The impact of anthropogenic air pollution from city to global health

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Global Change Seminar
University of Edinburgh

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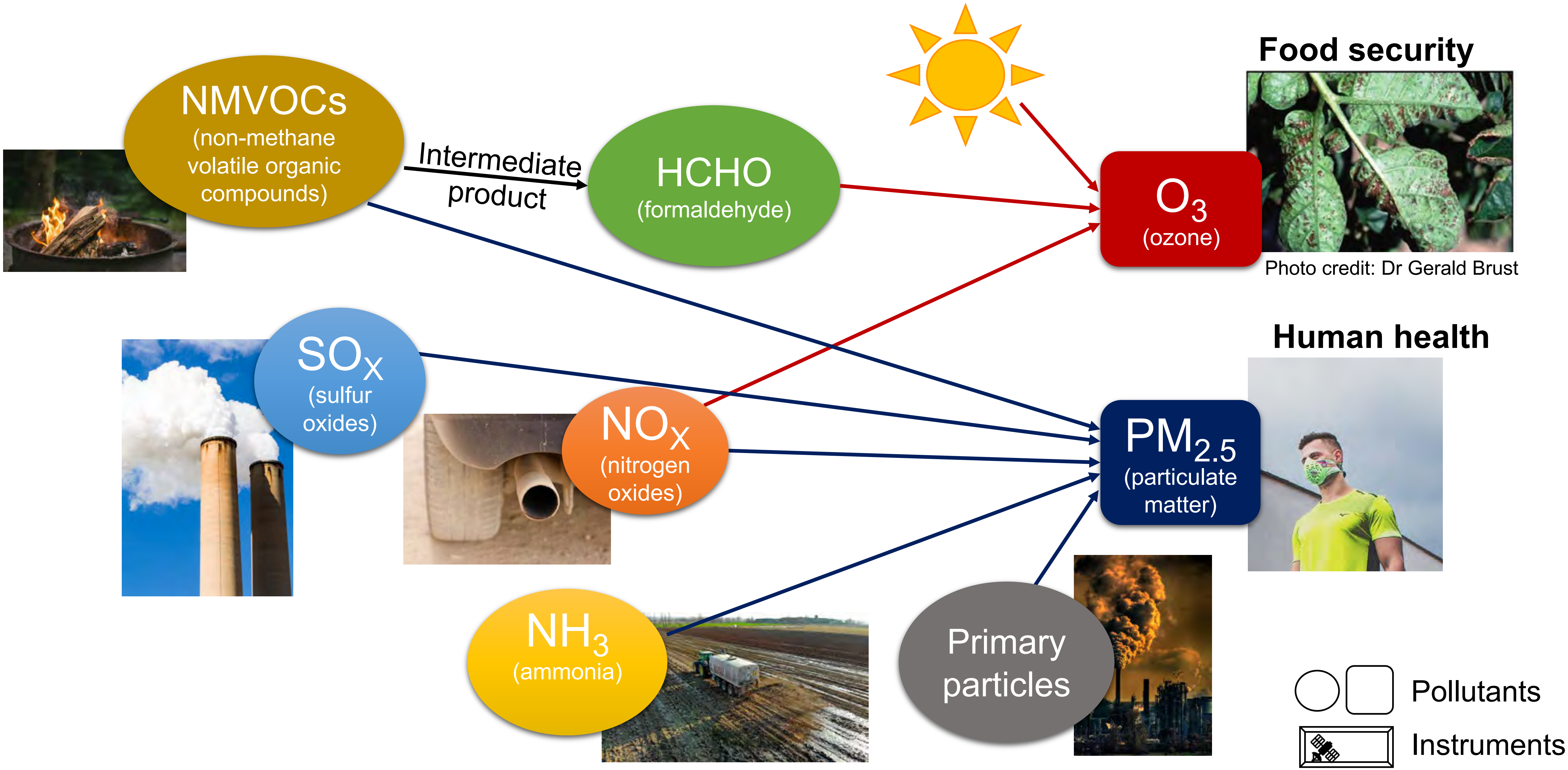
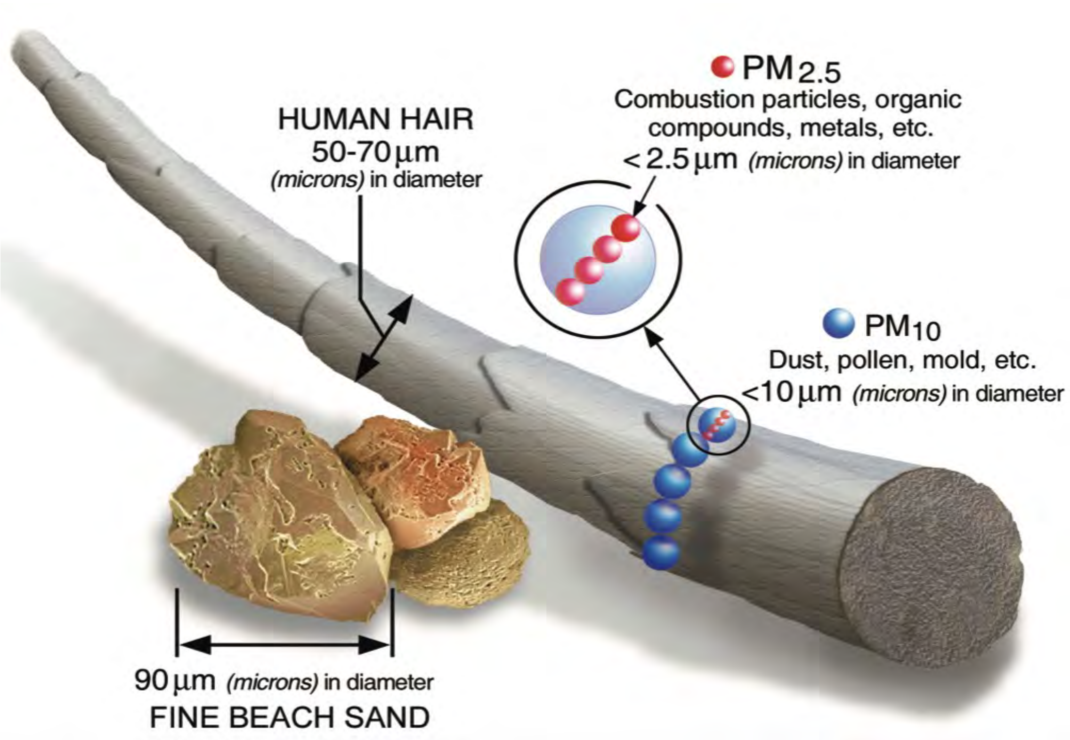
The cocktail of air pollutants we breathe

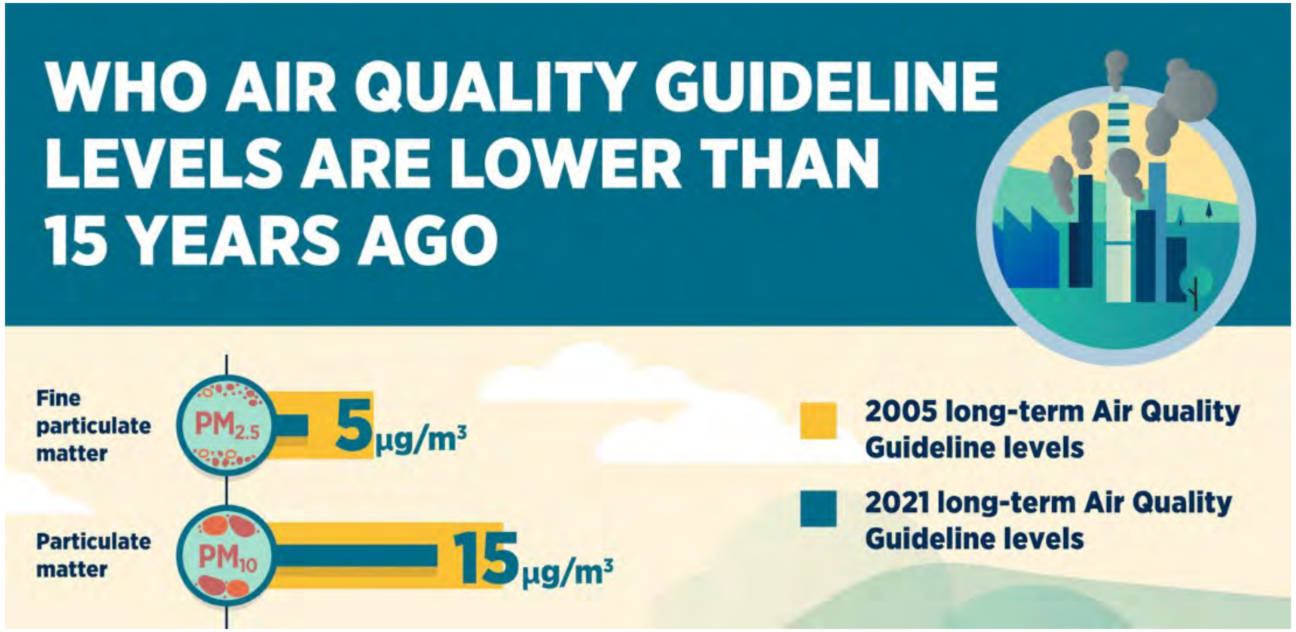


PM is fine enough to be inhaled deep into the lungs

Particulate Matter (PM)



Source – US EPA



No safe level of exposure to PM

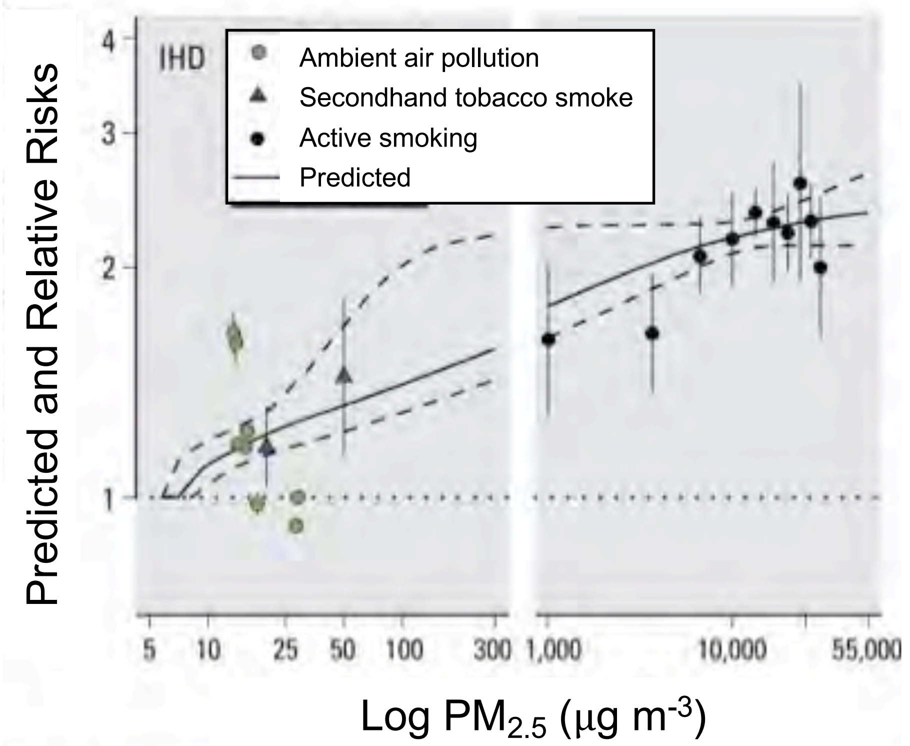
[WHO, 2021]

Air pollution may be damaging every organ of the body

Standard and widely used risk assessment models

Relates $PM_{2.5}$ concentrations to the likelihood of adverse health outcomes

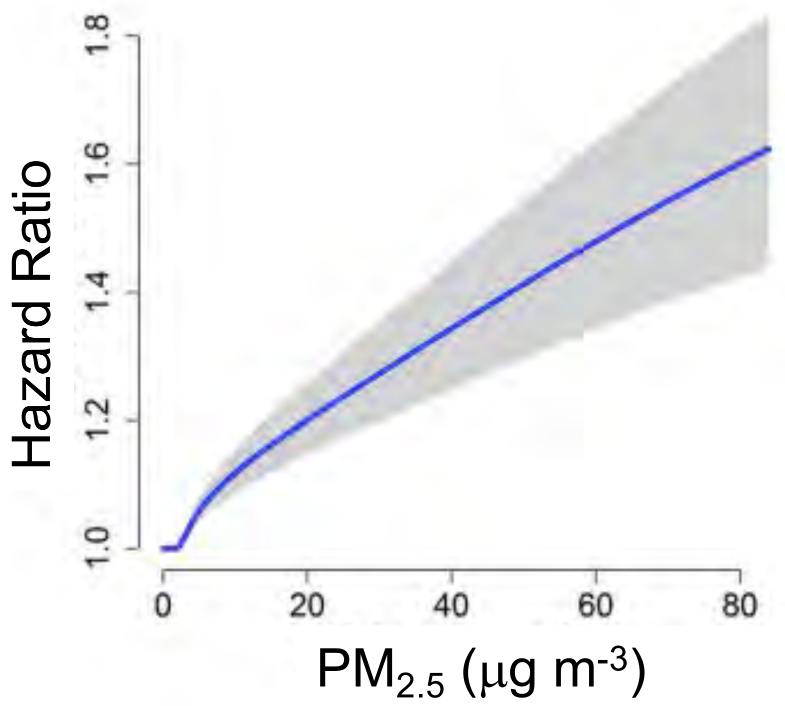
Integrated Exposure-Response (IER)



[Burnett et al., 2014]

Data includes active and passive smoking to address outdoor $PM_{2.5}$ > 40 $\mu g\ m^{-3}$

Global Exposure Mortality Model (GEMM)



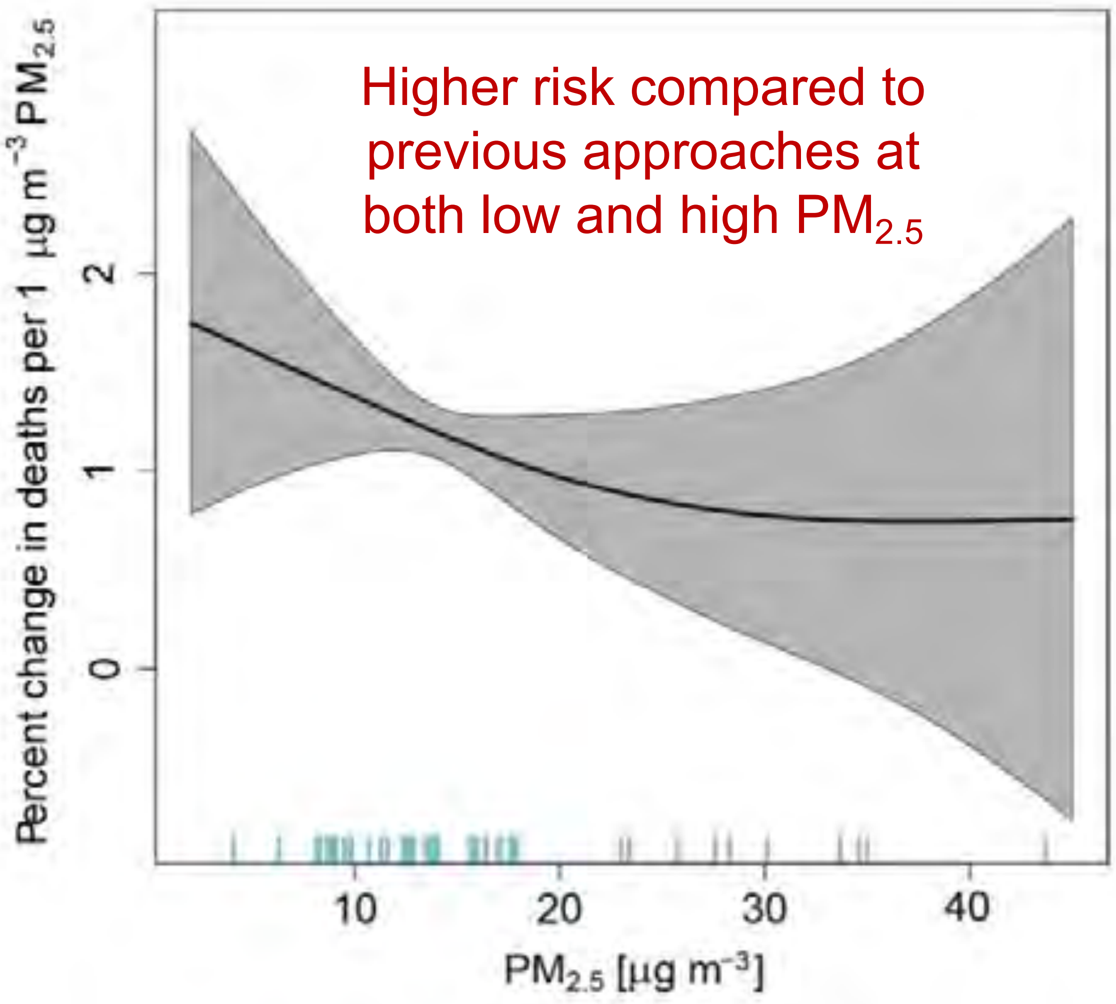
[Burnett et al., 2018]

