Long-term trends in city-wide air quality: A space-based perspective

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The Problem

Air Pollution

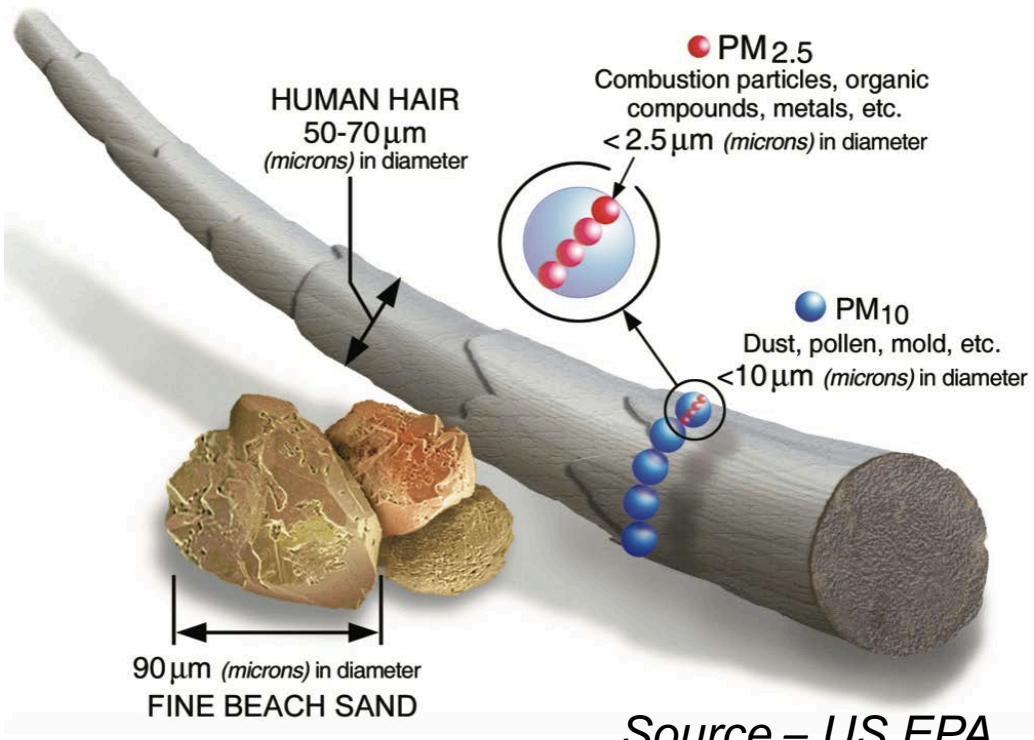
- Estimated excess mortality in Europe — *European Heart Journal, 2019*
- 4.2 millions deaths worldwide in 2015 — *Cohen et al., 2017*
- Unsafe air quality at 2,000 UK sites — *The Guardian, 2019*
- Causes miscarriages — *Zhang et al., 2019*
- Damages 'every organ in the body' — *Schraufnagel et al, 2019*
- Takes decade off memory — *The Times, 2019*

Gurgaon, India (3rd Nov'16, 1.30 pm)

What's common??? Particulate Matter (PM) & Nitrogen dioxide (NO_2)

The Problem

Particulate Matter (PM)



Source – US EPA

Nitrogen dioxide (NO_2)

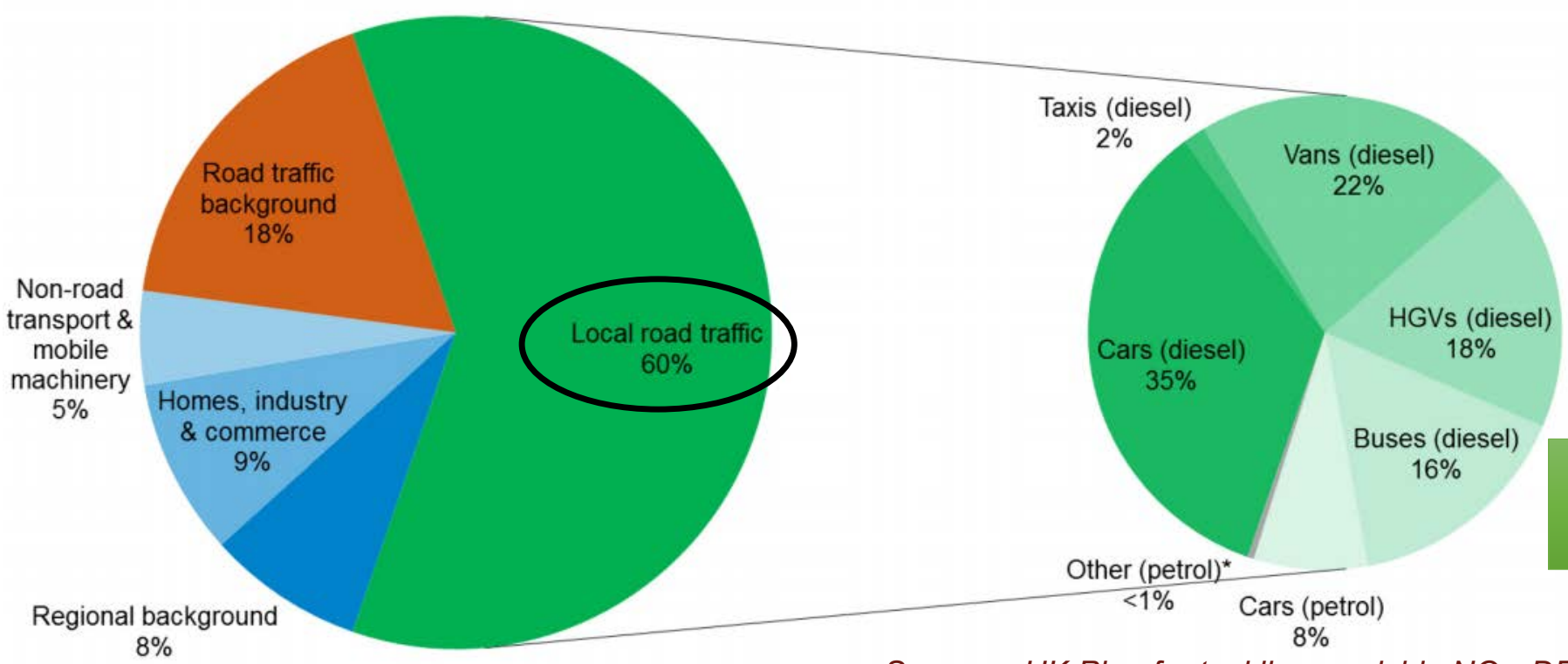
Source – newatlas.com

$PM_{2.5}$ ~79%	Emissions reductions* (1970-2017)	NO_X ~72%
25 µg m^{-3} ✓	Annual mean compliance limits**	40 µg m^{-3} ✗

* National Atmospheric Emissions Inventory ** UK National Air Quality Objectives

The Problem

Sources of UK roadside NO_2 for 2015

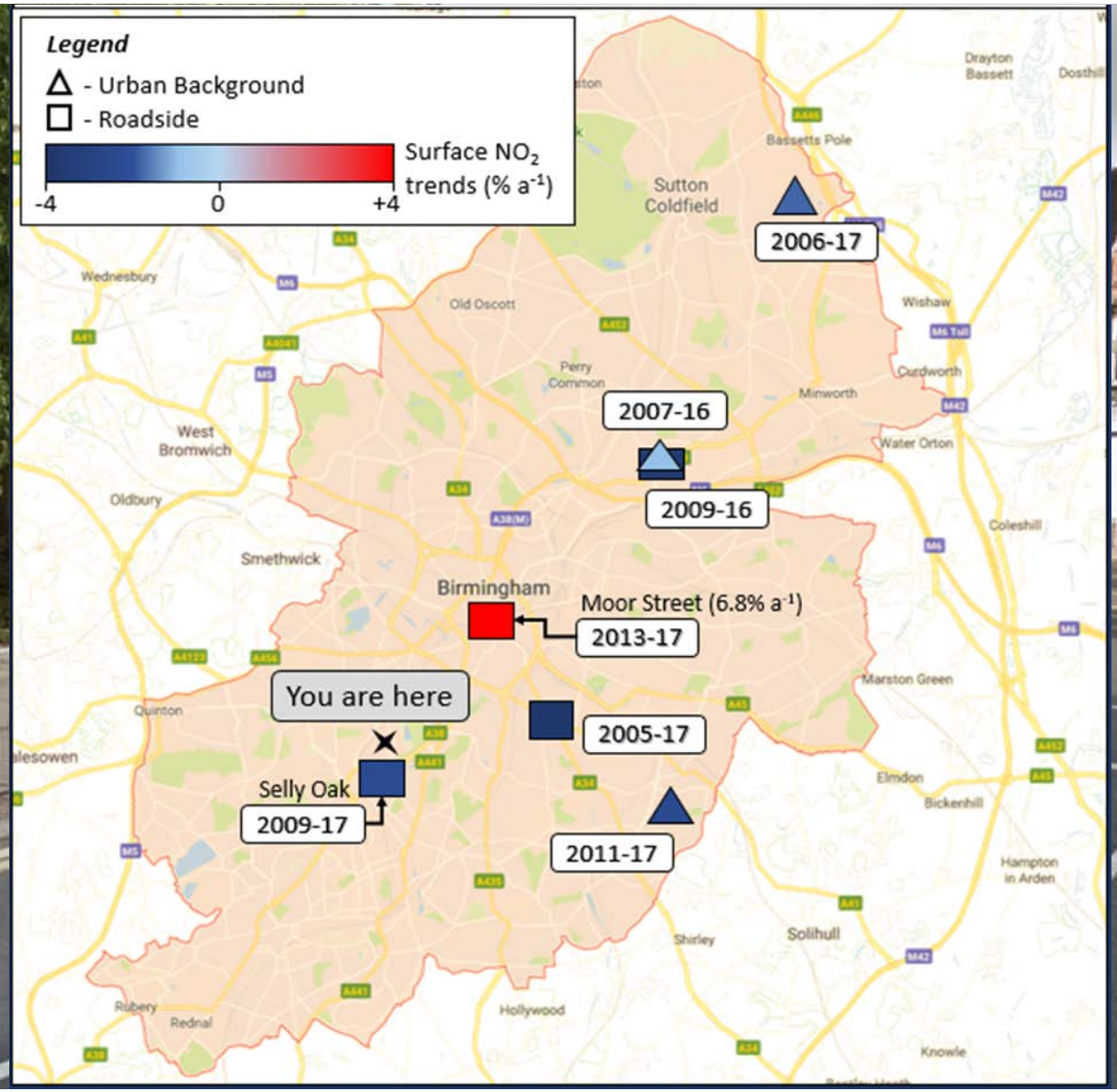


Diesel ~ 91%
Petrol ~ 9 %

Source – UK Plan for tackling roadside NO_2, DEFRA 2017

How do we know if NO_2 is going down?

