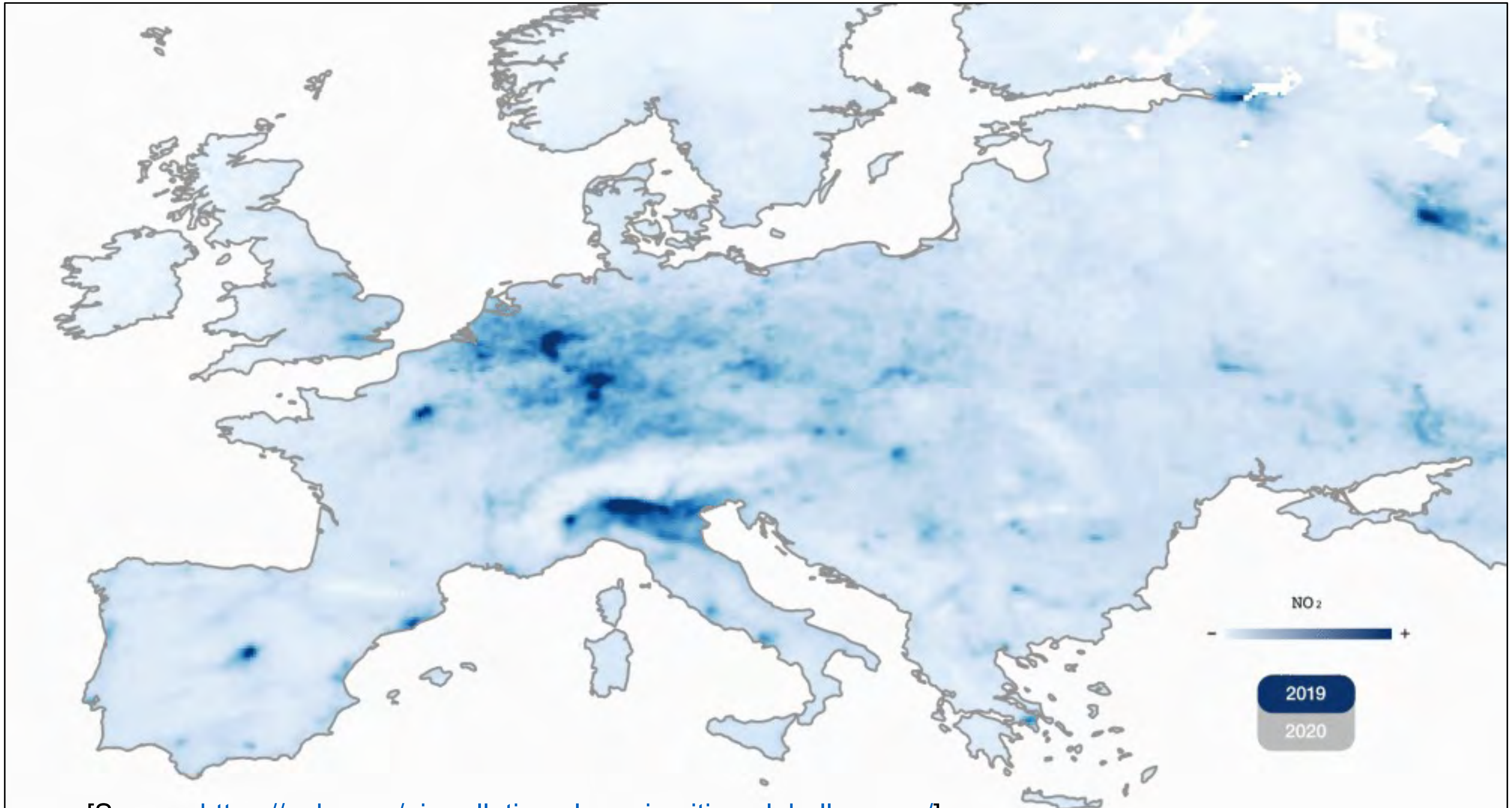
UK air quality during the Spring 2020 lockdown:

relative role of sources and meteorology



[Source: https://epha.org/air-pollution-clears-in-cities-globally-maps/]

maraisresearchgroup.co.uk/ **UoB APAC Seminar** 21 April 2021 **Eloïse A Marais**

