

Using Satellites to Monitor Air Quality in Cities



TRACE

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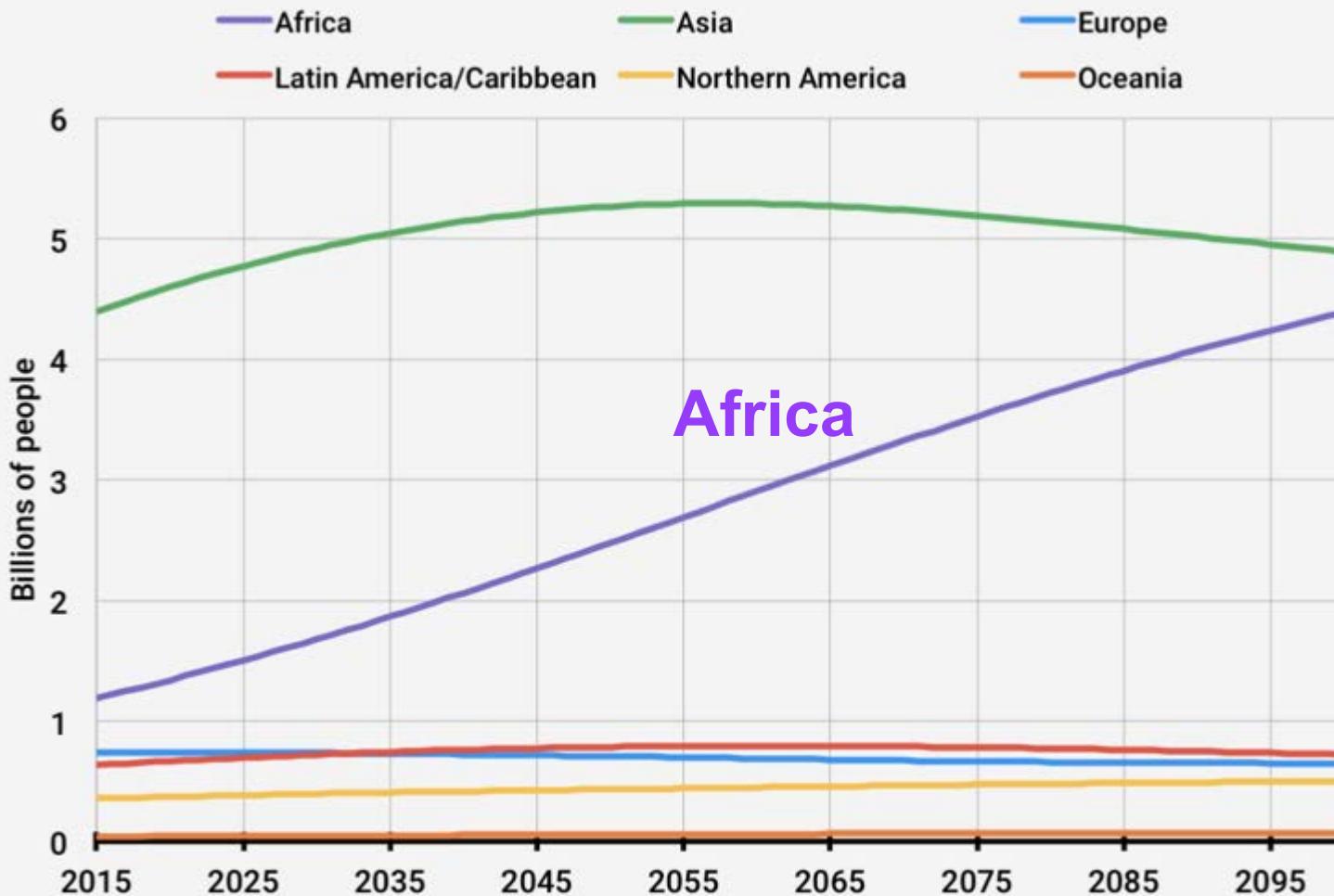
with PhD students **Alfred Bockarie** and **Karn Vohra**

Part One

**Building Capacity to Assess the Impact of Air
Quality on Health in Africa**

Africa's Population is Growing Rapidly

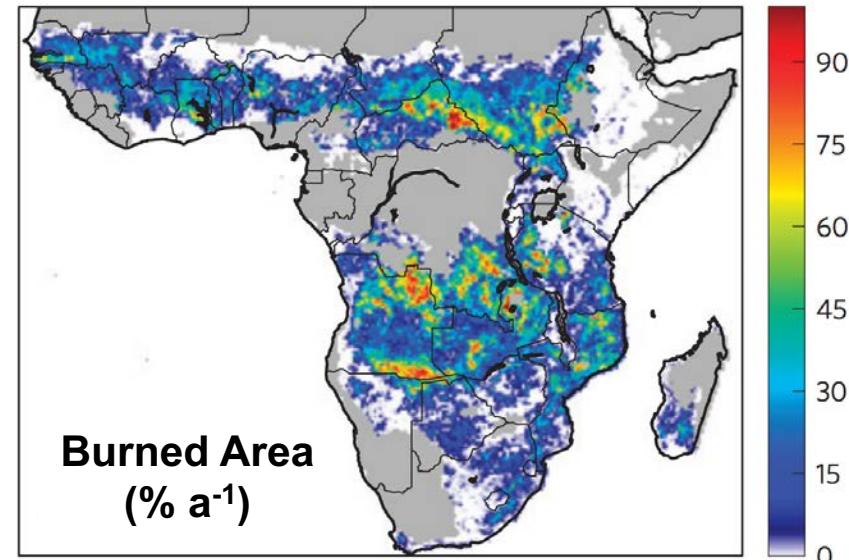
Population projections, 2015-2100



[UN, 2015]

Sources of Inefficient Combustion in Africa

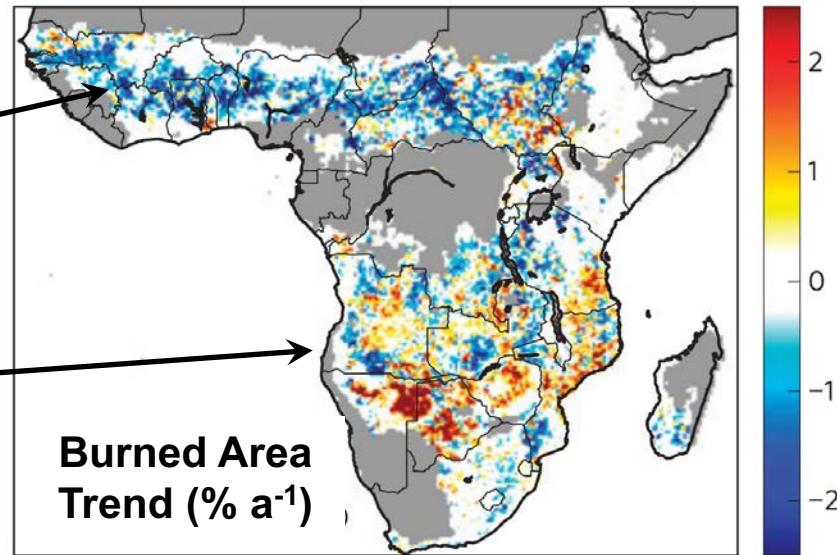
Open Fires



Burned Area
(% a⁻¹)

Trends driven by cropland expansion

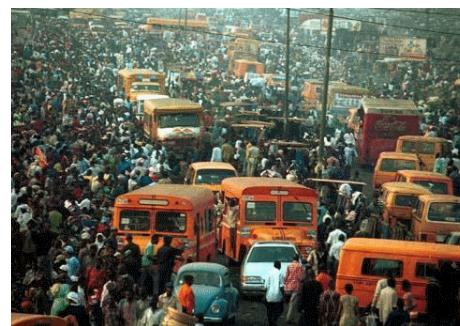
Variability attributed to decadal oscillations



Burned Area
Trend (% a⁻¹)

Sources of Inefficient Combustion in Africa

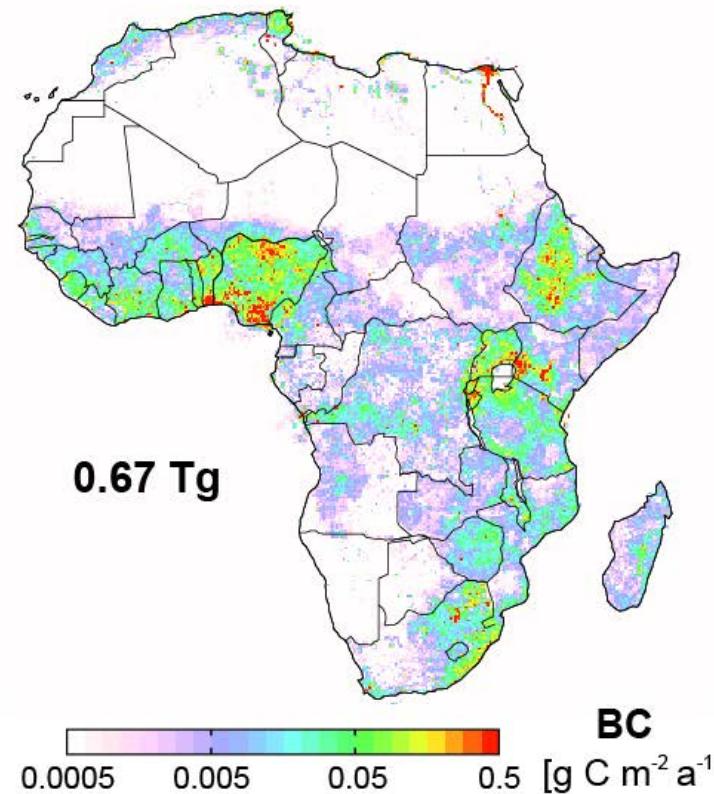
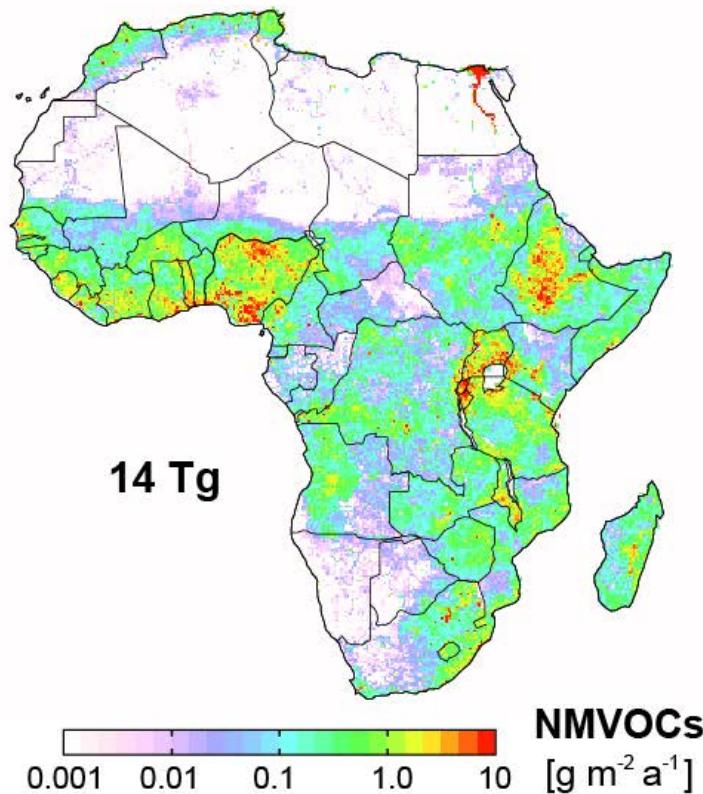
Anthropogenic Activity



Building Capacity to Model Anthropogenic Emissions in Africa

DICE-Africa

(Diffuse and Inefficient Combustion Emissions in Africa)

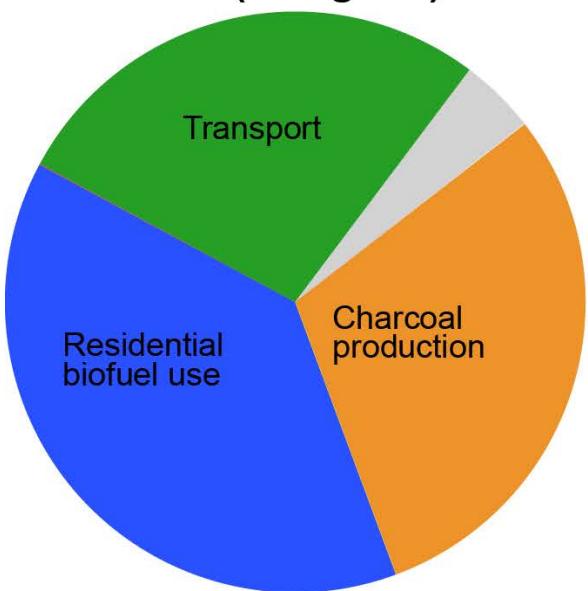


[Marais and Wiedinmyer, 2016]

