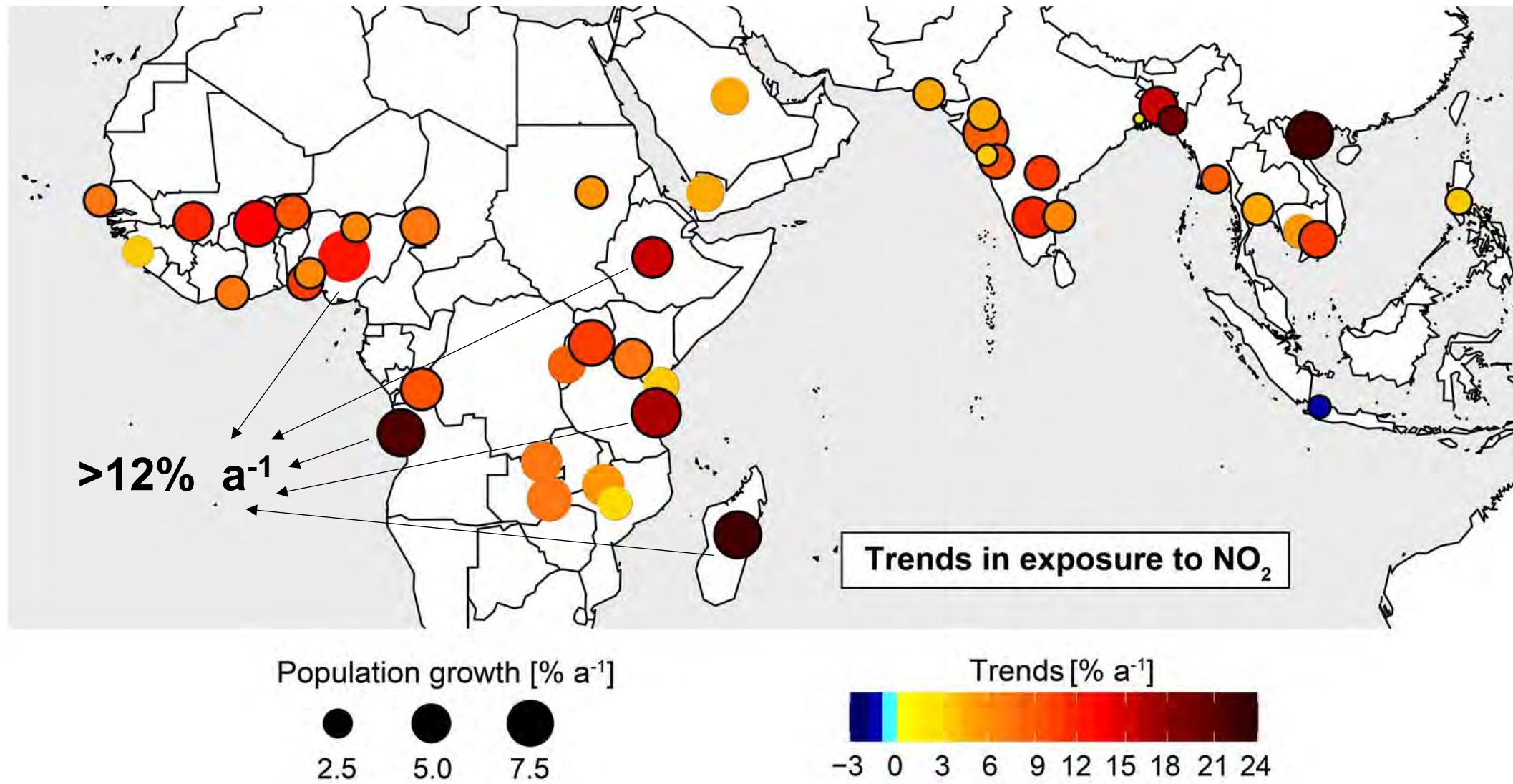
The large increase in South Asian cities is driven by an increase in PM<sub>2.5</sub> precursor emissions and not desert dust

# Rapid increase in urban population exposure to PM<sub>2.5</sub>



[Vohra et al., Sci. Adv., 2022]

# Rapid increase in urban population exposure to NO<sub>2</sub>



[Vohra et al., *Sci. Adv.*, 2022]

# Summary

- Most pollutants in almost all tropical cities are increasing. Increase driven by anthropogenic activities.
- Only Jakarta shows evidence of air quality improvements in NO<sub>2</sub>, not in PM<sub>2.5</sub>.
- Ozone formation to transition from strongly NO<sub>x</sub>-sensitive to the more challenging to regulate VOC-sensitive regime.
- Annual increases in urban population exposure, **1 to 18%** for PM<sub>2.5</sub> and **2 to 23%** for NO<sub>2</sub> from 2005 to 2018.

## Reference

K. Vohra, E. A. Marais, W. J. Bloss, J. Schwartz, L. J. Mickley, M. Van Damme, L. Clarisse, P.-F. Coheur, Rapid rise in premature mortality due to anthropogenic air pollution in fast-growing tropical cities from 2005 to 2018, **Sci. Adv.**, doi:10.1126/sciadv.abm4435, 2022.

# Fossil fuel combustion and PM<sub>2.5</sub>

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



Dominant anthropogenic source of PM<sub>2.5</sub> and easily controllable



But challenging to isolate fossil fuel-PM<sub>2.5</sub> using satellite and ground-based observations and so we use a model

