

Using Satellite Observations to Launch Urban Air Quality Monitoring into the 21st Century



TRACE

Dr Eloise A Marais (eloise.marais@le.ac.uk)



UNIVERSITY OF
LEICESTER

Acknowledgements

Research Group



Karn

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Engineering and Physical Sciences
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Collaborators and Contributors



UNIVERSITY OF
BIRMINGHAM



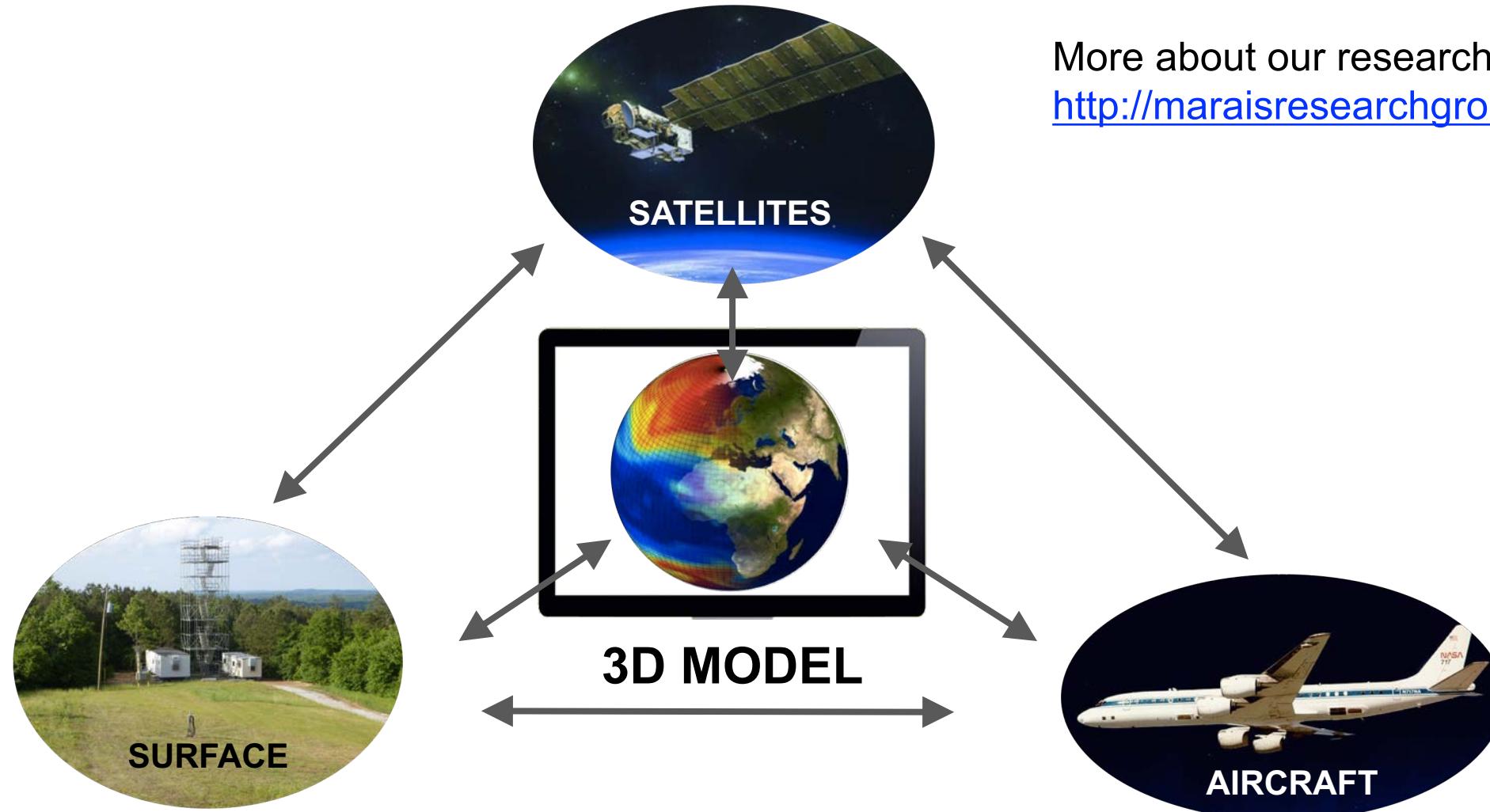
defra
Department for Environment
Food and Rural Affairs



Copernicus Accelerator Mentor

Luísa Bernardes
Portugal Social innovation

Atmospheric Chemistry and Air Quality Research

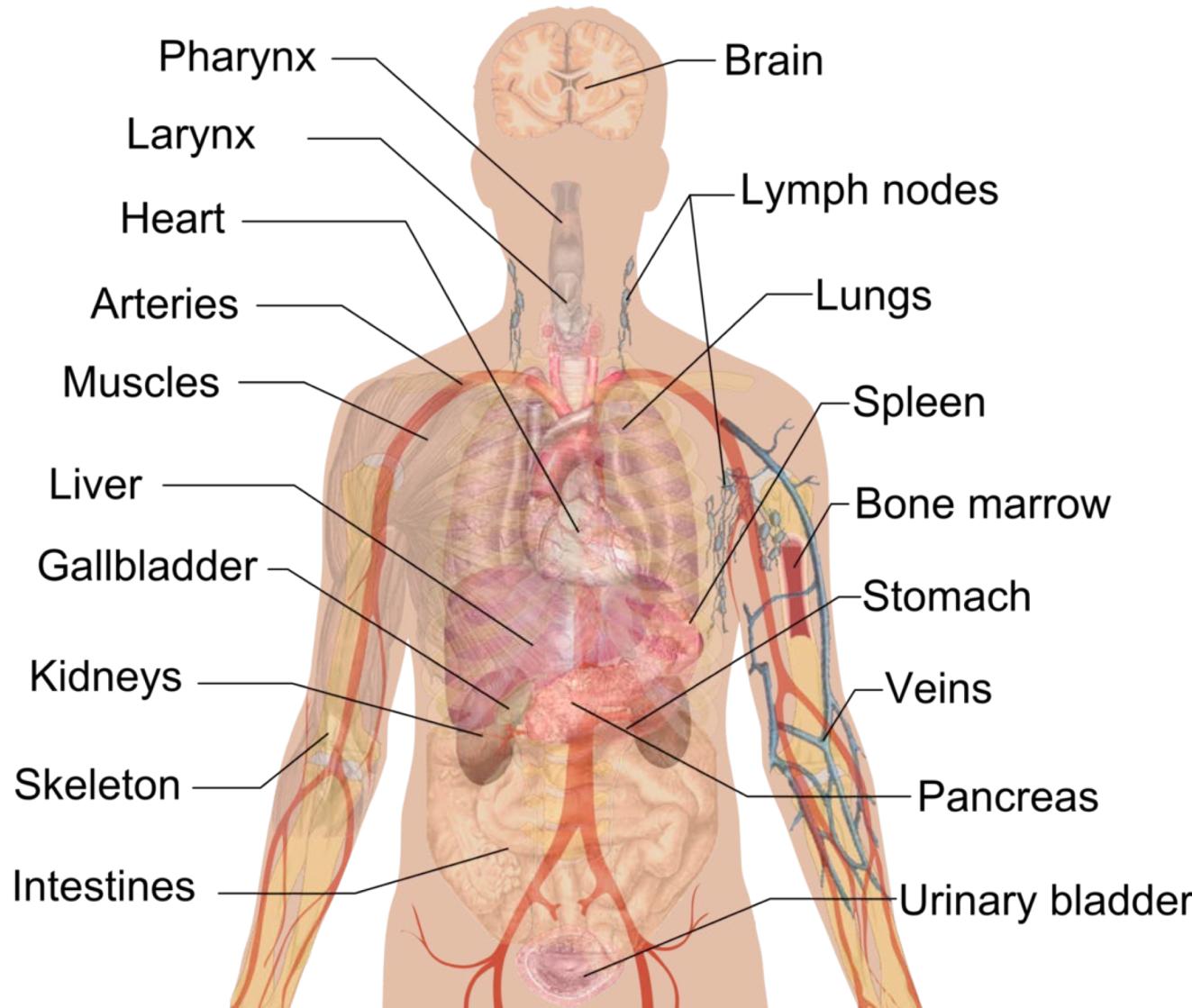


More about our research here:
<http://maraisresearchgroup.co.uk/>

Integrate data from multiple platforms to better understand atmospheric chemistry and inform prescient policy

Air Pollution is Pervasive

Internal organs



Every organ in our body may be susceptible to its deleterious effects

[Schraufnagel et al., 2019]