41 cohort studies and model constrained using 4 parameters

4-9 million premature deaths worldwide from long-term exposure to $PM_{2.5}$

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]

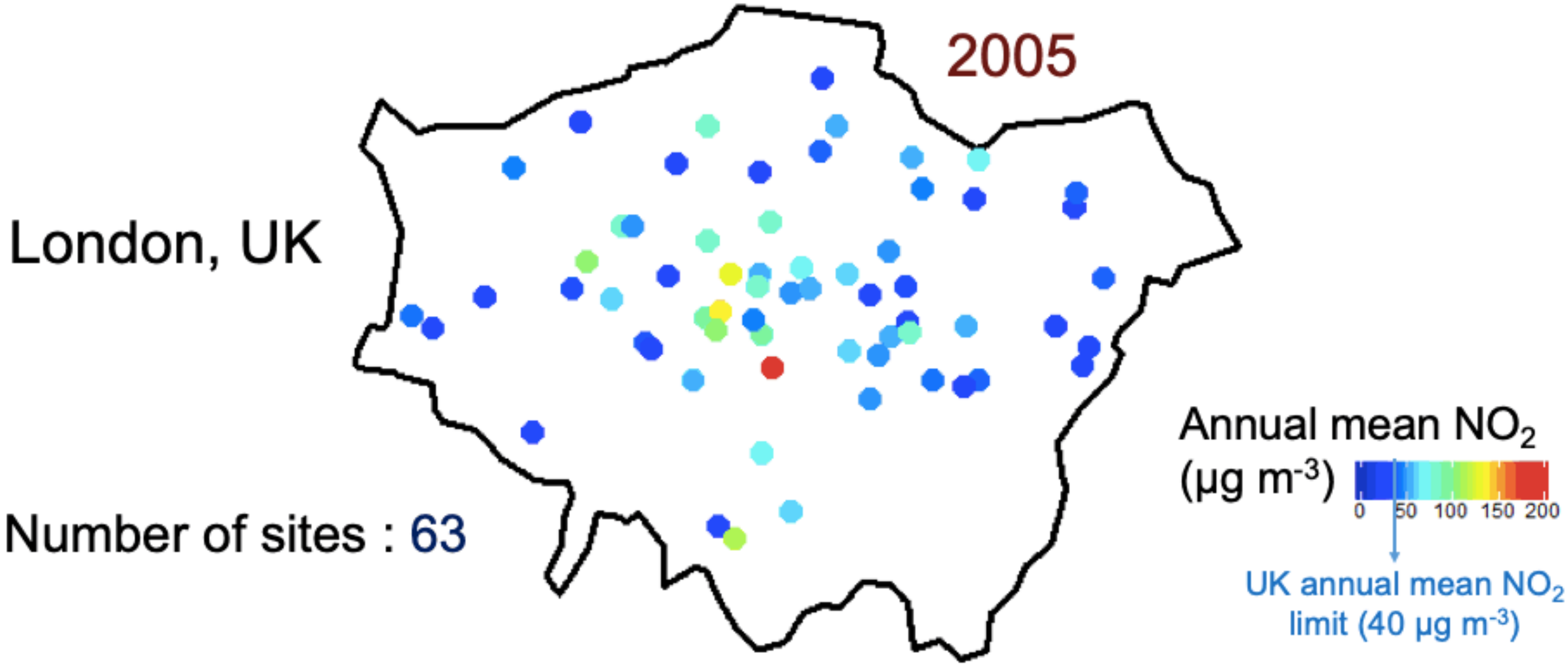
Routine surface monitoring in cities is challenging

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

Selly Oak, Birmingham

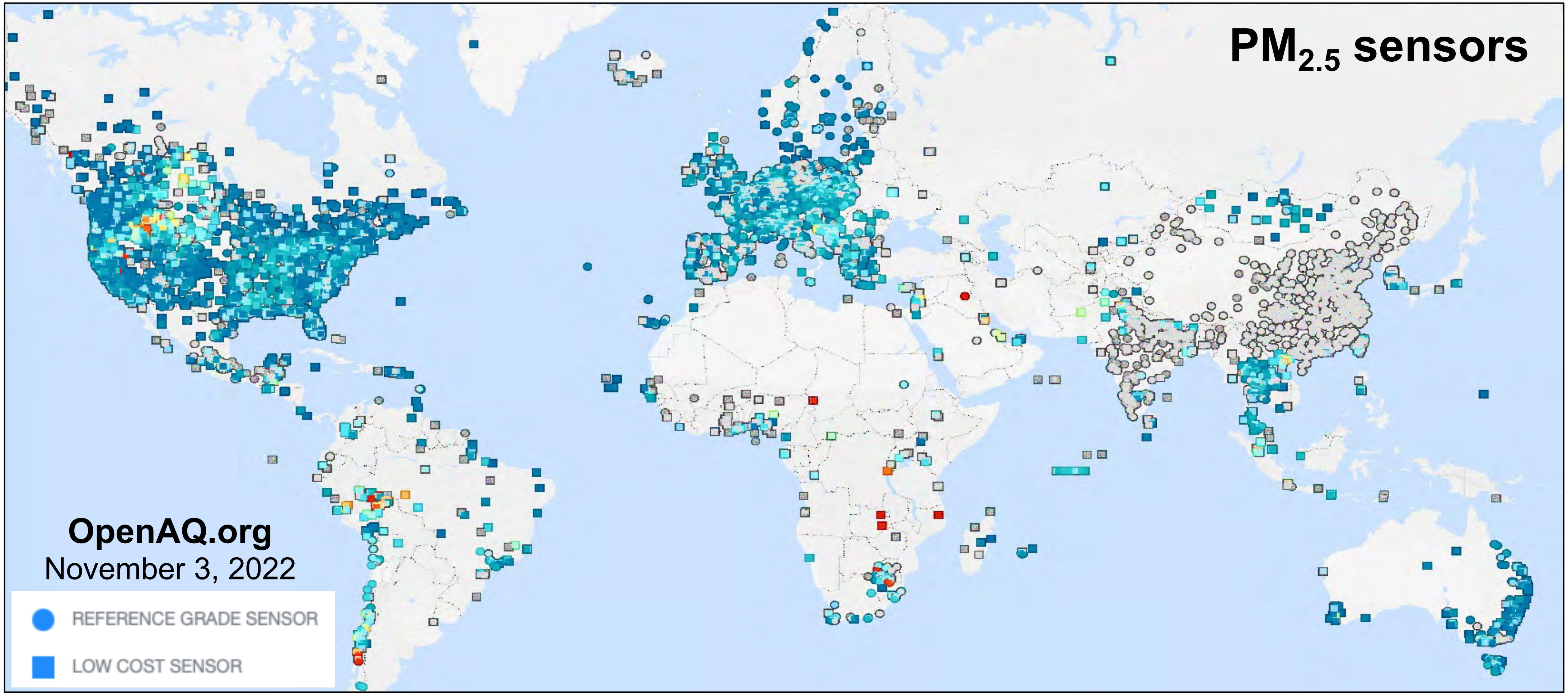
Routine surface monitoring in cities is challenging

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



Data from *London Air Quality Network (LAQN)*

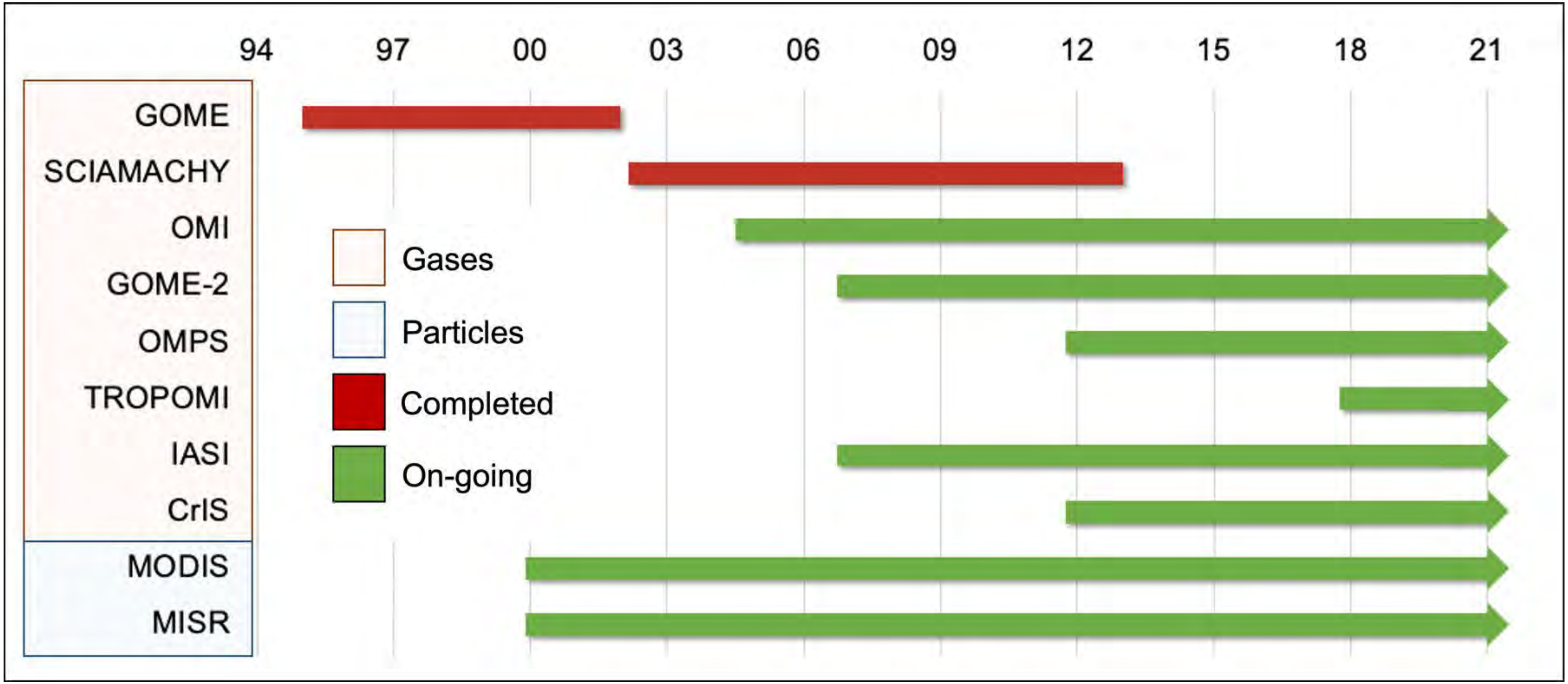
Limited surface monitoring in the rapidly developing world



< 1 monitor per million people in the tropics

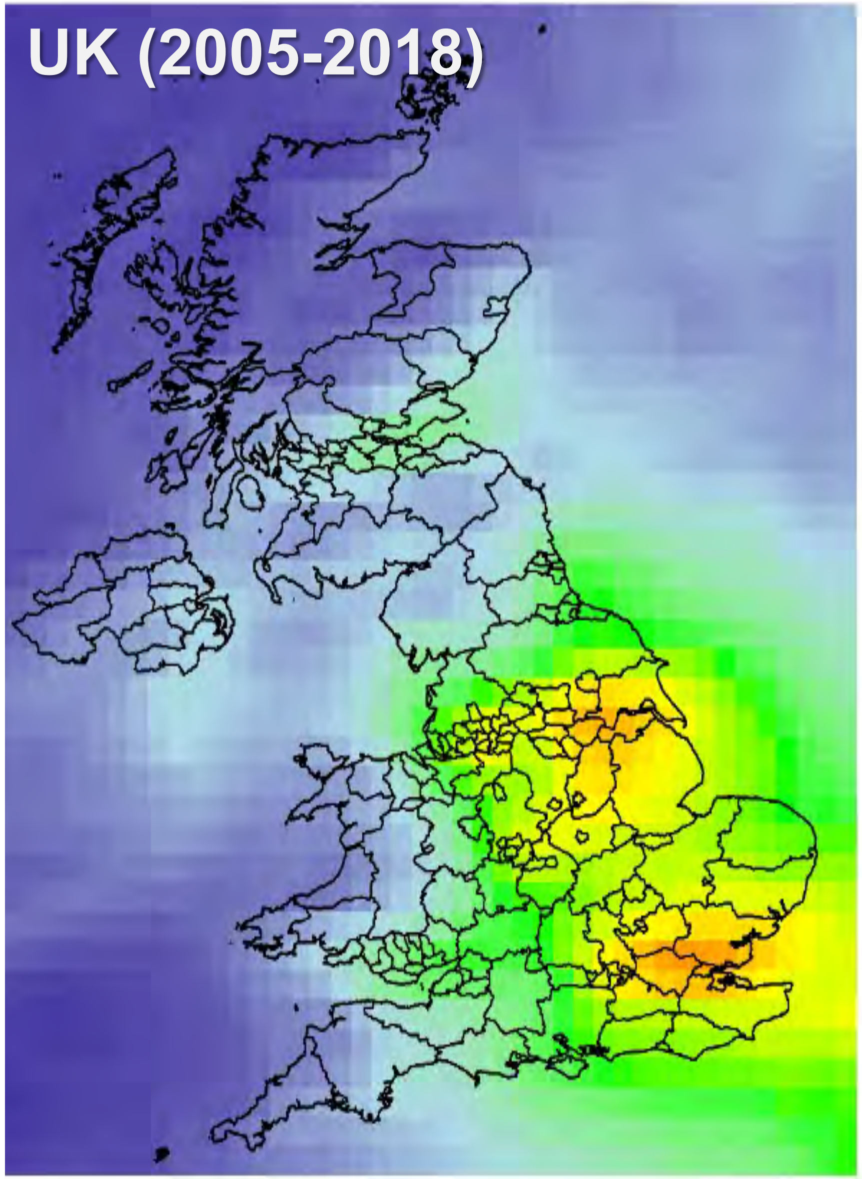
[Martin et al., 2019]