# We use GEOS-Chem to simulate air pollutant concentrations

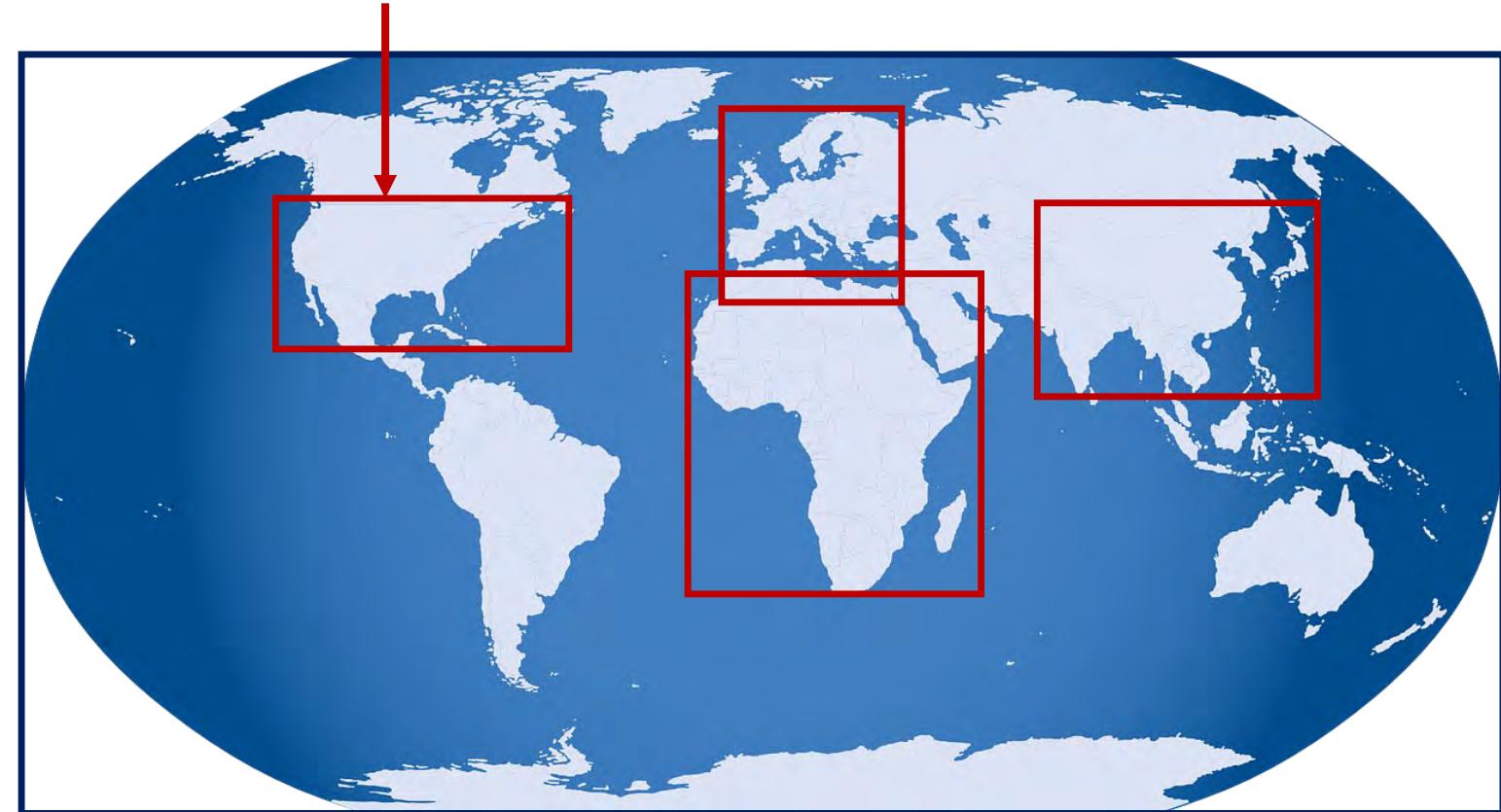
GEOS-Chem is state-of-the-art 3D global chemical transport model

Global and  
regional emissions

**GEOS**  
**Chem**

NASA  
Meteorology

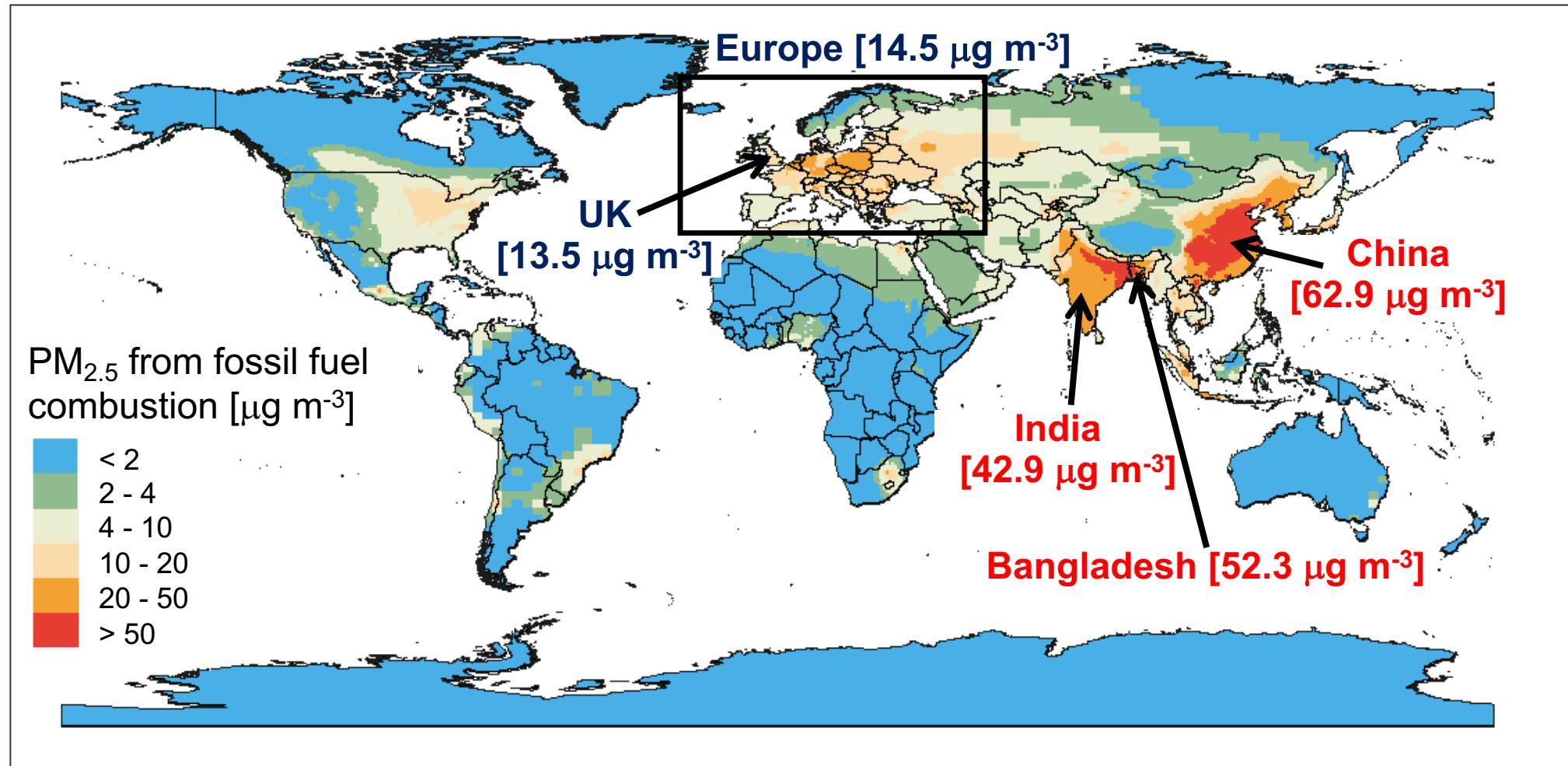
Regional simulations at  $0.5^\circ \times 0.67^\circ$