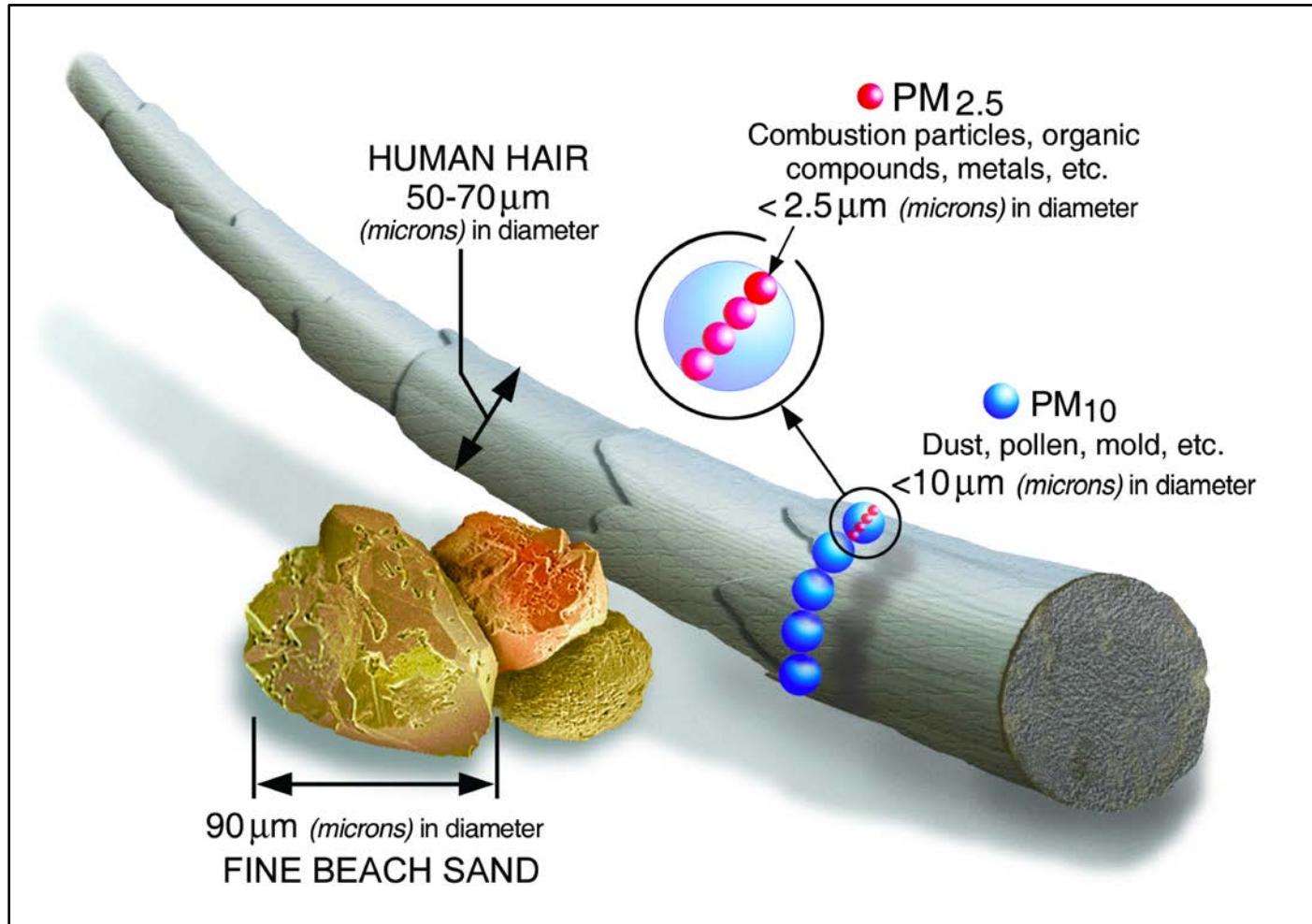
Recommended:

<https://www.theguardian.com/environment/interactive/2019/may/17/air-pollution-may-be-damaging-every-organ-and-cell-in-the-body-finds-global-review>

Fine Particles ($\text{PM}_{2.5}$) are Most Deadly

$\text{PM}_{2.5}$:

Particles floating in the atmosphere that are small enough to penetrate deep into the lungs

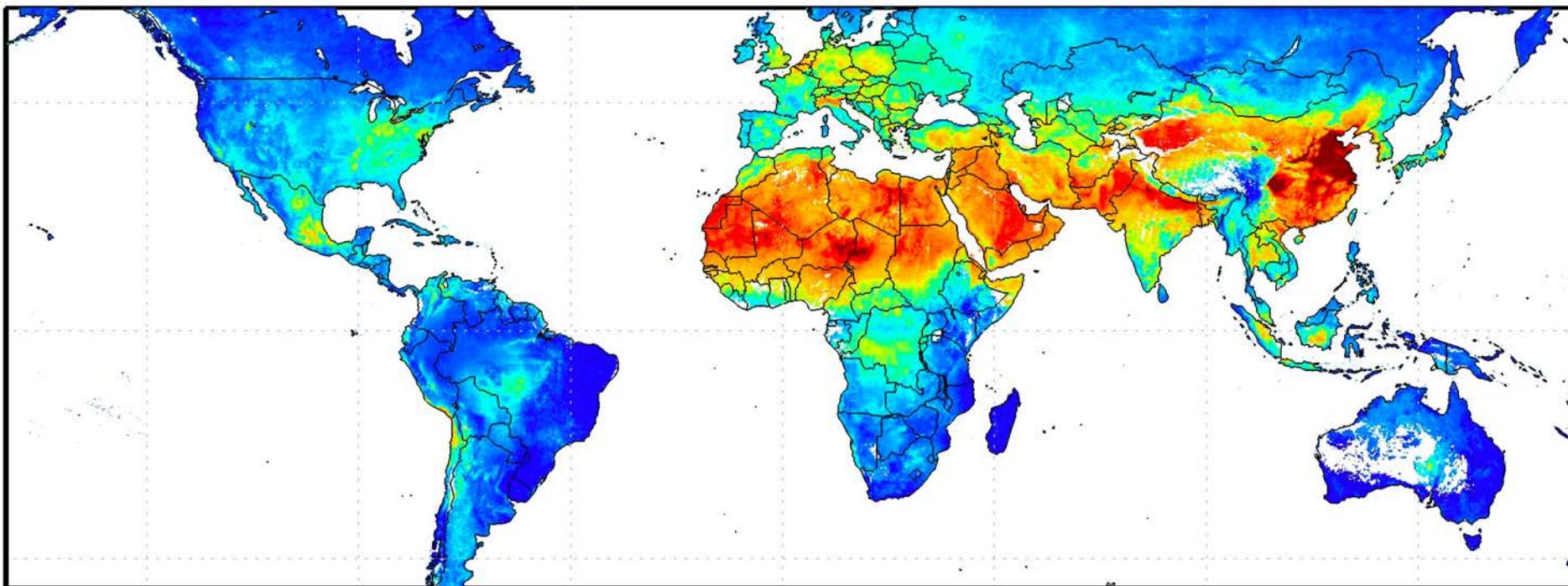


[US EPA]

Direct association between PM_{2.5} exposure and hazardous health outcomes

Global Distribution of PM_{2.5}

Multiyear (2001-2006) Annual Average PM_{2.5}



WHO limit
(future UK target)



UK limit



[van Donkelaar et al., 2010]



Most of the world is exposed to PM_{2.5} above the WHO limit

PM_{2.5} comes from Many Sources

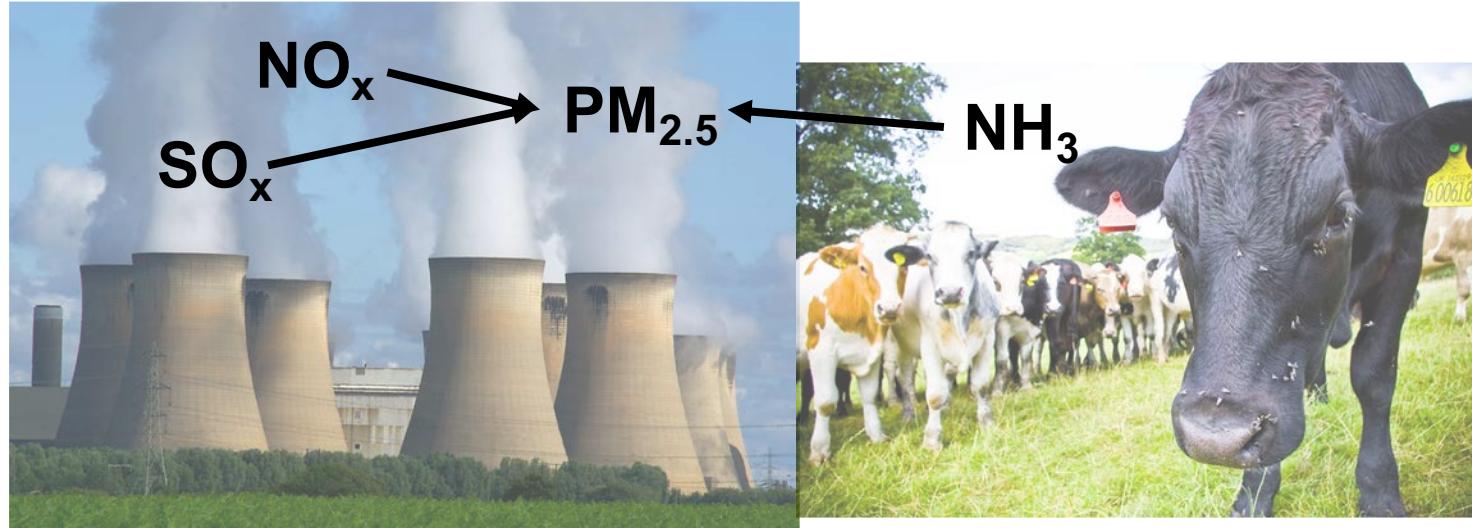
Anthropogenic:

Energy generation, industry, agriculture, residential fuels, vehicles, construction, road dust, ...