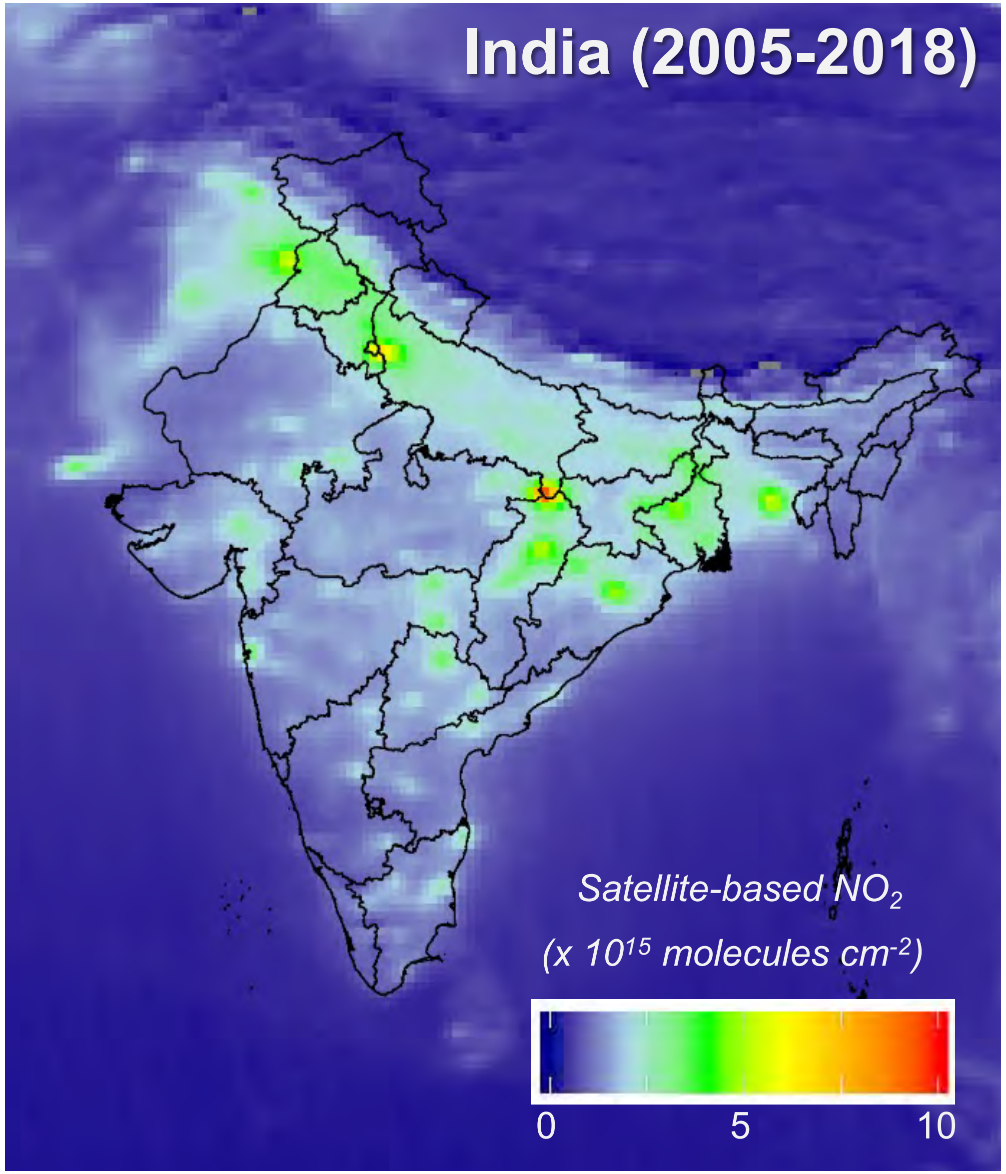
Long and consistent record of atmospheric composition from space-based instruments



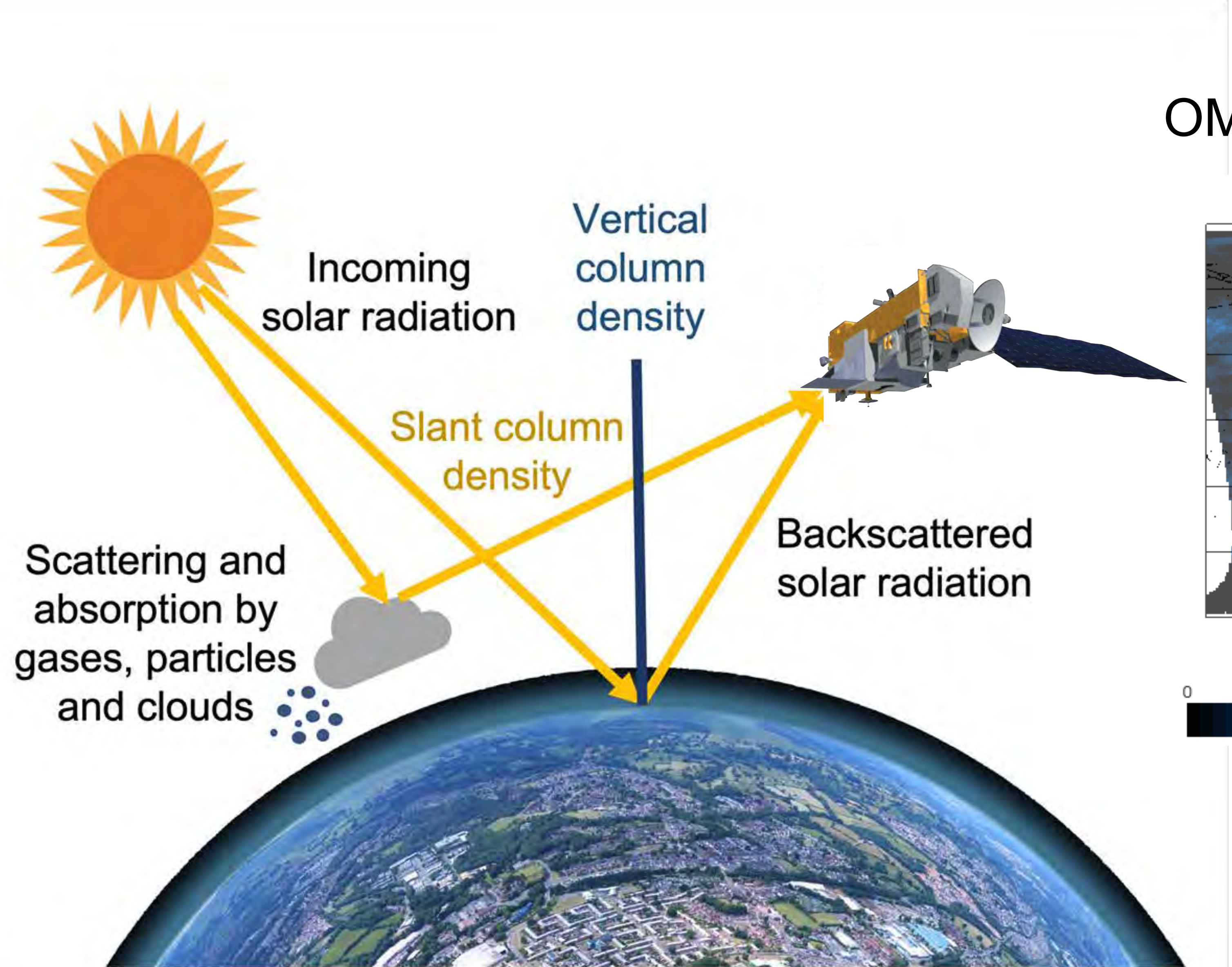
OMI for **NO_2** and **HCHO** (proxy for NMVOCs); **IASI** for **NH_3**; **MODIS** for **AOD** (proxy for $PM_{2.5}$)

Space-based instruments provide extensive data coverage

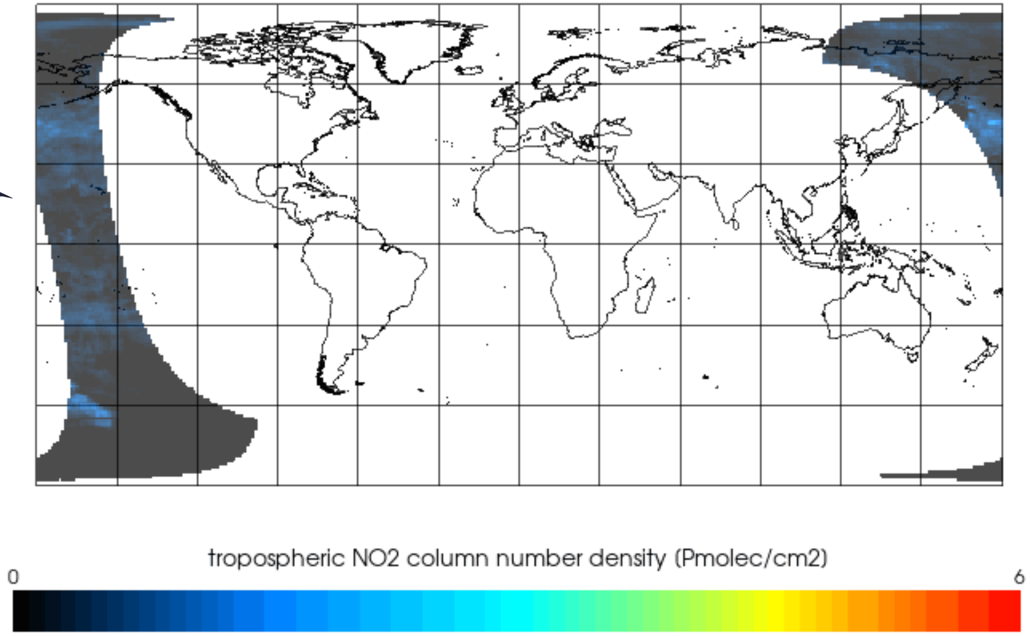




How do satellites measure atmospheric composition?



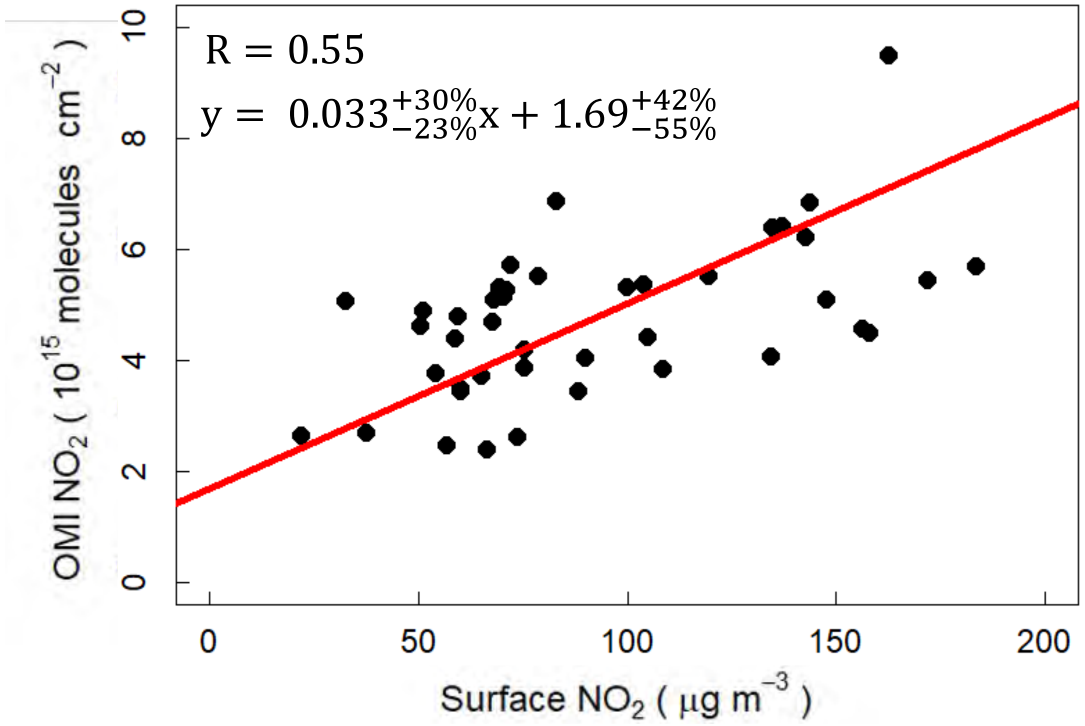
OMI overpass time : 13h30 local time



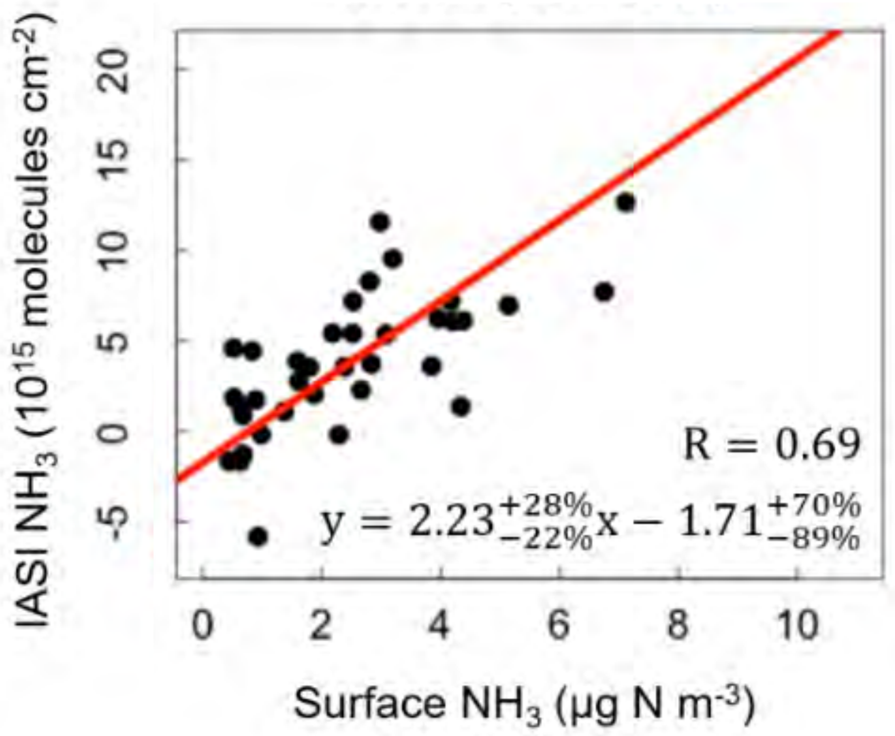
OMI NO_2 for each orbit

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

Satellite versus surface NO_2 in **Delhi**, India (2011-2018)



Satellite versus surface NH_3 at the background site **Harwell**, UK (2011-2015)