↑  
Global simulation at  $2^\circ \times 2.5^\circ$  spatial resolution

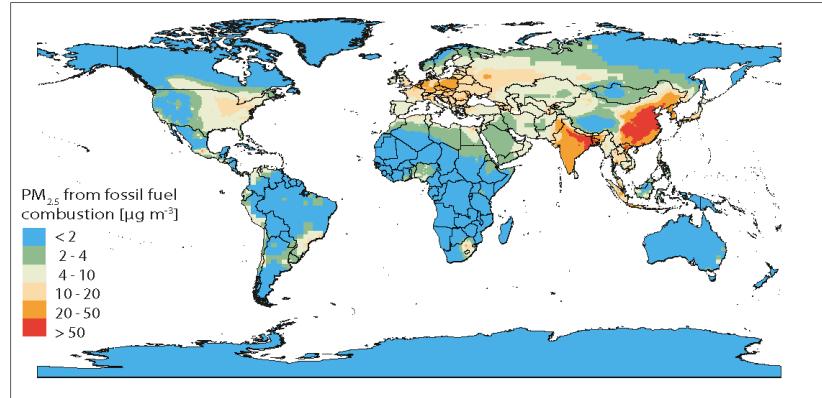
# Model estimate of fossil fuel PM<sub>2.5</sub> in 2012

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

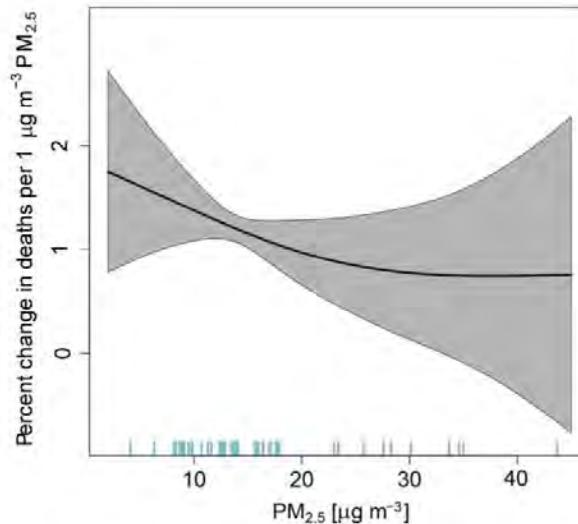


Hotspots are in China, Bangladesh, India, and central Europe

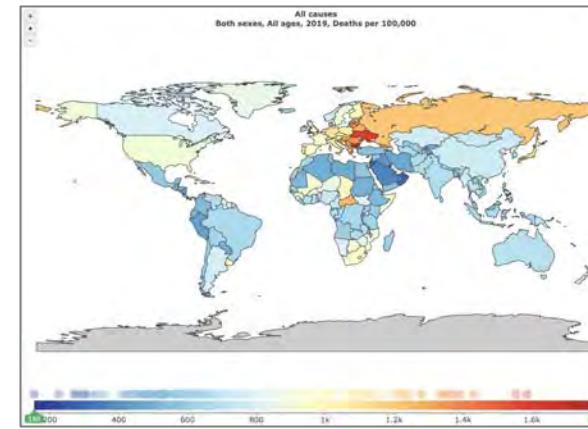
# Methodology for health impact calculation



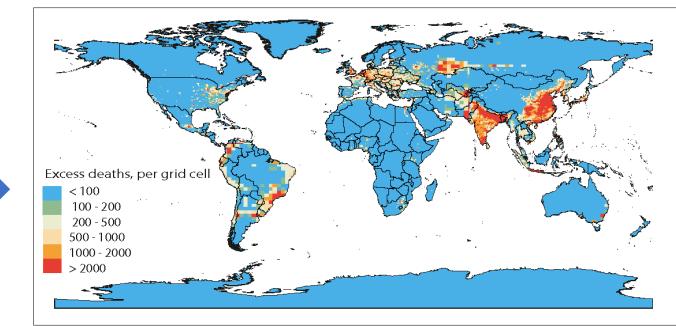
Fossil-fuel PM<sub>2.5</sub> from GEOS-Chem