Direct Emissions (Primary)



Physical and Chemical Formation Processes (Secondary)

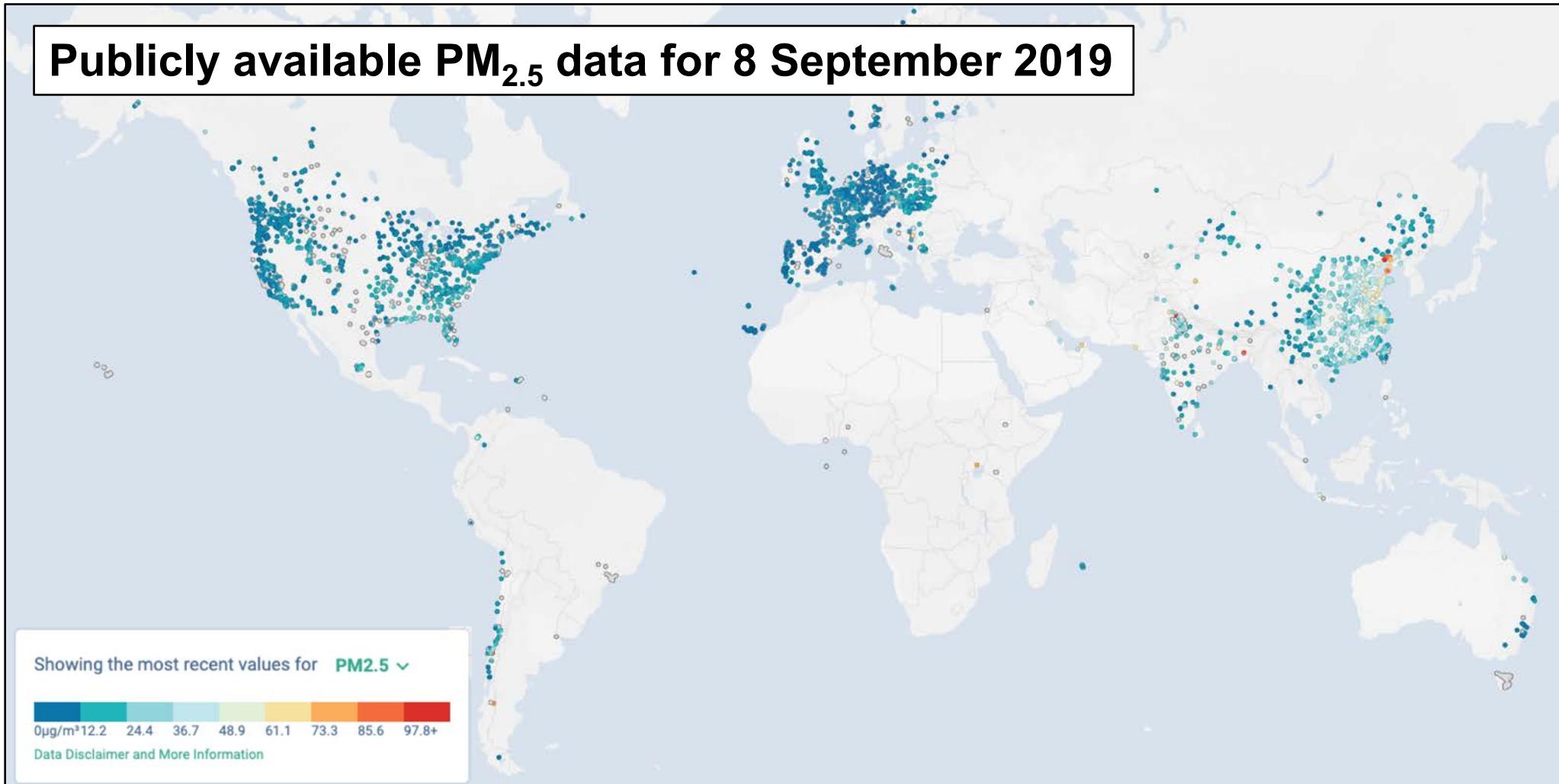


Also **natural sources**: ocean, soils, trees, wildfires, volcanoes, ...

This complexity makes it challenging to monitor and regulate

The Current Approach

No routine monitoring in many parts of the world



The Current Approach

Large gaps in space, time and pollutants

UK monitoring network



London



Birmingham

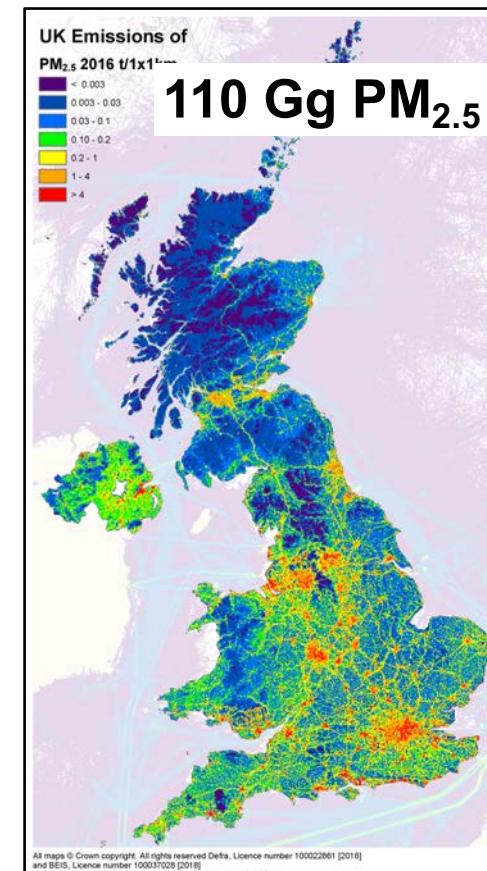
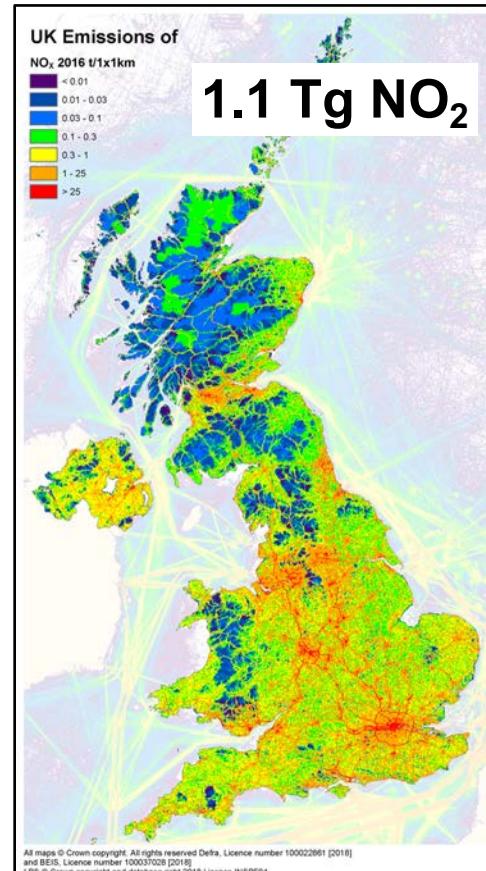


UK-AIR website: <https://uk-air.defra.gov.uk/interactive-map>

The Current Approach

Air quality monitoring tools can have large uncertainties

High Spatial Resolution UK Emissions Inventory



NAEI website: <https://naei.beis.gov.uk/data/map-uk-das>

Hinders development of effective policies and leads to large fines (>£60M)

The Solution

Earth observations are the only viable way to address deficiencies in air quality monitoring and management strategies!



Tool for Recording and Assessing the City Environment

Data are freely available, but requires expertise to process and interpret

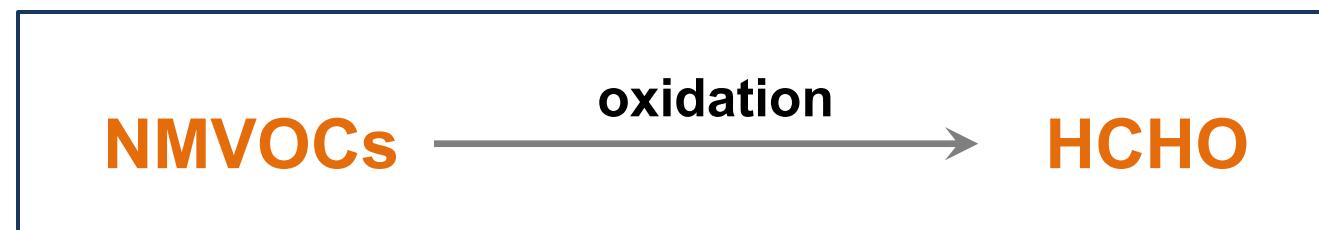
The Solution

Products available from space-based instruments and relationship to air pollution

Satellite Product	Air Pollutant
Nitrogen dioxide (NO_2)	NO_2
Formaldehyde (HCHO)	Non-methane volatile organic compounds (NMVOCs)
Ammonia (NH_3)	NH_3
Sulfur dioxide (SO_2)	SO_2
Carbon monoxide (CO)	CO
Aerosol optical depth (AOD)	$\text{PM}_{2.5}$