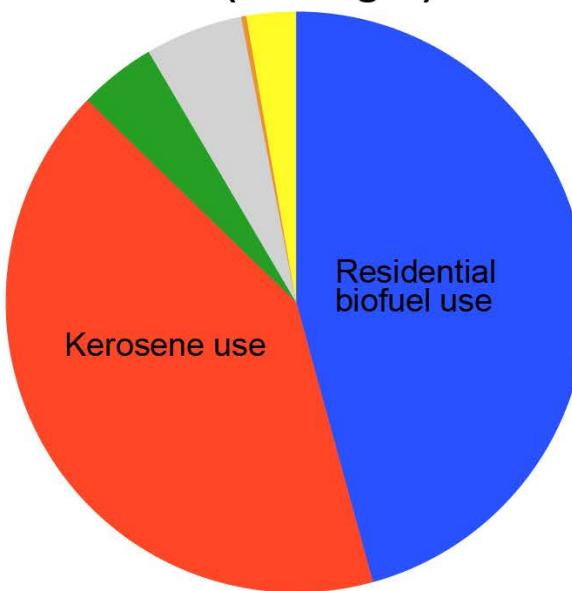
Building Capacity to Model Anthropogenic Emissions in Africa

Sector Emissions from DICE-Africa

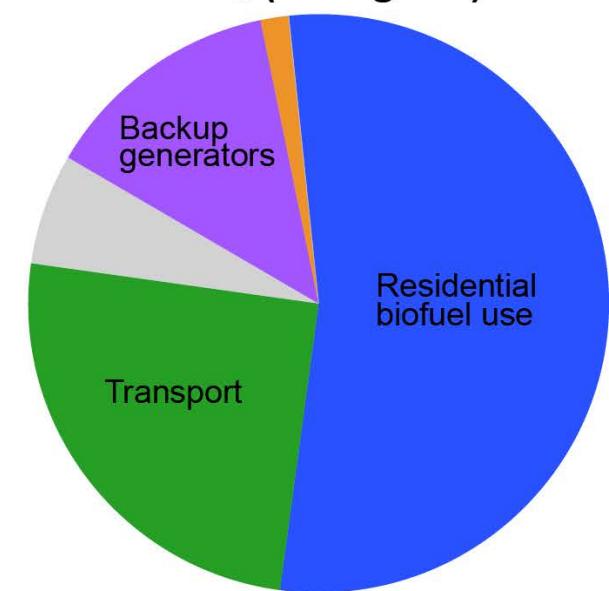
CO (81 Tg CO)



BC (0.67 Tg C)



NO_x (1.0 Tg NO)



■ Residential biofuel use
■ Commercial biofuel use

■ Charcoal production
■ Kerosene use

■ Gas flares
■ Transport

■ Backup generators

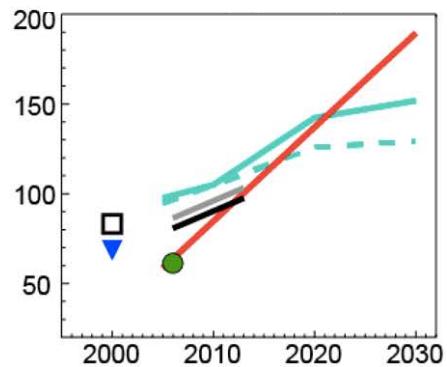
Residential biofuel use dominates all chemical species emissions

BC and CO emissions similar in magnitude to open fire emissions

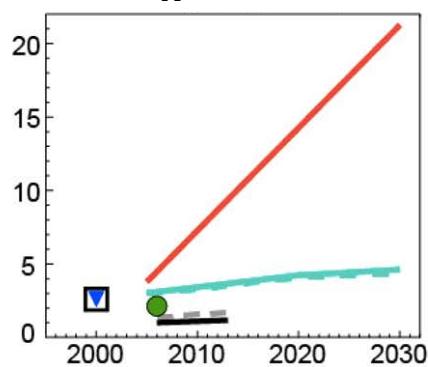
NO_x emissions very low (high ozone production efficiencies)

Emissions Trends and Projections for Africa

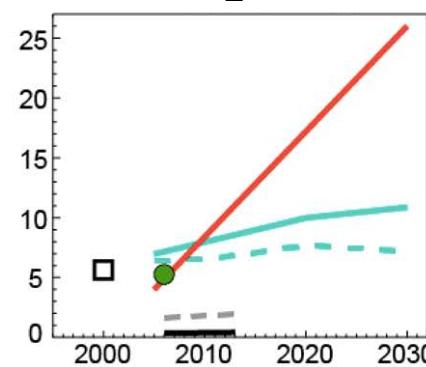
CO (Tg)



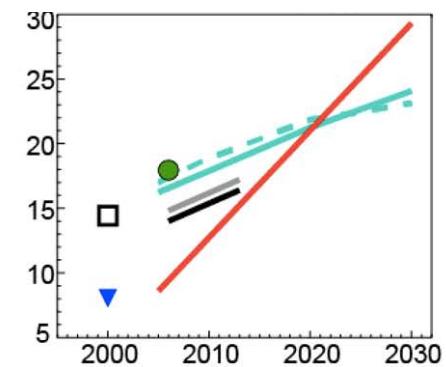
NO_x (Tg NO)



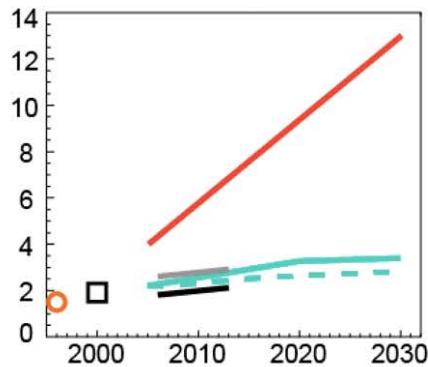
SO₂ (Tg)



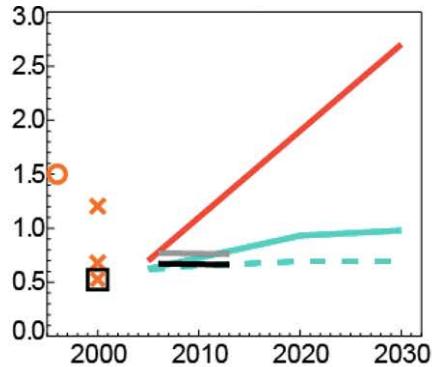
NMVOCs (Tg)



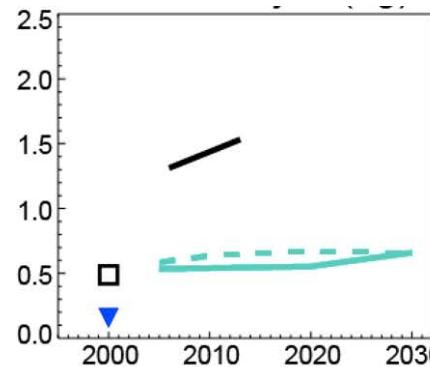
OC (Tg C)



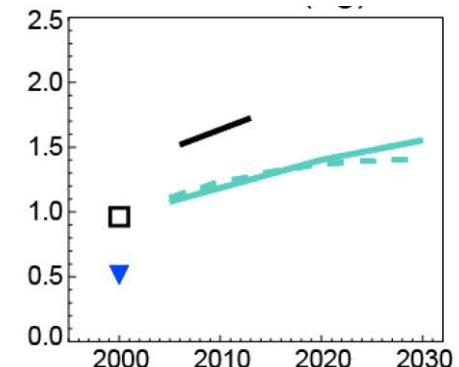
BC (Tg C)



HCHO (Tg)



Benzene (Tg)



— DICE-Africa

— RCP 4.5

○ Bond et al. (2004)

--- This study + hard coal

--- RCP 8.5

× Bond et al. (2013)

— This study + trash burning

● EDGAR v4.2

□ ACCMIP

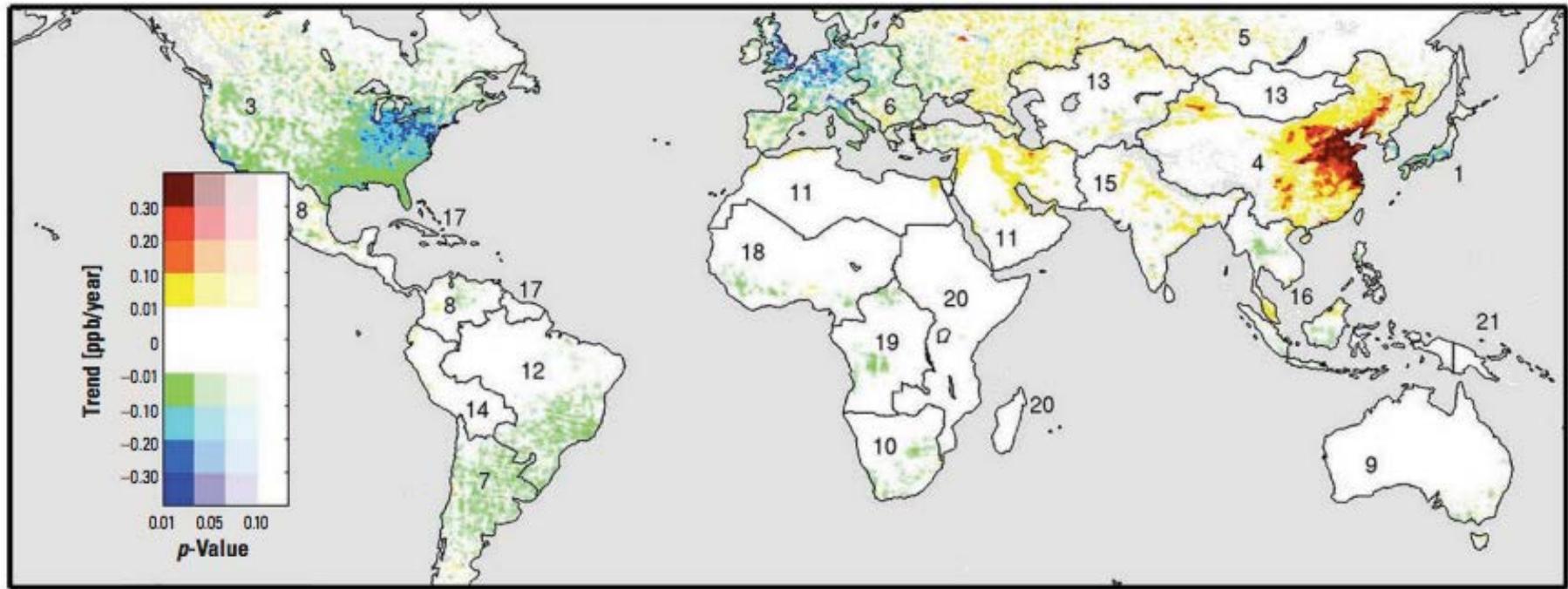
— Liousse et al. (2014)

▼ RETRO v2

Wide range of emissions trends and projections. Which is correct?