Meta-analysis concentration-response function from cohort studies



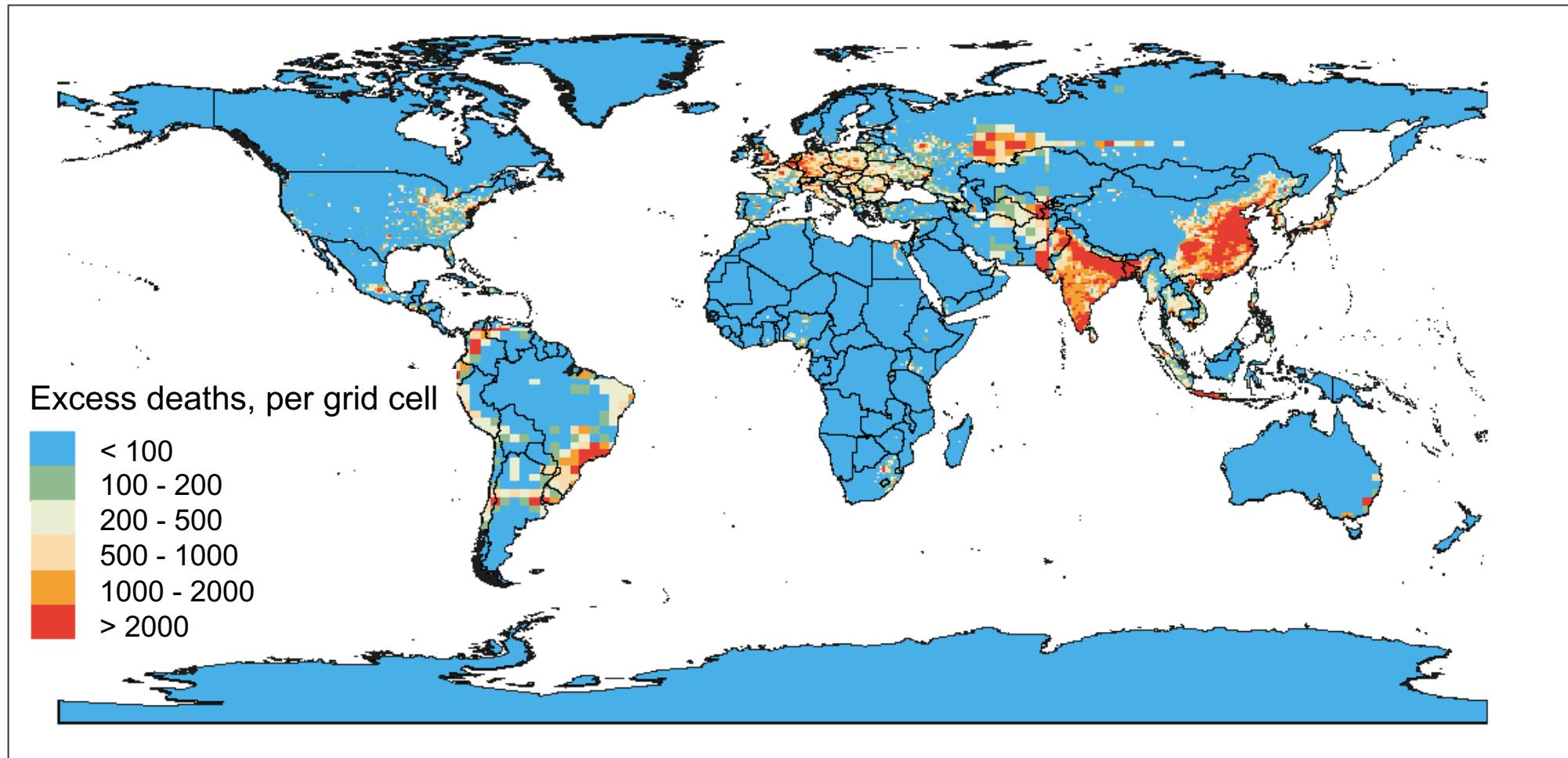
Baseline mortality from Global Burden of Disease



Global premature mortality estimates

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

# Estimated global premature mortality from fossil fuel combustion



**10.2 million** premature deaths attributed to fossil-fuel PM<sub>2.5</sub> in 2012

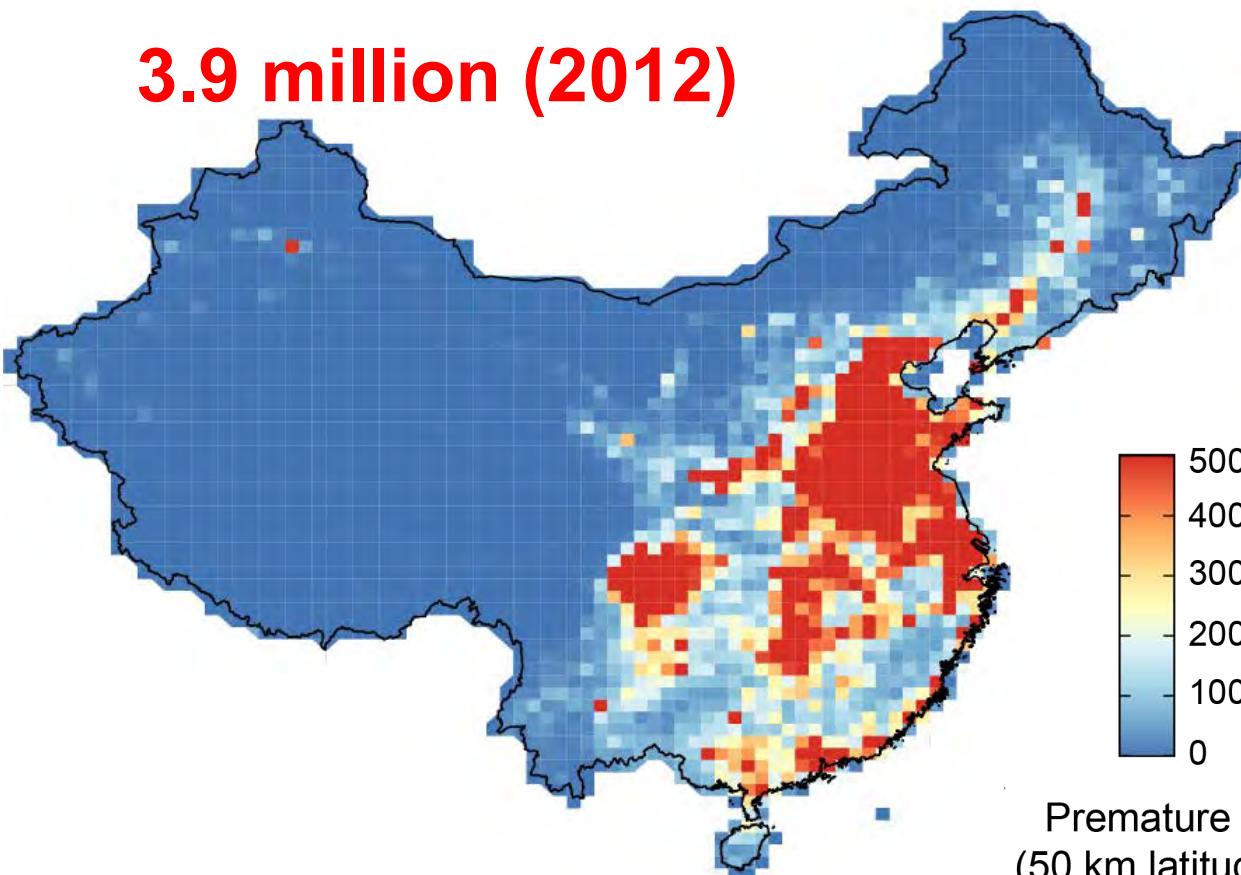
[−47 million, 17 million]