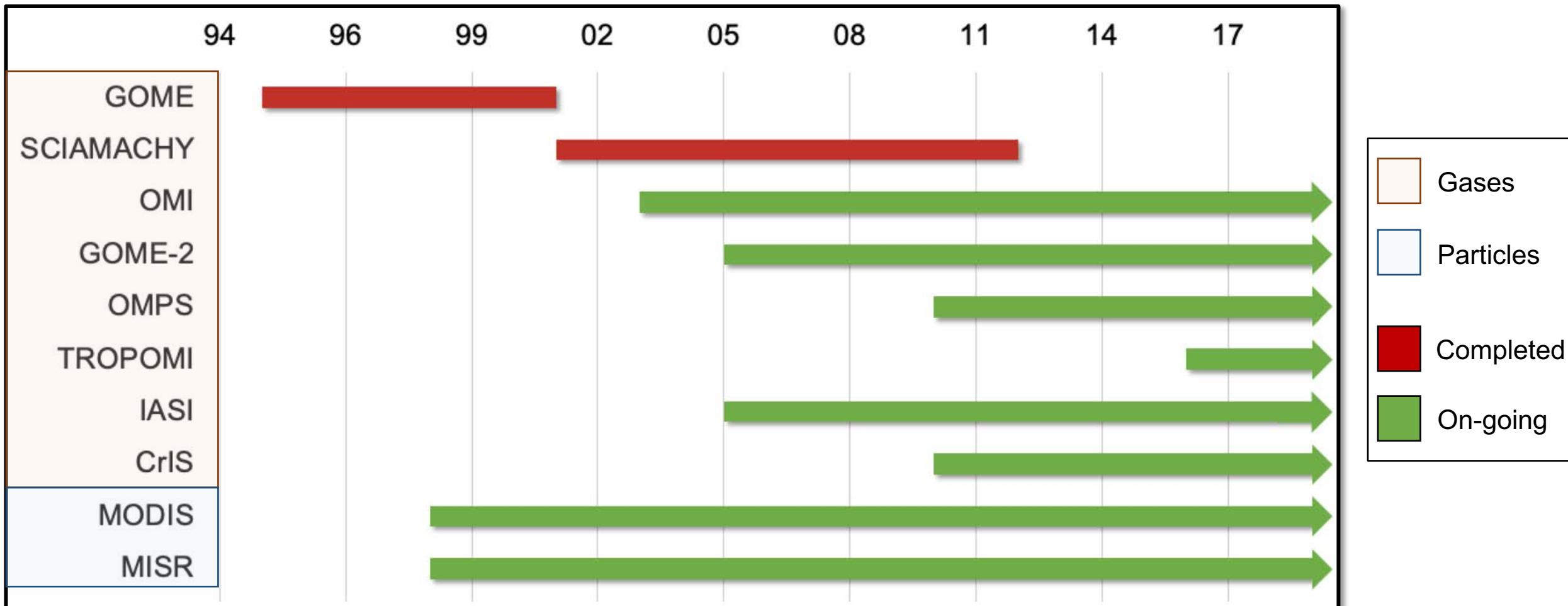
Gases ←

Particles ←



The Solution

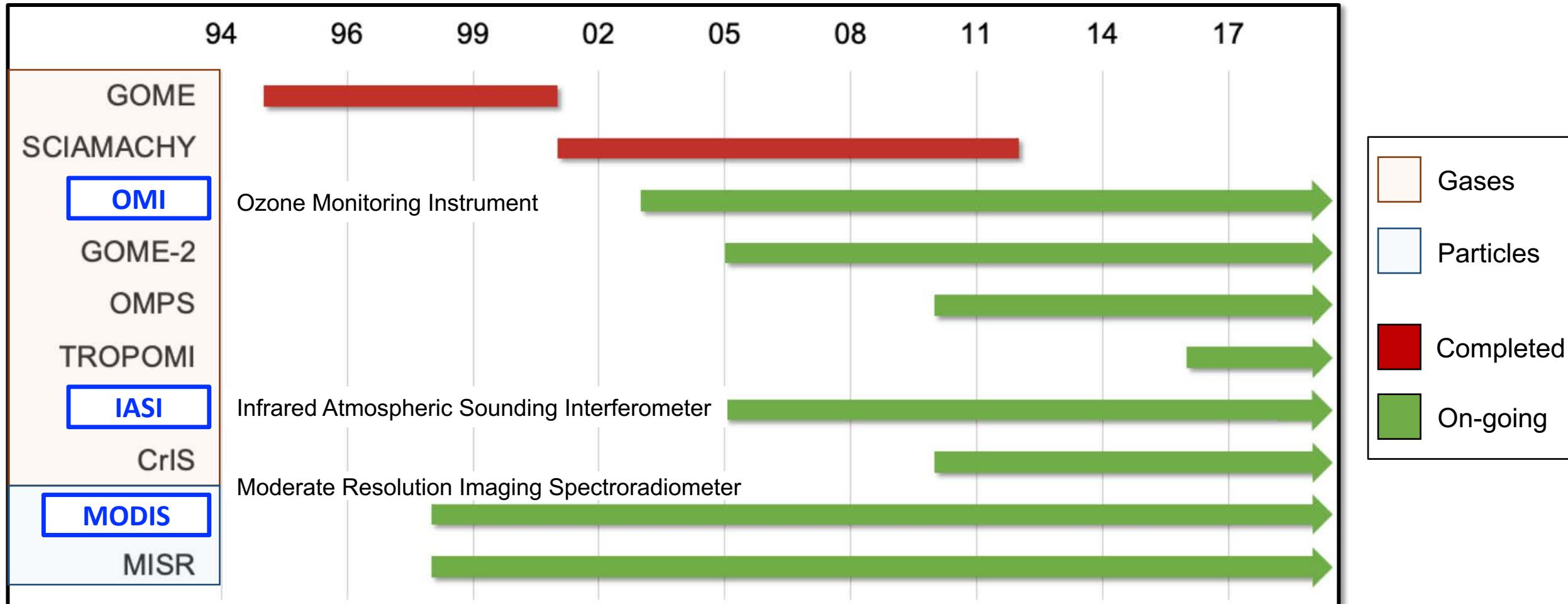
Sensors in space have been providing petabytes of data for more than 2 decades



The Solution

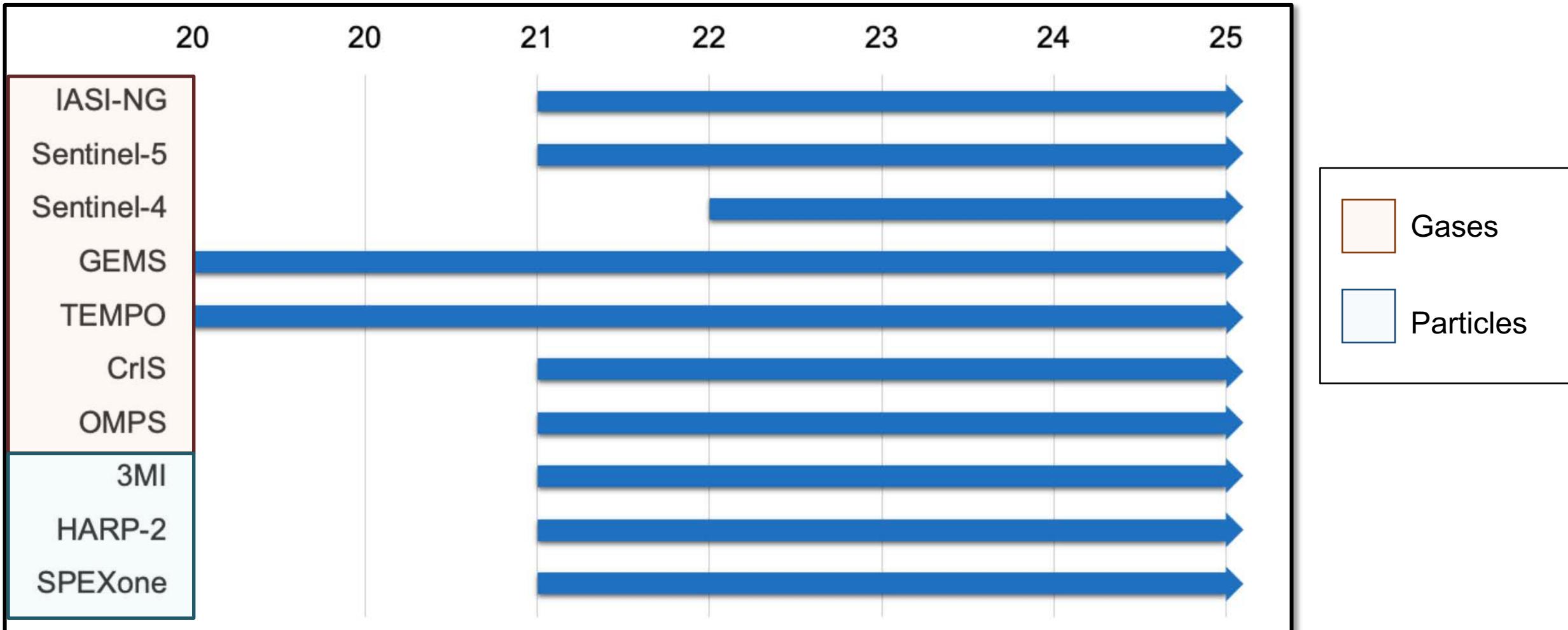


What we're using to develop TRACE



The Solution

The future record will be at lower cost and finer scales than ever before



The Solution

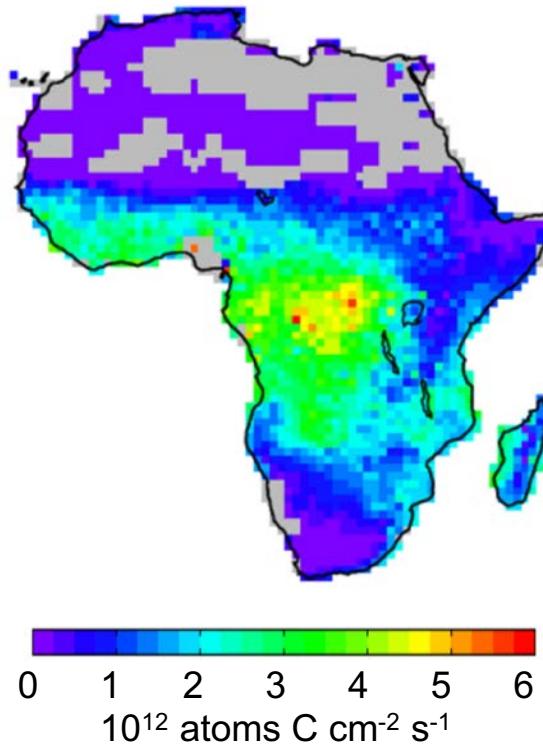


A data transformation and interpretation service to convert satellite observations into useful information about air quality.