No trend in satellite record

Trends in surface NO_2 inferred with satellite NO_2



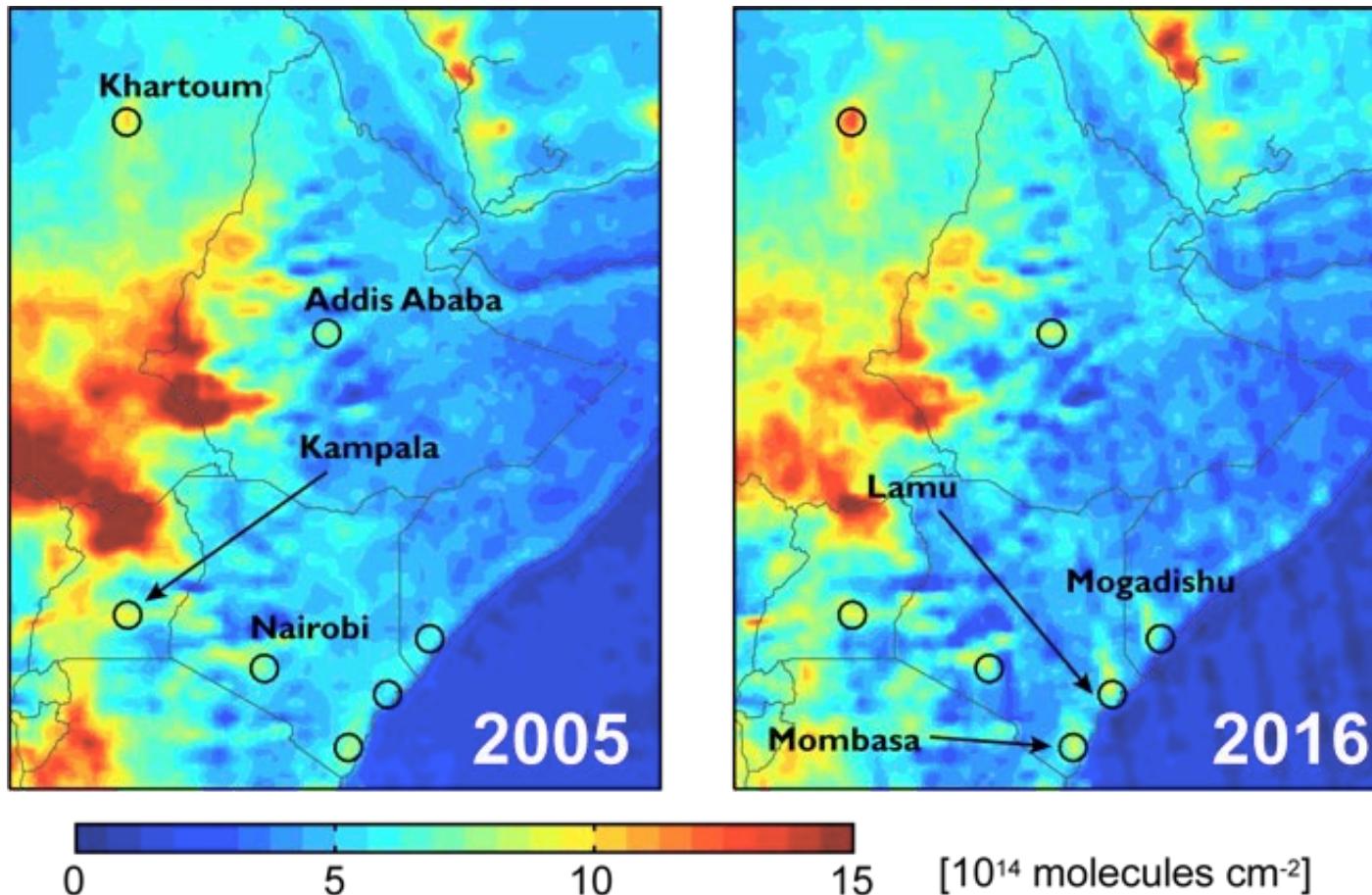
[Geddes et al., 2016]

Surface NO_2 inferred with GOME, SCIAMACHY, and GOME-2

Trend in Africa muted and opposite to what's projected

Some evidence of increases in NO₂

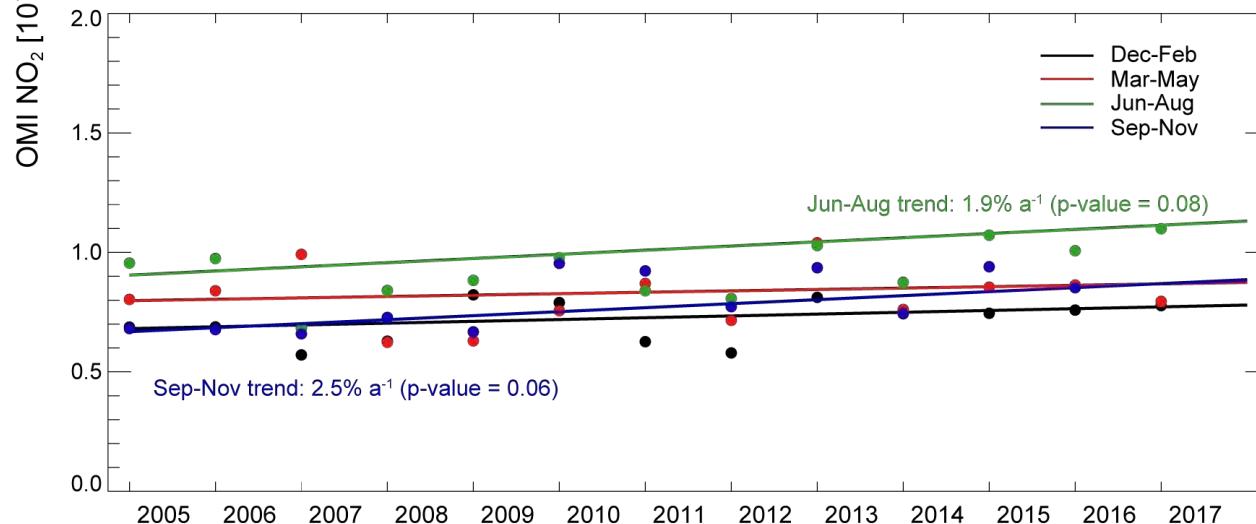
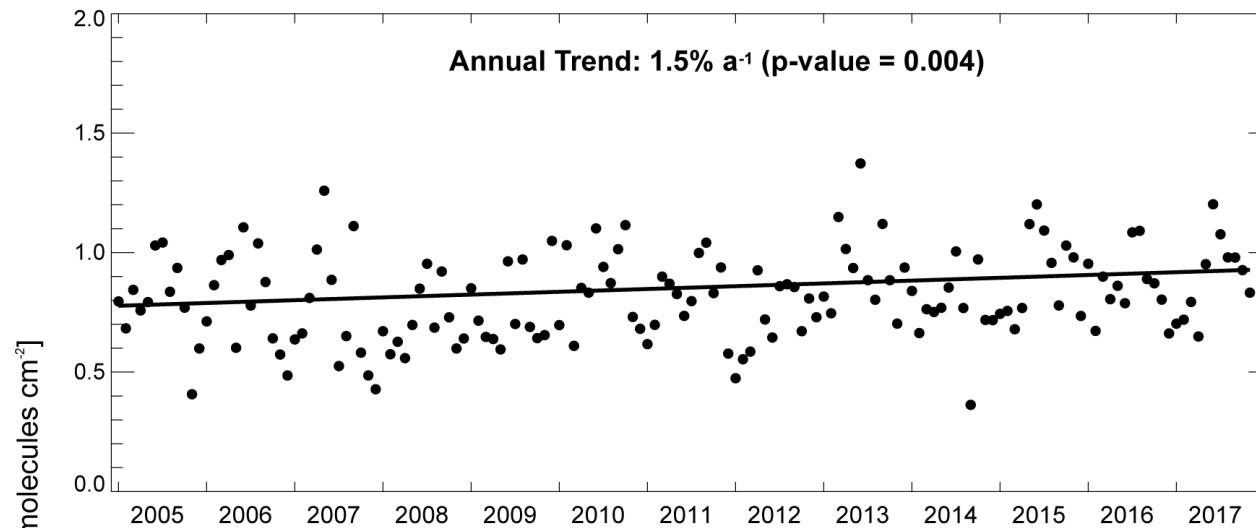
East Africa annual mean OMI NO₂



Increase in OMI NO₂ in cities and at ports, but column concentrations are low.

Trend Estimate for Addis Ababa

Trends in OMI tropospheric column NO₂ in Addis Ababa from 2005 to 2017



NO₂ concentrations in UK cities are at least double that in Addis Ababa

Inventory of air pollution from charcoal production, use, transport

Production increasing at 6-9% per year

Most charcoal used in-country.
Some exported (South Africa, Namibia, Somalia).