[Vohra et al., *Environ. Res.* 2021]

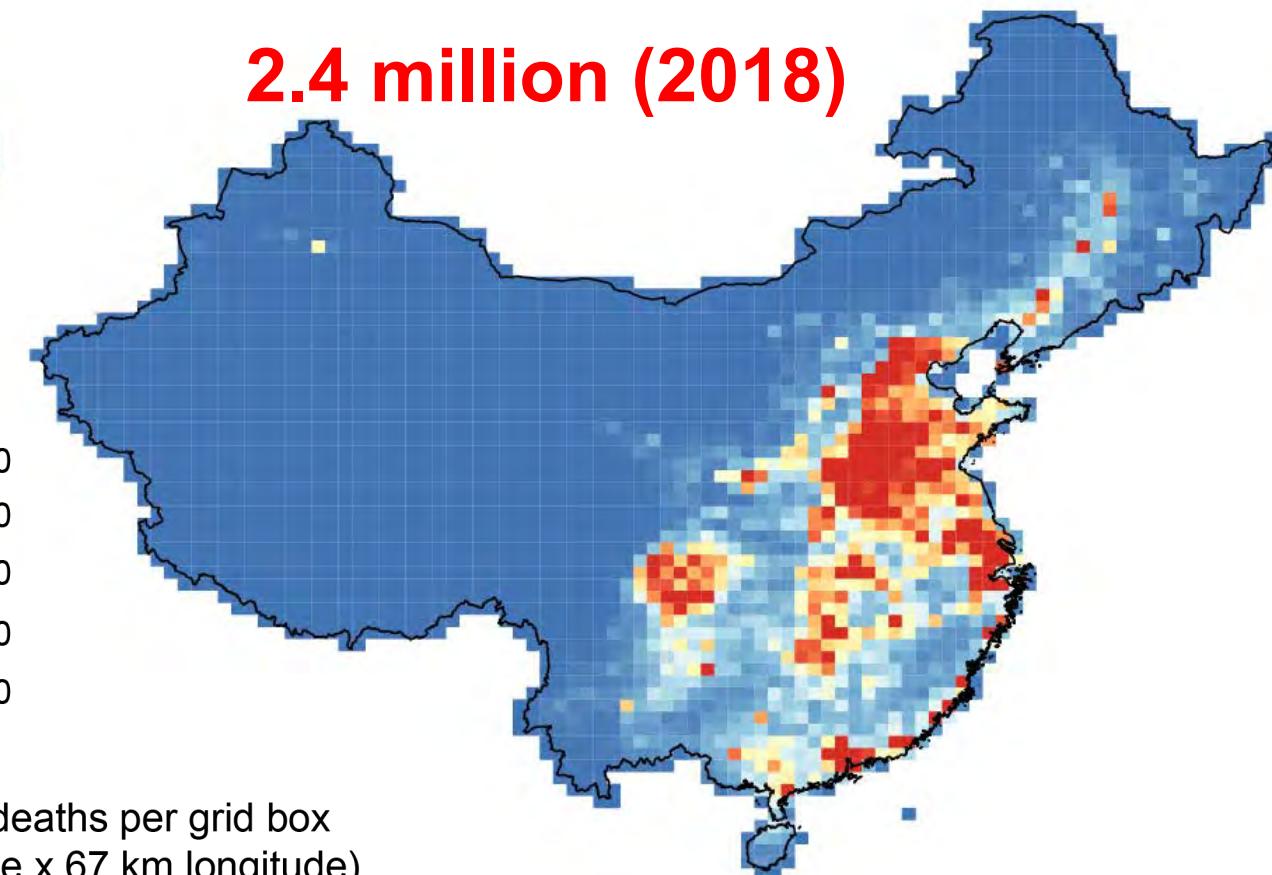
# Policies can help mitigate these premature deaths

## China

**3.9 million (2012)**



**2.4 million (2018)**



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

Dramatic reduction in PM<sub>2.5</sub> in China from 2012 to 2018 decreases premature deaths by 1.5 million

[Vohra et al., *Environ. Res.* 2021]