The Solution

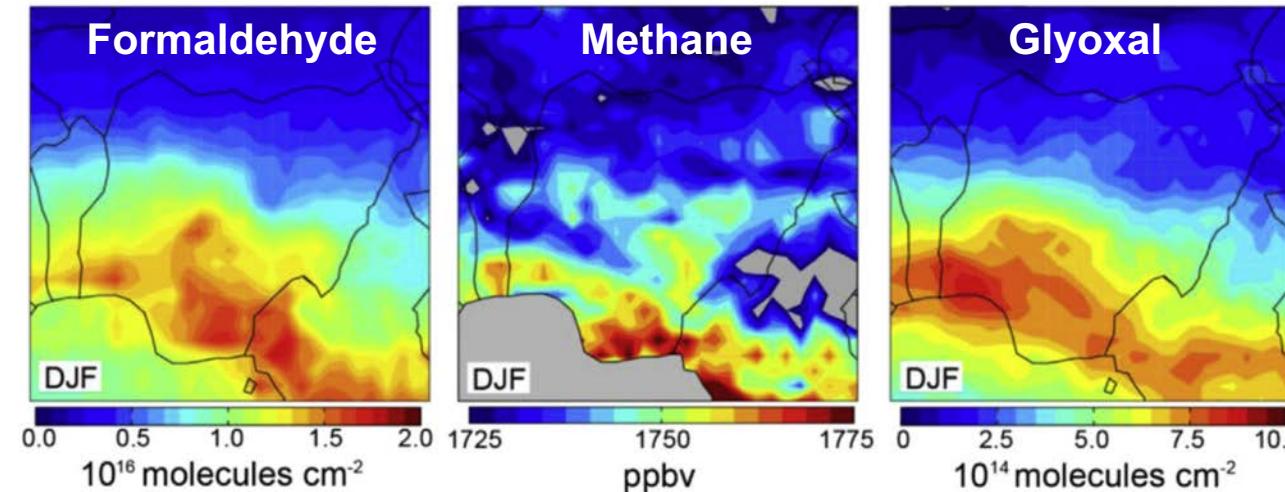
Widespread use in research; limited application to air quality policy

Biogenic Emissions from Trees in Africa



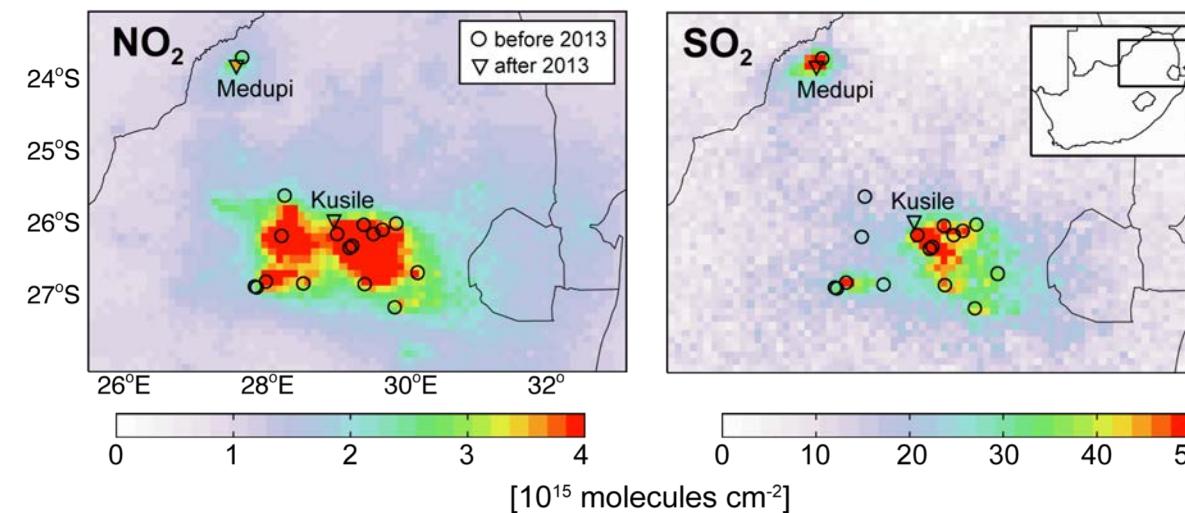
[Marais et al., 2012]

Identify and Interpret Pollution Sources in Nigeria



[Marais et al., 2014]

Combustion Emission Hotspots in South Africa

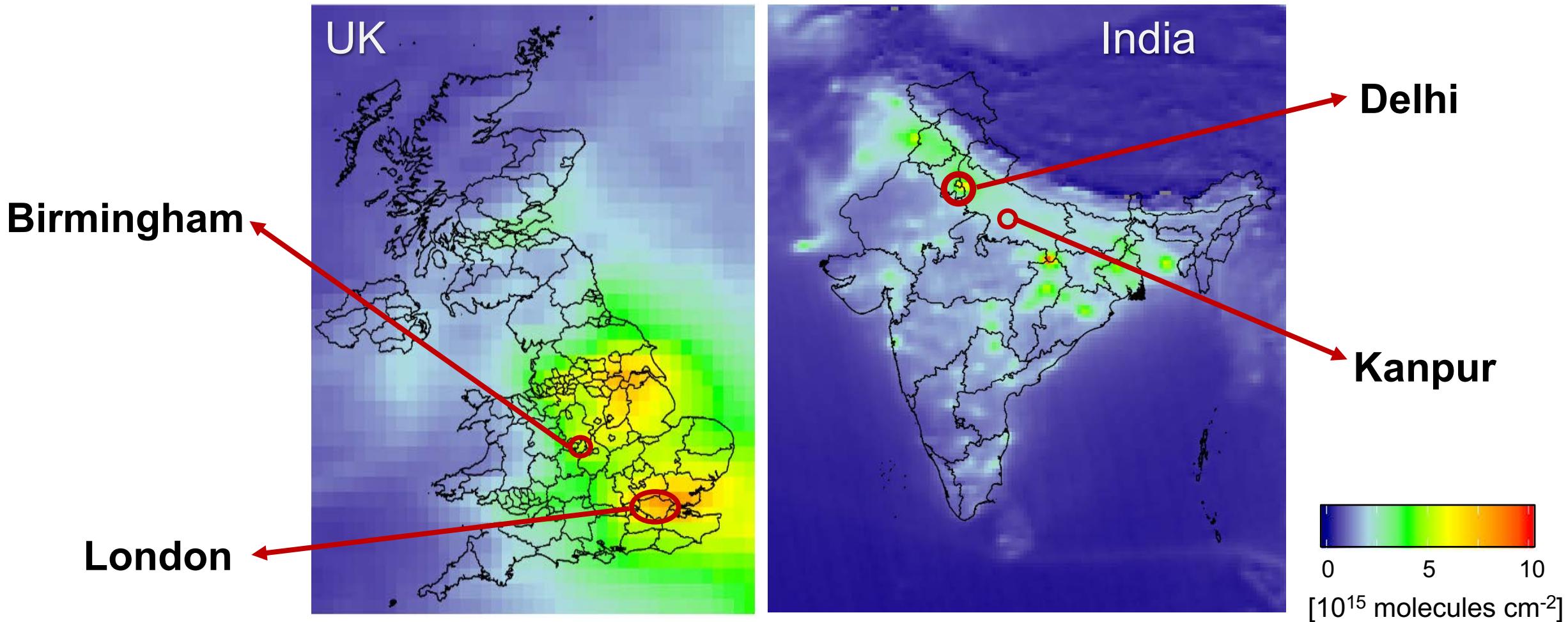


[Marais et al., 2019]