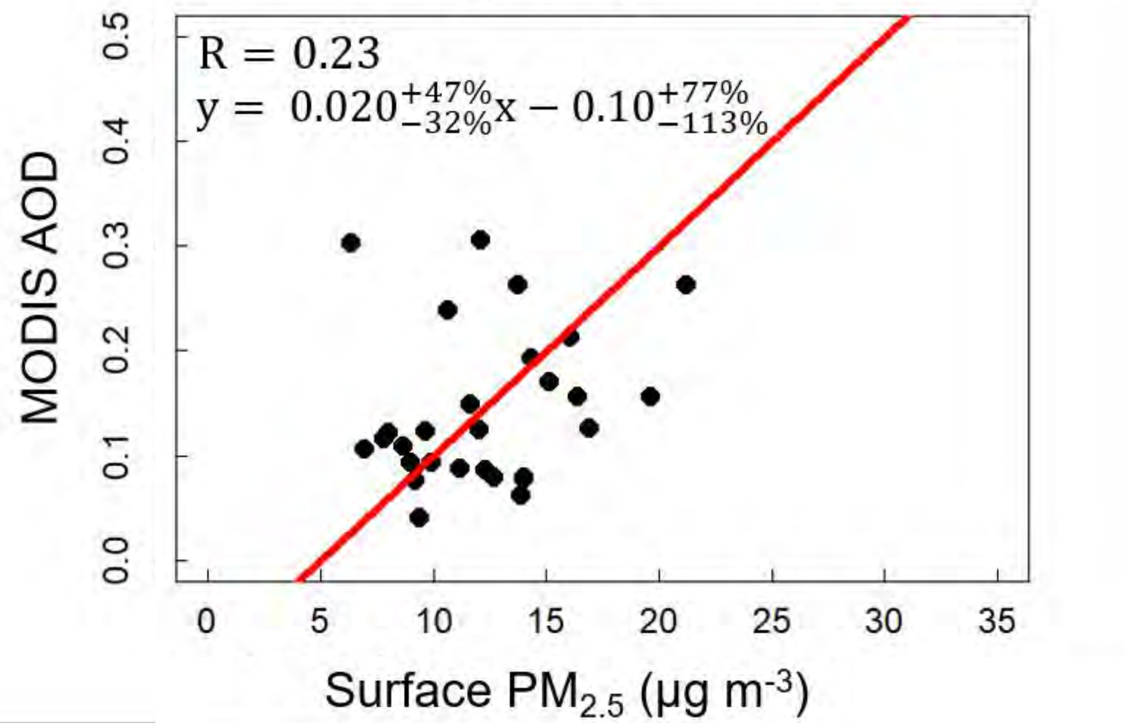


Temporal consistency between satellite and surface measurements of NO_2 and NH_3

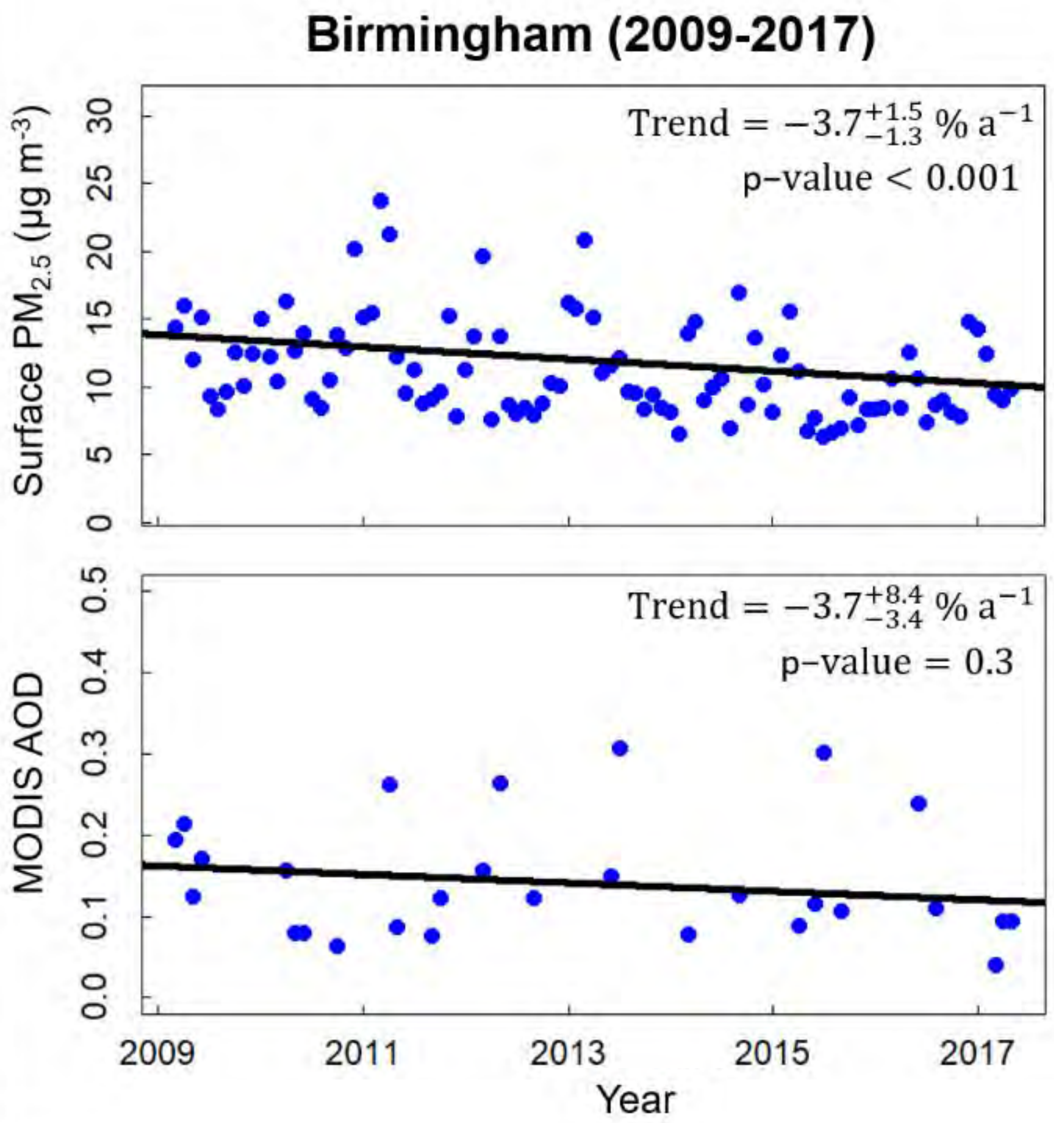
[Vohra et al., *Atmos. Chem. Phys.*, 2021]

Satellite observations of AOD reproduce long-term trends in $PM_{2.5}$

Satellite AOD versus surface $PM_{2.5}$ in **Birmingham**, UK (2009-2017)



Data from Birmingham City Council



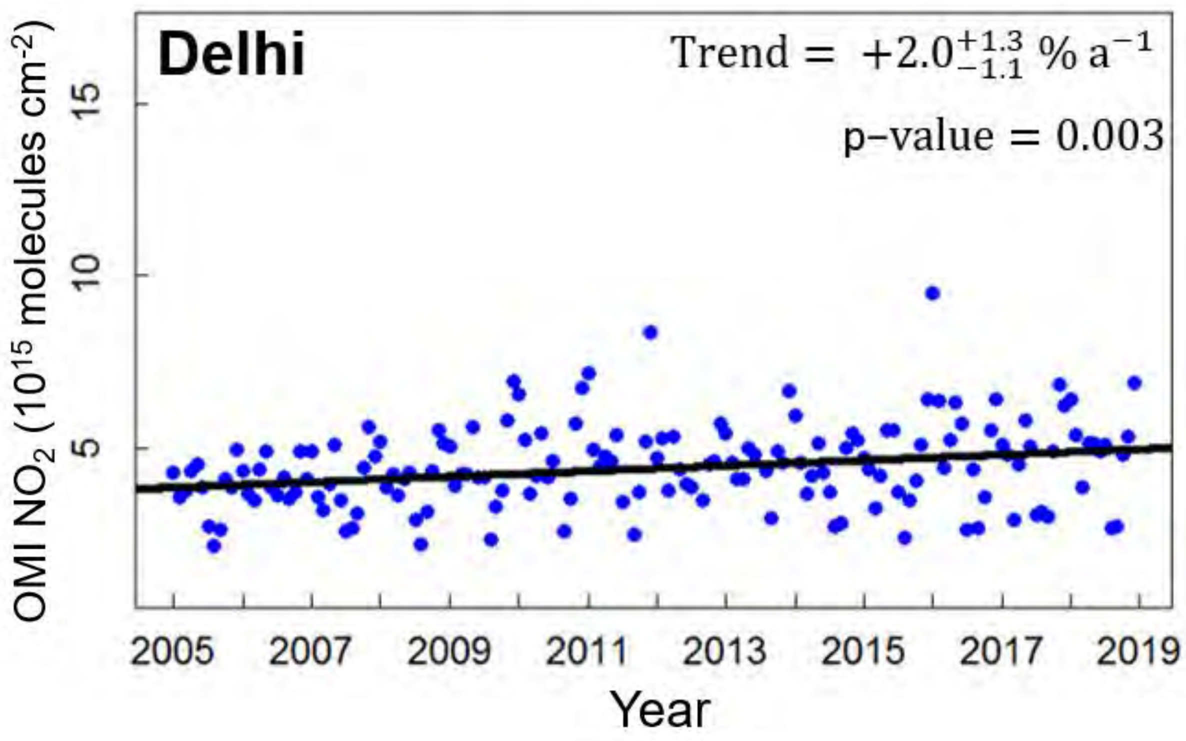
Complicated by meteorological conditions, aerosol composition & vertical distribution

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

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

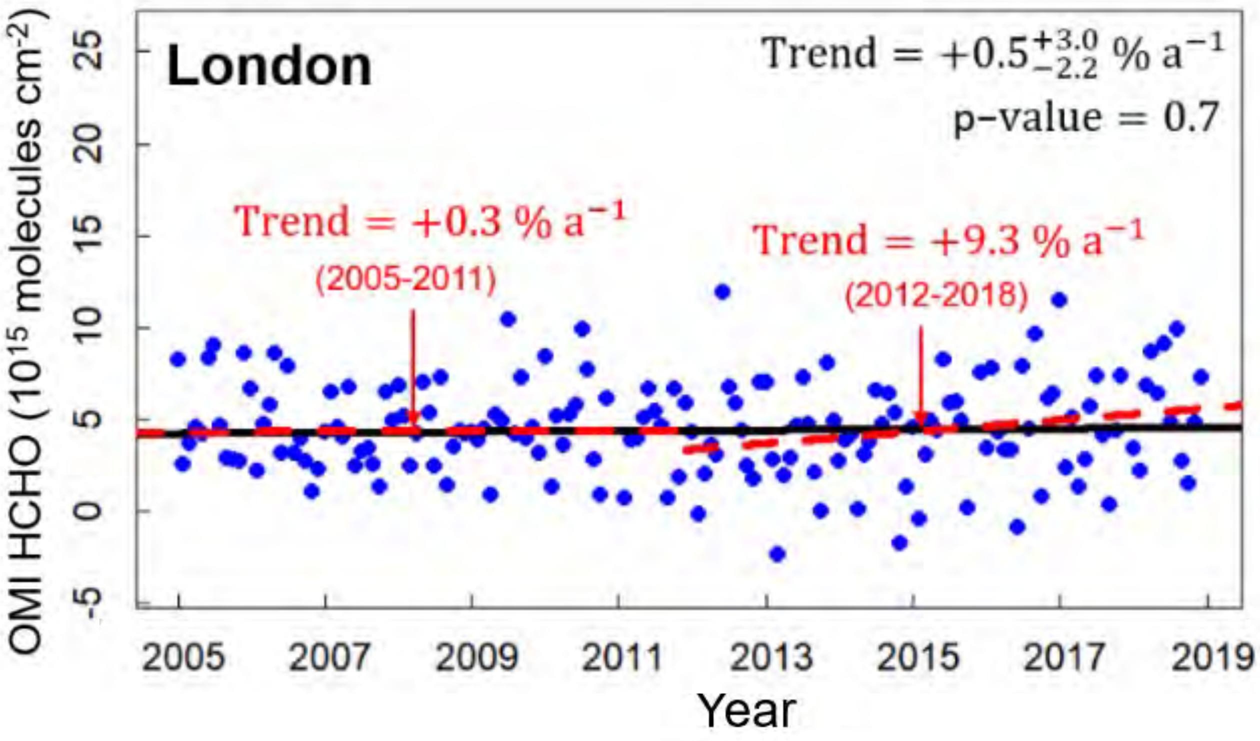
We apply trend analysis to long-term record of satellite observations

Trends in Delhi NO_2



No evidence of efficacy of recent pollution control measures

Trends in London NMVOCs

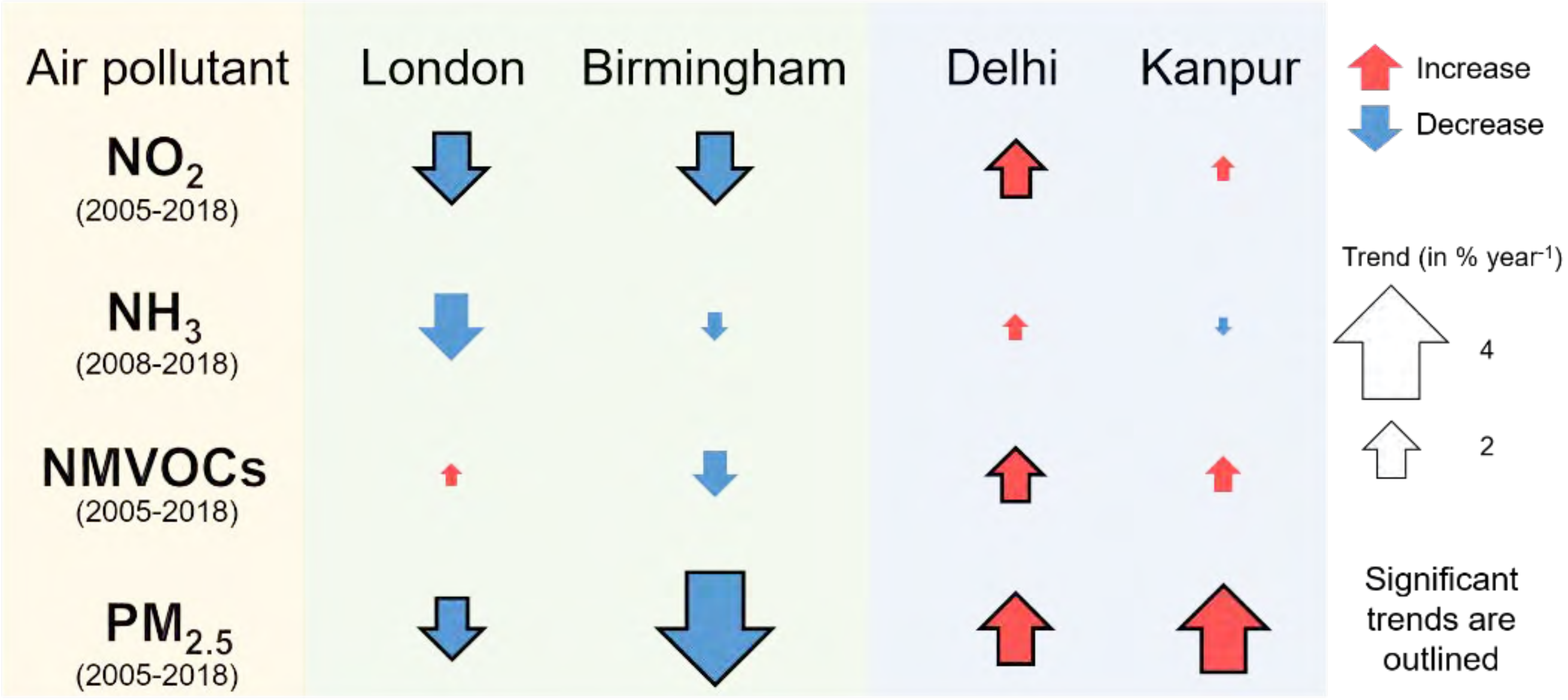


Recent dramatic increase in reactive NMVOCs

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

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

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



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

Summary

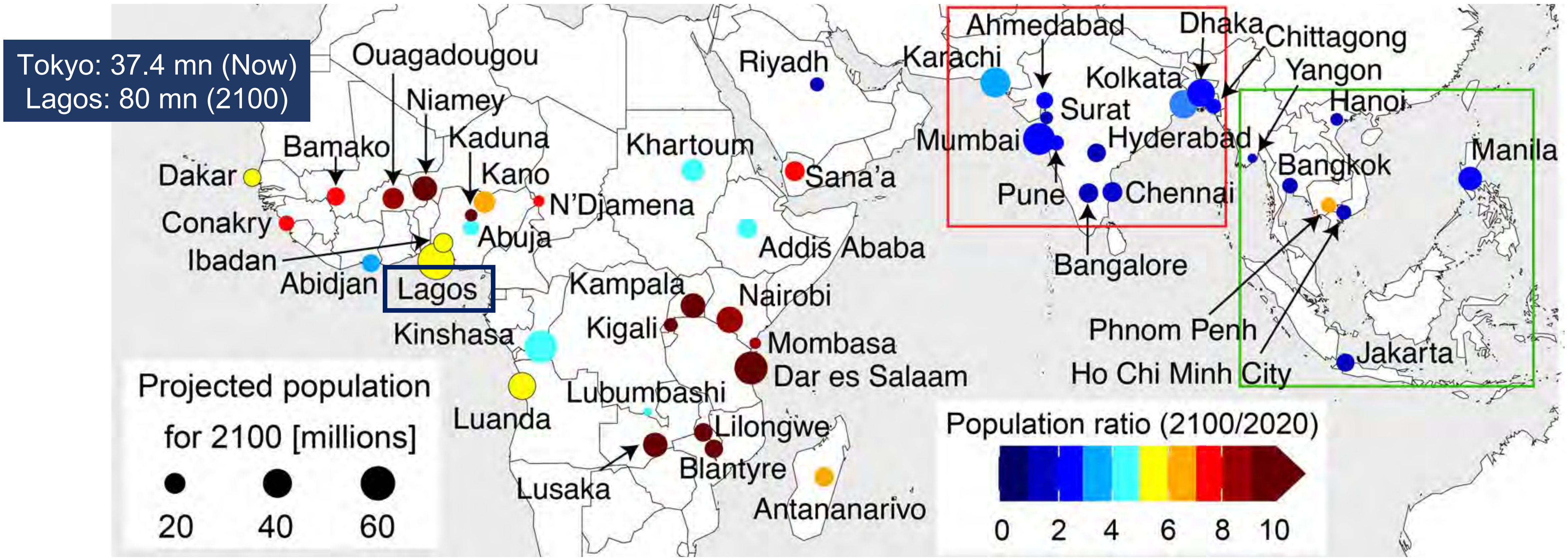
- Satellite observations of atmospheric composition assessed against available surface observations before quantifying trends in cities.
- In Indian cities, all pollutants (except NH_3 in Kanpur) on the rise. No improvements in air quality despite recent pollution control measures.
- In UK cities, declining 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