# Implications of and response to our 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>)



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

**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

**Heightened immediate urgency to transition to cleaner and more sustainable energy sources**

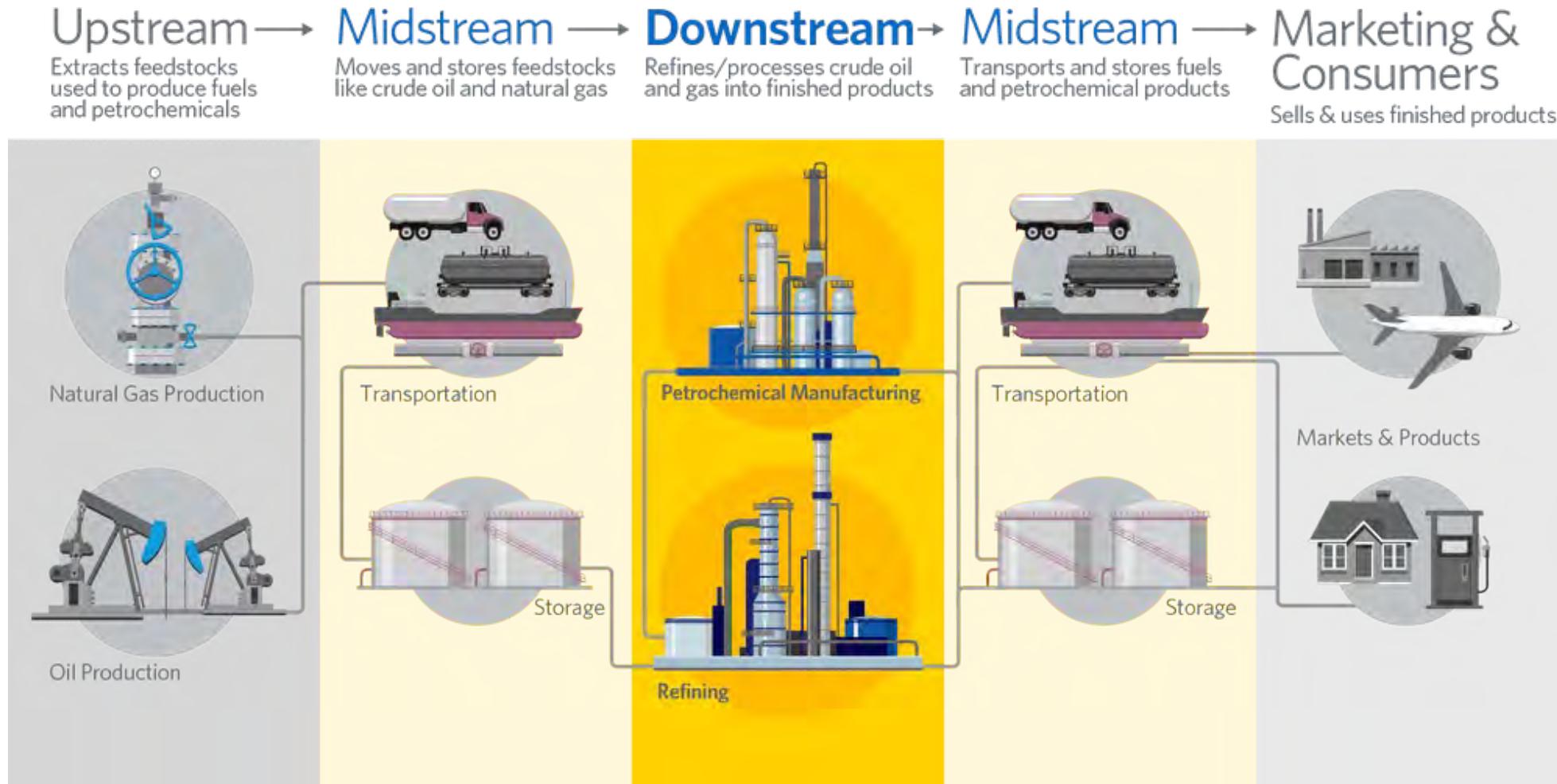
# Summary

- **10.2 million adult premature deaths** from fossil-fuel related PM<sub>2.5</sub> pollution in 2012. 62% in China and India.
- Substantial reduction in fossil fuel use in China led to 38% decline in premature deaths from 3.9 million in 2012 to 2.4 million in 2018.
- Our premature mortality estimates higher than previous studies because we use an updated health risk assessment model and a finer spatial resolution chemical transport model.

## Reference

K. Vohra, A. Vodonos, J. Schwartz, E. A. Marais, M. P. Sulprizio, L. J. Mickley, Global mortality from outdoor fine particle pollution generated by fossil fuel combustion: Results from GEOS-Chem, *Environ. Res.*, 195, 110754, doi:10.1016/j.envres.2021.110754, **ISI Web of Science Highly Cited Paper**, 2021.

# The major segments of the oil and gas (O&G) lifecycle



Source AFPM.org

We are collaborating with Stockholm Environment Institute (SEI) to assess the health effects of exposure to air pollution linked to the complete O&G lifecycle

# Large pollutant emissions from the Texas O&G lifecycle

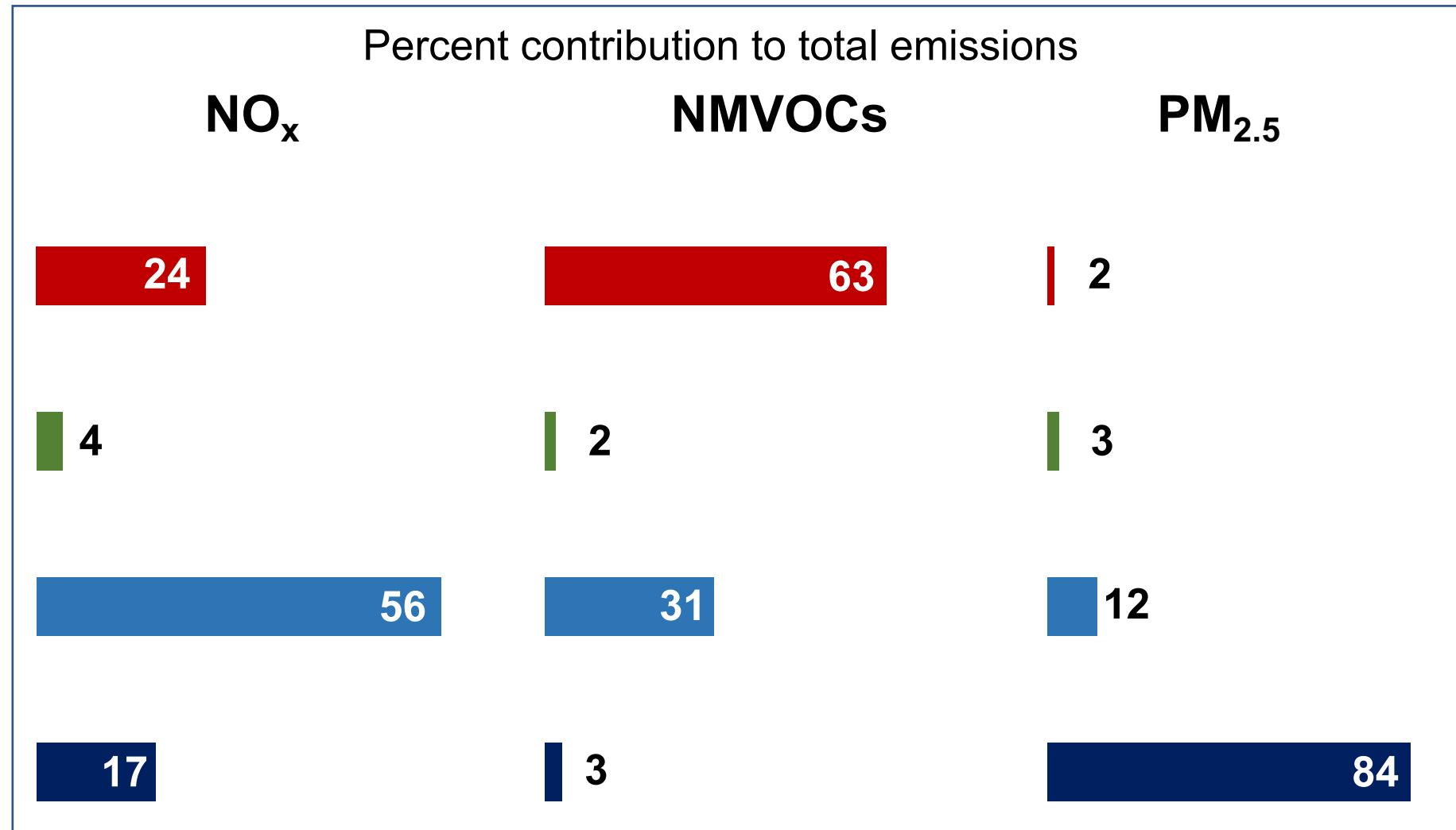
 **Upstream**  
Exploration and production