The Solution

Develop TRACE by targeting 4 dynamic cities and working with end users

Background is multiyear (2005-2018) NO₂ from the OMI instrument

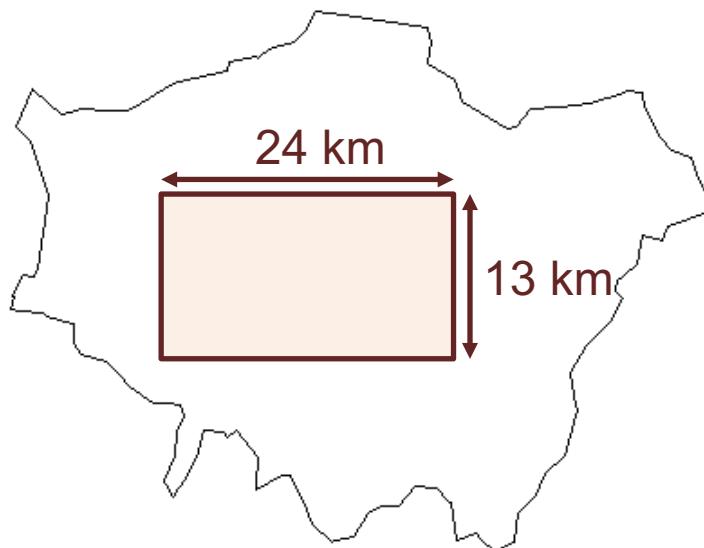


The Solution

Relevant space-based instruments have coarse spatial resolution

OMI

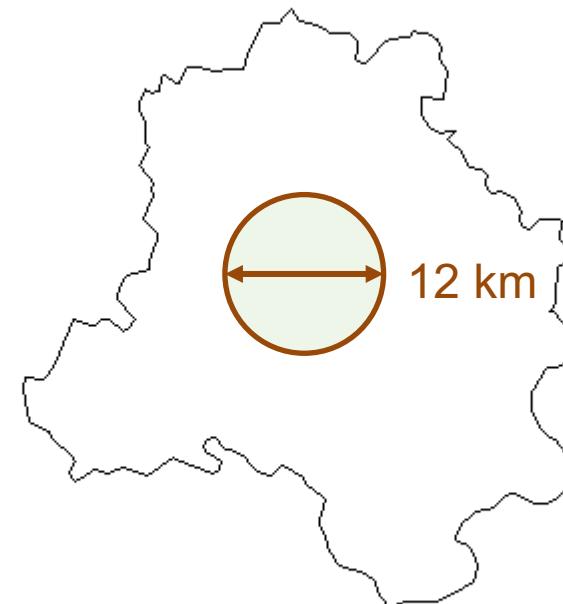
Ozone Monitoring Instrument



London
(1600 km^2)

IASI

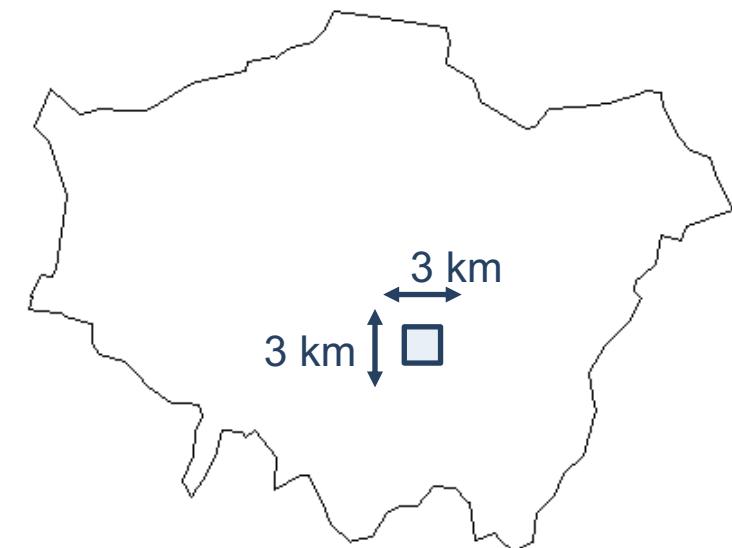
Infrared Atmospheric Sounding
Interferometer



Delhi
(1500 km^2)

MODIS

Moderate Resolution Imaging
Spectroradiometer



London
(1600 km^2)

Use to monitor and assess air quality throughout large cities

The Solution

Satellites measure solar backscattered light through the whole atmospheric column

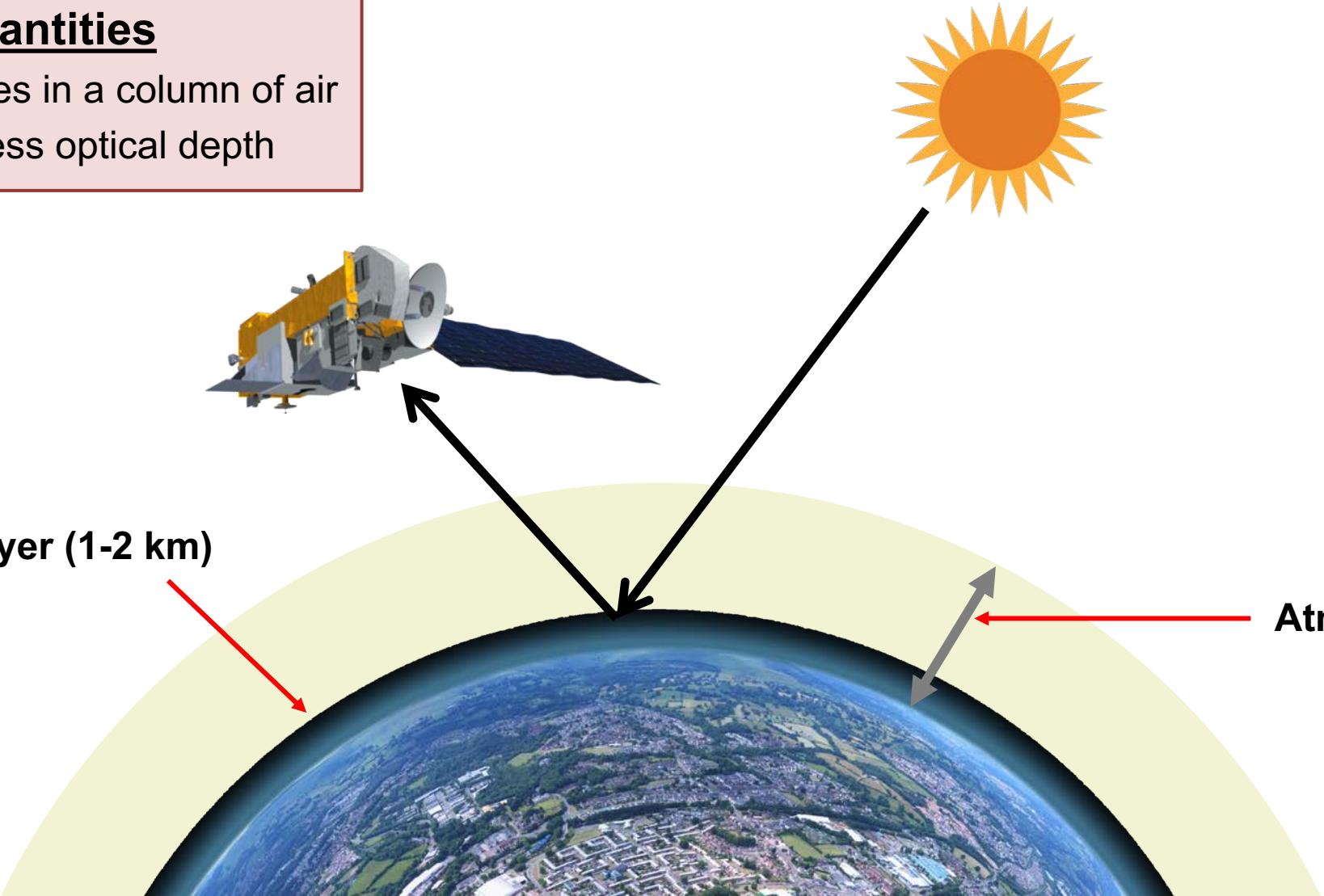
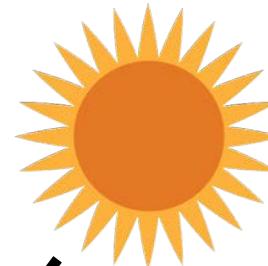
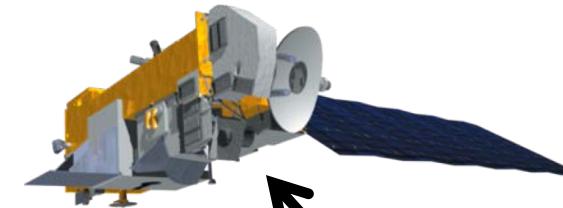
Measured quantities

Gases: Molecules in a column of air

Aerosols: Unitless optical depth

Pollution layer (1-2 km)