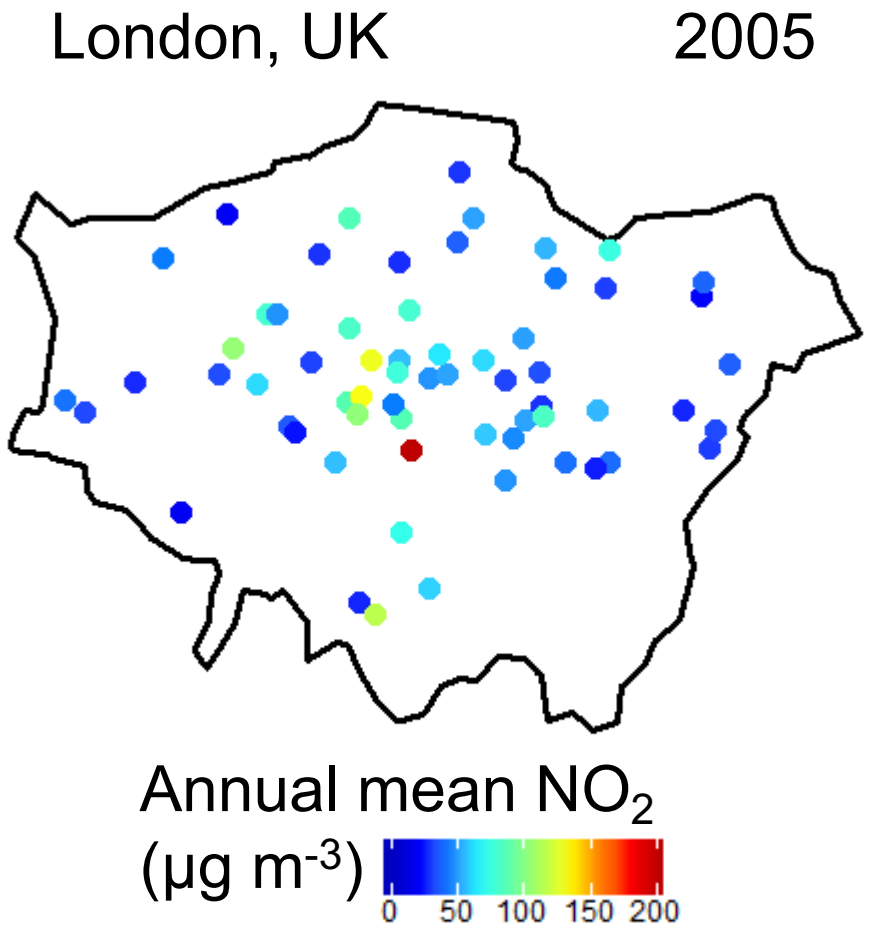
The Current Approach



The Current Approach

Surface monitoring networks have their limitations

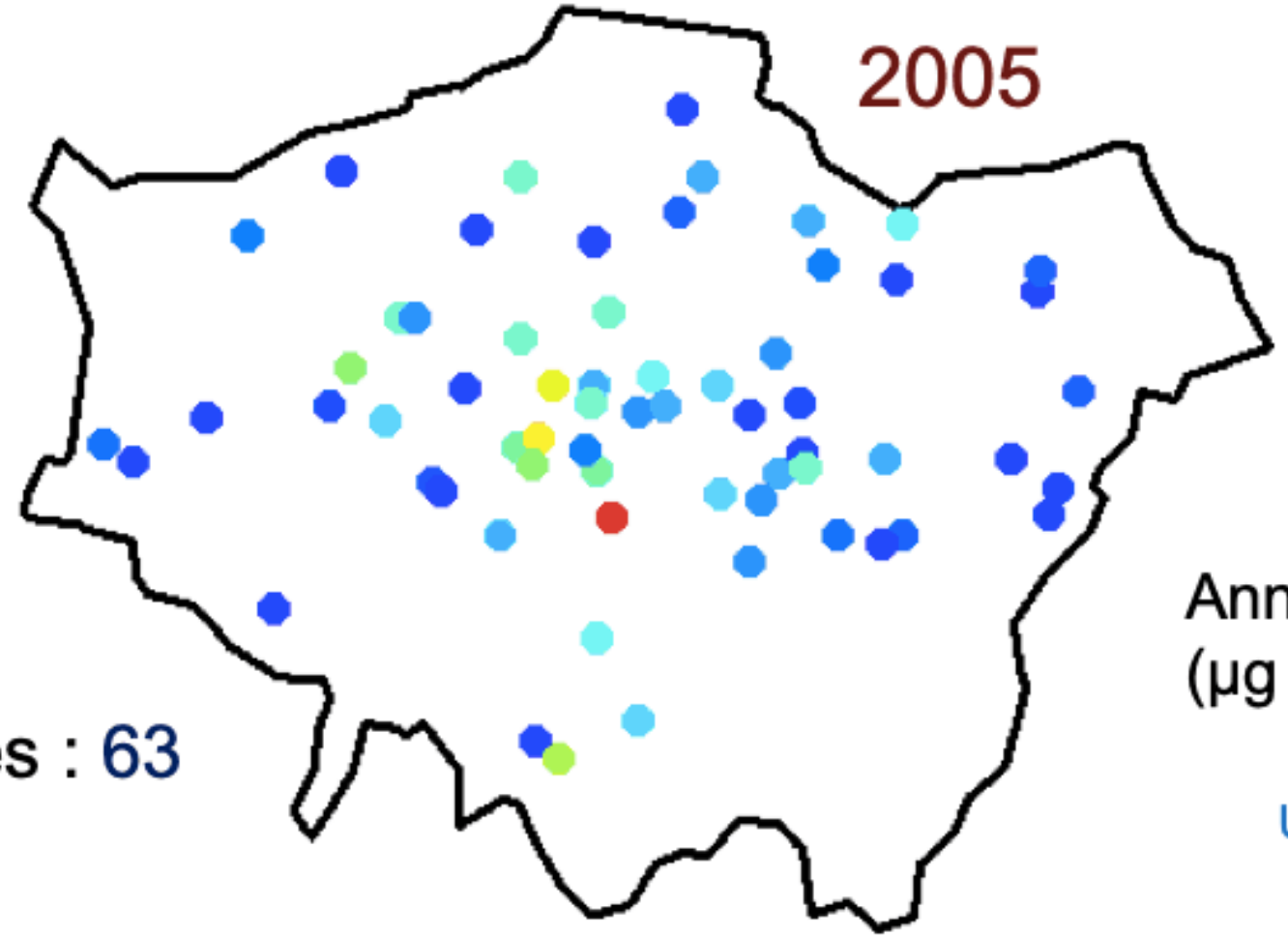
- ❑ Expensive to set up and maintain
- ❑ Limited spatial and temporal coverage
- ❑ Limited pollutants monitored
- ❑ Issues with data quality



Data from *London Air Quality Network (LAQN)*

The Current Approach

- Inconsistent (sites come and go over time)

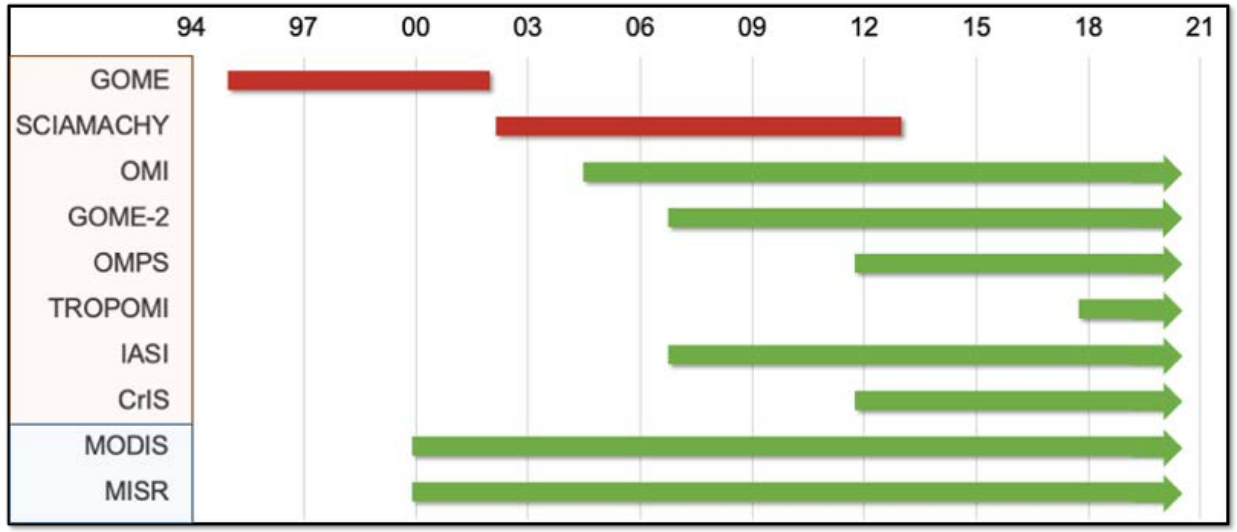


Data from *London Air Quality Network (LAQN)*

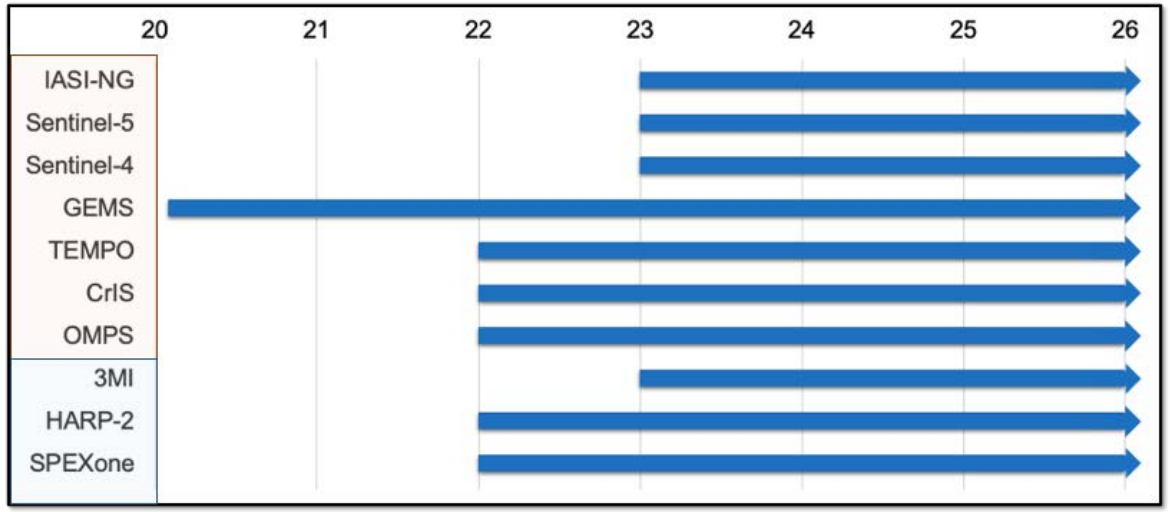
The Solution

Satellites are the only solution to address this global challenge

Sensors in space have been providing us with petabytes of data for more than 2 decades