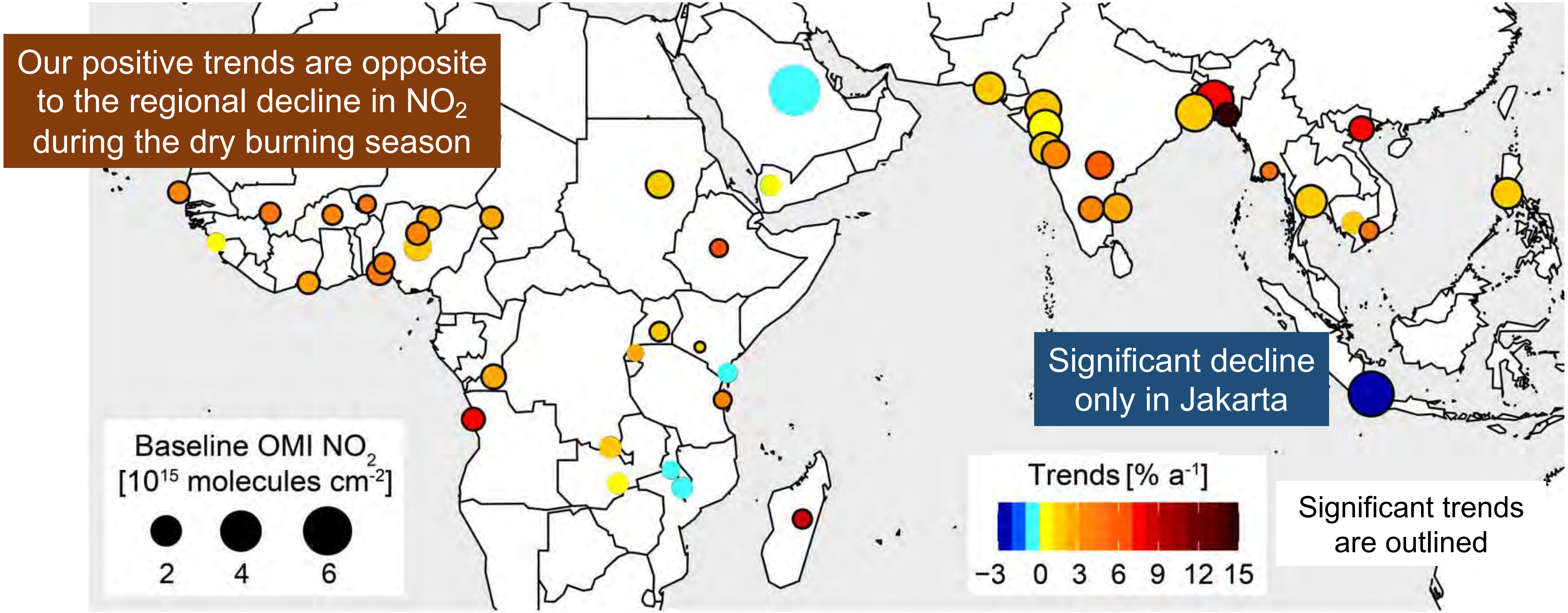
46 cities in tropical Asia, Africa and the Middle East will be megacities by 2100



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_2 in tropical future megacities in 2005-2018

NO_2 increases in 41 cities by 0.1-14.1 % a^{-1}

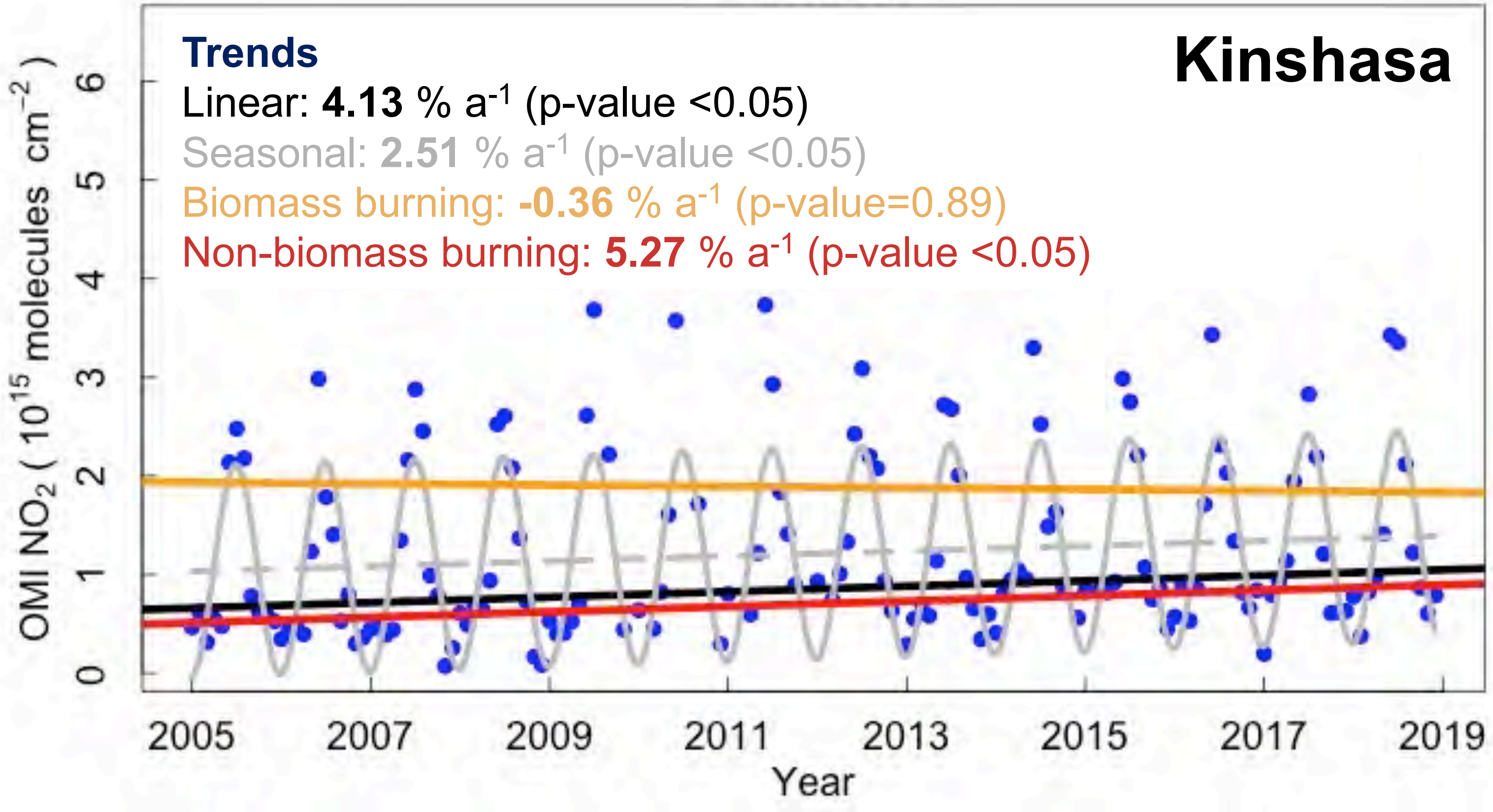


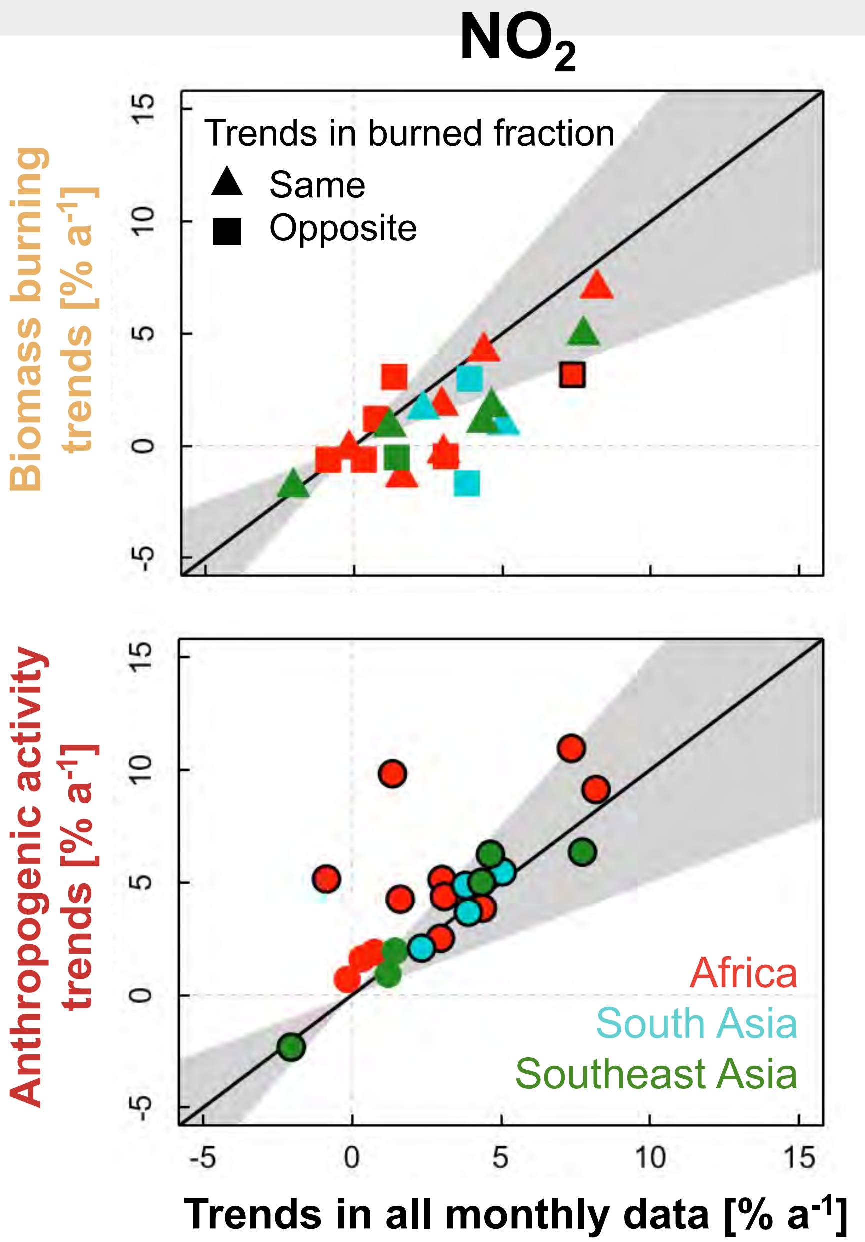
Steep increases in NO_2 with implications for ozone and $PM_{2.5}$ formation

[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

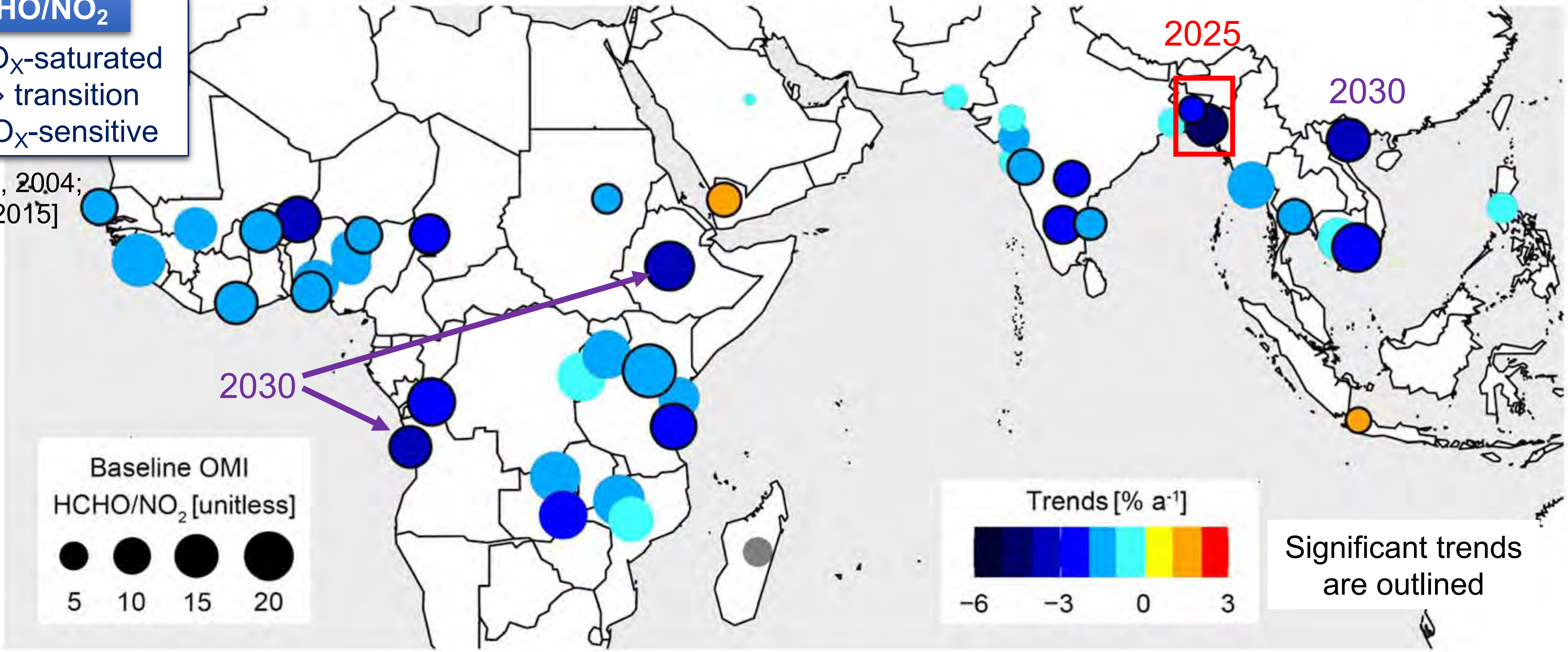
Trends in ozone production regimes in 2005-2018

Satellite observations of HCHO/NO_2 are used as proxy for ozone production regimes

HCHO/NO_2

< 1 ⇒ NO_X-saturated
~ 1-4 ⇒ transition
> 4 ⇒ NO_X-sensitive

[Martin et al., 2004; Jin et al., 2015]