Production



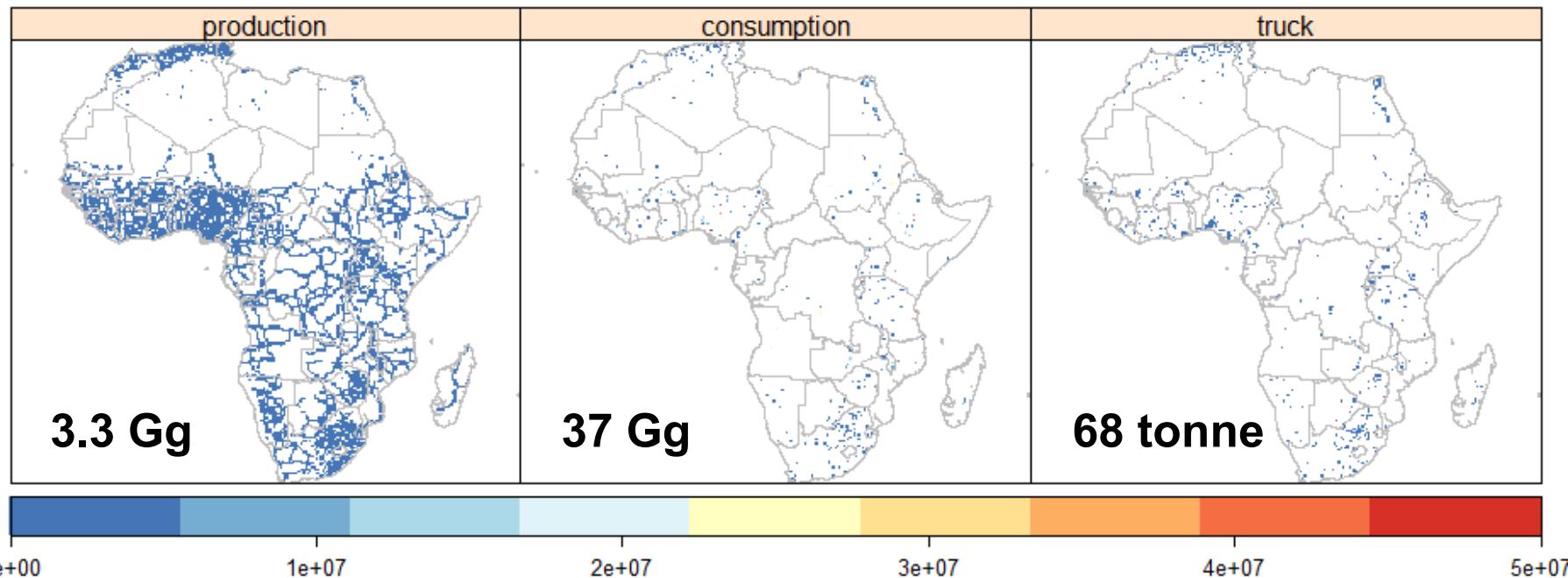
Transport



Use

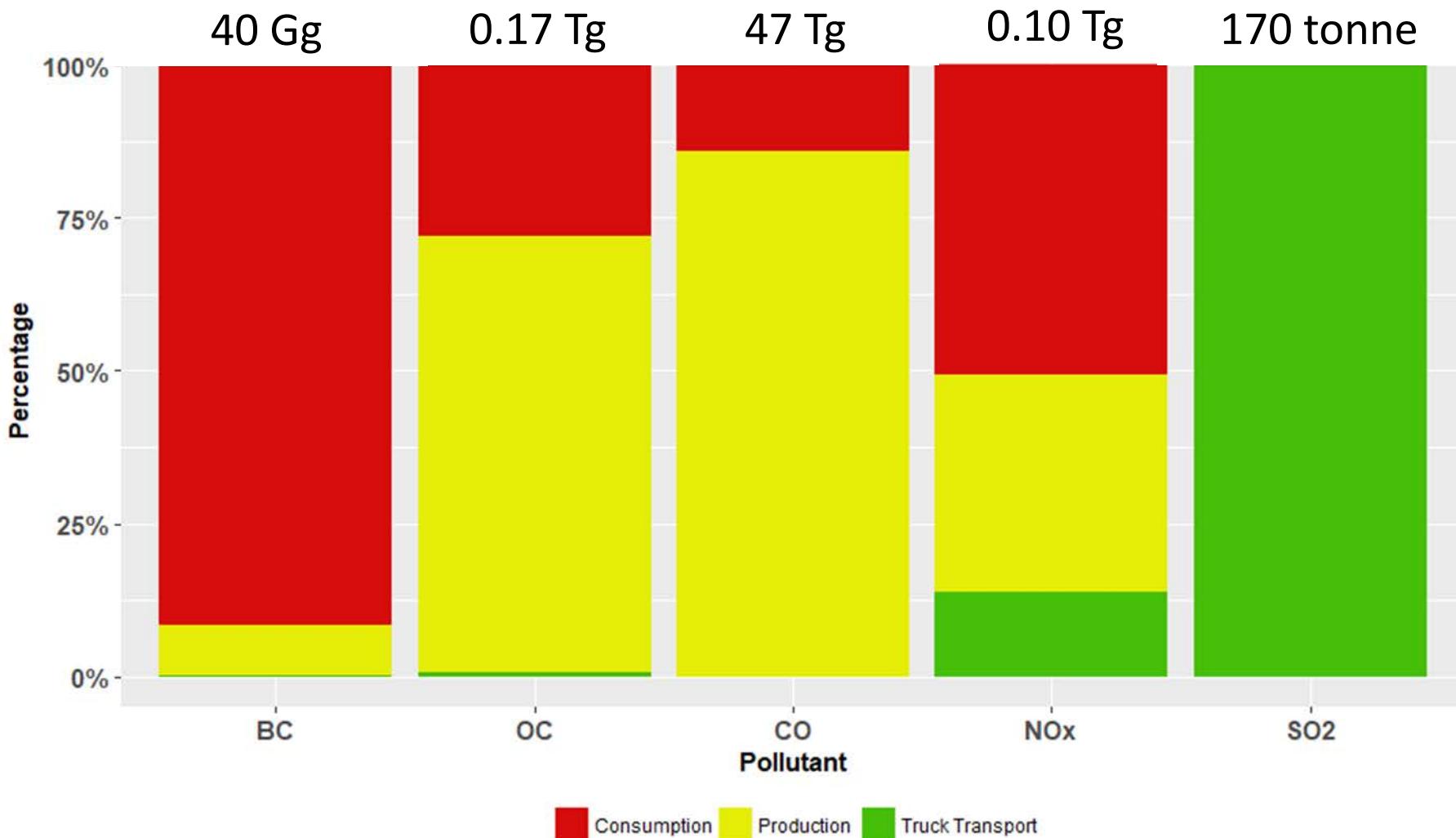
Spatial Distribution of Pollutants

Black carbon (BC) Emissions in grams per gridsquare



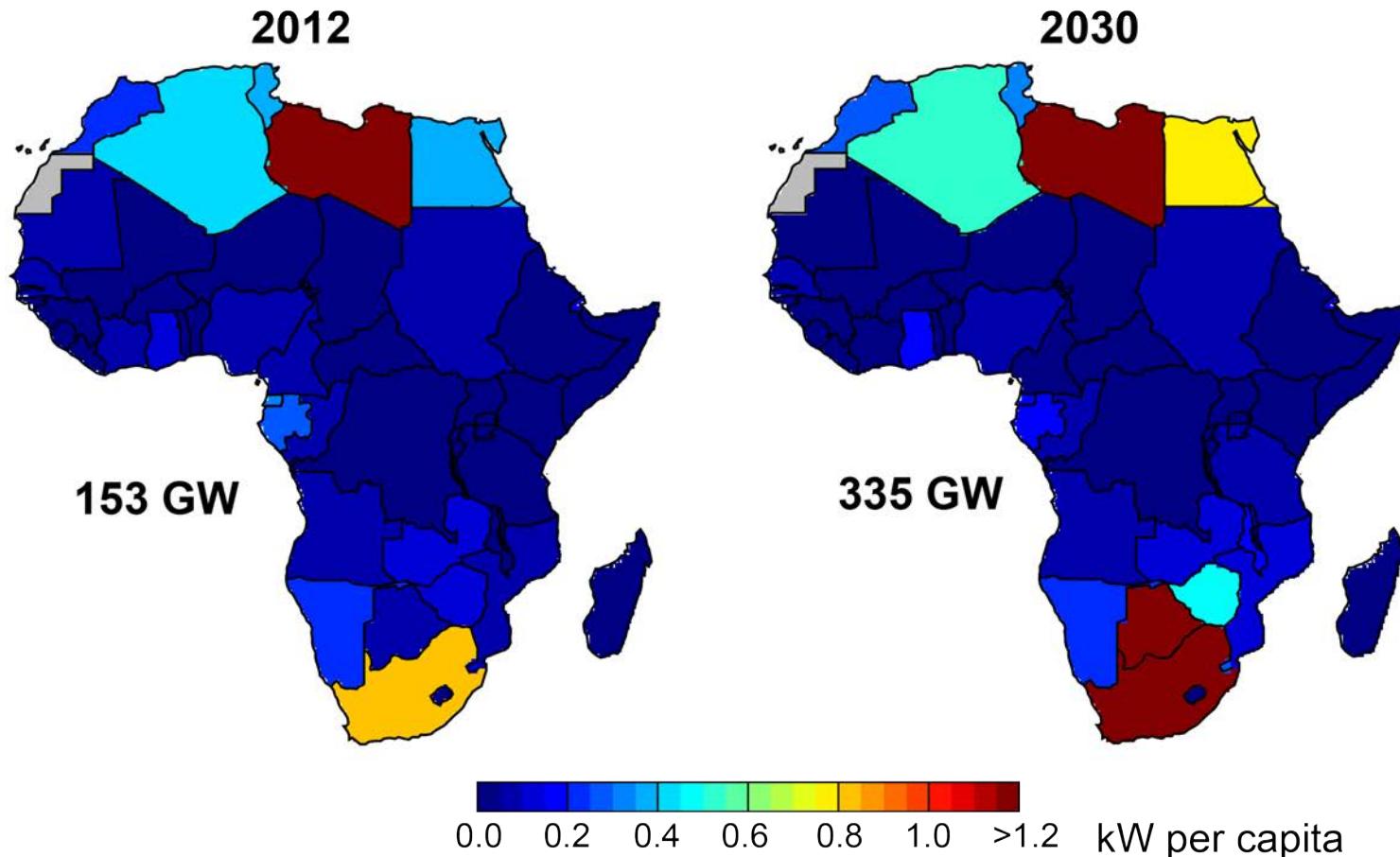
Emissions are on a $0.1^\circ \times 0.1^\circ$ grid

Contribution of activities to pollutant emissions



Future Fossil Fuel Impact on Health

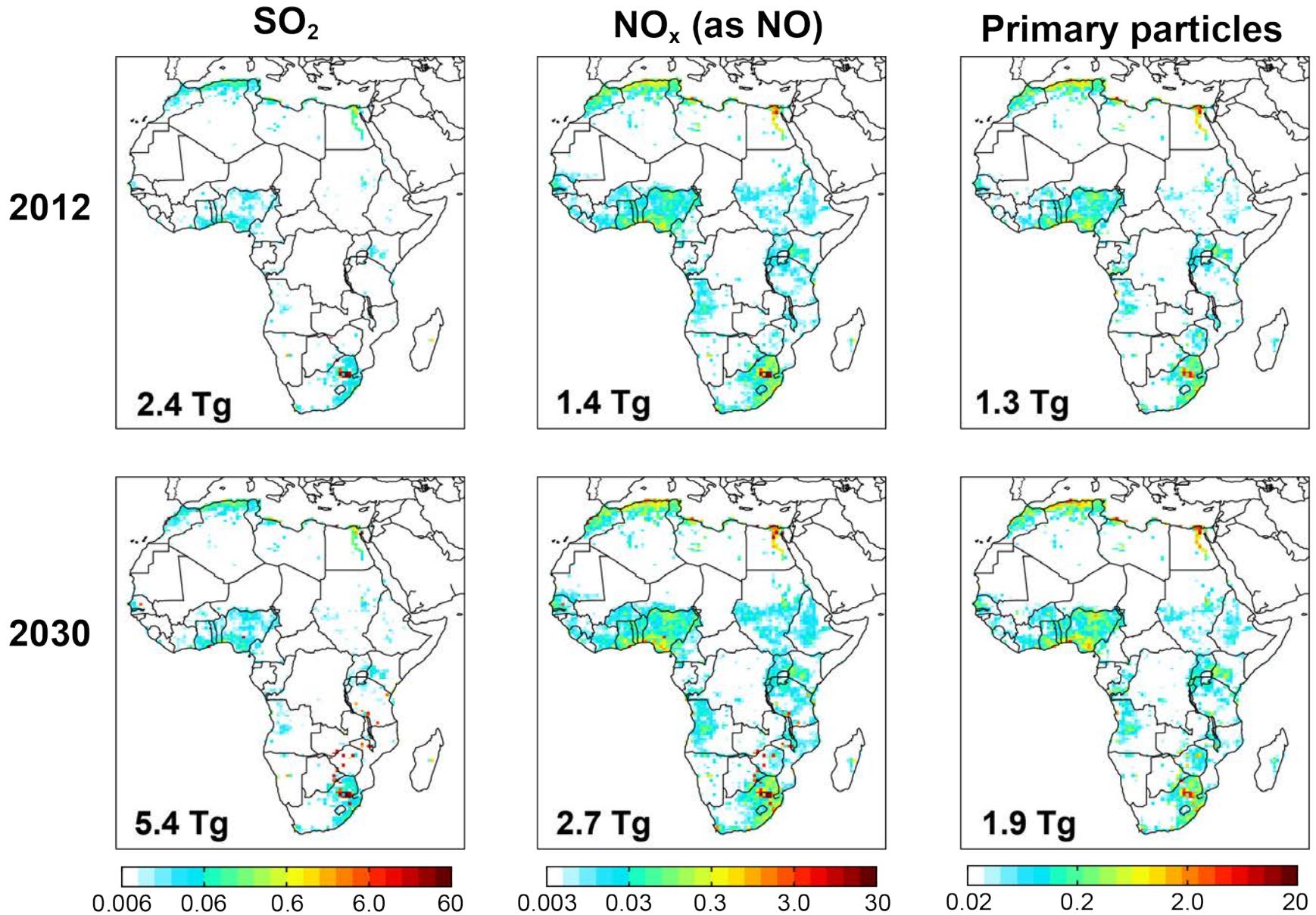
Per capita generating capacity



2012-2030 installed capacity increase: 120%

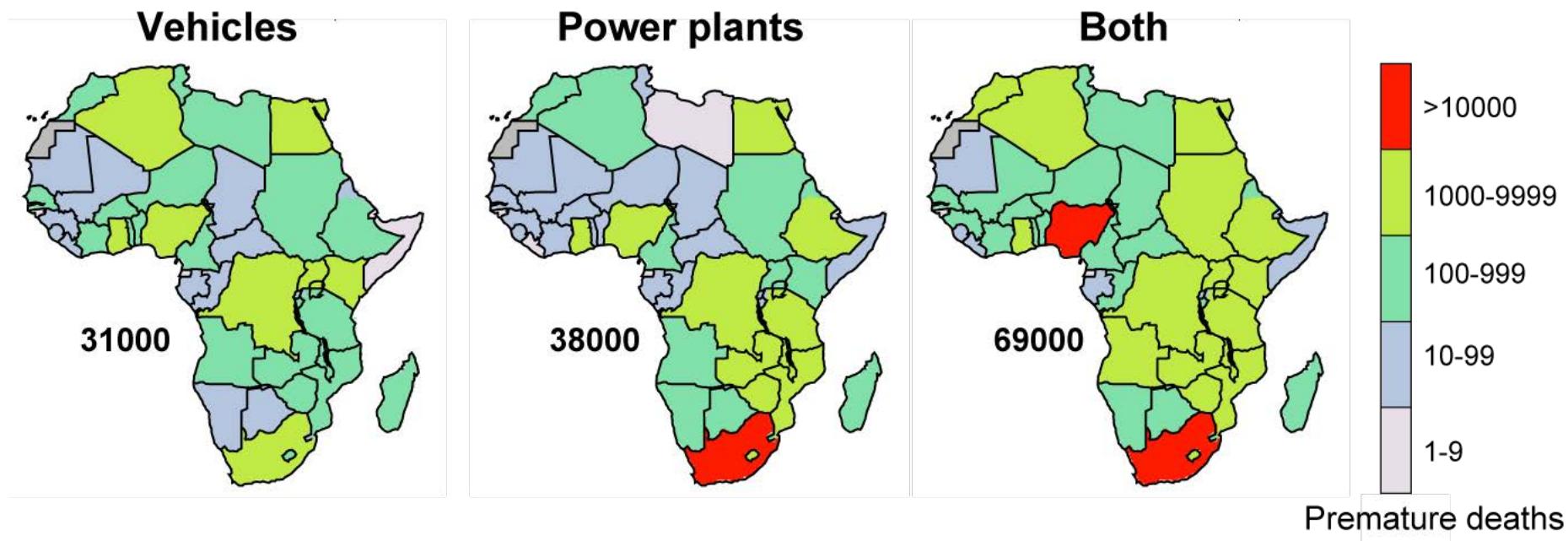
2012-2030 population increase: 54%.