Future missions will be cheaper and will have finer spatial resolution



Gases

Particles

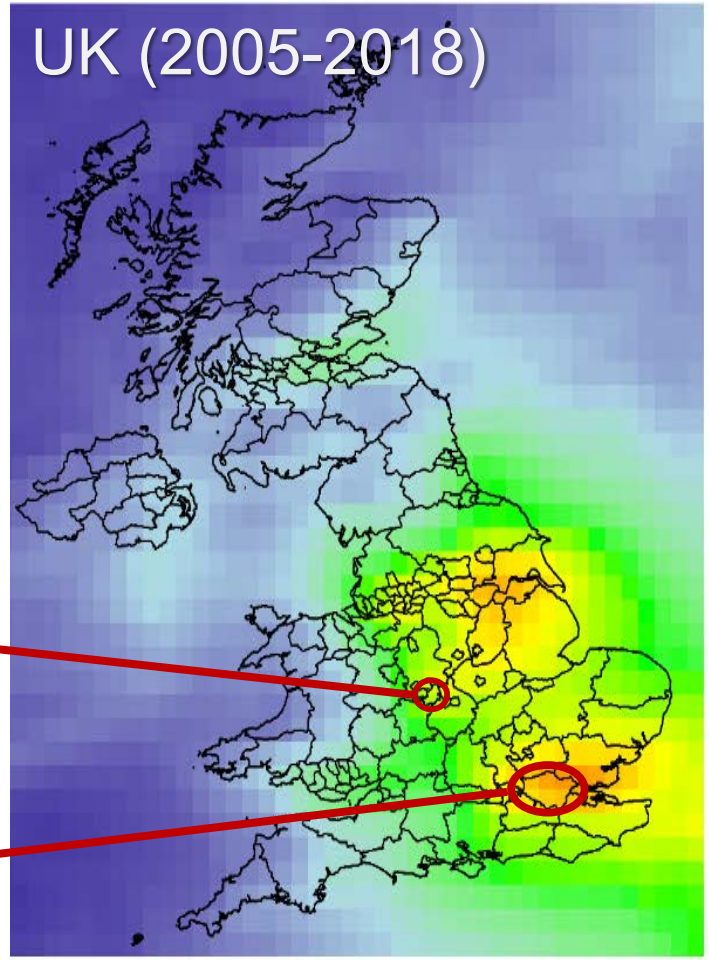
Completed

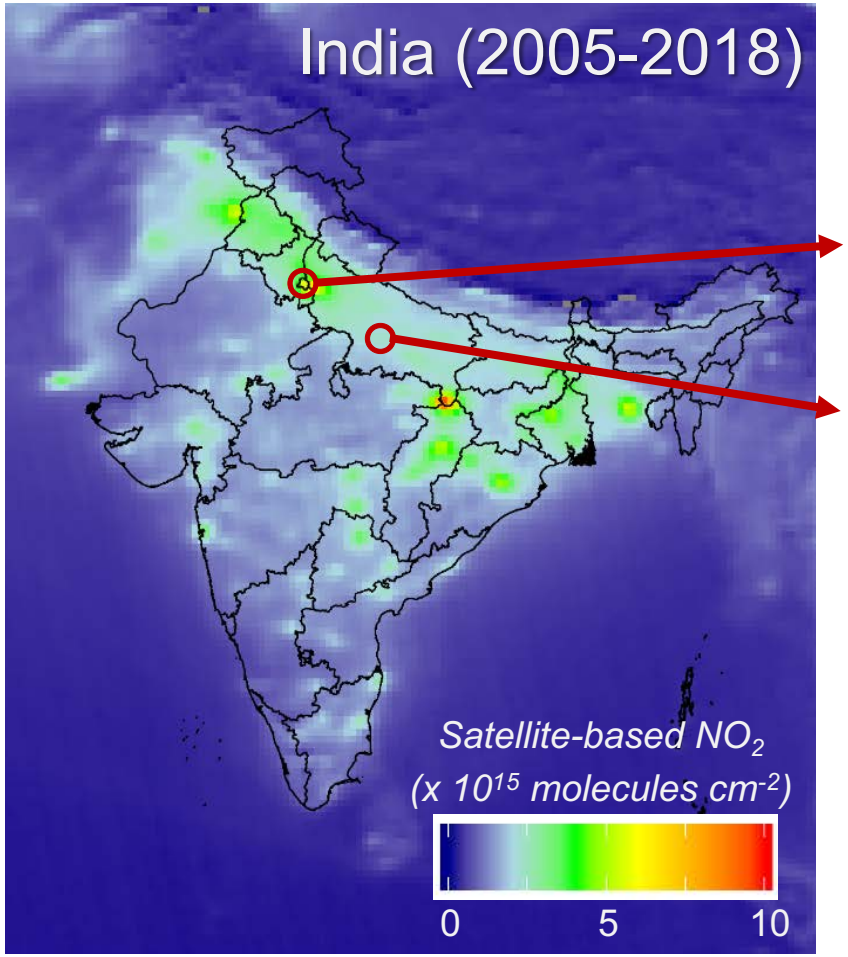
On-going

Future

Space-based instruments provide extensive data coverage

We develop our approach focusing on 4 dynamic cities





Birmingham

London

Delhi

Kanpur

* Maps on different scales

Satellites help monitor these air pollutants

NMVOCs (non-methane volatile organic compounds)

Intermediate product

OMI

HCHO (formaldehyde)

O_3 (ozone)

Food security

Photo credit: Dr Gerald Brust

OMI

SO_X (sulphur oxides)

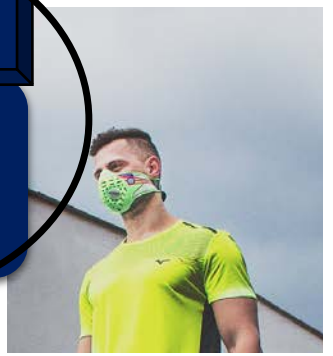
NO_X (nitrogen oxides)

OMI

MODIS

$PM_{2.5}$ (particulate matter)

Human health



NH_3 (ammonia)

IASI

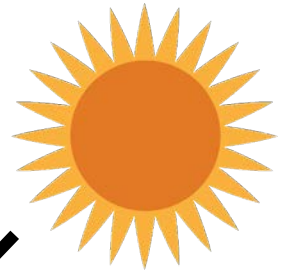
Primary particles

Pollutants

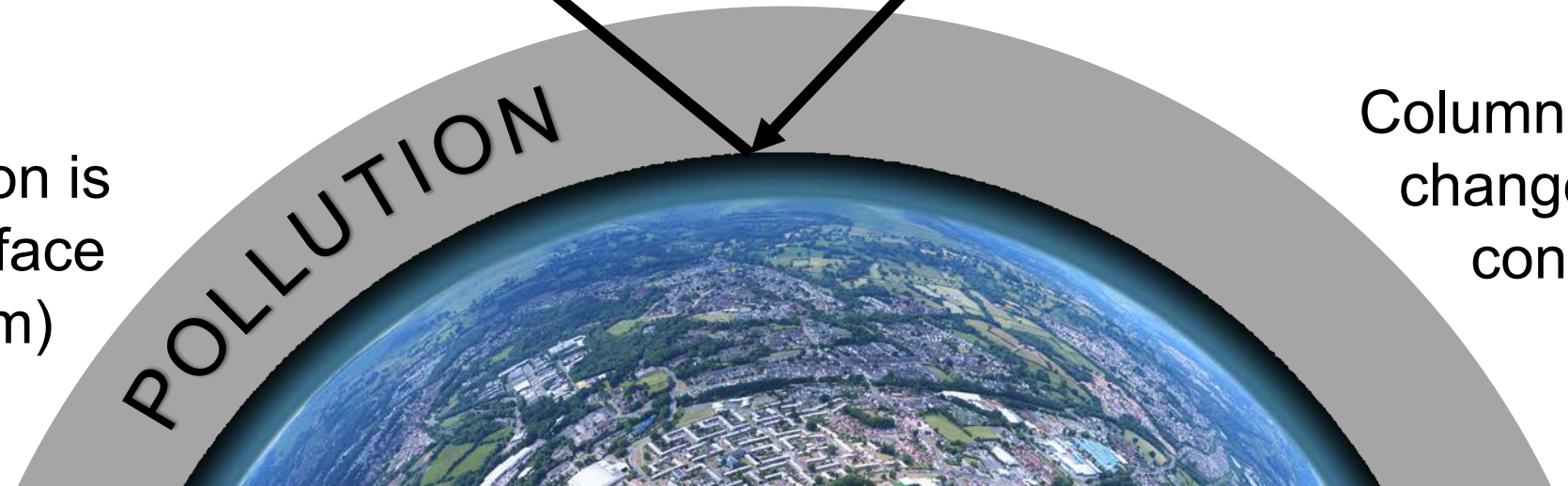
Instruments

Satellite columns reflect changes in surface pollution

Satellite measures whole atmospheric column (>10 km)

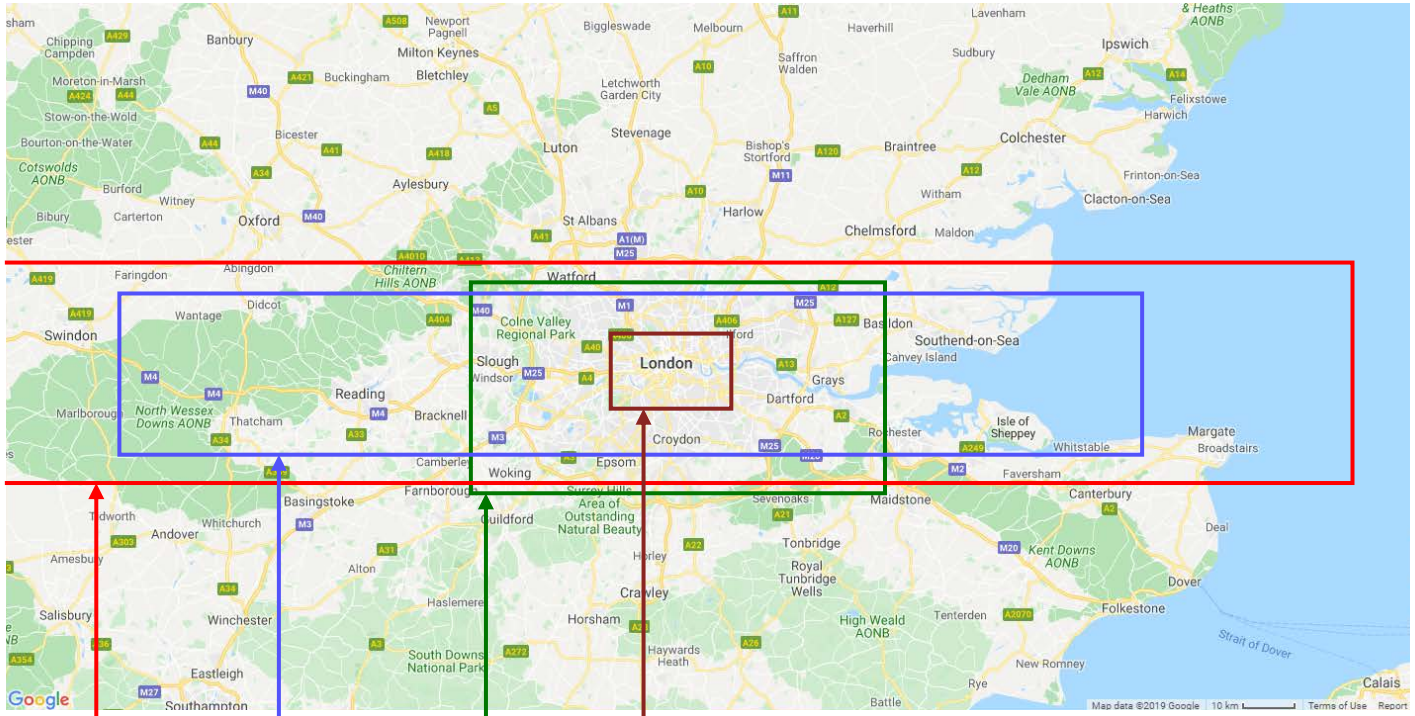


Air pollution is at the surface (~1-2 km)