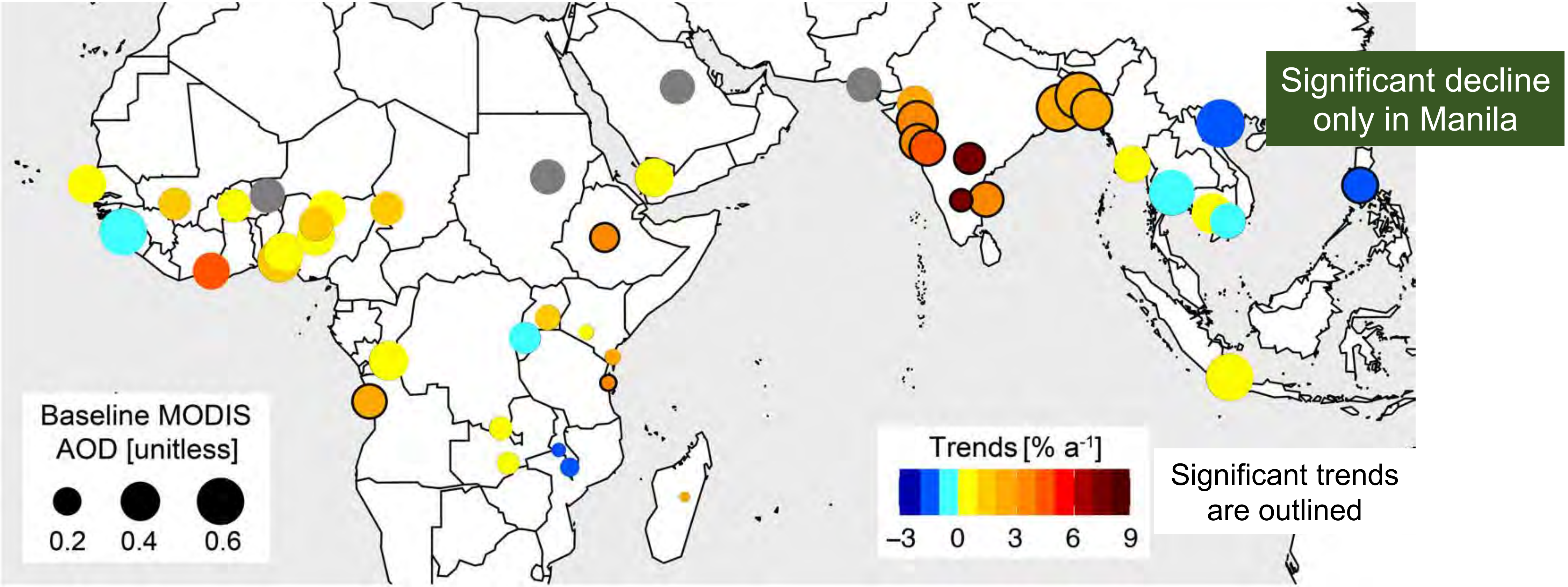
Significant trends are outlined

All cities except Riyadh are in NO_x-sensitive regime; Jakarta and Sana'a will remain in NO_x-sensitive regime; Gradual transition to NO_x-saturated regime may occur as early as 2025

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

Trends in $PM_{2.5}$ in tropical future megacities in 2005-2018

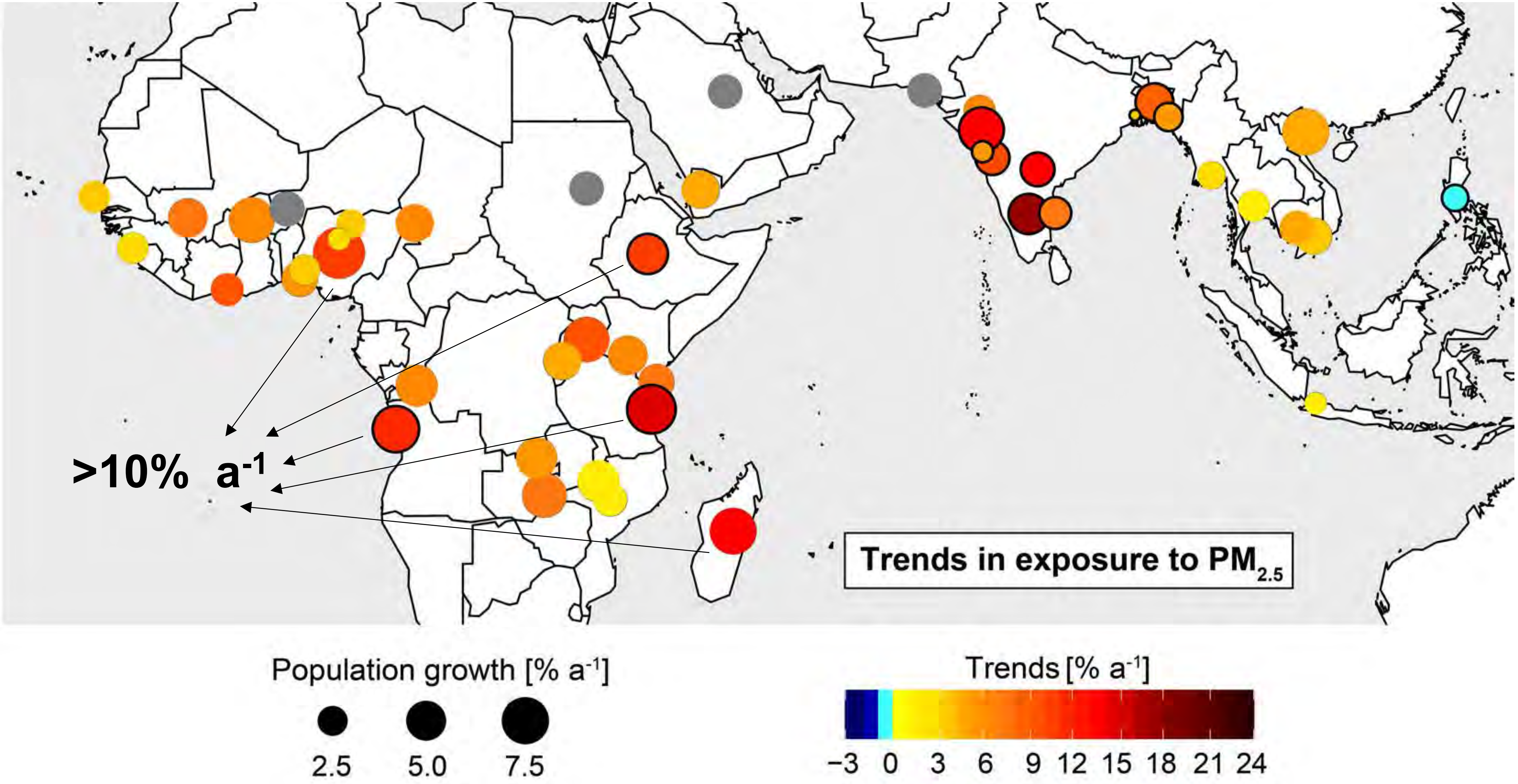
Large and significant increases of 3-8 % a^{-1} in $PM_{2.5}$ over Indian subcontinent



The large increase in South Asian cities is driven by an increase in $PM_{2.5}$ precursor emissions and not desert dust

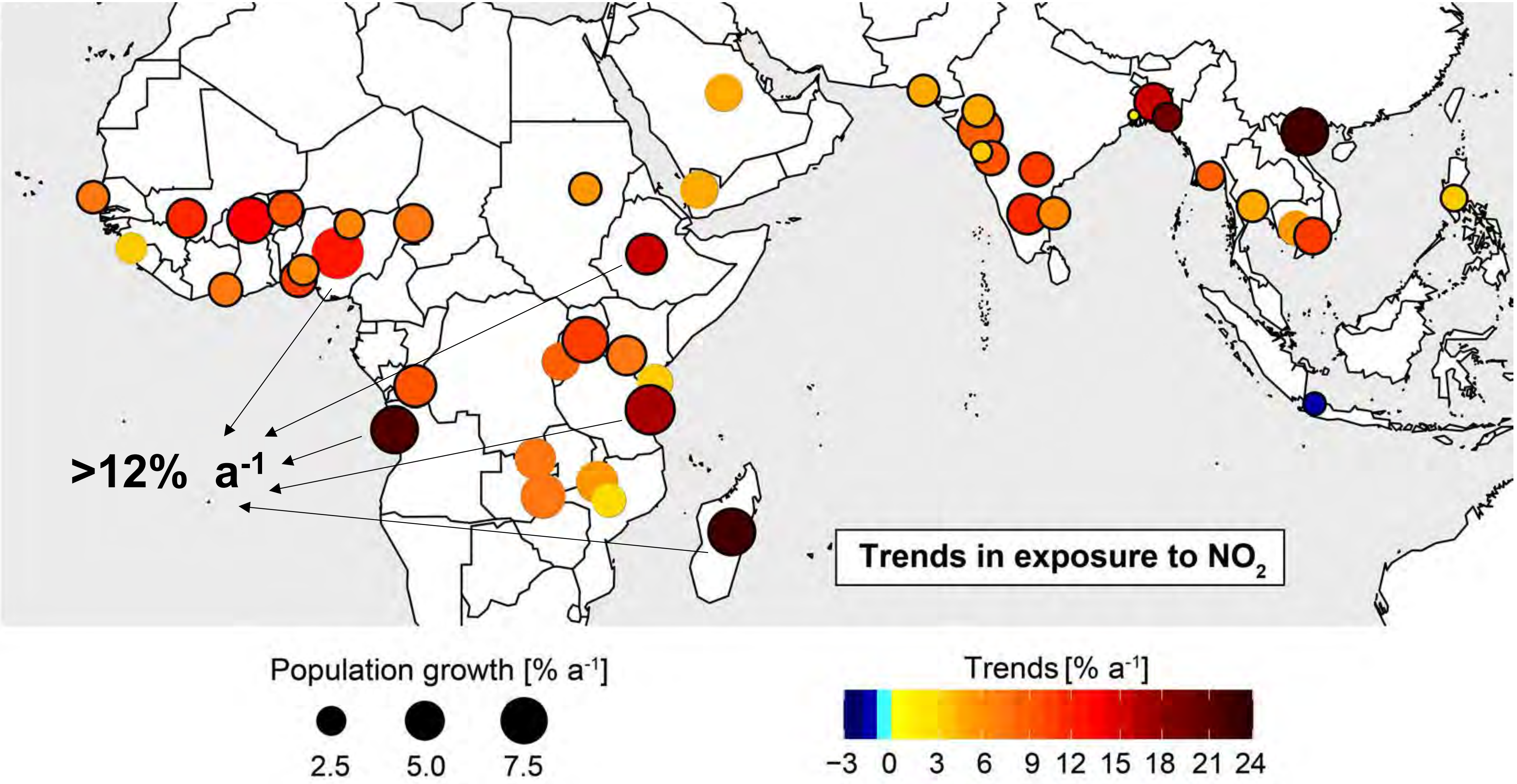
[Vohra et al., *Sci. Adv.*, 2022]

Rapid increase in urban population exposure to $PM_{2.5}$



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

Rapid increase in urban population exposure to NO_2



[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_2, not in $PM_{2.5}$.
- Ozone formation to transition from strongly NO_x-sensitive to the more challenging to regulate VOC-sensitive regime.
- Annual increases in urban population exposure, **1 to 18%** for $PM_{2.5}$ and **2 to 23%** for NO_2 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 $PM_{2.5}$

$PM_{2.5}$ precursors formed from a range of activities that combust fossil fuels

Dominant anthropogenic source of $PM_{2.5}$ and easily controllable

But challenging to isolate fossil fuel-$PM_{2.5}$ using satellite and ground-based observations and so we use a model

We use GEOS-Chem to simulate air pollutant concentrations

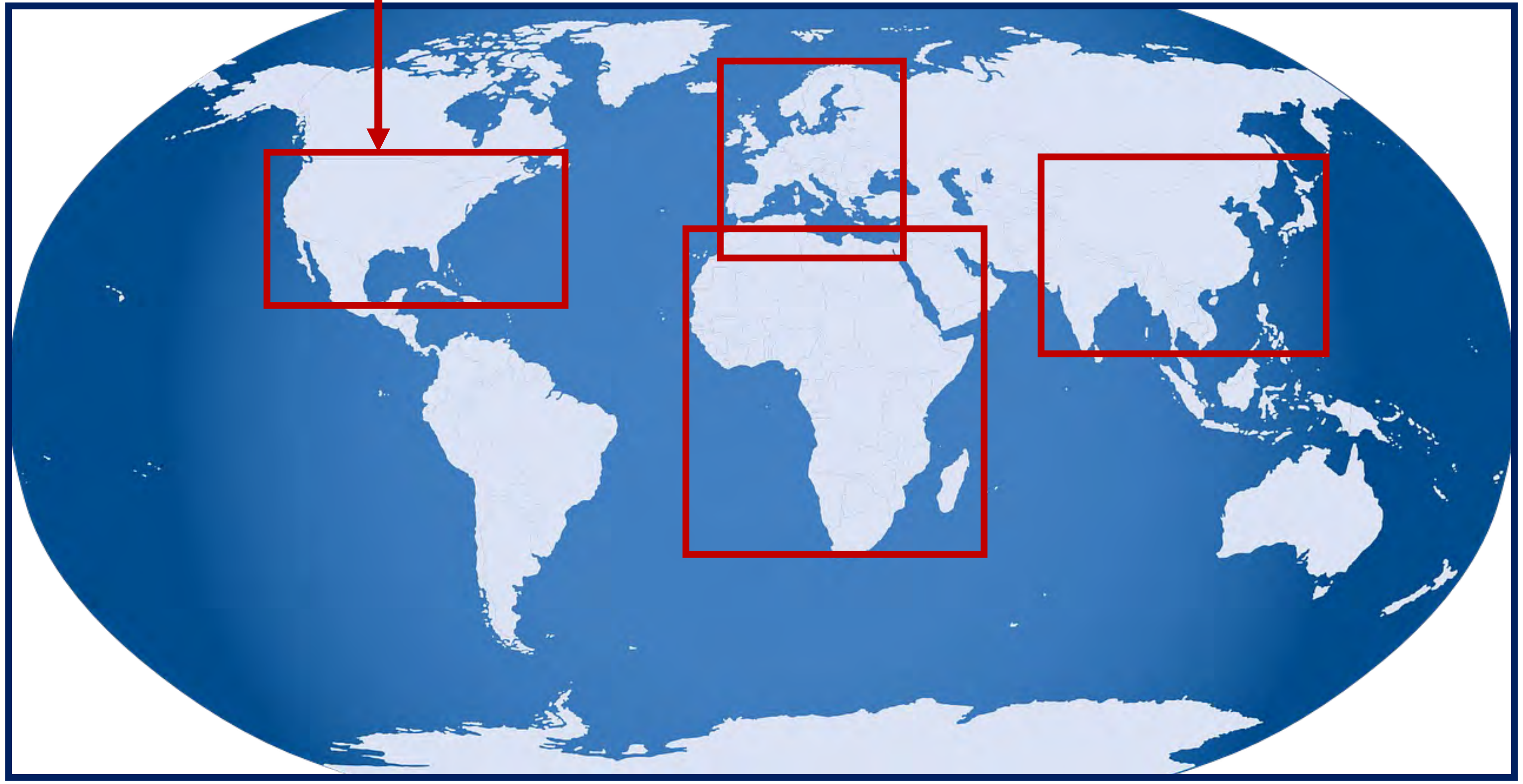
GEOS-Chem is state-of-the-art 3D global chemical transport model