Air Pollution Emissions ($\text{g m}^{-2} \text{ a}^{-1}$)



Health Burden for People > 14 years

Additional deaths in 2030 due to exposure to fine particles (PM_{2.5})



Large proportion of health burden can be attributed to population increase

Part Two

Air Quality Monitoring with Satellite Observations

Debilitating Fines for Infringements

UK given days to show it will comply with EU air quality laws

UK and eight other states will need to take drastic measures on illegal air pollution to avoid court referrals next week, says EU



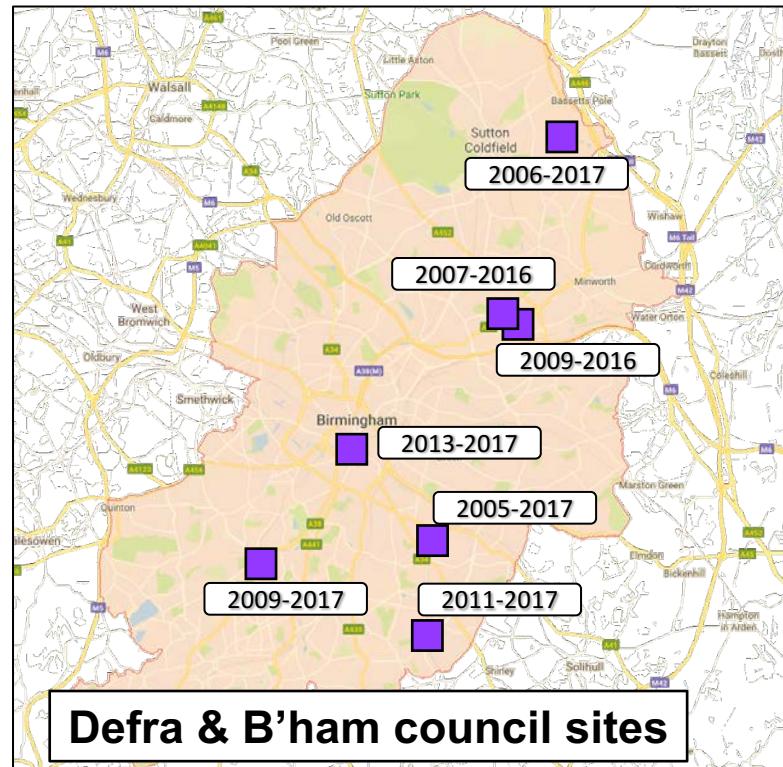
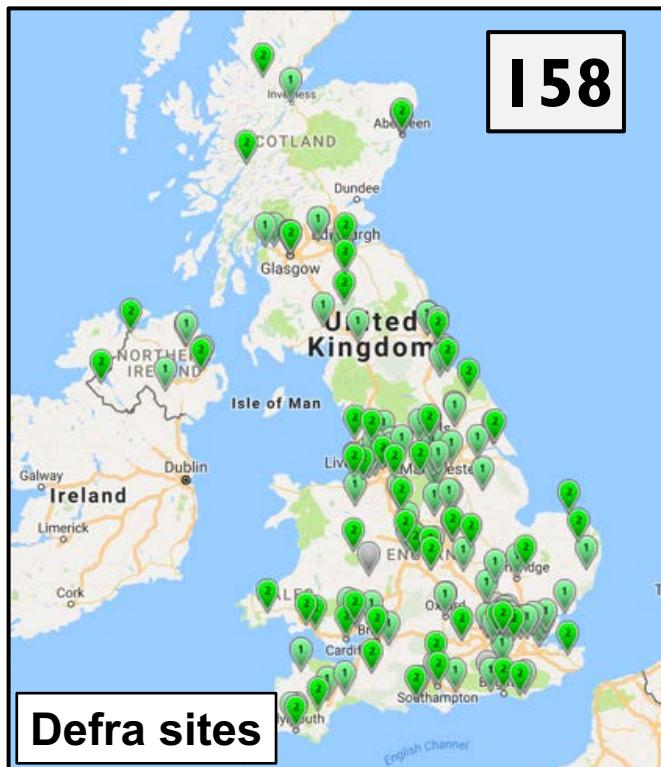
The
Guardian

UK and city councils face fines of millions of GBP

Air Pollution and Green Space Monitoring in Cities

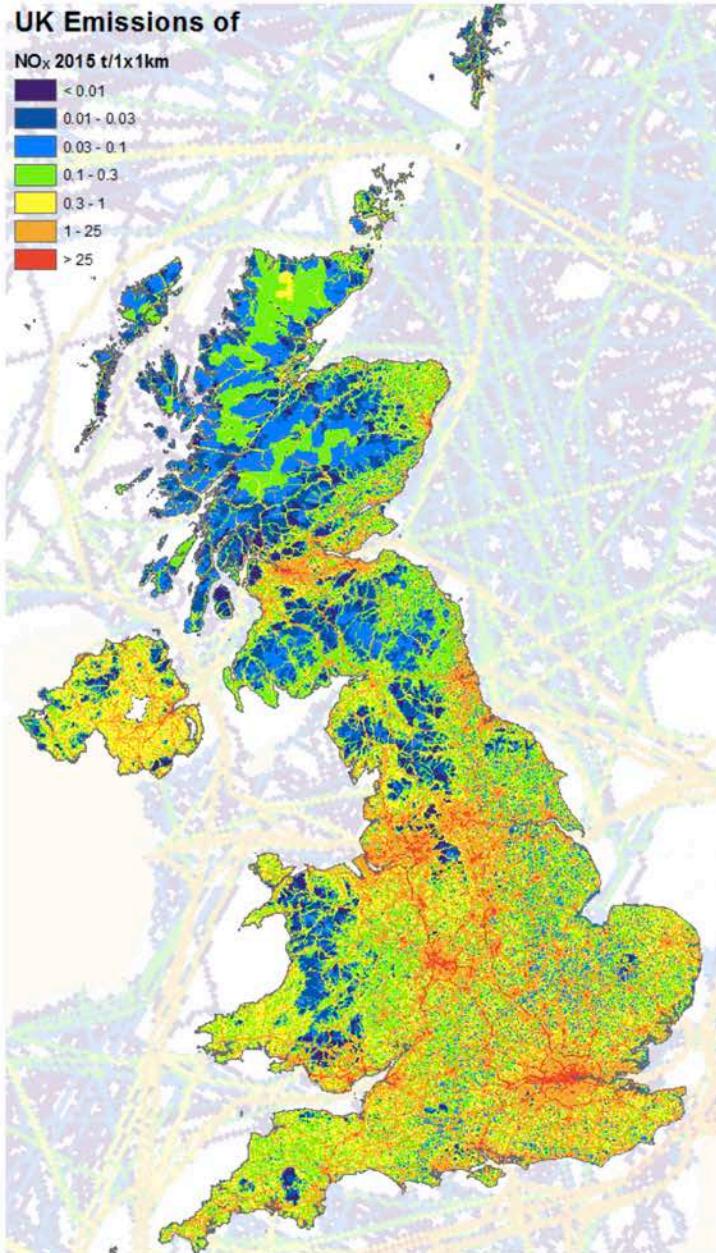
COSTLY to MONITOR

£52,000-£173,000 per monitor



LARGE GAPS

Long-term Changes in Emissions

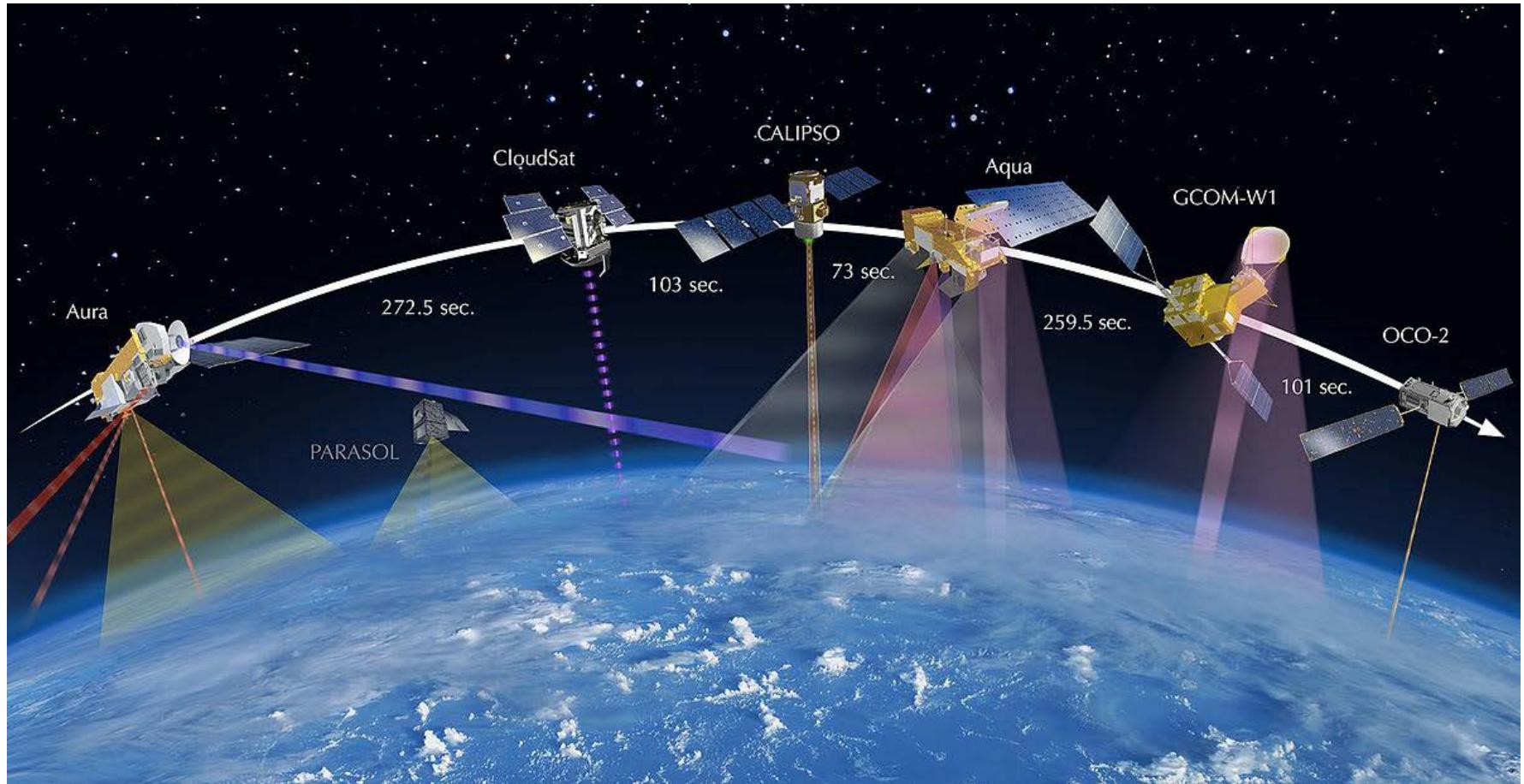


UK Emissions of NO_x in 2015

Missing information:
long-term changes in pollution sources

Satellite observations as the Solution

NASA Afternoon-Train (A-Train)



Long record of diverse observations

12+ years of air pollutants and vegetation dynamics from NASA and ESA satellites

NASA Aura



ESA MetOp-A



NASA Terra



HCHO

NO₂

SO₂

NH₃

CO

AOD

LAI

EVI

○ Air pollutants regulated by EU

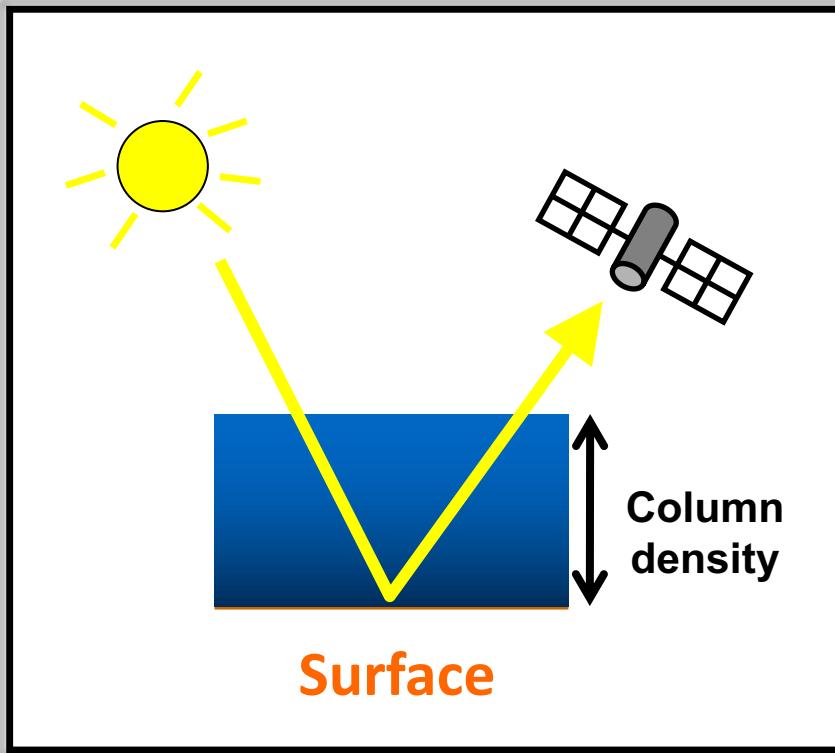
○ Constraints on regulated air pollutants