Column is sensitive to changes in surface concentration

Measurements are at coarse resolution so we sample the whole city



OMI (24 km x 13 km, 2004-present)

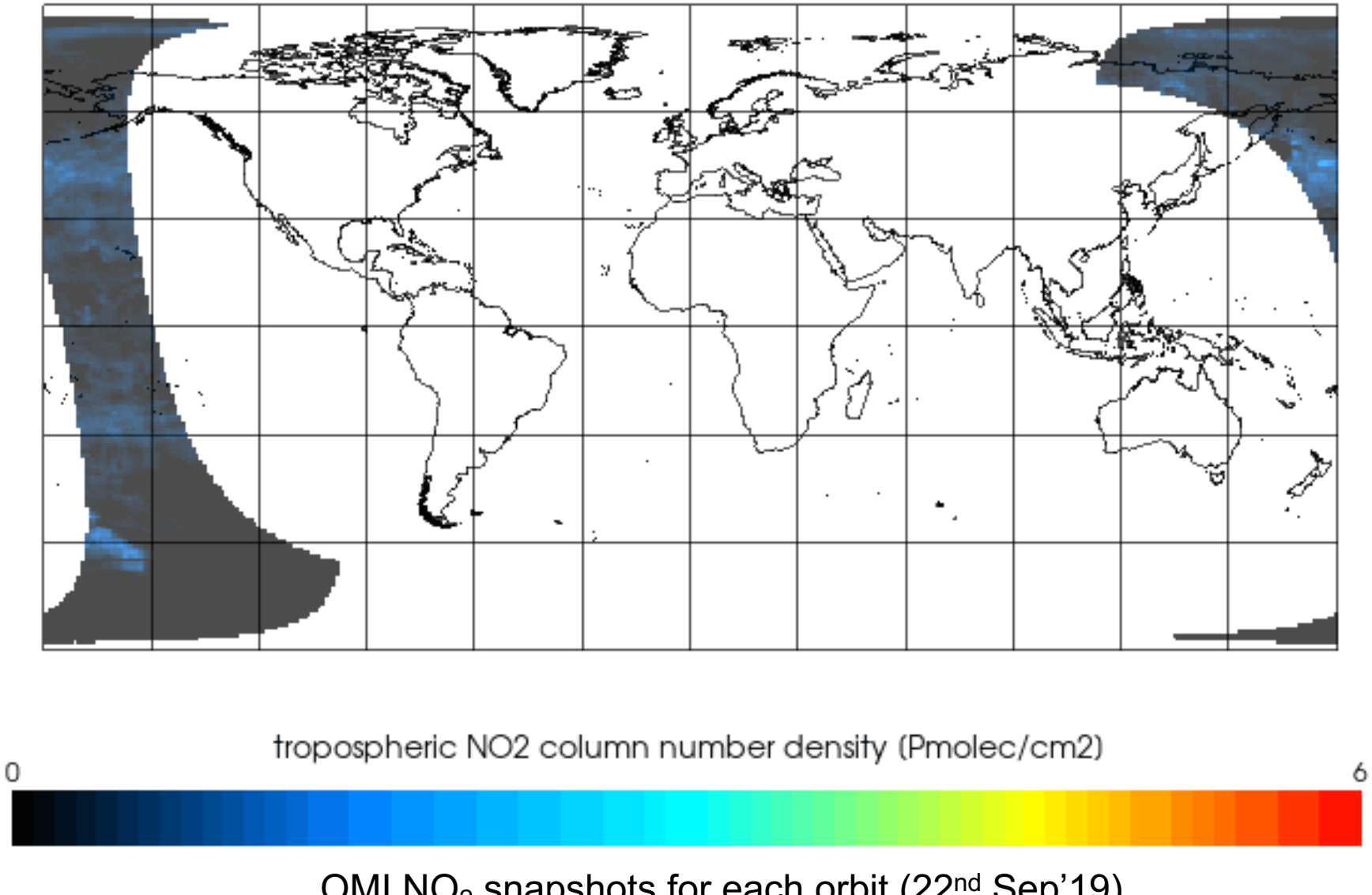
GOME-2 (80 km x 40 km, 2007-present)

SCIAMACHY (200 km x 30 km, 2002-2012)

GOME (320 km x 40 km, 1995-2001)

OMI achieves global coverage in a day

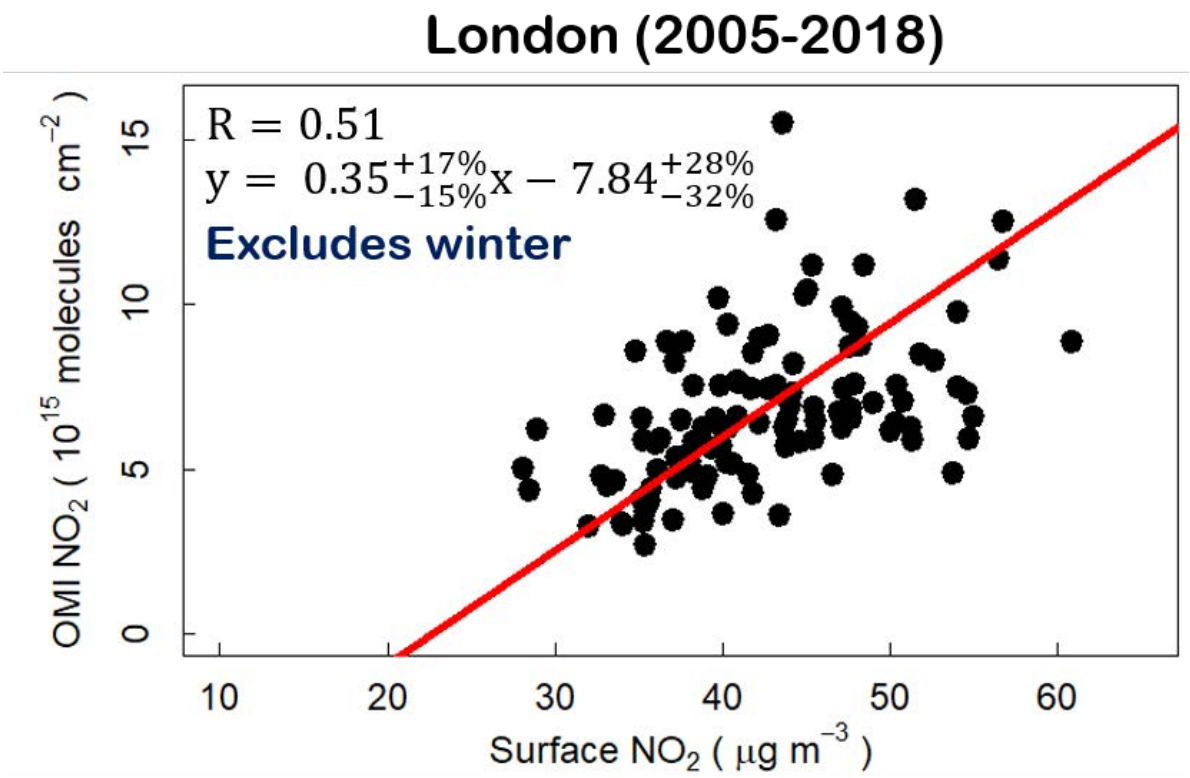
OMI overpass time : 13h30 local time



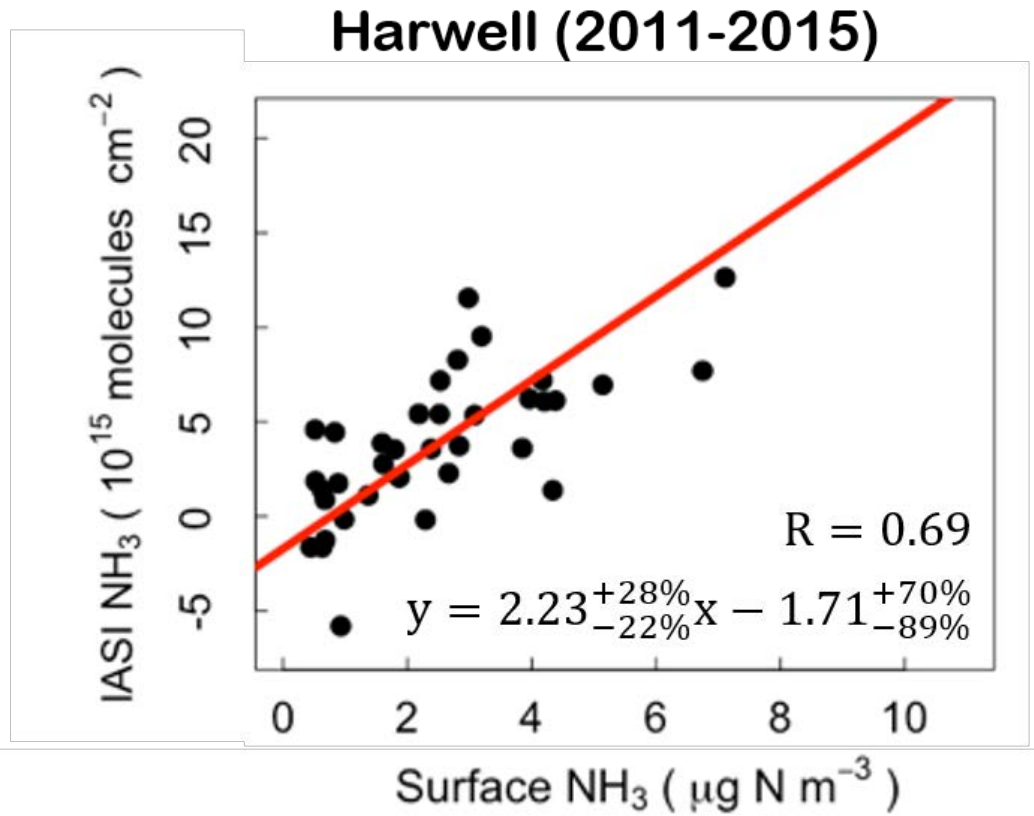
OMI NO_2 snapshots for each orbit (22nd Sep'19)

We conduct careful assessment with surface monitors (where available)