Global and regional emissions

GEOS Chem

NASA Meteorology

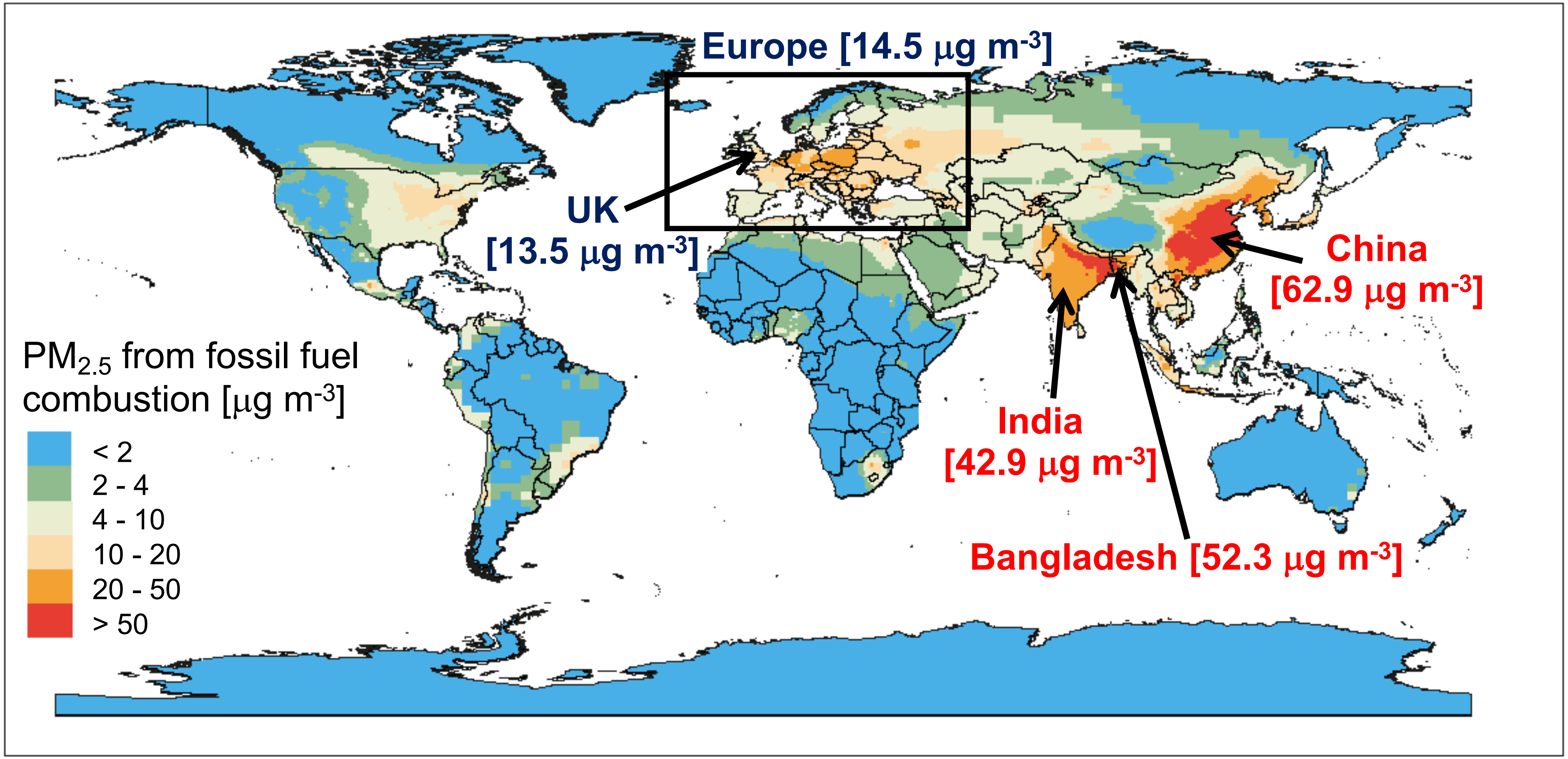
Regional simulations at 0.5°×0.67°



Global simulation at 2°×2.5° spatial resolution

Model estimate of fossil fuel $PM_{2.5}$ in 2012

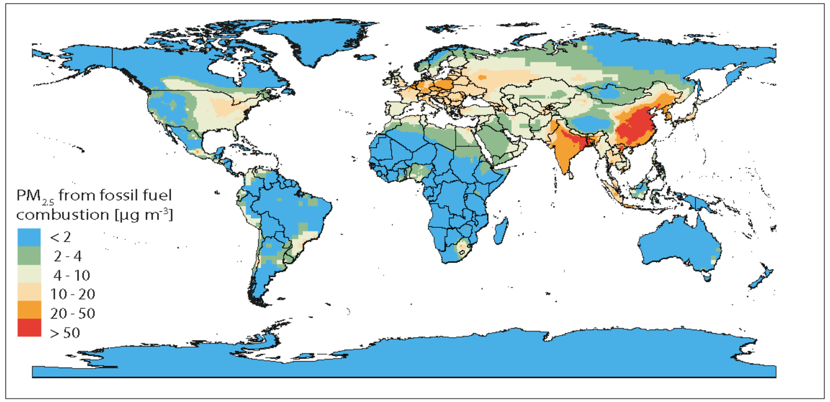
Difference between model simulations with and without fossil fuel $PM_{2.5}$



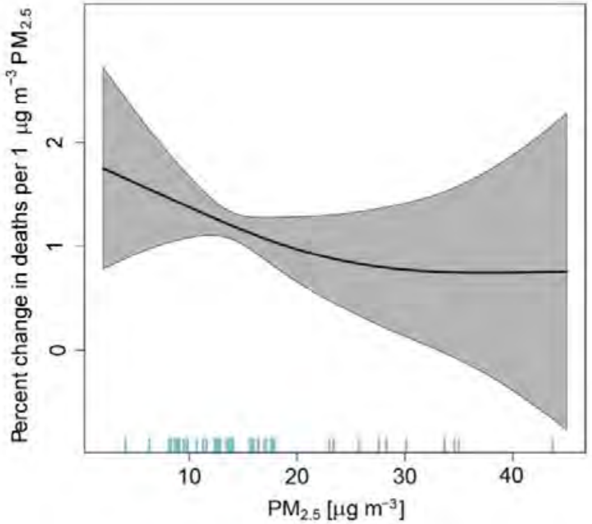
Hotspots are in China, Bangladesh, India, and central Europe

Model simulations by Harvard ACMG

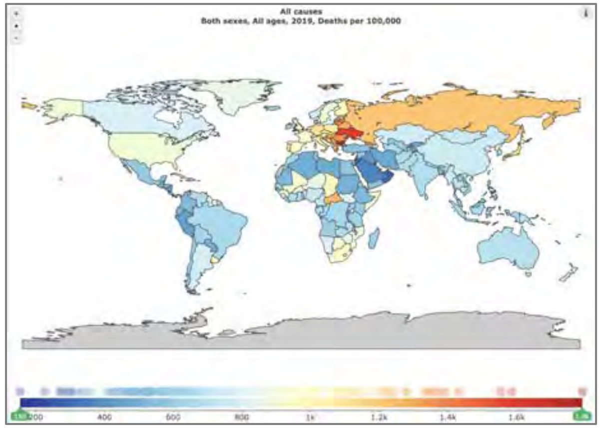
Methodology for health impact calculation



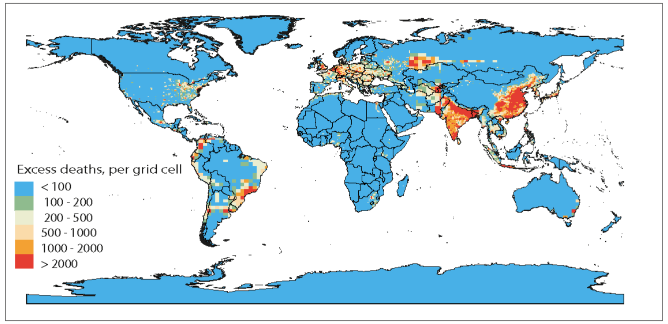
Fossil-fuel PM$_{2.5}$ from GEOS-Chem



Meta-analysis concentration-response function from cohort studies



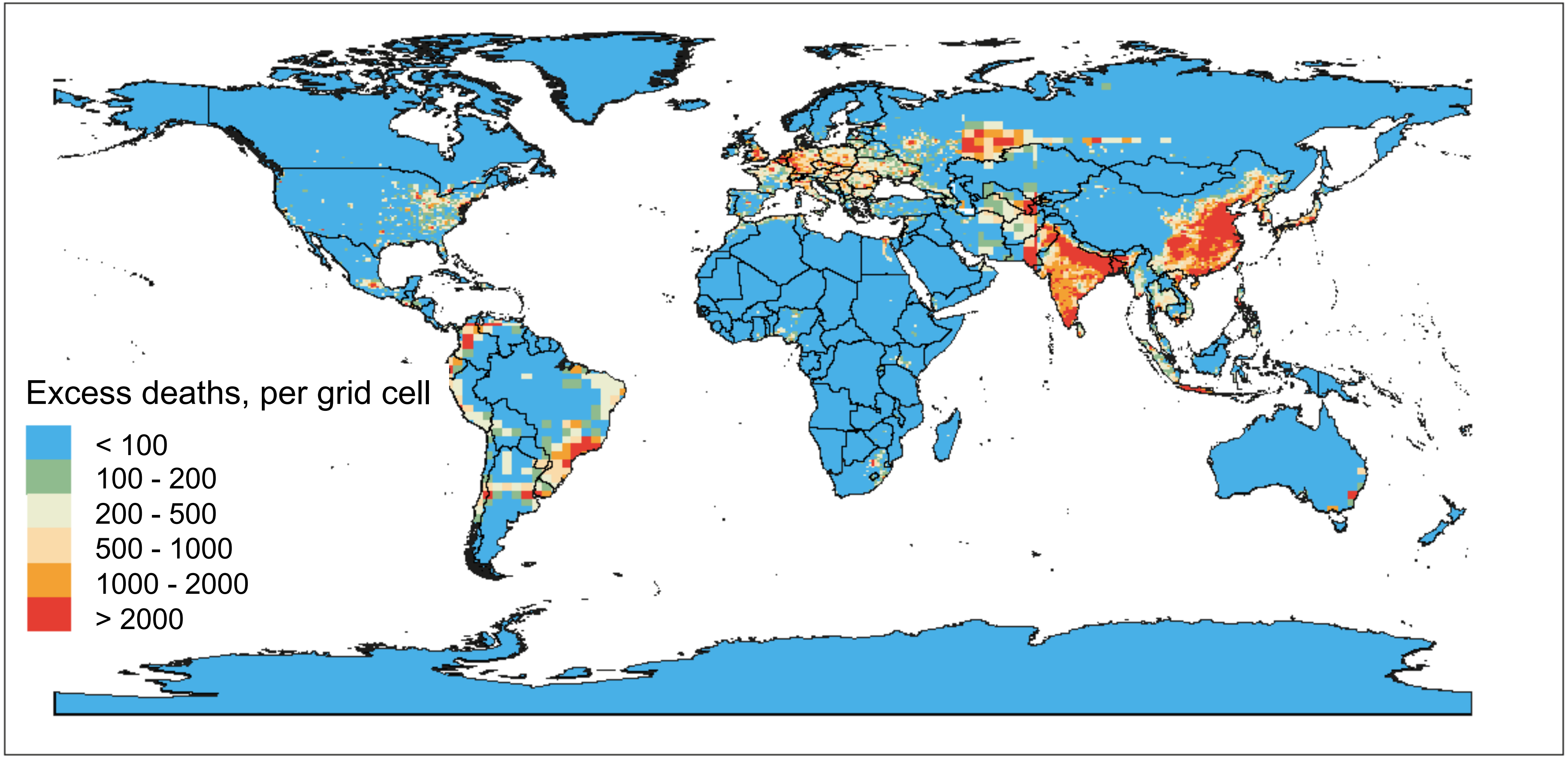
Baseline mortality from Global Burden of Disease



Global premature mortality estimates

We use the derived fossil-fuel PM$_{2.5}$ with baseline mortality in the meta-analysis concentration-response function to estimate global premature mortality

Estimated global premature mortality from fossil fuel combustion



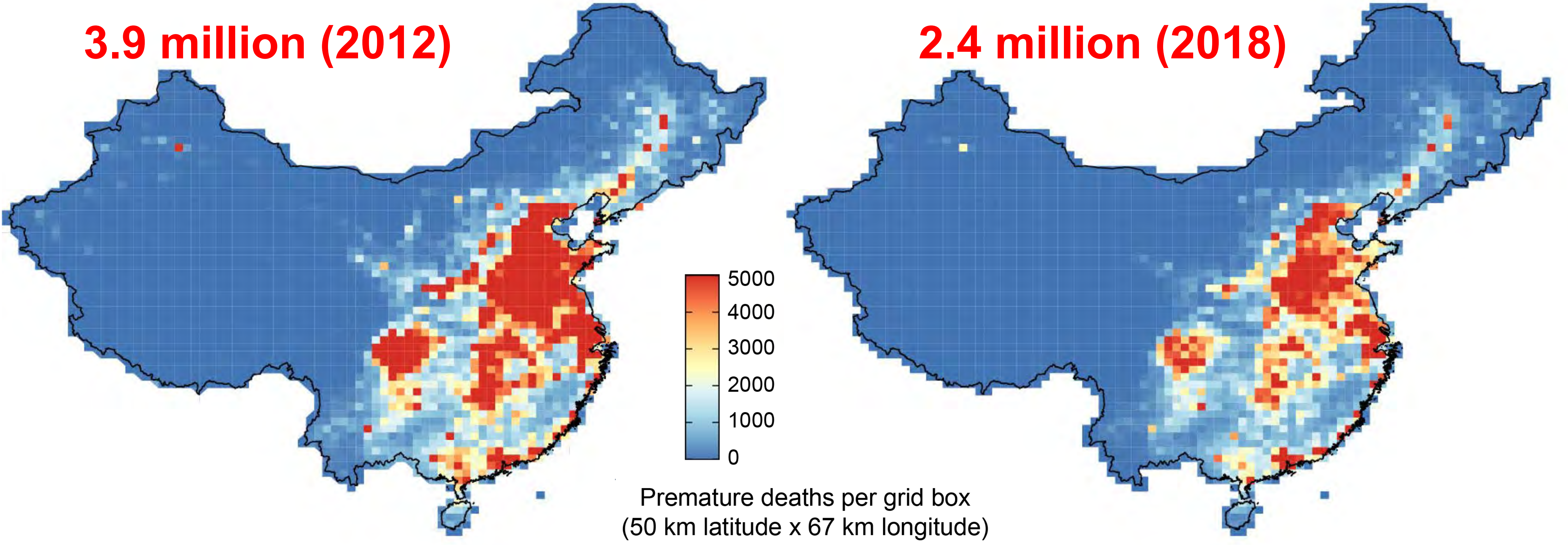
10.2 million premature deaths attributed to fossil-fuel $PM_{2.5}$ in 2012

[-47 million, 17 million]

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

Policies can help mitigate these premature deaths

China



Dramatic reduction in $PM_{2.5}$ 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 $PM_{2.5}$)

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 $PM_{2.5}$ pollution in 2012. 62% in China and India.

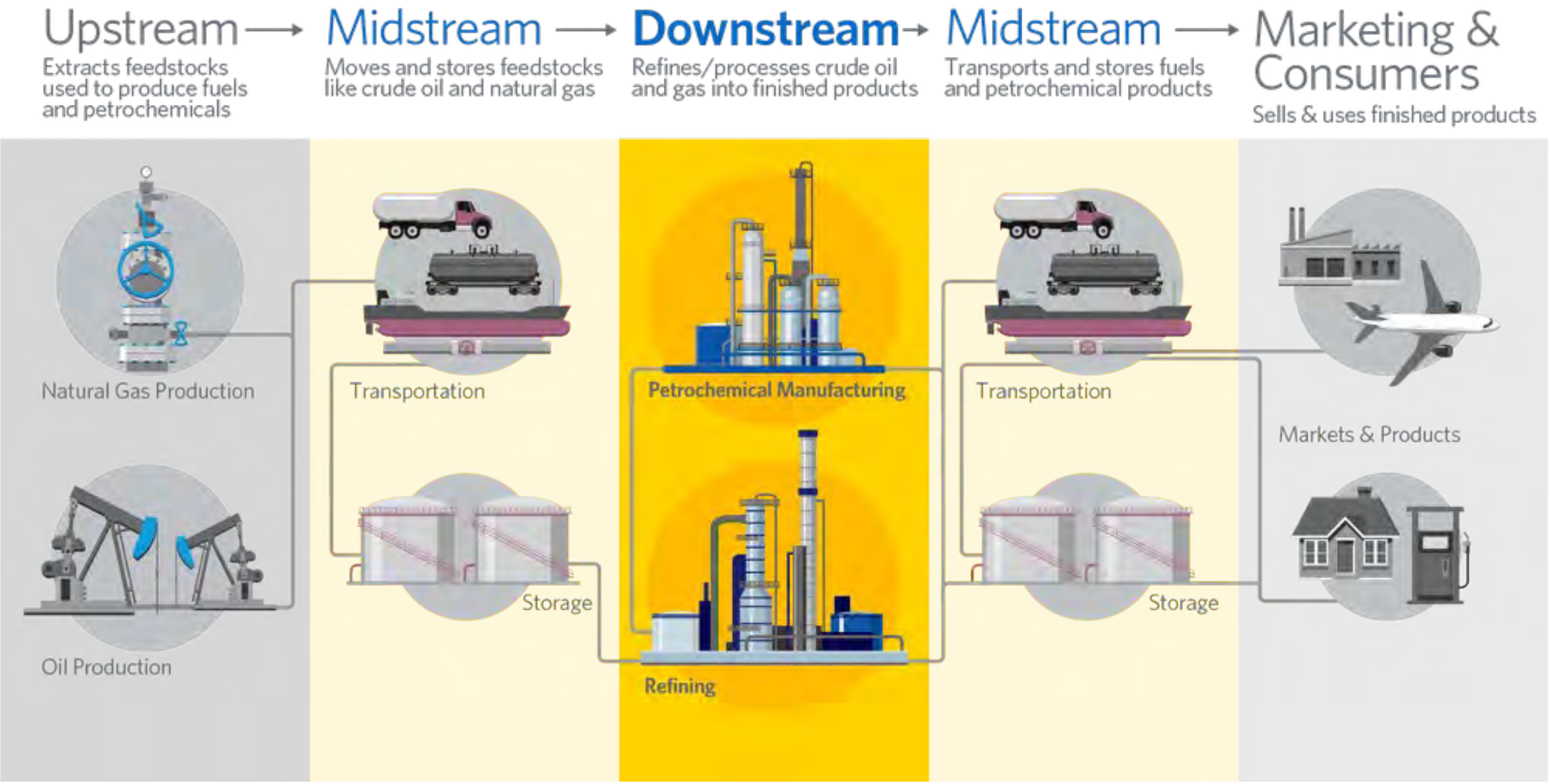
- Substantial reduction in fossil fuel use in China led to 38% decline in premature deaths from 3.9 million in 2012 to 2.4 million in 2018.