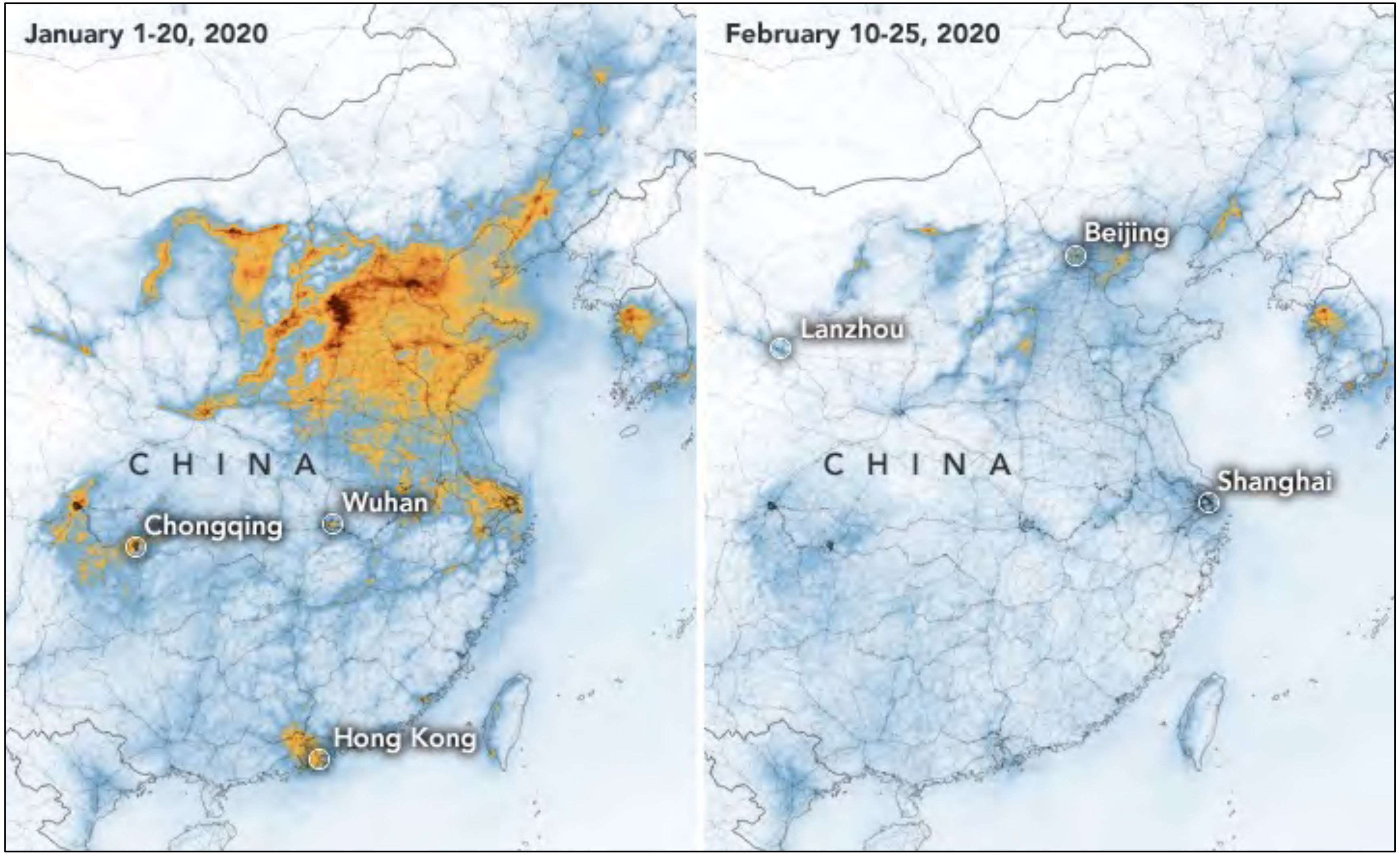
Dramatic improvements in air quality during lockdowns