Satellite versus surface NO_2 in London



Satellite versus surface NH_3 in Harwell



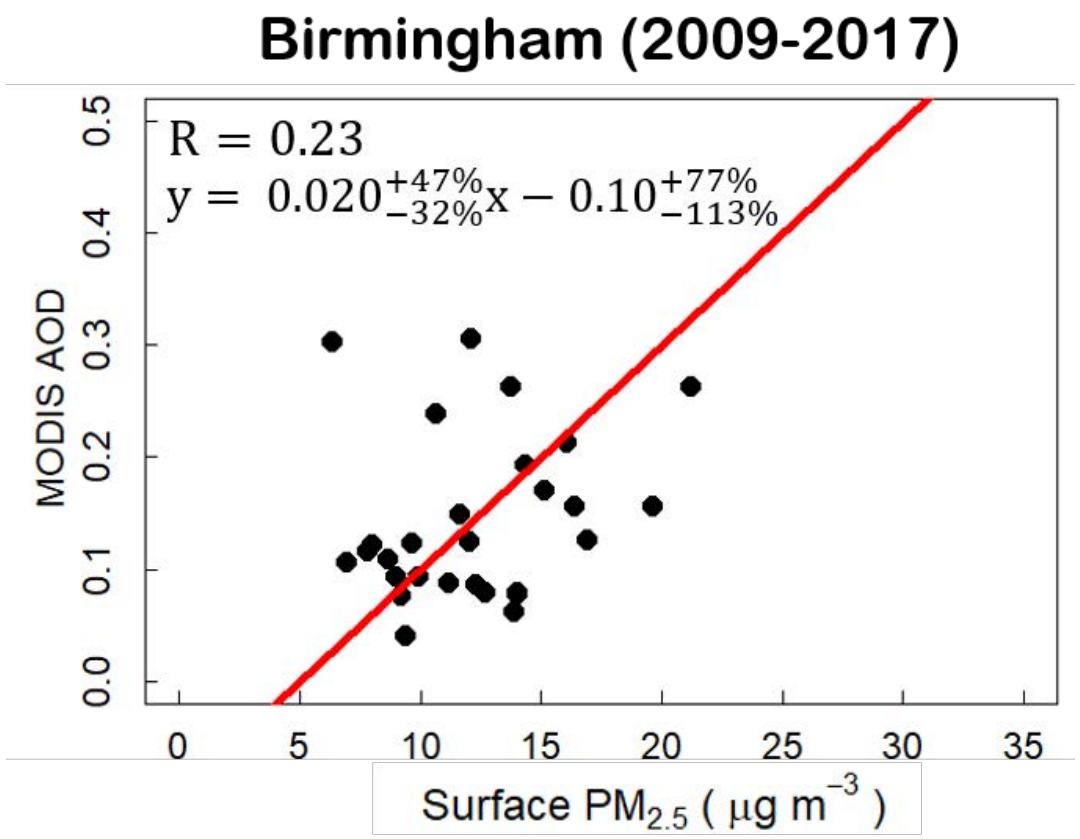
Points are monthly averages

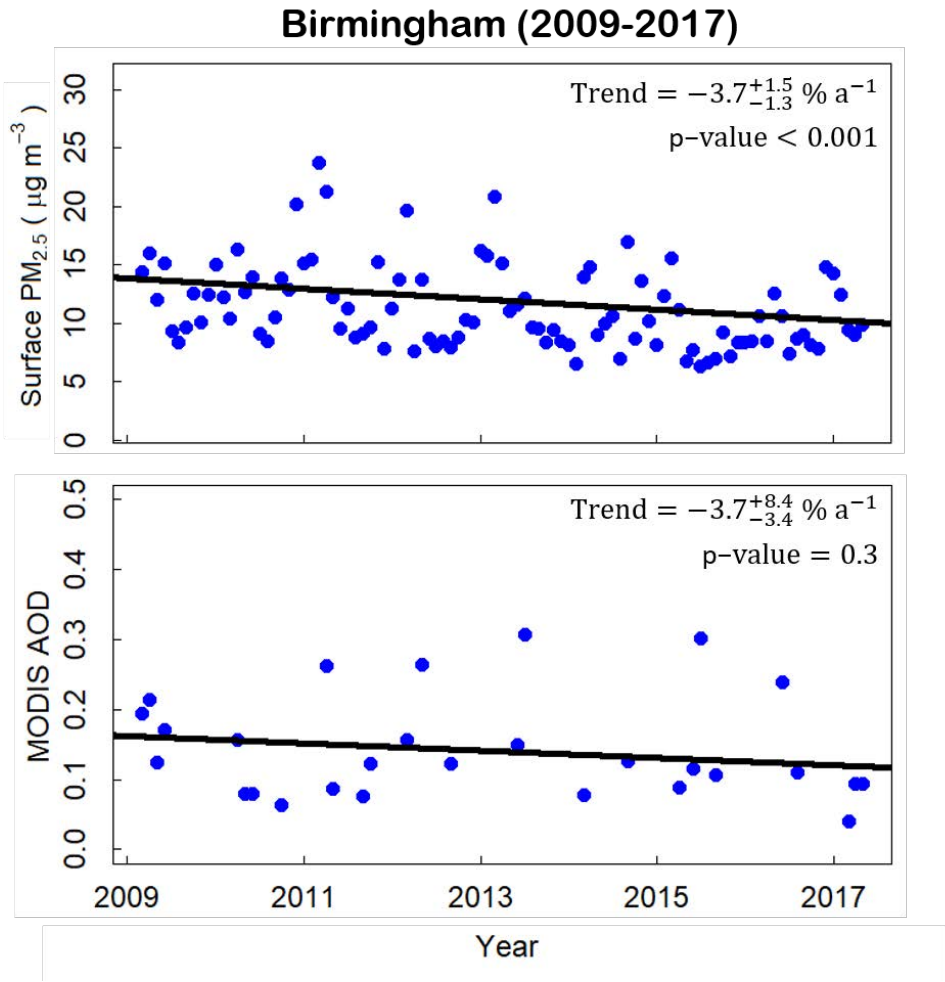
Pearson's correlation coefficient (R-value) indicates consistency

[Vohra et al., *ACPD, in review*]

We conduct careful assessment with surface monitors (where available)

Satellite versus surface $PM_{2.5}$ in Birmingham



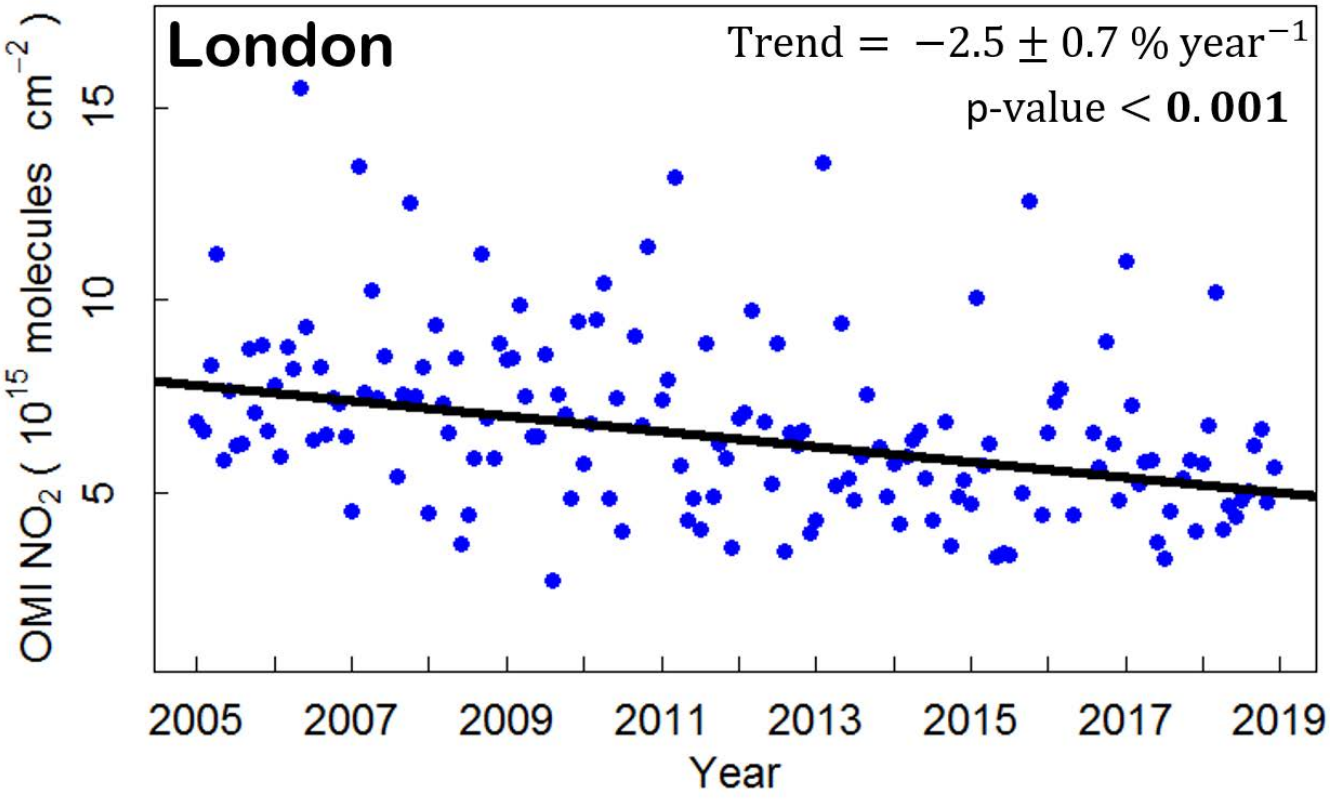


Similar results were obtained for London

[Vohra et al., *ACPD, in review*]

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

A) Trend in London NO_2

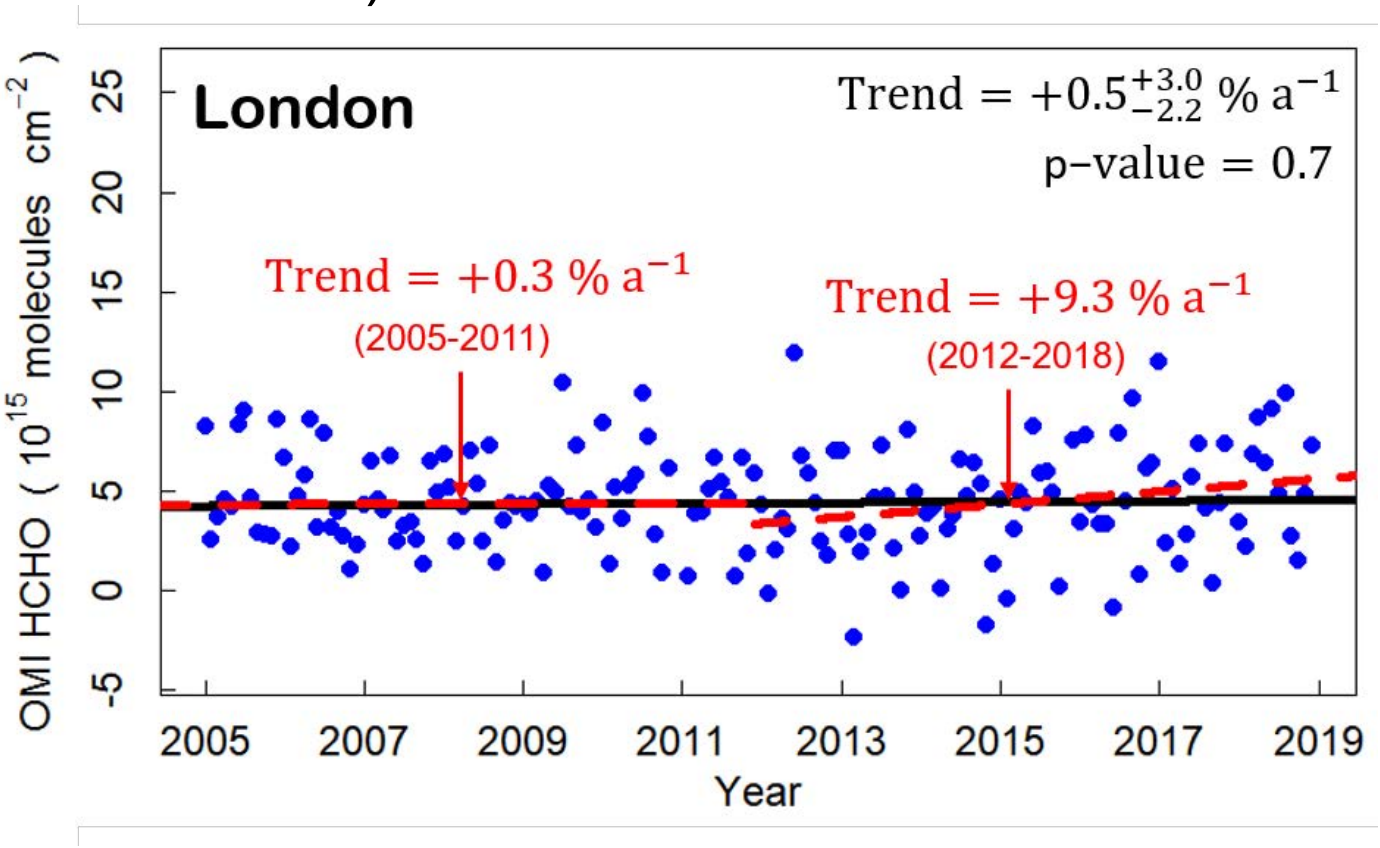


NO_2 over London decreased by **35 %** from 2005 to 2018

[Vohra et al., *ACPD, in review*]