- 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.

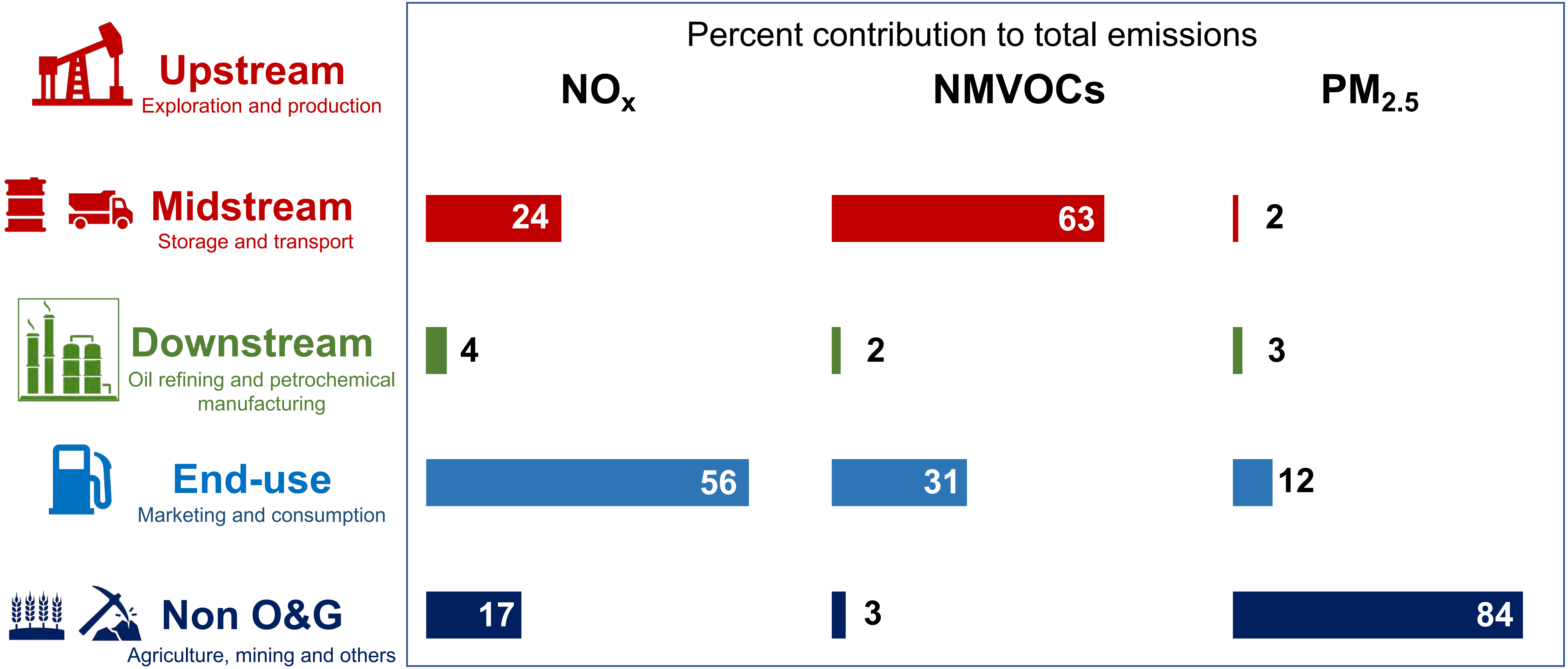
The major segments of the oil and gas (O&G) lifecycle



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

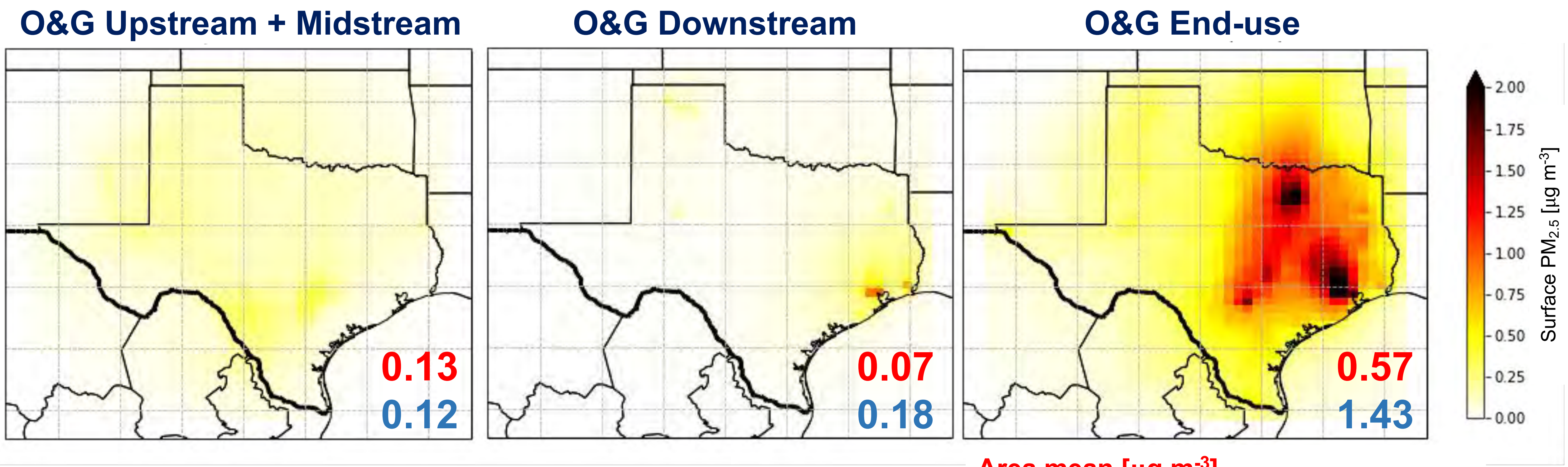


Texas O&G lifecycle contributes to 84% of NO_x, 97% of NMVOCs and 16% of primary $PM_{2.5}$ emissions

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

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

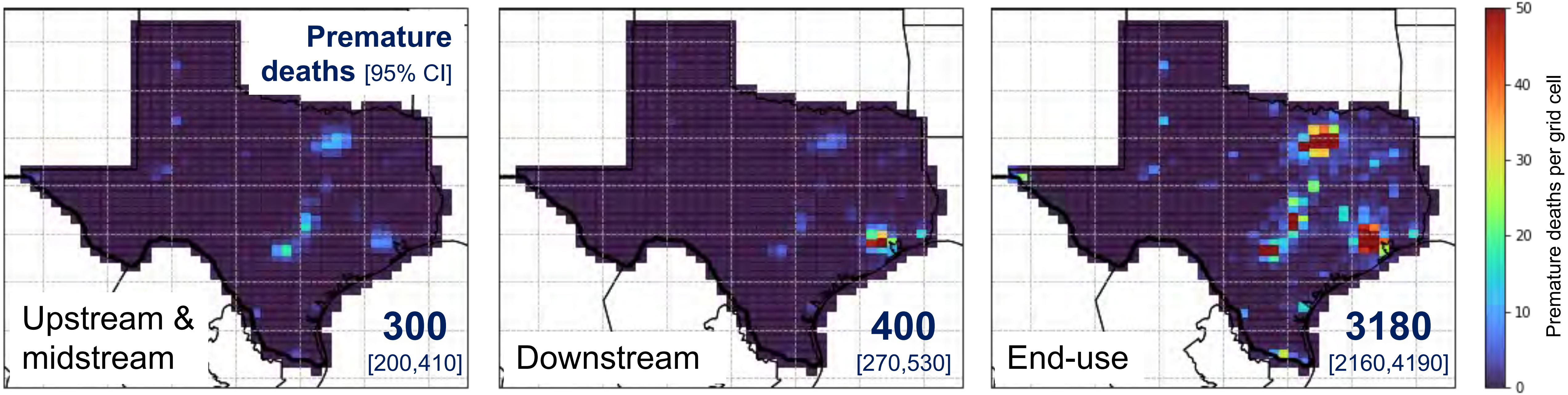


Area mean [μg m^{-3}]
Population-weighted mean [μg m^{-3}]

Oil and gas activities in Texas contribute to 0.77 μg m^{-3} (8.2%) of PM$_{2.5}$, mostly (0.57 μg m^{-3}) from end use

Premature mortality from the oil and gas lifecycle in Texas

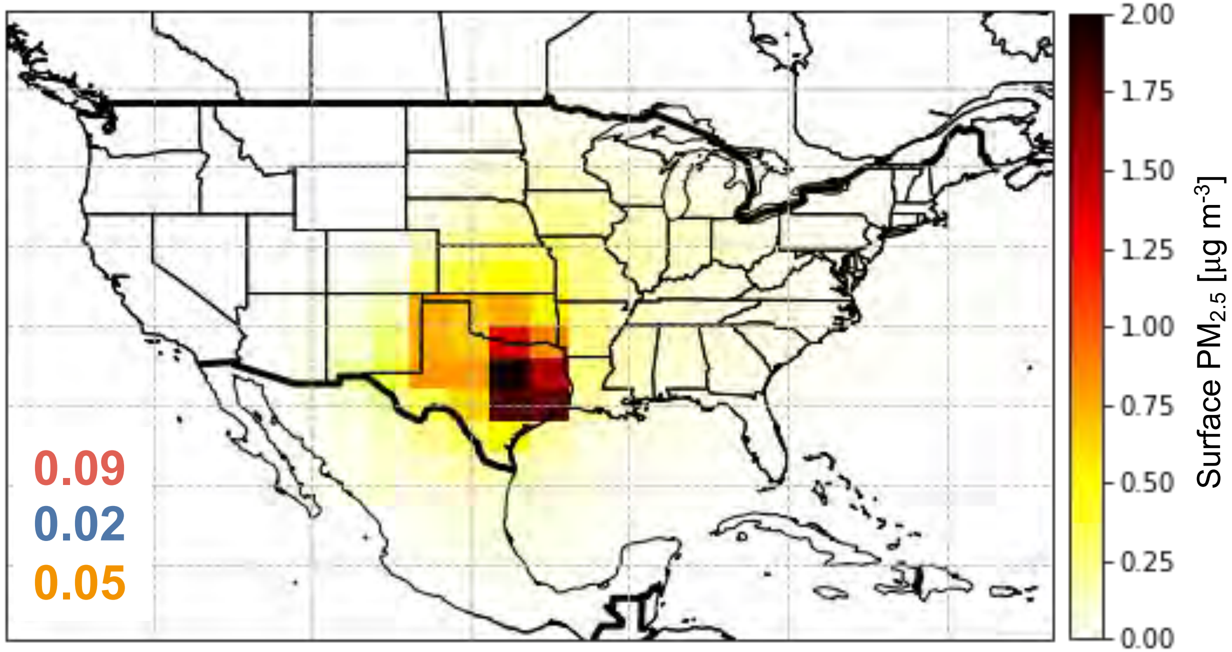
We estimate adult premature deaths (all-cause mortality) from long-term $PM_{2.5}$ exposure linked to each major segment of the O&G lifecycle in Texas

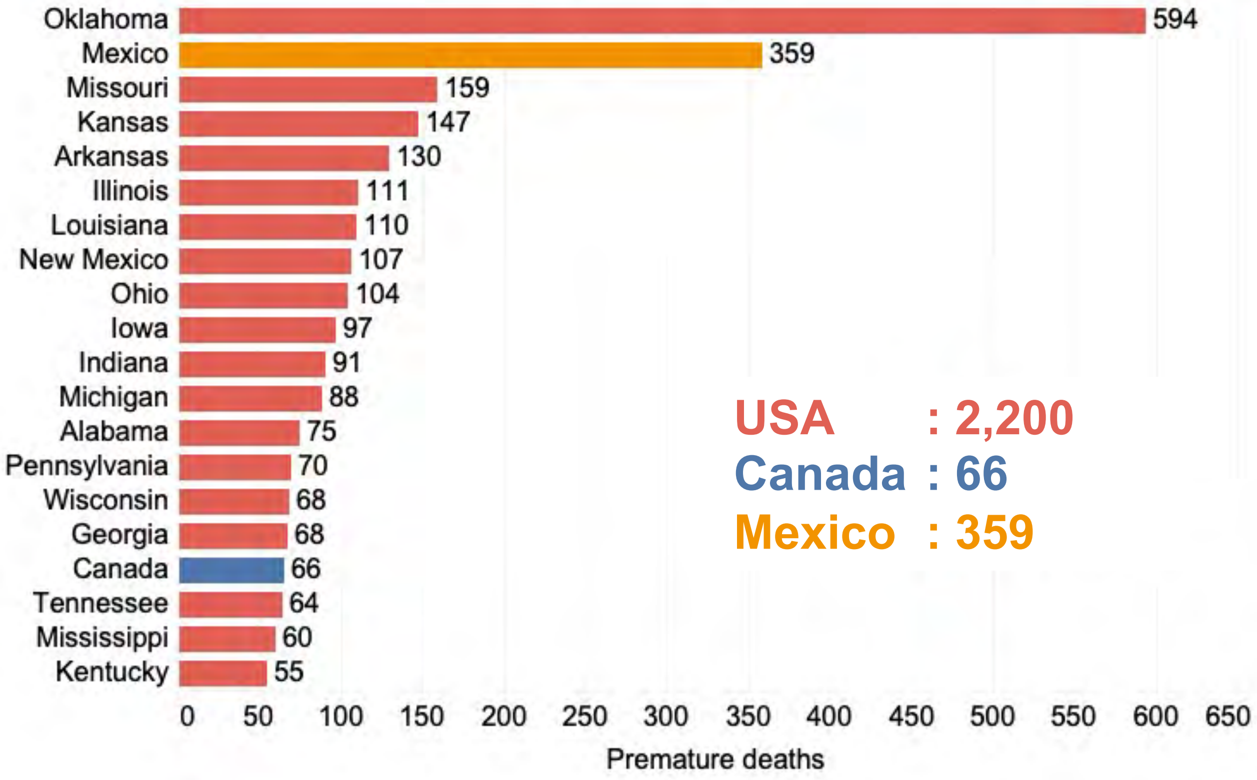


3,840 premature deaths from the oil and gas emissions (**82%** from end-use, **10%** from downstream and **8%** from upstream activities)

Impact of Texas oil and gas emissions on surrounding areas

First look at global simulations run at coarse grid resolution (2.0°×2.5°) to assess the impact on neighbouring states and countries





Next steps include running the model at finer resolution (0.25°×0.3125°) to assess the impact of US-wide oil and gas activities

Conclusion

Interactive dashboards

Air quality trends

Fossil fuel mortality

- 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 $PM_{2.5}$ and NO_2 but there are large VOCs emissions (>60%) from oil and gas production.

Any Questions? Email k.vohra@ucl.ac.uk @kohra_thefog