○ Vegetation extent/cover

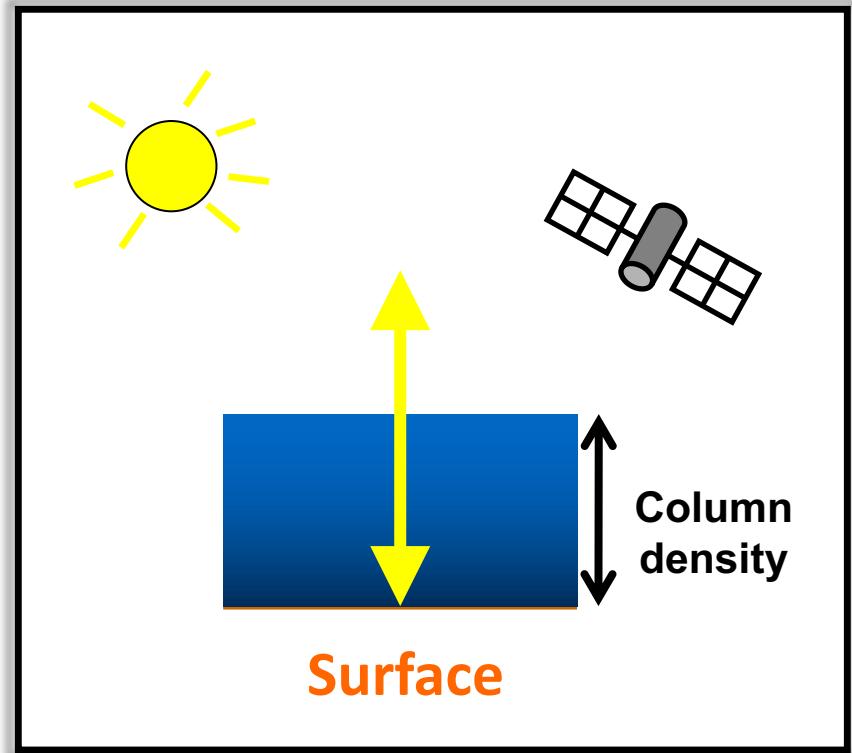
○ Vegetation greenness

Retrieval of Satellite Observations

One: Spectral Fitting



Two: Air Mass Factor



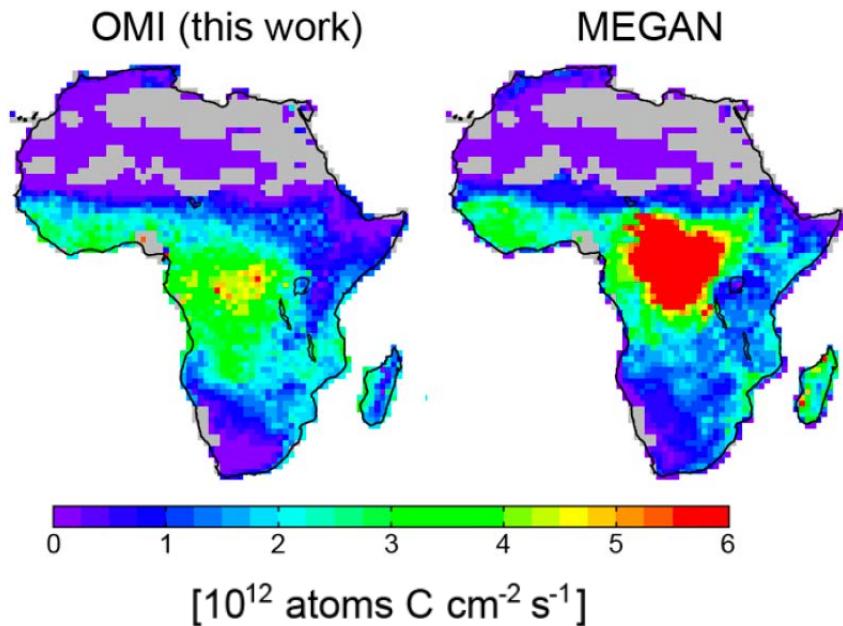
Concentration along viewing path

True vertical column

Challenge: Does variability in column represent variability at the surface?

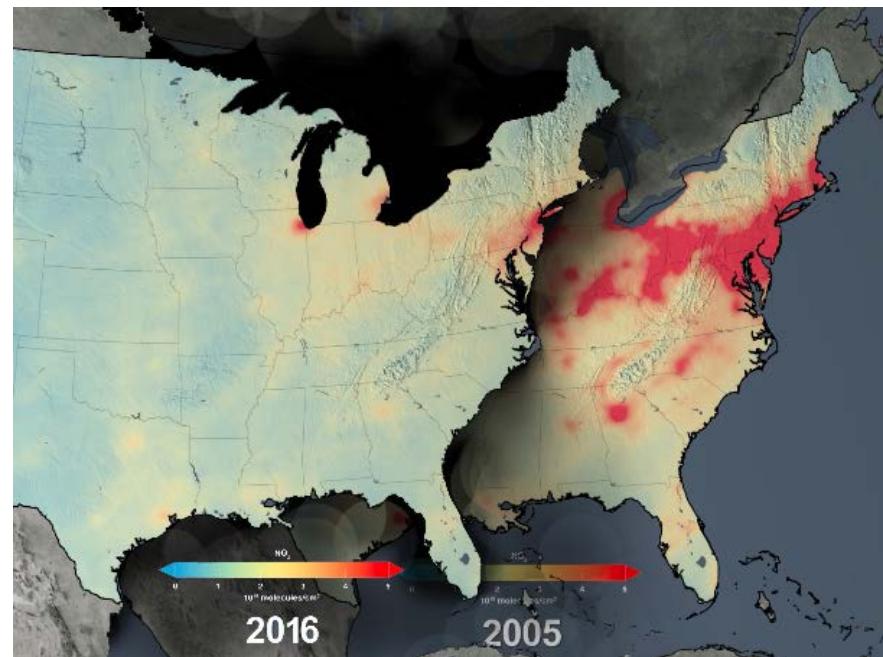
Examples of Constraints on Surface Sources

Biogenic Isoprene Emissions from space-based formaldehyde observations



[Marais et al., 2012; 2014]

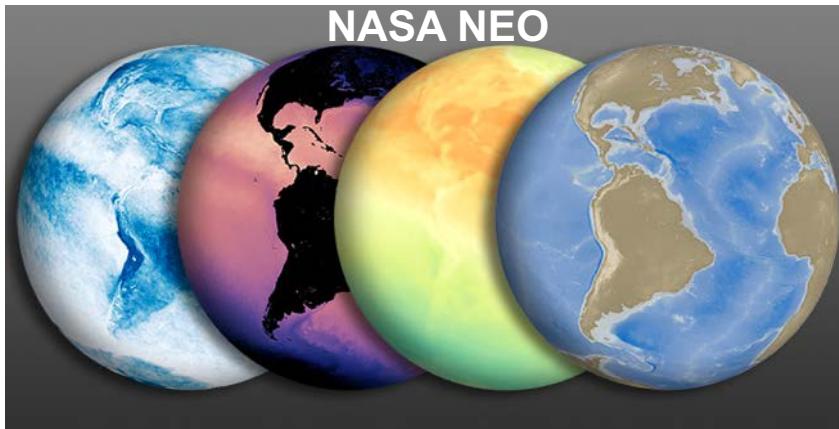
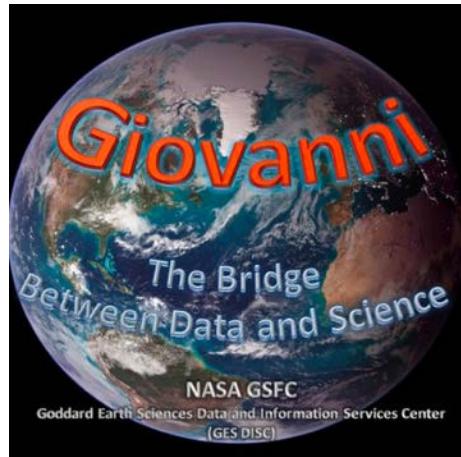
Decline in NO_2 over the Northeast US



[<https://aura.gsfc.nasa.gov/science/gallery-omi.html>]

The link between policymakers and scientists is often tenuous.

Increasing Number of Online Tools



Tool for Recording and Assessing the City Environment



TRACE

**Online database of air pollution concentrations
and vegetation dynamics from EO to evaluate
AQ and green space at the city level**

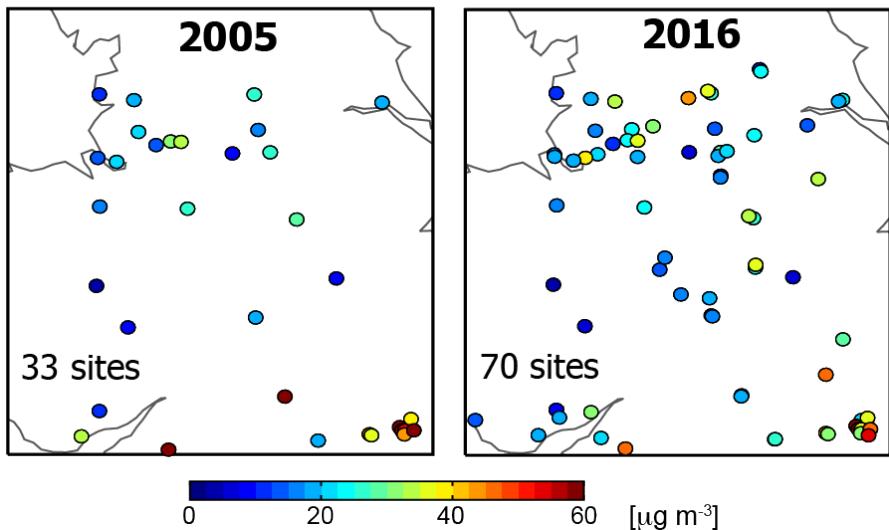
Developed with Involvement of Multiple Sectors



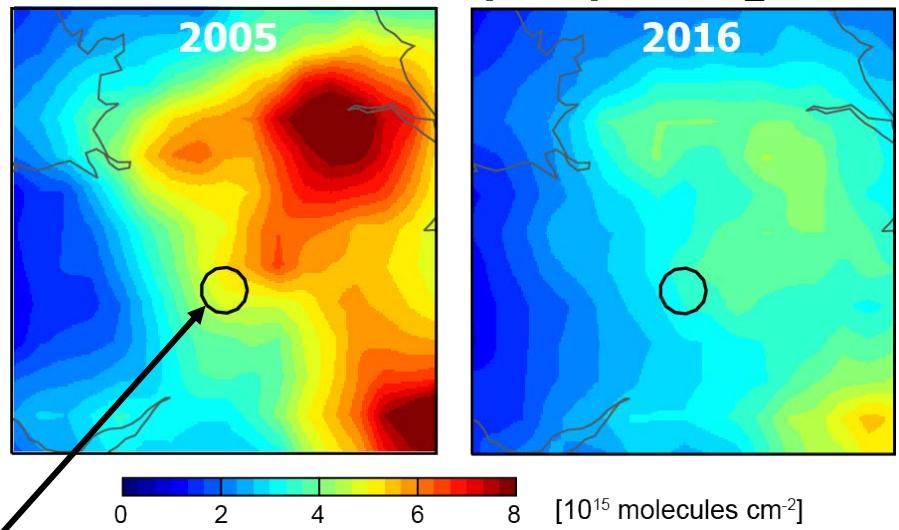
Complete coverage achieved with EO

NO₂ is a precursor of ozone and fine particles

DEFRA (surface) NO₂



Aura OMI (EO) NO₂

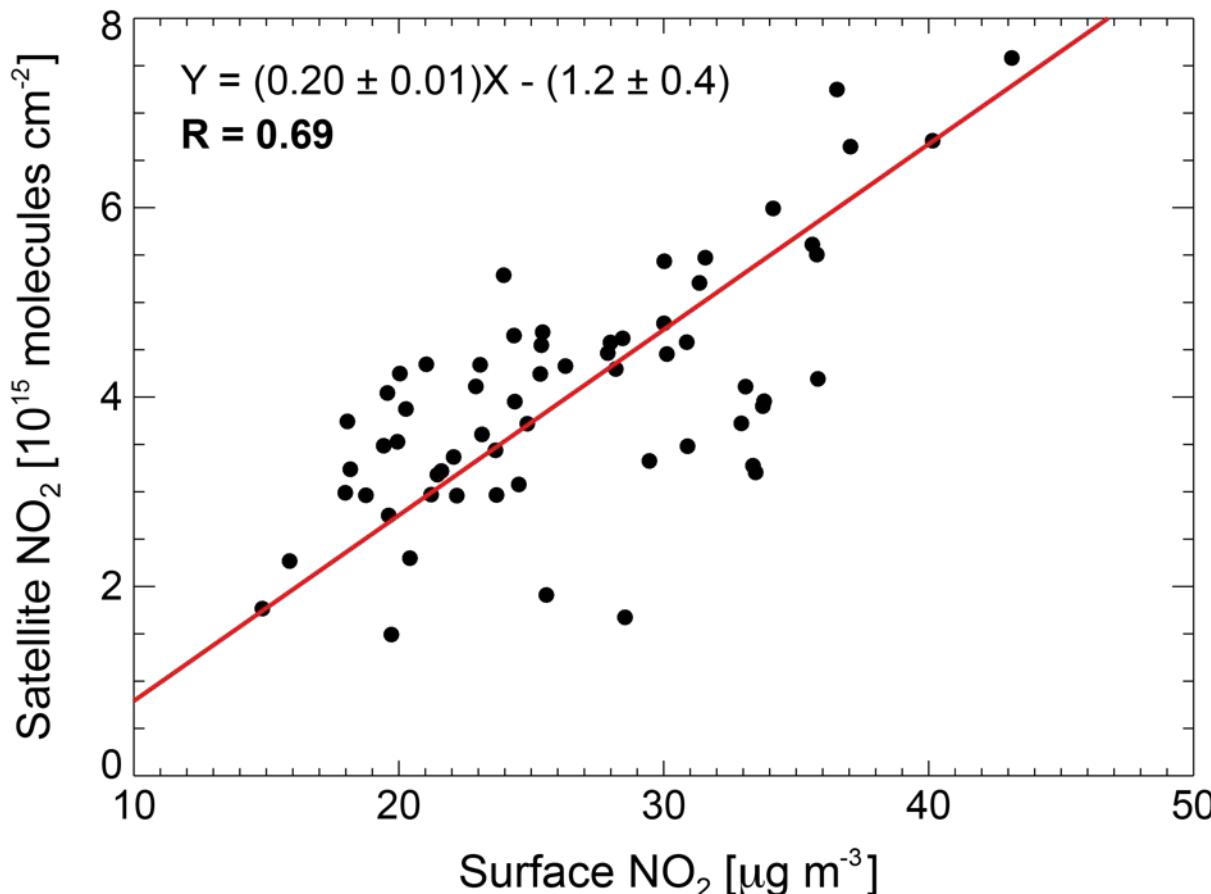


Birmingham: 3% per year decline in NO₂

Validate over Birmingham

UK NO₂ out of compliance with EU standards

Consistency between surface and satellite NO₂:



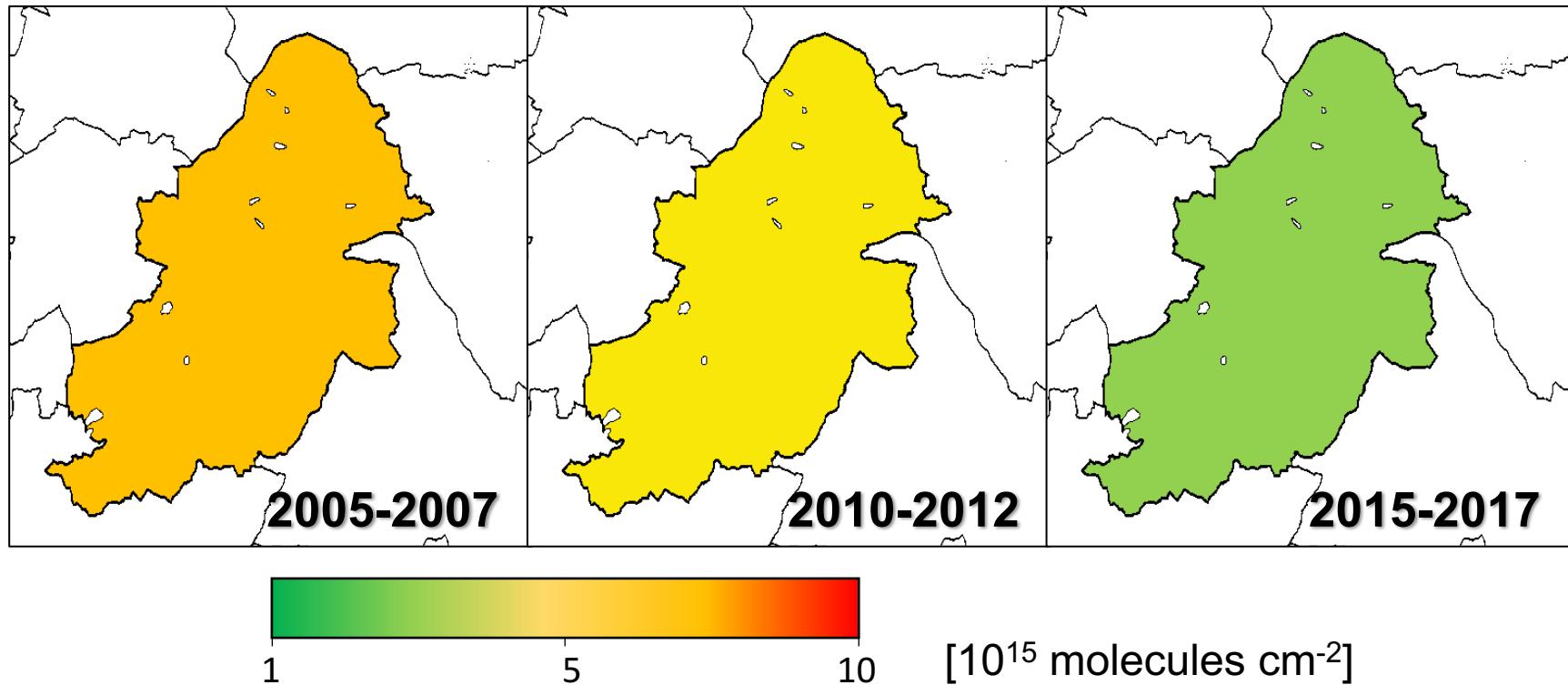
Data analysis by Karn Vohra, PhD student at UoB

Application to Birmingham

Decline in NO₂ over Birmingham

3.4% per year

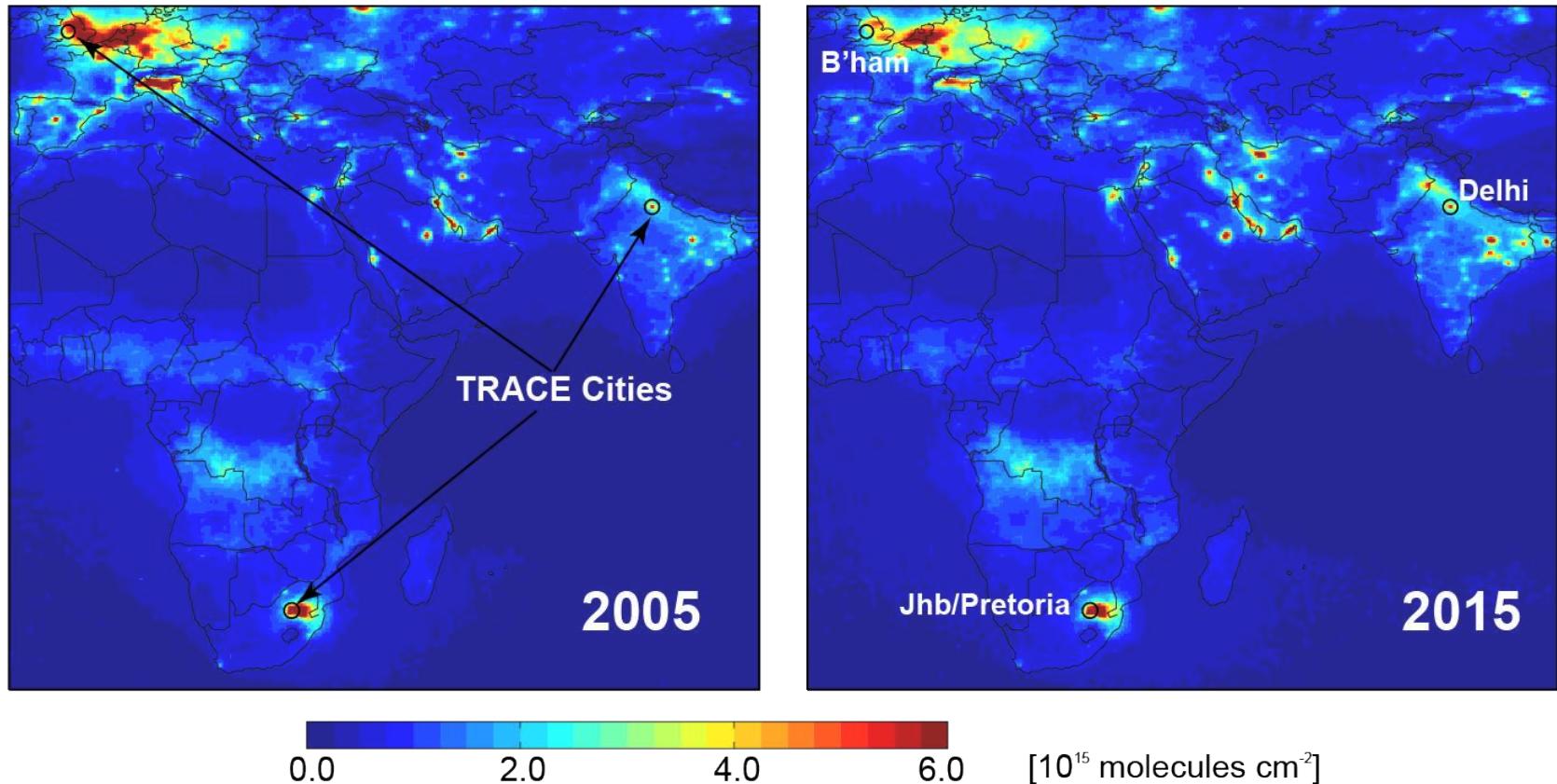
44% from 2005 to 2017



Apply to cities at different development stages

Initial target cities for TRACE

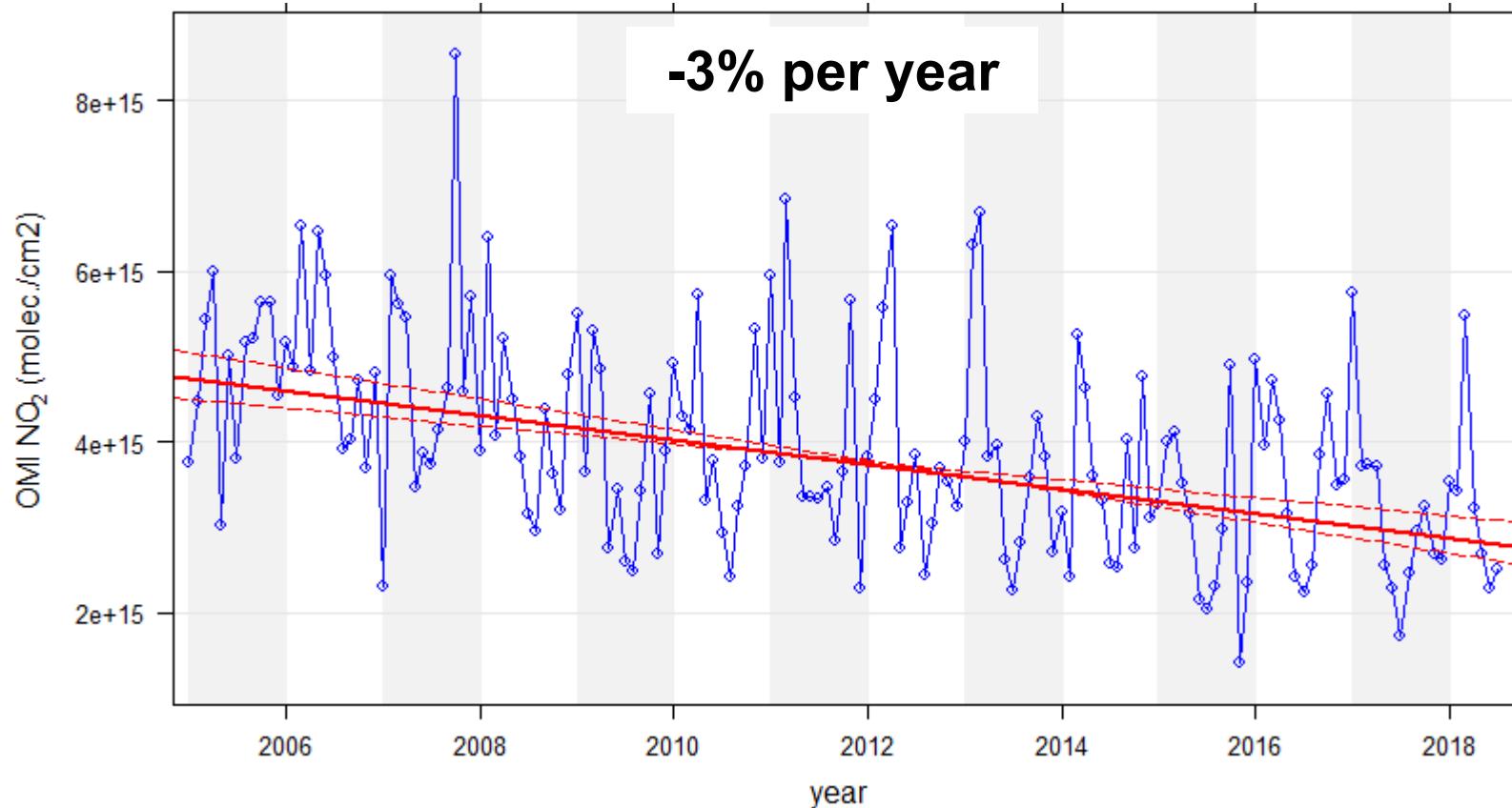
Maps of annual mean OMI NO₂



Now also includes: London, Kanpur and Bengaluru (India)