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

B) Trend in London NMVOCs

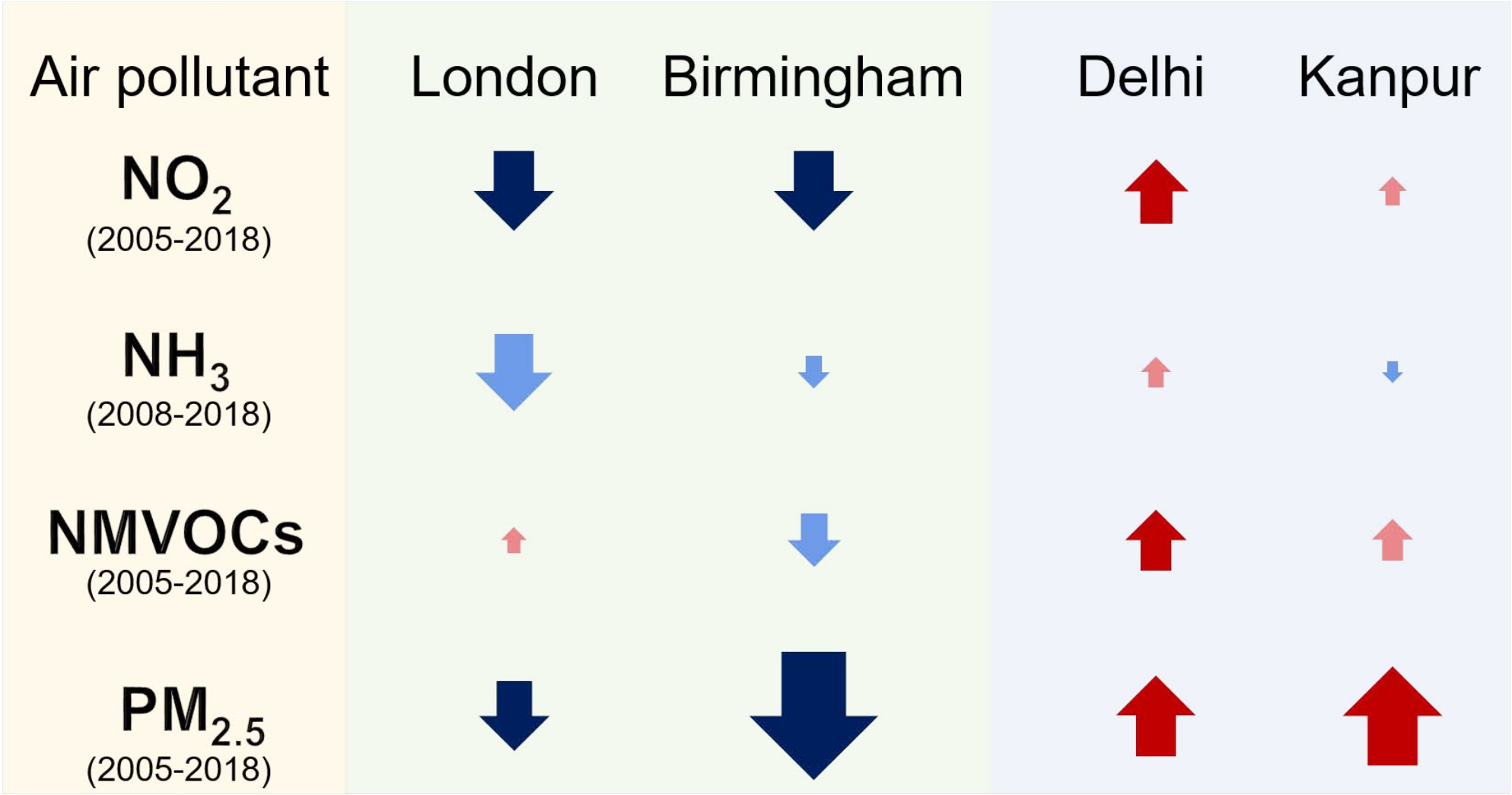


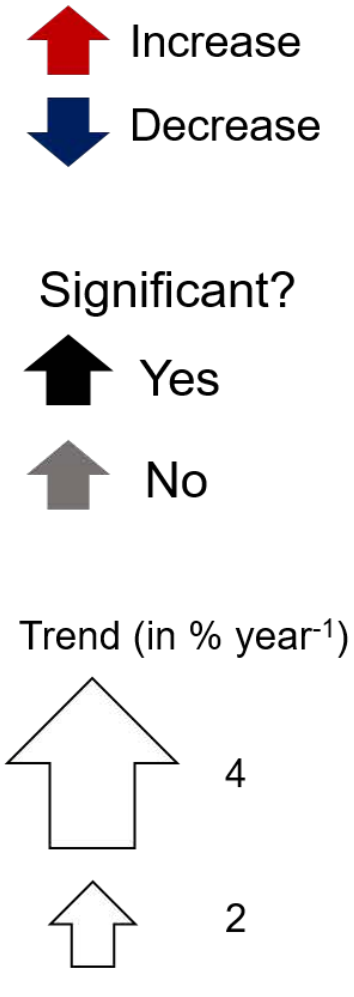
Reactive NMVOCs have increased by over **65** % in London since 2012

[Vohra et al., *ACPD, in review*]

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

(Arrow colour, intensity, and size indicate trend direction, significance and magnitude respectively)

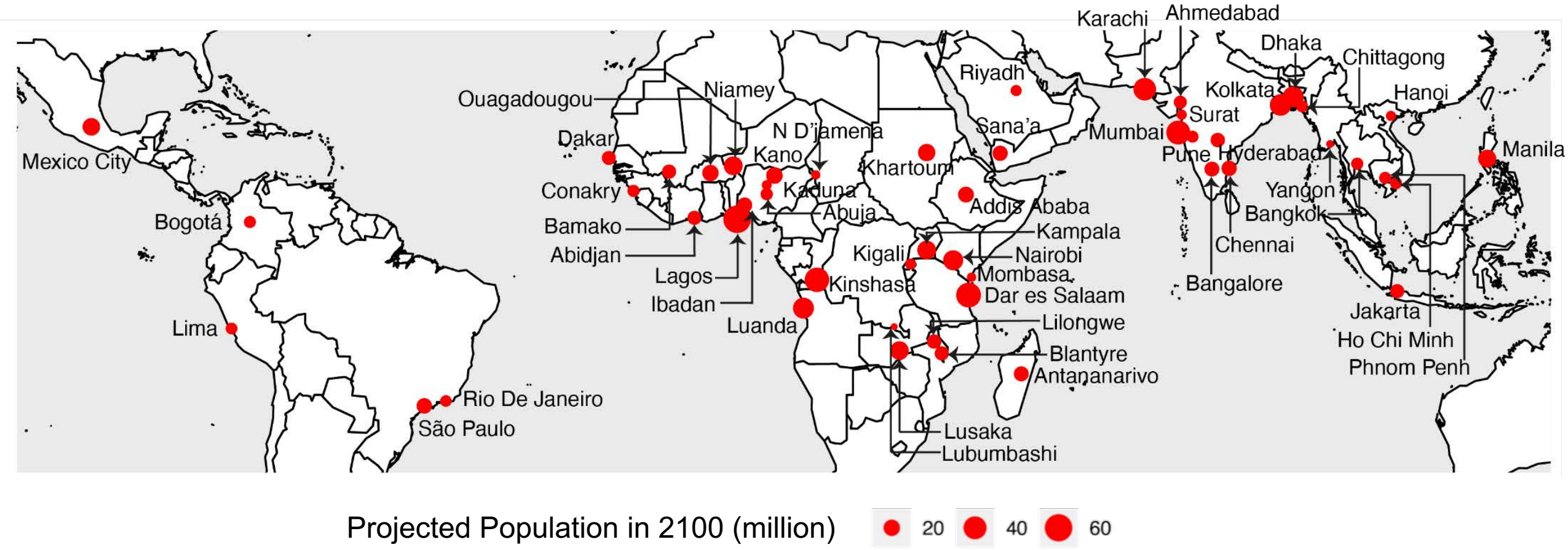




[Vohra et al., *ACPD, in review*]

Tropics are the next frontier in air pollution

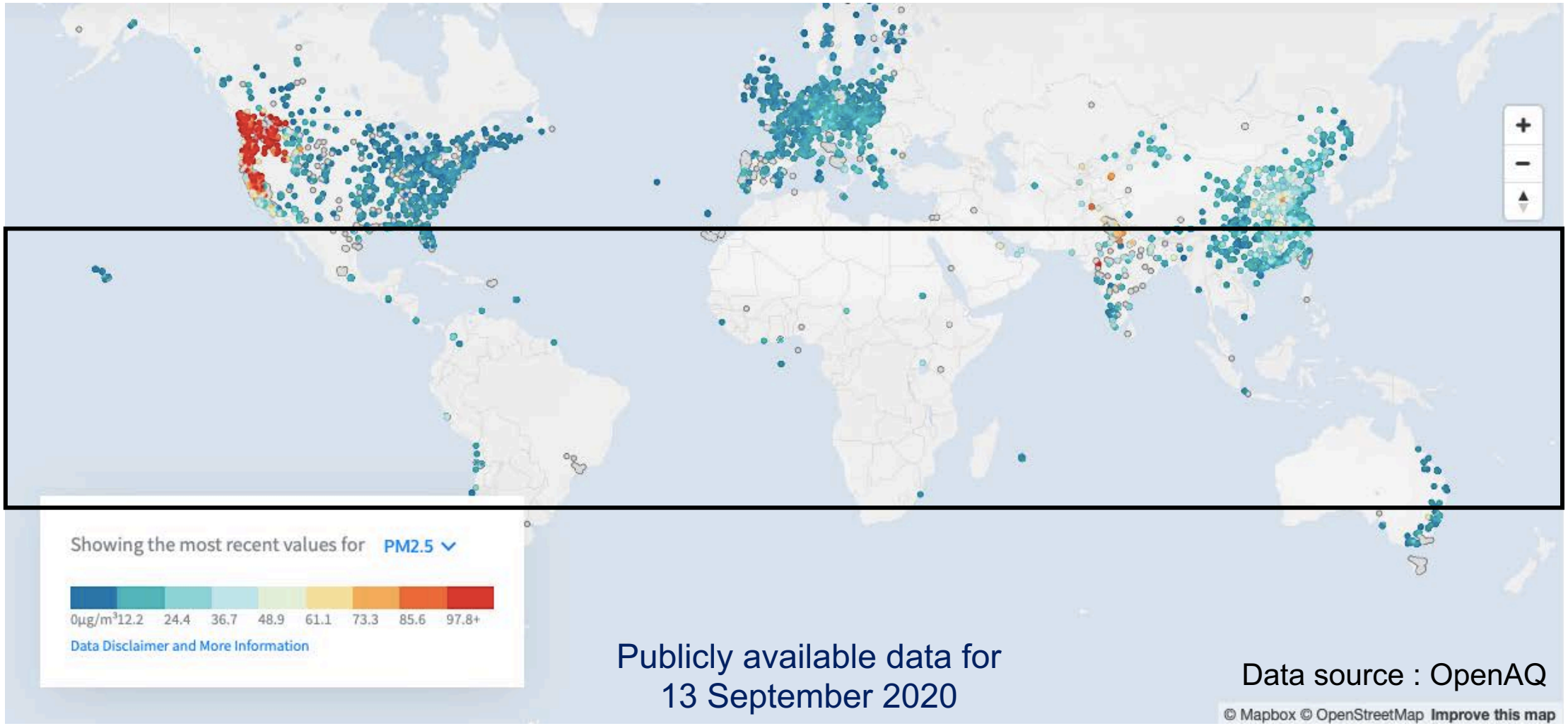
51 cities within the tropics will be megacities by 2100 **[Hoornweg & Pope, 2016]**