 **Midstream**  
Storage and transport

 **Downstream**  
Oil refining and petrochemical manufacturing

 **End-use**  
Marketing and consumption

 **Non O&G**  
Agriculture, mining and others



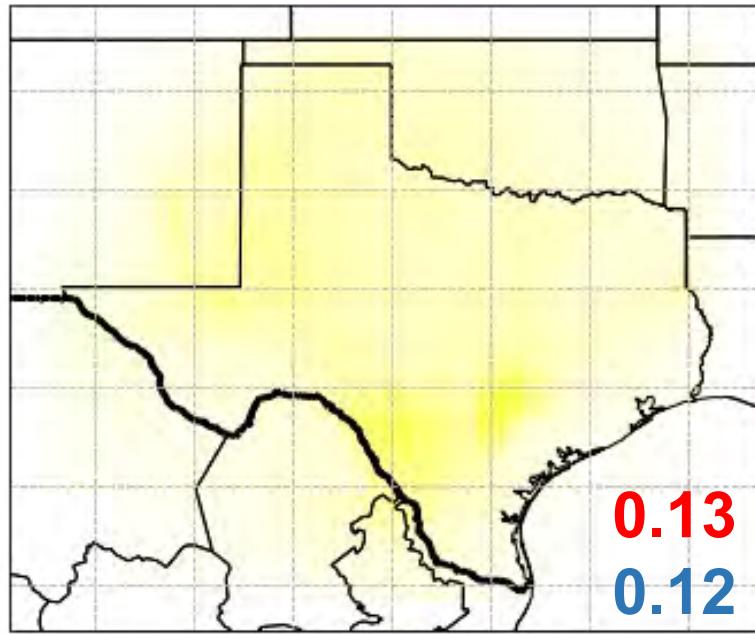
Texas O&G lifecycle contributes to 84% of NO<sub>x</sub>, 97% of NMVOCs and 16% of primary PM<sub>2.5</sub> emissions

*NEI 2017 emissions dataset processed by Brian McDonald, Colby and Colin Harkins at NOAA*

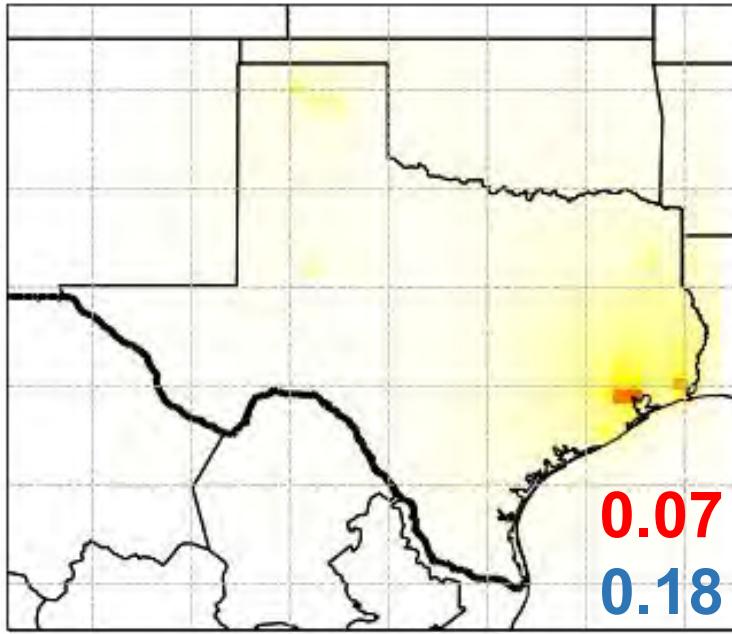
# $\text{PM}_{2.5}$ from oil and gas lifecycle for Texas in 2017

We run sensitivity simulations to assess the impact of each step in the oil and gas lifecycle

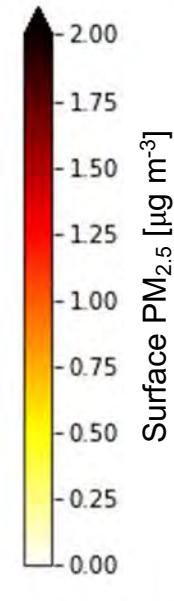
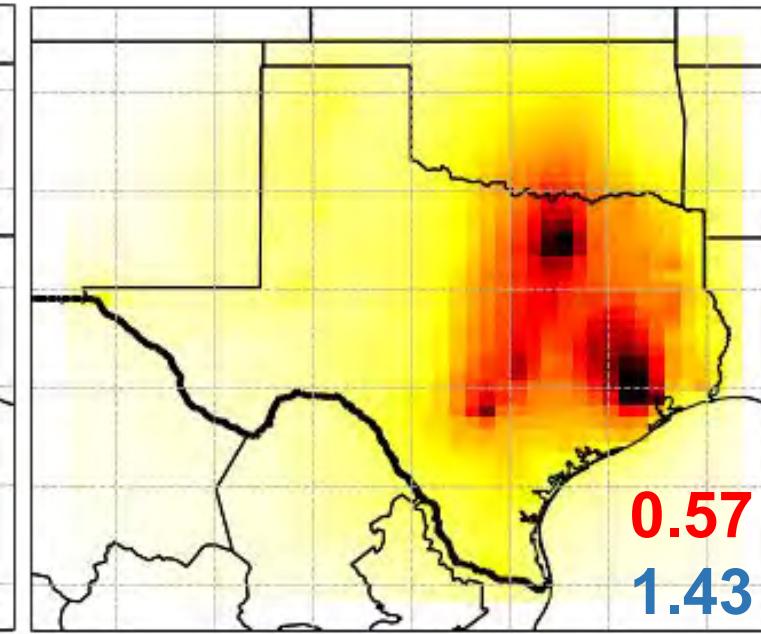
O&G Upstream + Midstream