Initial Application to London

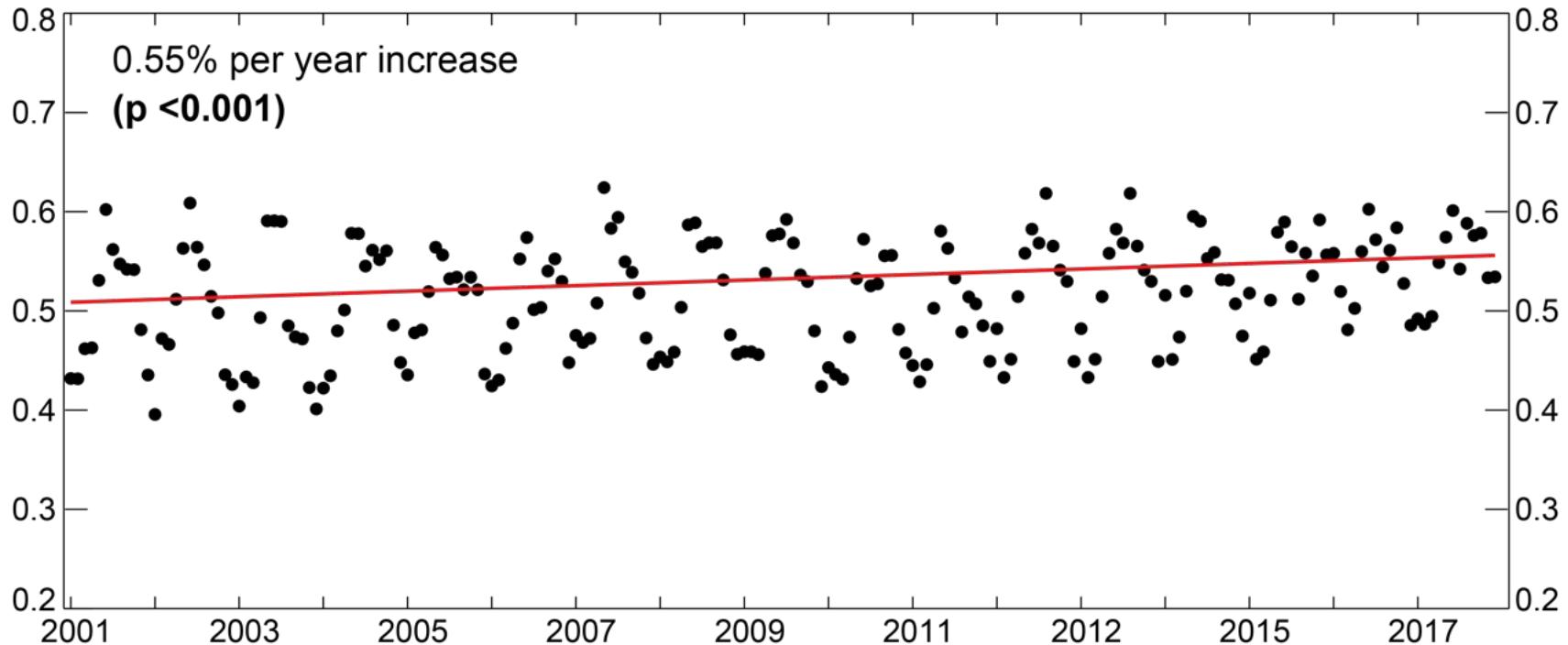
Decline in NO₂ over London similar to Birmingham



Still to be validated with surface observations

Birmingham Vegetation Greenness

Time series of monthly mean MODIS NDVI (vegetation greenness)



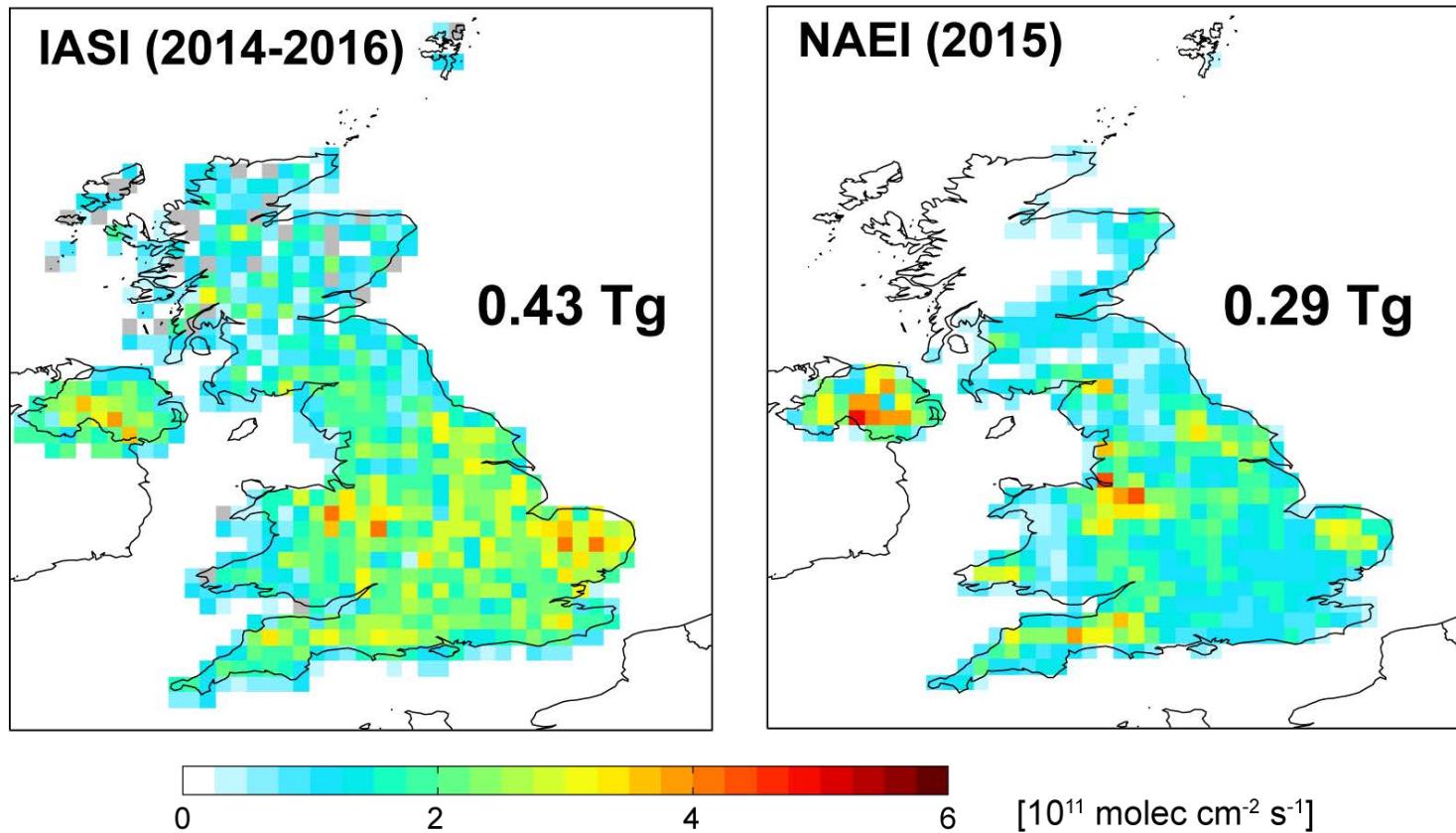
Significant seasonal trends: **1.1%** per year (**winter**), **0.61%** per year (**autumn**)

Implications for health of green spaces and ability to sequester carbon
(climate change)

Constrain Emissions: Ammonia (NH_3)

Ammonia (NH_3) is a precursor of aerosols

Agriculture is the dominant source

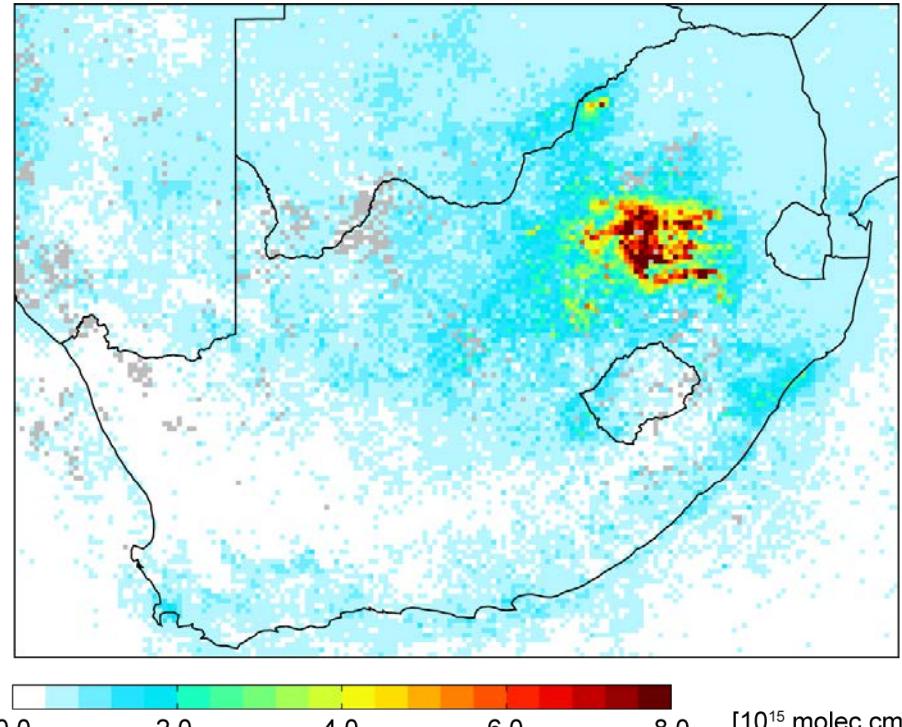
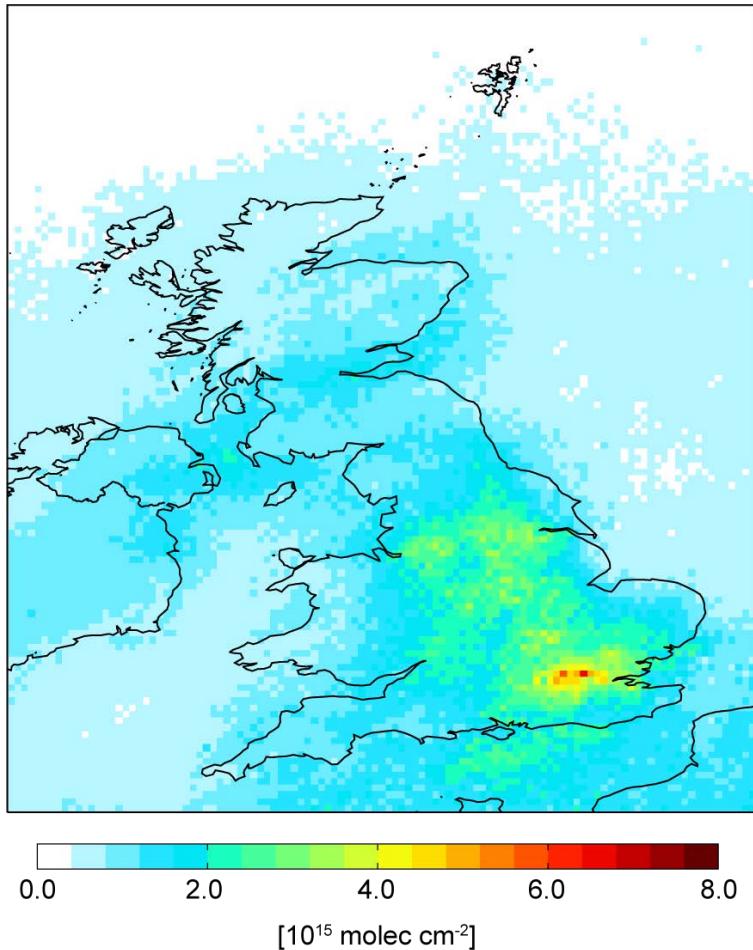


Spatial resolution: $0.25^\circ \times 0.25^\circ$

Reasonable correlation: $R = 0.64$

Future Constraints on Emissions

TROPOMI NO₂ for July 2018



Data availability:
<https://s5phub.copernicus.eu/dhus/#/home>

$0.1^\circ \times 0.1^\circ$ (~ 10 km \times 10 km) compared to $0.25^\circ \times 0.25^\circ$ for OMI