Projected Population in 2100 (million) 20 40 60

Tropics are the next frontier in air pollution

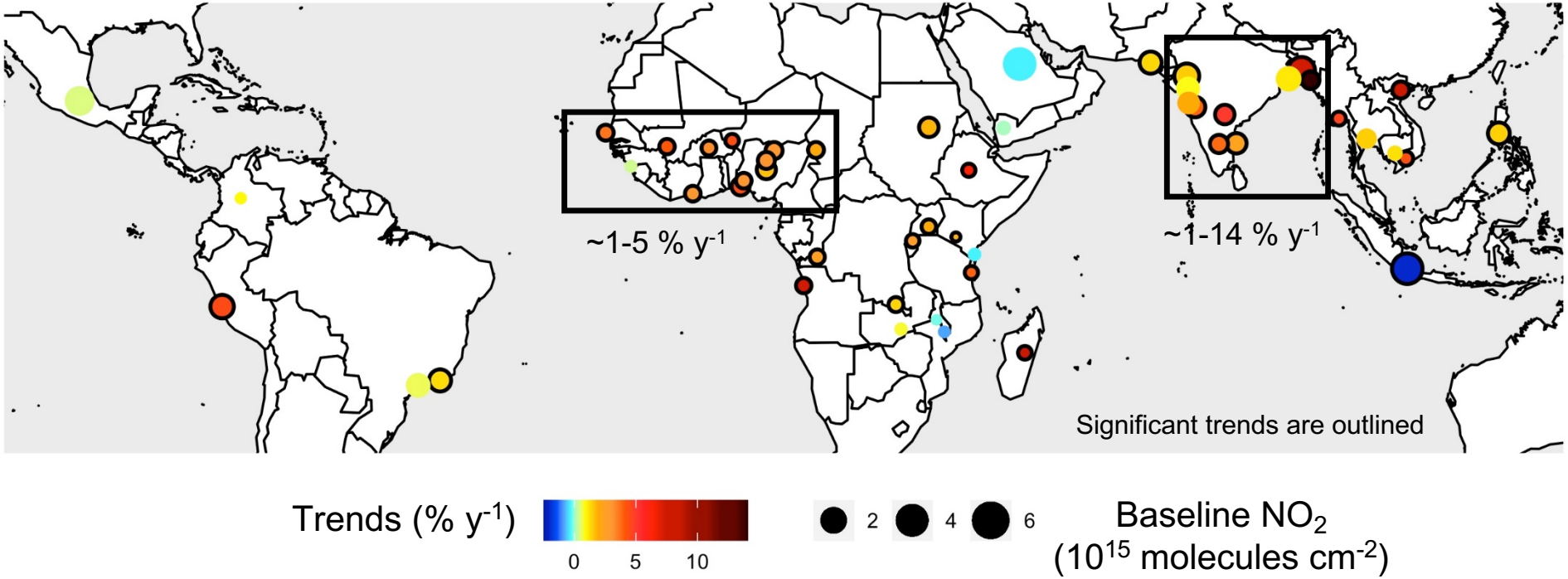
Currently, limited routine monitoring across the tropics



Megacity OMI NO_2 trends for 2005-2018

NO_2 is a precursor of tropospheric ozone, inorganic & organic nitrate aerosol

NASA OMI Level-2 Tropospheric column NO_2 version 3.0



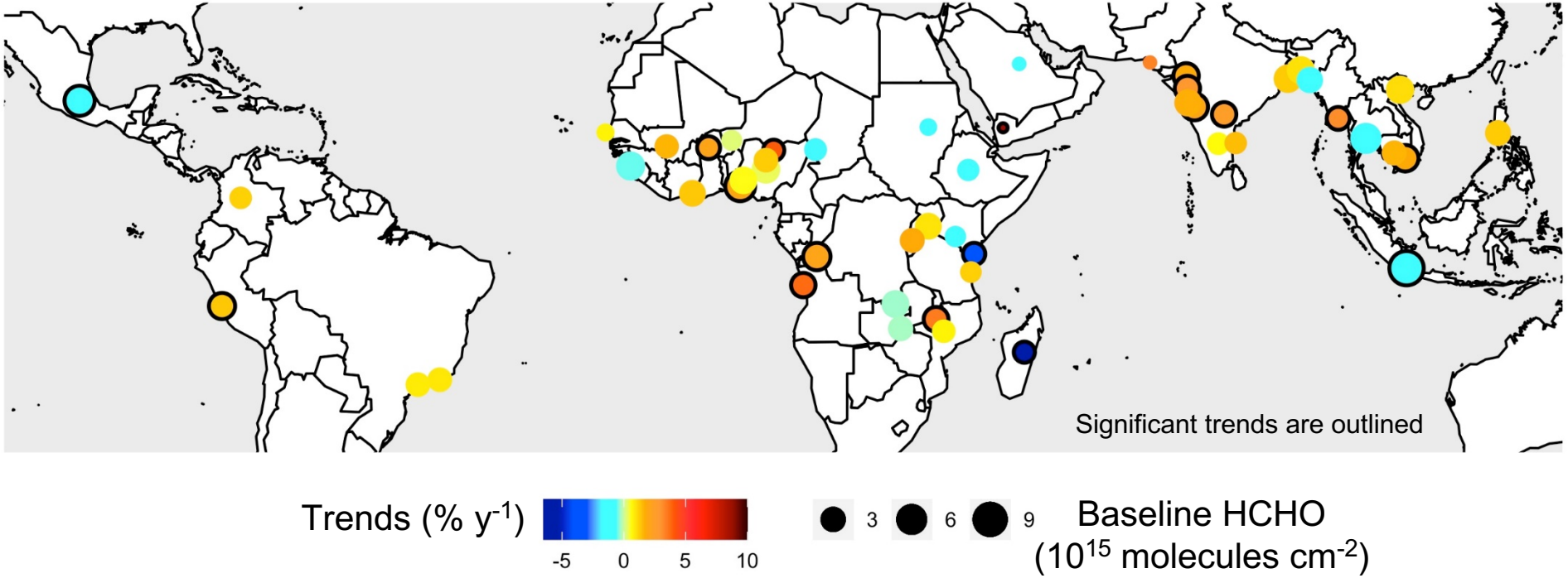
NO_2 has increased in 46 out of 51 cities

Year-round sources include anthropogenic sources like fossil fuel combustion, with large seasonal contributions from biomass burning

Megacity OMI HCHO trends for 2005-2018

HCHO is a precursor of tropospheric ozone & carbon dioxide

QA4ECV OMI Level-2 Total column HCHO version 1.2



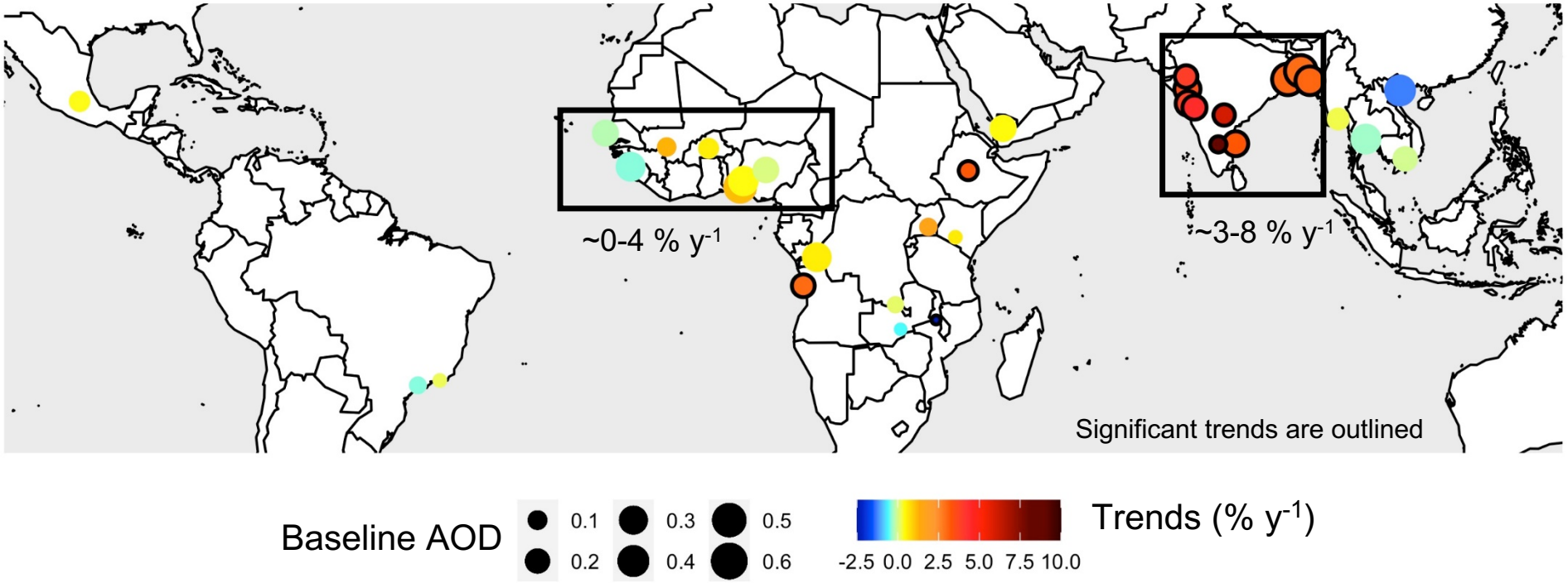
HCHO (reactive NMVOCs) has increased in 37 out of 51 cities

Year-round sources include anthropogenic sources (industry and domestic combustion) and biogenic sources, with seasonal contributions from biomass burning