Atmosphere layer
> 10 km

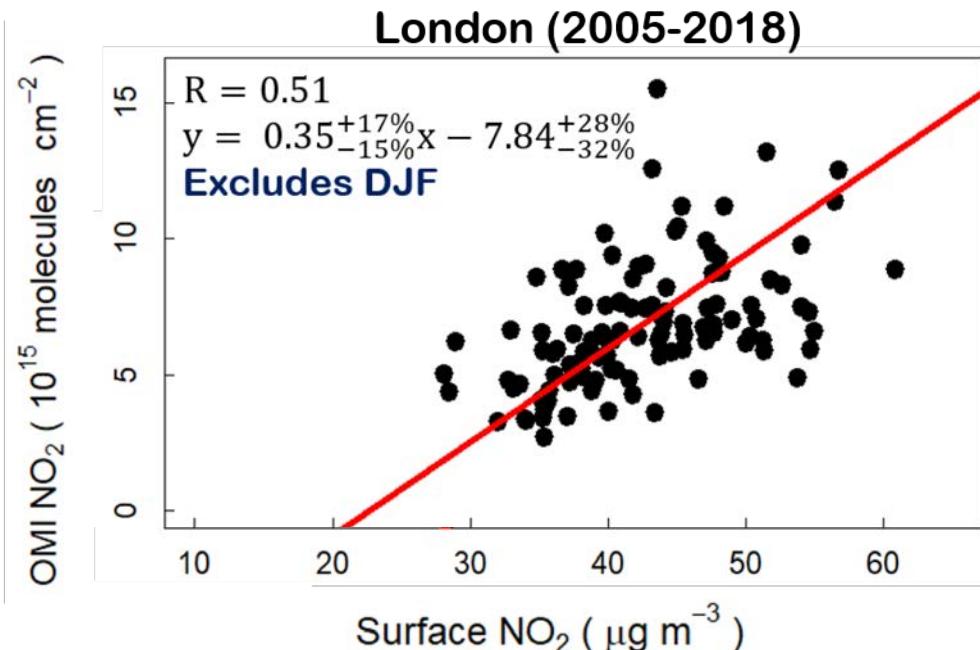


The Product

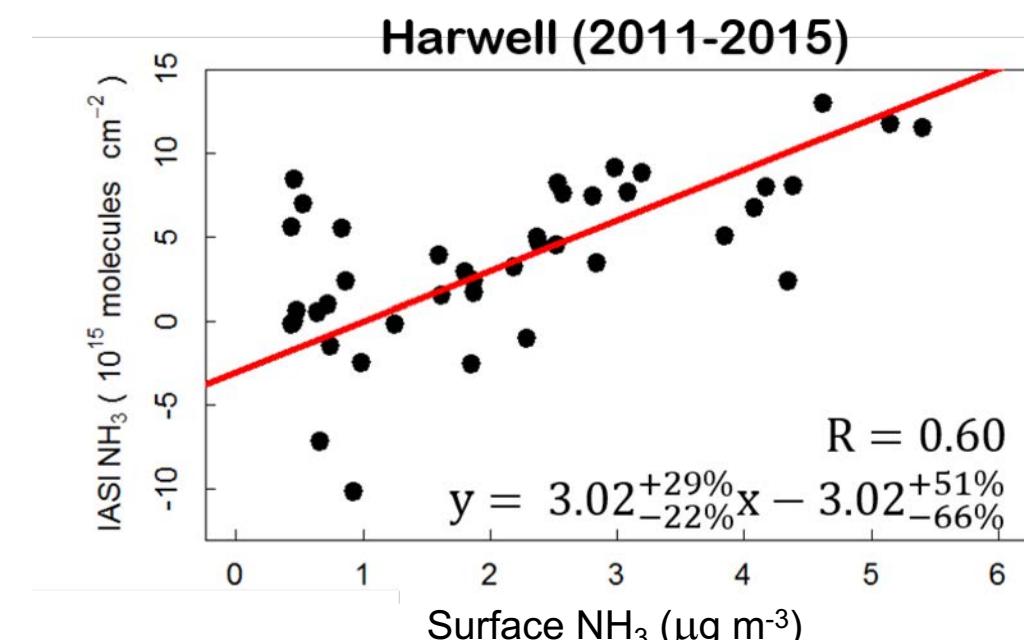
Quality Assurance:

Quality checks with surface observations where these are available

Satellite versus surface NO₂ in London



Satellite versus surface NH₃ at the supersite n Harwell



Points are monthly averages

Pearson's correlation coefficient (R value) indicates consistency

The Product

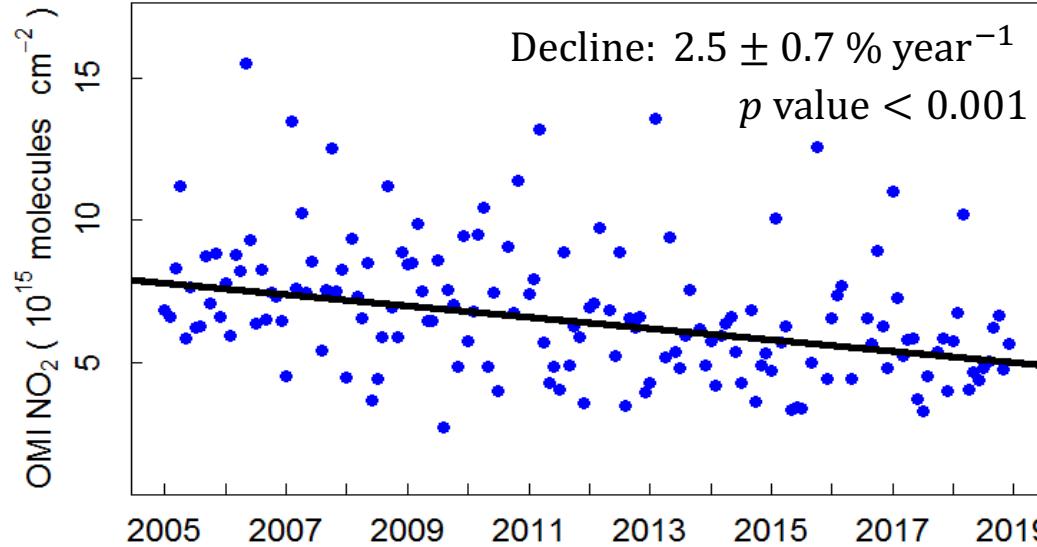
Quality Assurance Progress

Component	Completed	Passed
NO_2		
NH_3		
SO_2		
AOD	 	 
HCHO	 	
CO		

The Product

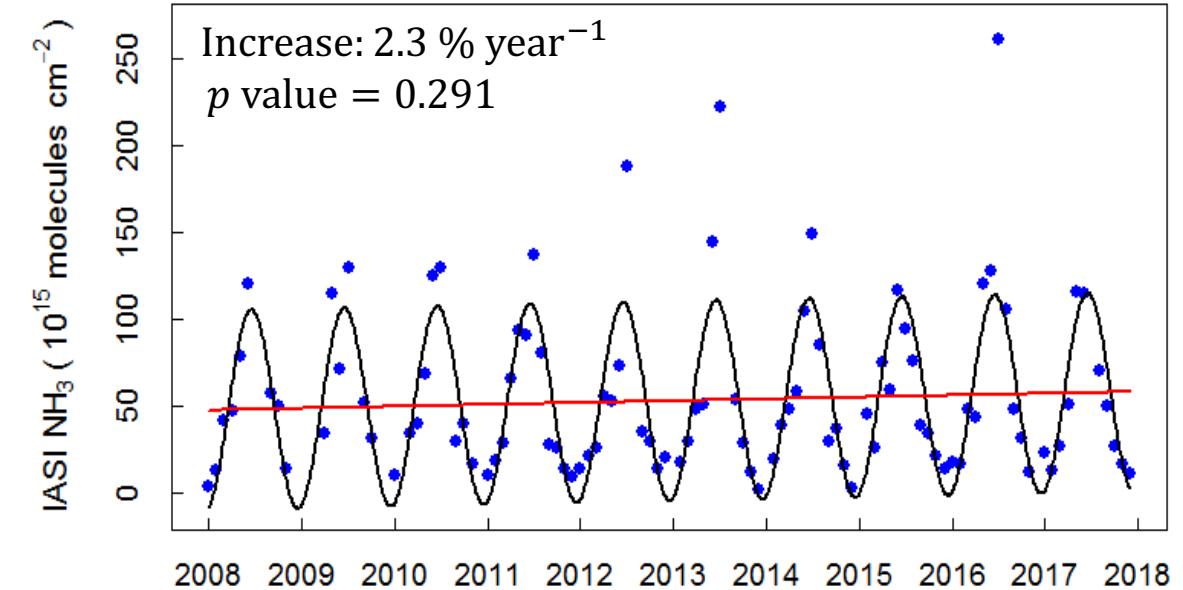
We use robust statistics to derive long-term trends