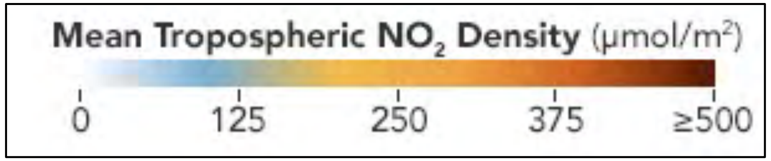
Source: https://edition.cnn.com/2020/04/23/india/india-air-pollution-coronavirus-nasa-intl/

Brief reprieve from air pollution. India Gate in Delhi not masked by a curtain of air pollution

Improvements in air quality visible from space

TROPOMI tropospheric columns of NO_2 before vs during lockdown





[Source: https://eoimages.gsfc.nasa.gov/images/imagerecords/146000/146362/china_trop_2020056.png]

TROPOMI:
TROPOspheric Monitoring Instrument

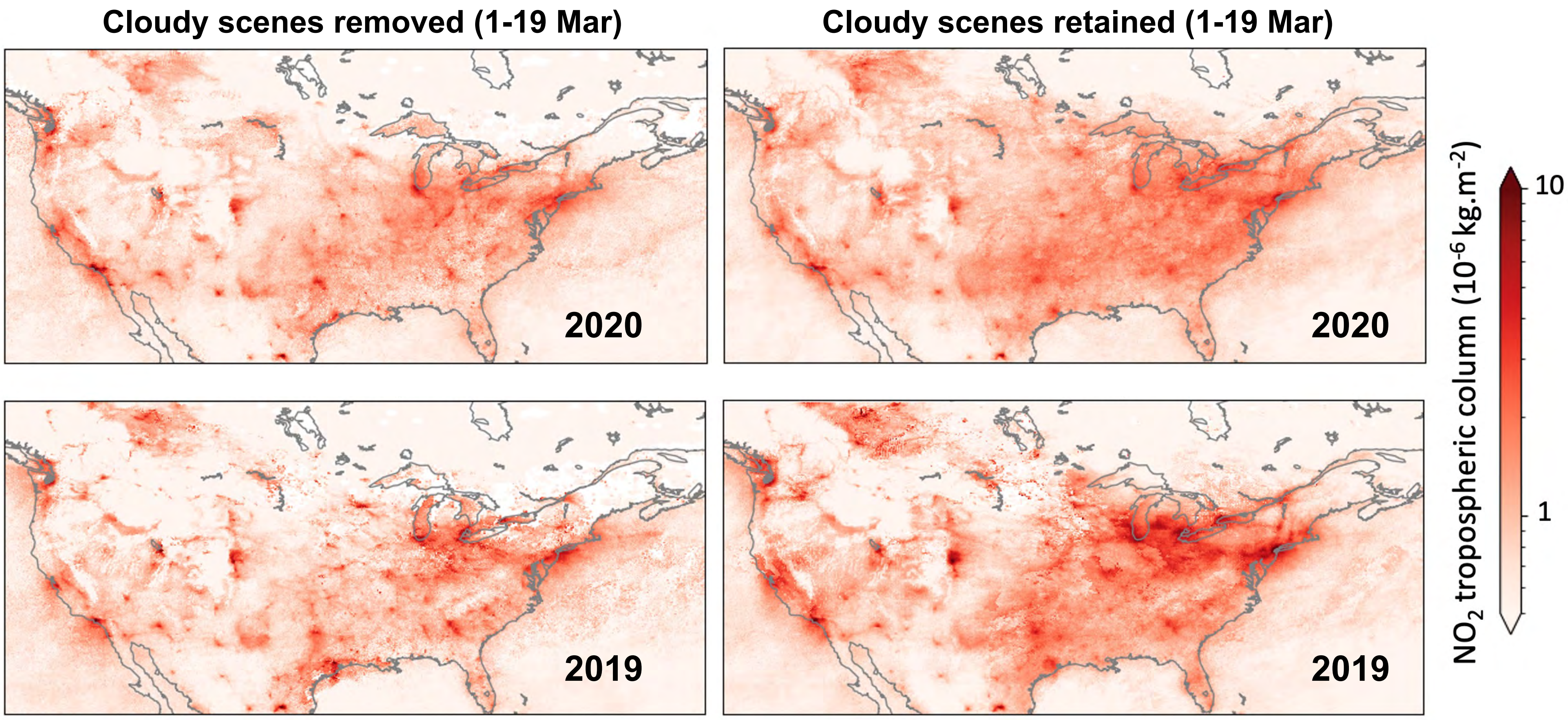
TROPOMI sees NO_2 and provides constraints on NO_x