Megacity MODIS AOD trends for 2005-2018

Aerosols can be either absorbing or scattering

NASA MODIS Level-2 Dark Target AOD Collection 6.1



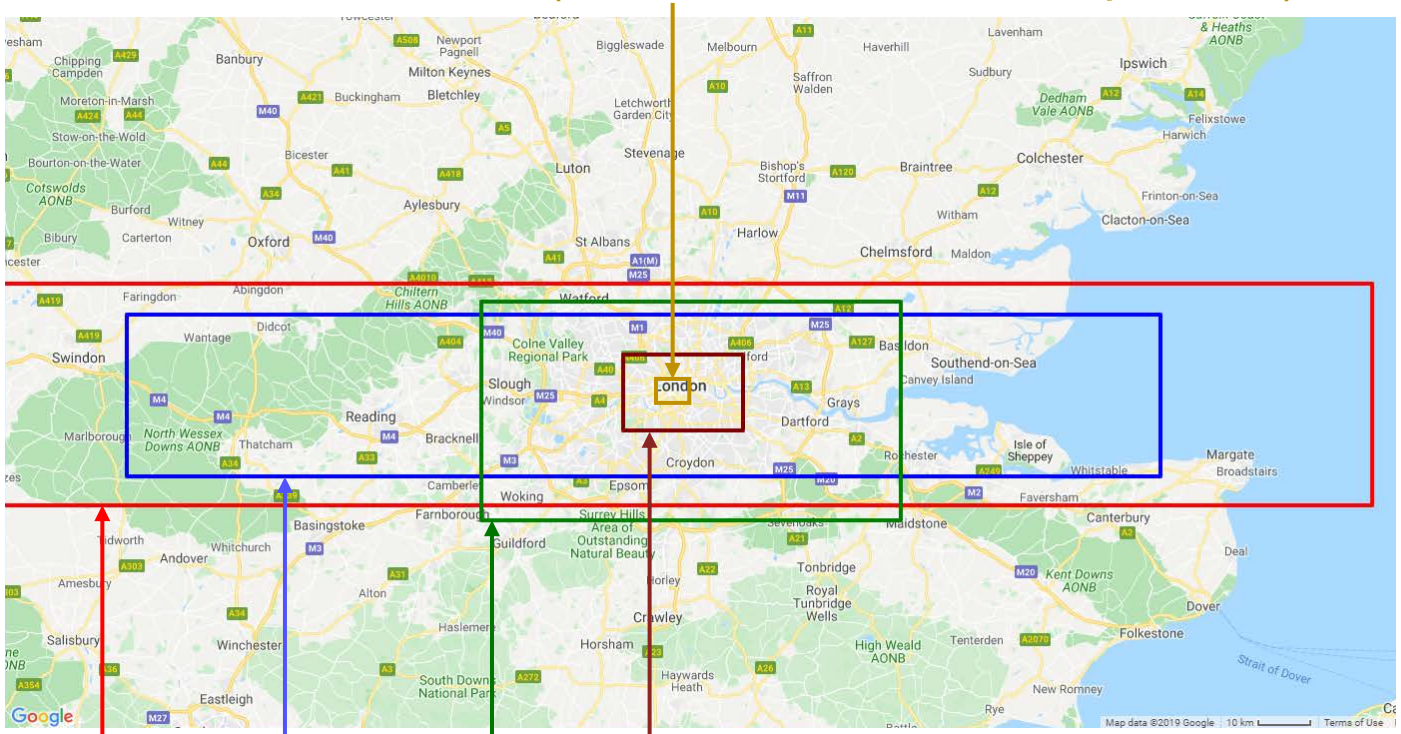
AOD has increased in 25 out of 33 cities

Dominant sources are many: secondary sources from NO_x, NH_3, NMVOCs, primary sources of windblown dust, crop and trash burning, residential and open fires

What's happening?

Next generation high spatial resolution space-based measurements

TROPOMI (5.5 km x 3.5 km, 2017-present)



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GOME-2 (80 km x 40 km, 2007-present)

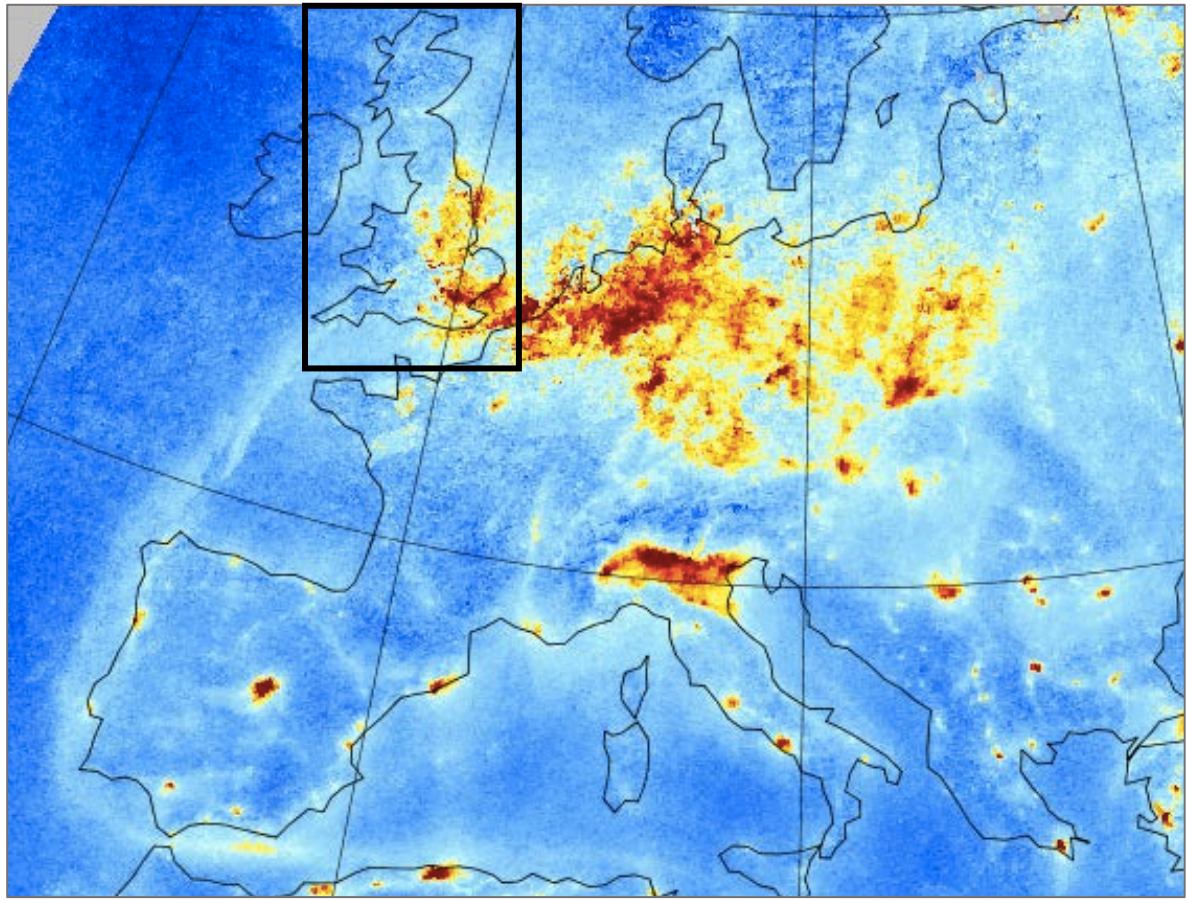
SCIAMACHY (200 km x 30 km, 2002-2012)

GOME (320 km x 40 km, 1995-2001)

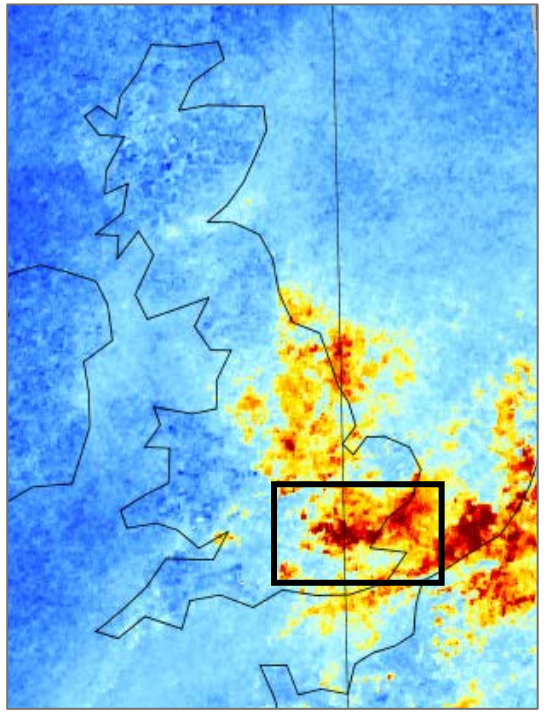
What's happening?

High spatial resolution TROPOMI NO_2 (October 2019)

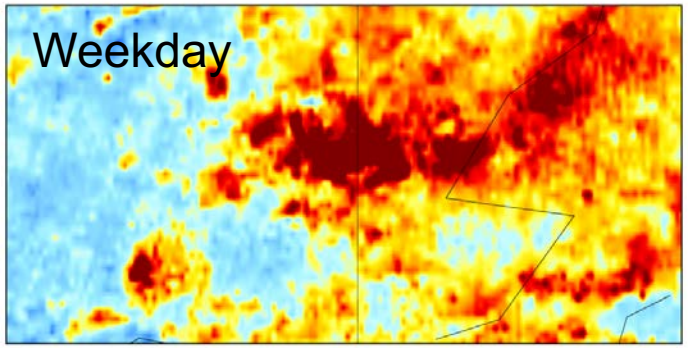
Europe

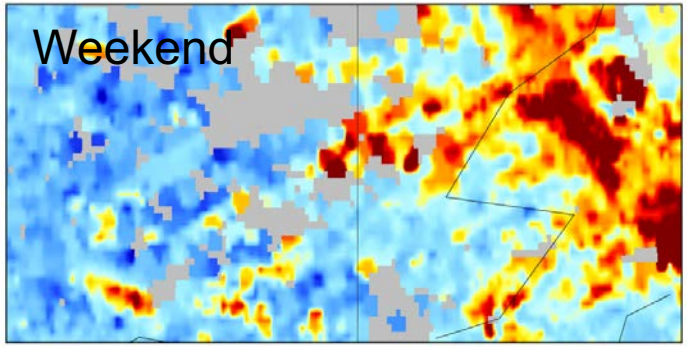


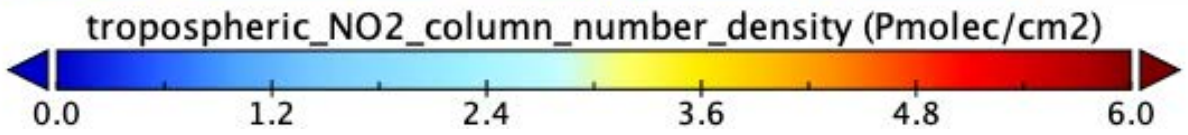
UK



London







Assess impact of lockdown?

Conclusion and Next steps

- ✓ Satellite observations provide long-term and consistent global coverage of air pollutants
- ✓ Air quality related policies have been effective in the UK but no evidence observed yet for India
- ✓ Preliminary results show rapid increases in precursors of short-lived air pollutants for most future tropical megacities

Next, we will:

- Interpret the drivers of these trends
- Tease out biomass burning contribution to the trends
- Compare trends to widely used global emission inventories

Any Questions? Contact Karn (kxv745@bham.ac.uk)

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