London NO₂



Decline according to the monitoring network only
1.8% year⁻¹

Delhi NH₃

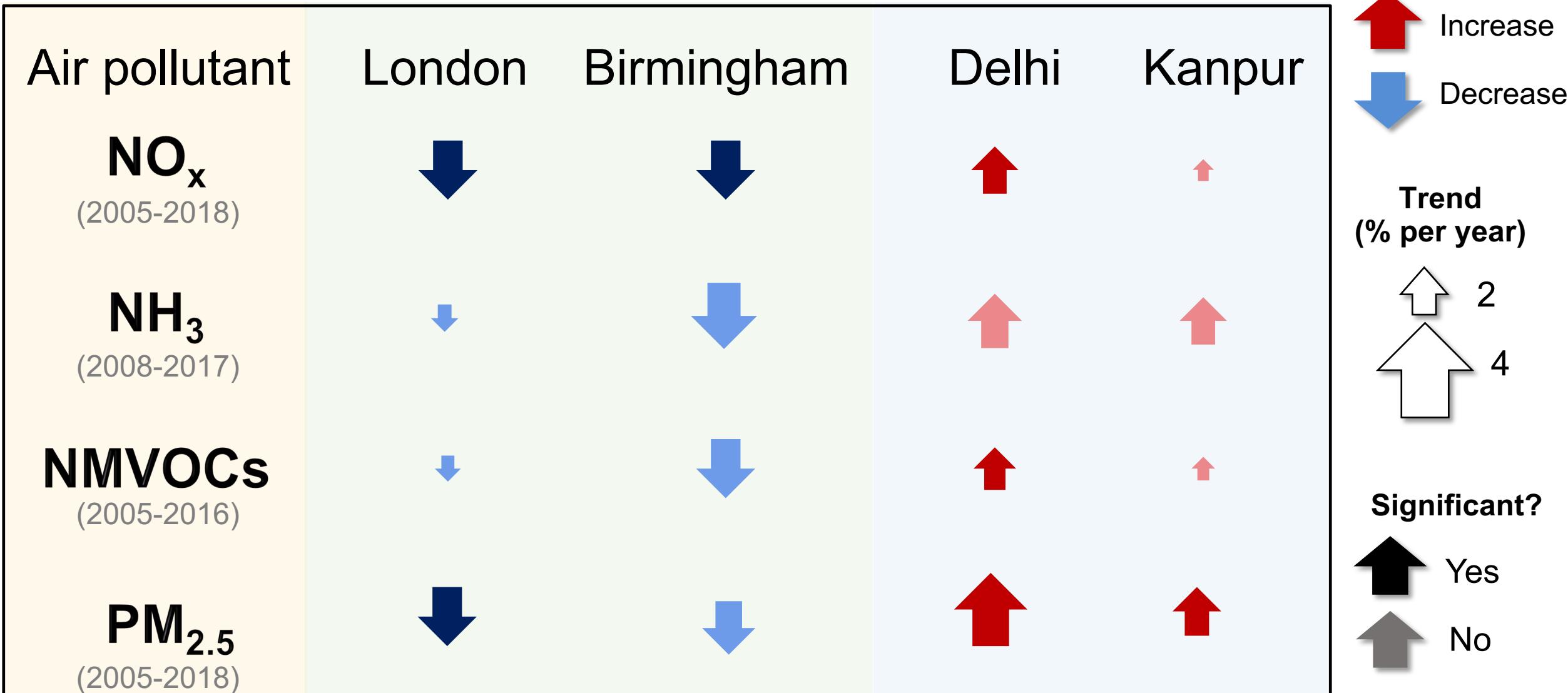


No surface network or publicly available model data to compare to satellite-derived estimate

We apply trend analysis to all atmospheric components in all 4 cities

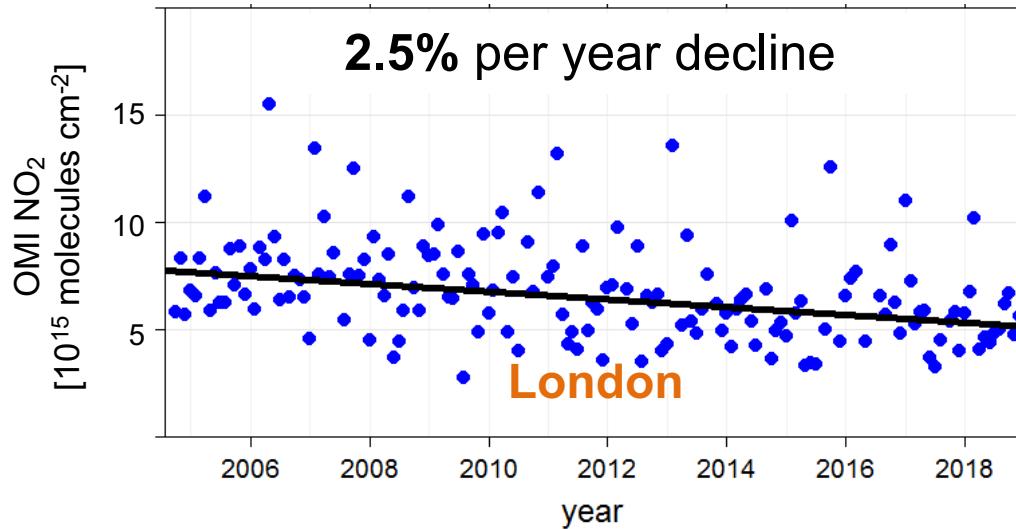
The Product

Long-term trends in pollutants for the four target cities



The Product

Business-as-usual ability to meet air quality standards

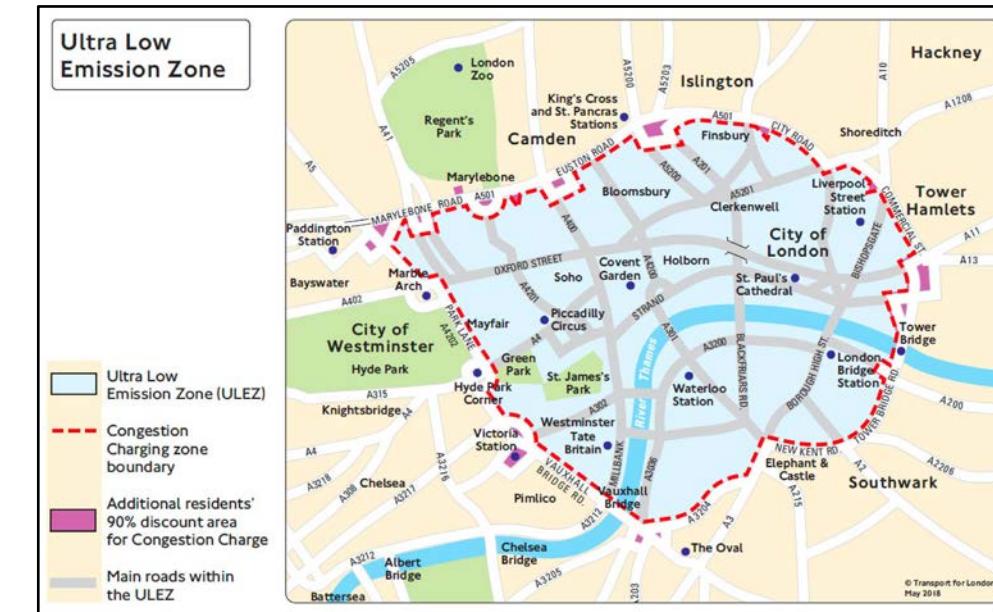


Will the ULEZ be enough to meet targets?

Use TRACE to monitor efficacy of ULEZ

NO₂ standard for UK and India:
40 µg m⁻³ (annual mean)

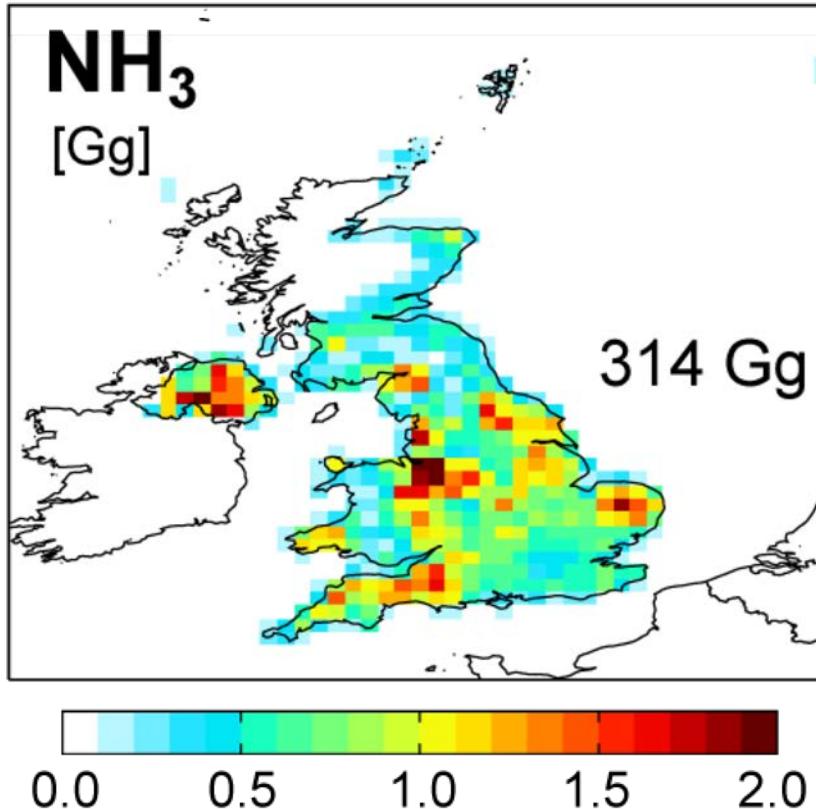
London Marylebone site:
85 µg m⁻³ in 2018
 (current approach will take **45 years** to be compliant)



Ongoing and Upcoming Developments

Improve the UK National Emissions Inventory

UK inventory of NH_3 emissions



>80% from agriculture



Increasingly important precursor of $\text{PM}_{2.5}$



Opportunities to Join The Team

Opportunities posted here: <http://maraismaraisresearchgroup.co.uk/joinus.html>

Current Opportunities:

ESA Living Planet Fellowship (Closes 1 November):

<https://eo4society.esa.int/2019/09/04/call-for-lpf-research-proposals-2019/>

Schlumberger Faculty for the Future (Closes 7 November):

<https://facultyforthefuture.net/>

Near-Future Opportunities:

NERC CENTA Doctoral Training Programme (opens November 2019):

<http://www.centa.org.uk/>

Contact me (eloise.marais@le.ac.uk) if interested/willing in providing CASE support

ERC postdoctoral researcher (advertising opens soon)

Thank you for your time!



TRACE