$$NO_x = NO + \mathbf{NO_2}$$

Led to flurry of activity to document changes in air pollution in other countries/regions

Misuse of TROPOMI data leads to incorrect inferences about air quality

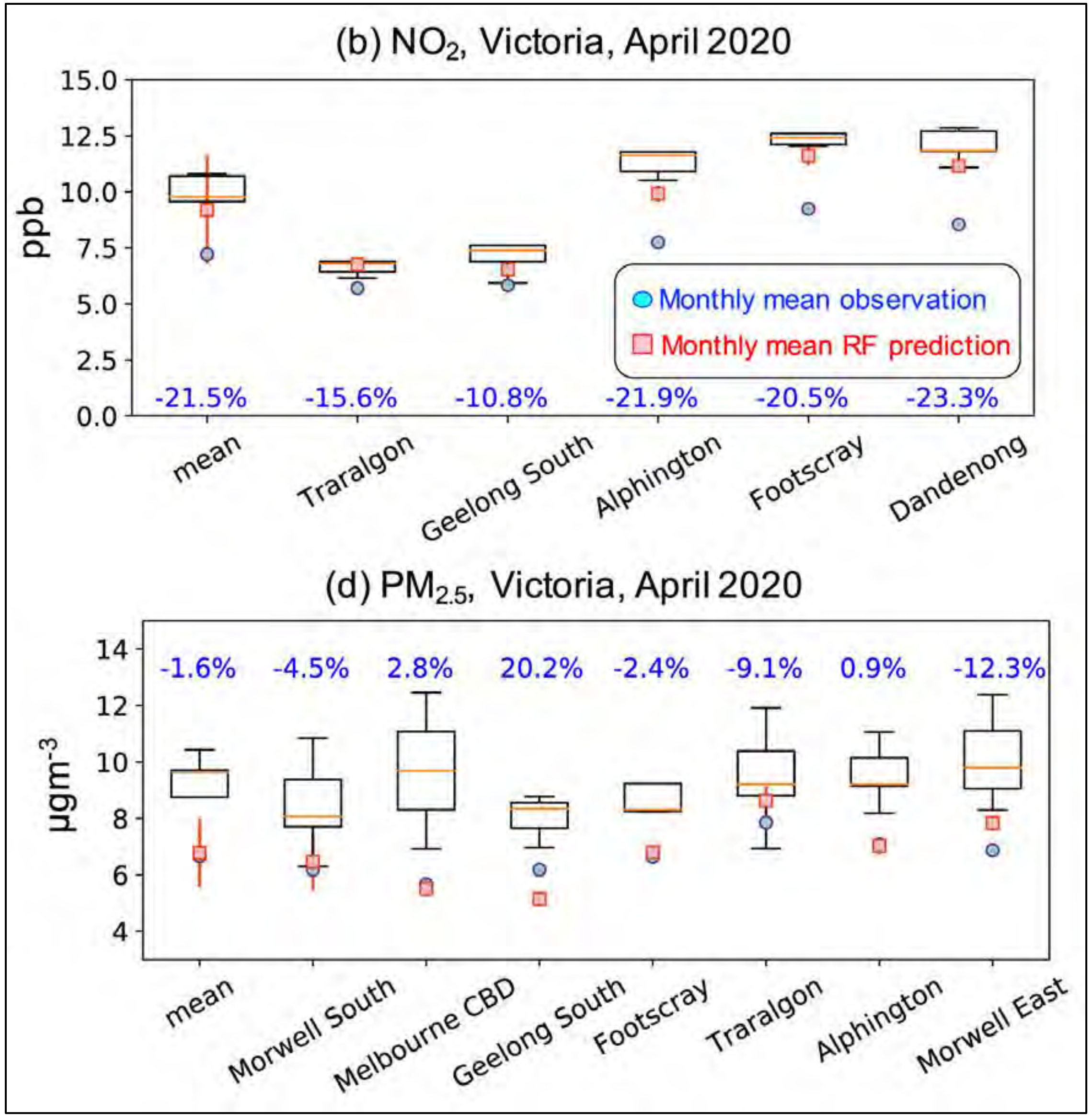
TROPOMI data publicly available for use by experts and novices, but detailed knowledge of this data is crucial!