O&G Downstream



O&G End-use



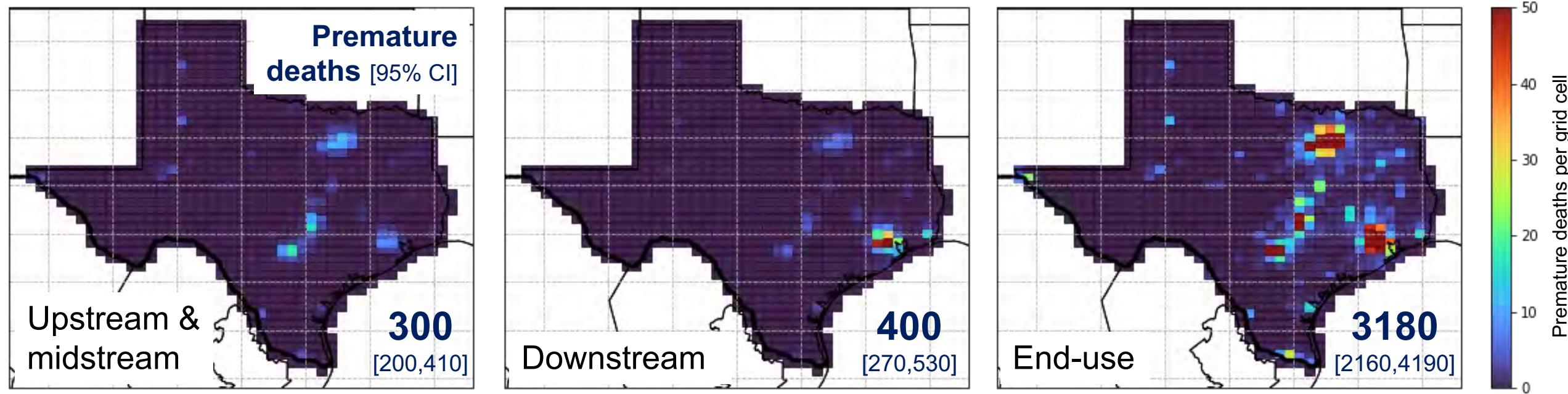
Area mean [μg m<sup>-3</sup>]

Population-weighted mean [μg m<sup>-3</sup>]

Oil and gas activities in Texas contribute to 0.77  $\mu\text{g m}^{-3}$  (8.2%) of PM<sub>2.5</sub>, mostly (0.57  $\mu\text{g m}^{-3}$ ) from end use

# Premature mortality from the oil and gas lifecycle in Texas

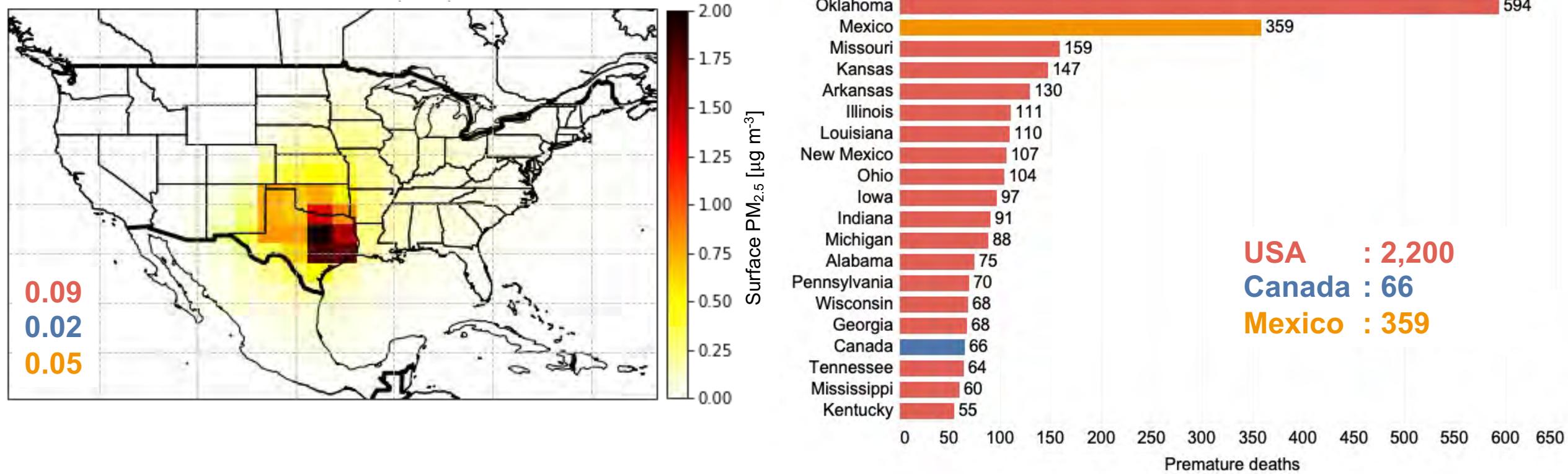
We estimate adult premature deaths (all-cause mortality) from long-term PM<sub>2.5</sub> exposure linked to each major segment of the O&G lifecycle in Texas



**3,840** premature deaths from the oil and gas emissions (**82%** from end-use, **10%** from downstream and **8%** from upstream activities)

# Impact of Texas oil and gas emissions on surrounding areas

First look at global simulations run at coarse grid resolution ( $2.0^\circ \times 2.5^\circ$ ) to assess the impact on neighbouring states and countries



Next steps include running the model at finer resolution ( $0.25^\circ \times 0.3125^\circ$ ) to assess the impact of US-wide oil and gas activities

# Conclusion

- Shift in dominance of air pollution from open burning of biomass to anthropogenic activity in urban areas where more people are exposed to air pollution.
- Our results highlight the immediate health crisis due to ongoing reliance on fossil fuels.
- End-use activities make the largest contribution to PM<sub>2.5</sub> and NO<sub>2</sub> but there are large VOCs emissions (>60%) from oil and gas production.

Interactive dashboards

Air quality trends



Fossil fuel mortality



Any Questions? Email [k.vohra@ucl.ac.uk](mailto:k.vohra@ucl.ac.uk)



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