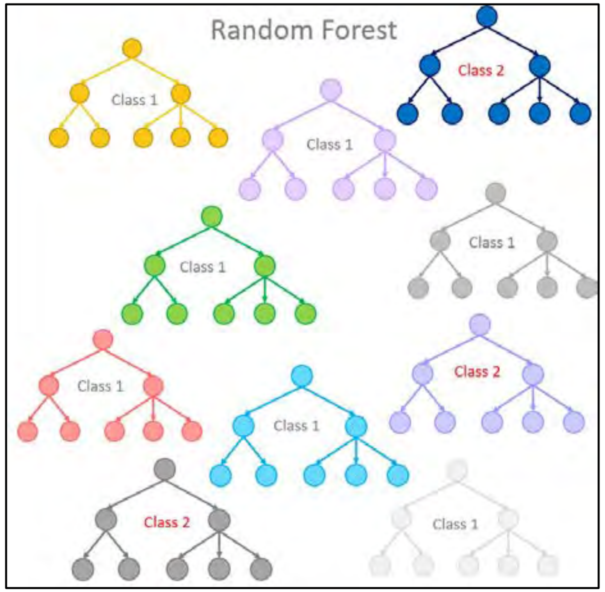
Leads to different conclusions about the magnitude of the decline in NO_x

[Source: https://atmosphere.copernicus.eu/flawed-estimates-effects-lockdown-measures-air-quality-derived-satellite-observations]

Interannual variability in meteorology also important



Normalize meteorology with machine learning



Lockdowns in summer in the southern hemisphere

Contribution of different factors:

All factors: yellow lines minus blue circles

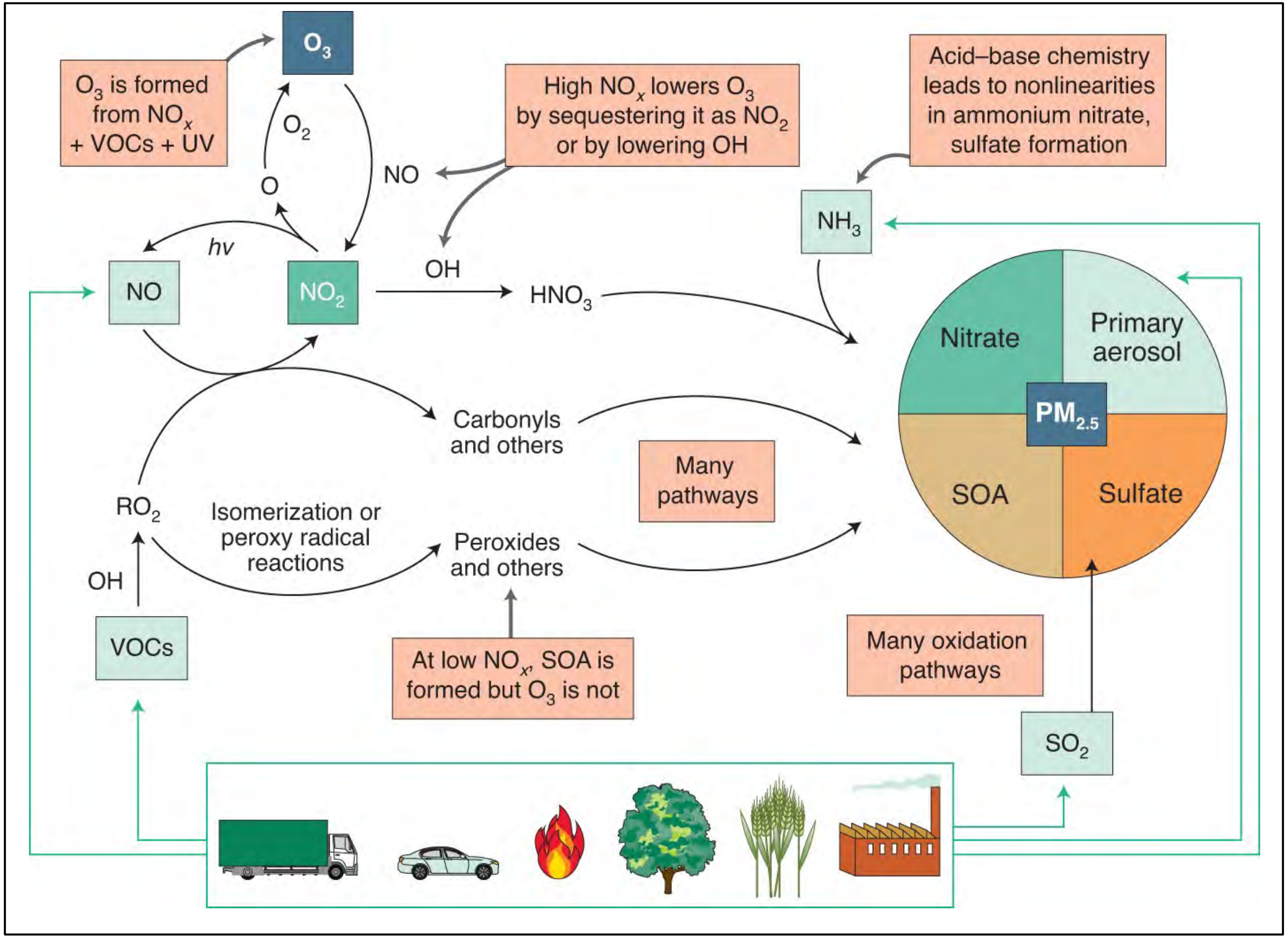
Emissions: yellow lines minus red boxes

Meteorology: red boxes minus blue circles (blue text)

Large decline in 2020 relative to multiyear mean, but not when normalize for variability in meteorology.

[Source: Ryan et al., 2020, https://www.sciencedirect.com/science/article/pii/S0269749121000762]

Chemical transformations also a key component



Non-linear ozone chemistry

Acid-base heterogeneous chemistry

Dependence of secondary organic aerosol (SOA) formation on sulfate and NO_x

Changes in oxidizing capacity (OH, O_3)

Aerosols impact availability of light

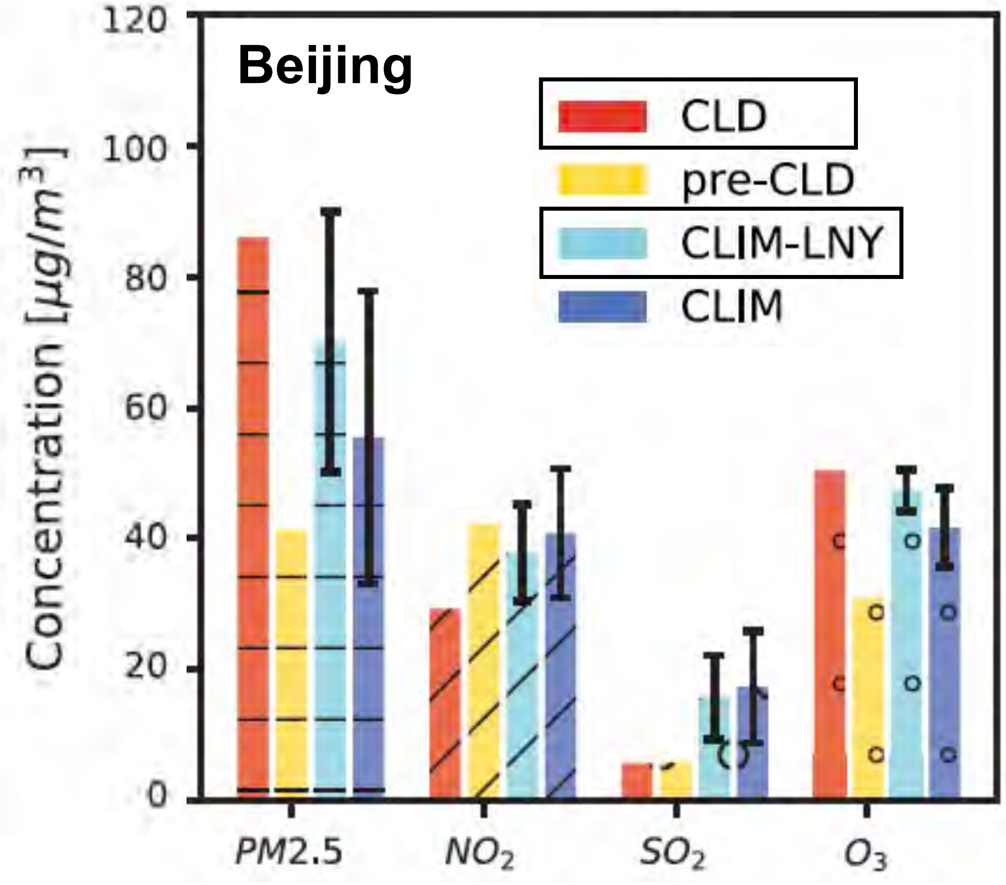
[Kroll et al., 2020, https://www.nature.com/articles/s41557-020-0535-z]

Chemical transformations also key factor

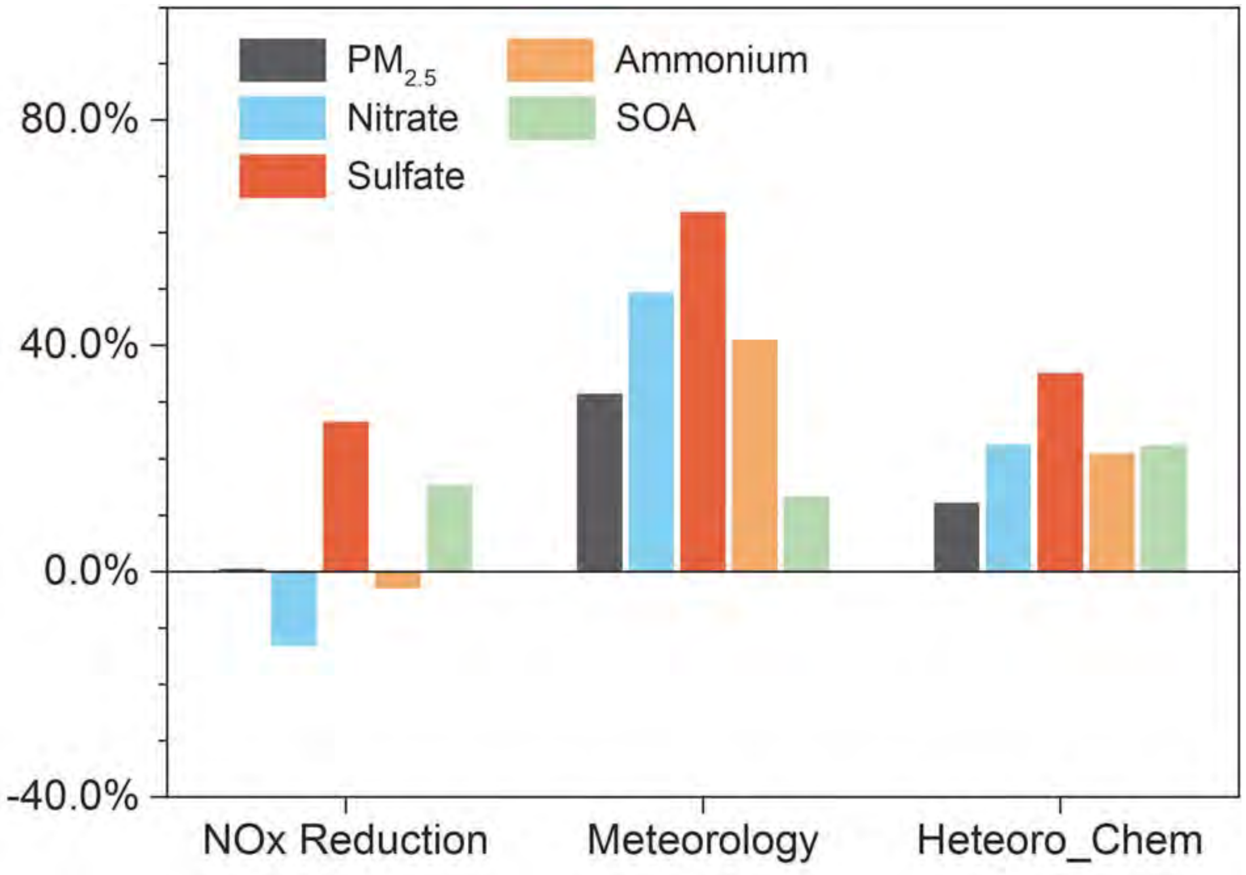
During city lockdowns in China $PM_{2.5}$ decreased almost everywhere, except over Beijing.

High relative humidity, stable conditions, positive feedbacks.

Monitoring station data

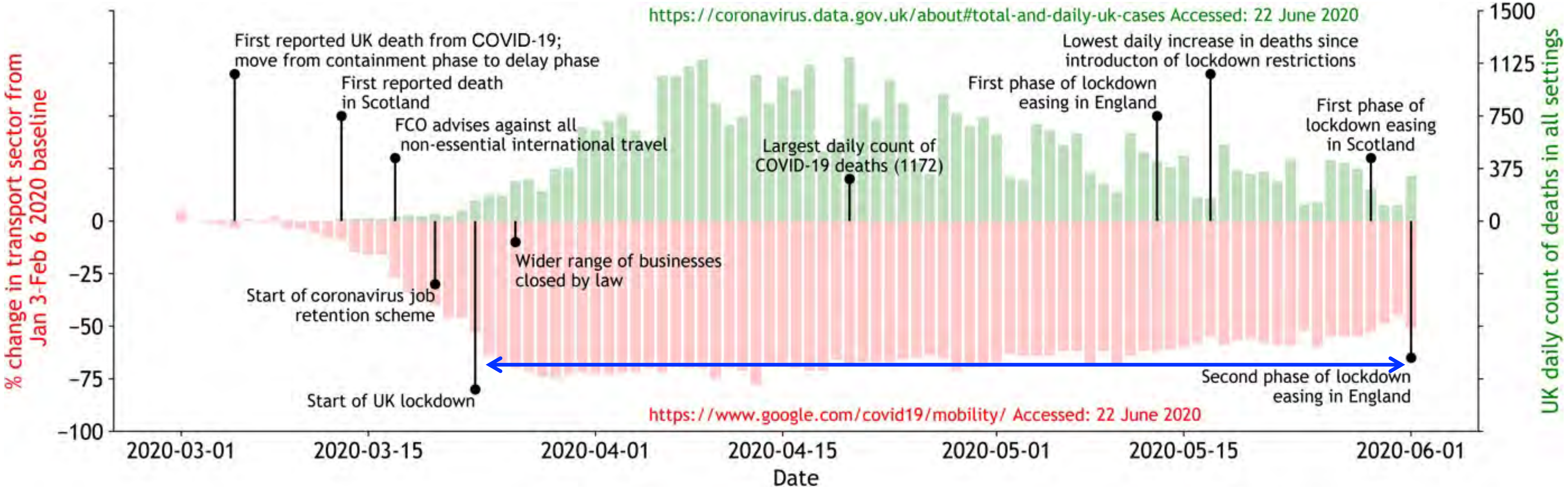


Model (WRF-Chem) perturbation simulations



[Source: Le et al., 2020, https://science.sciencemag.org/content/369/6504/702]

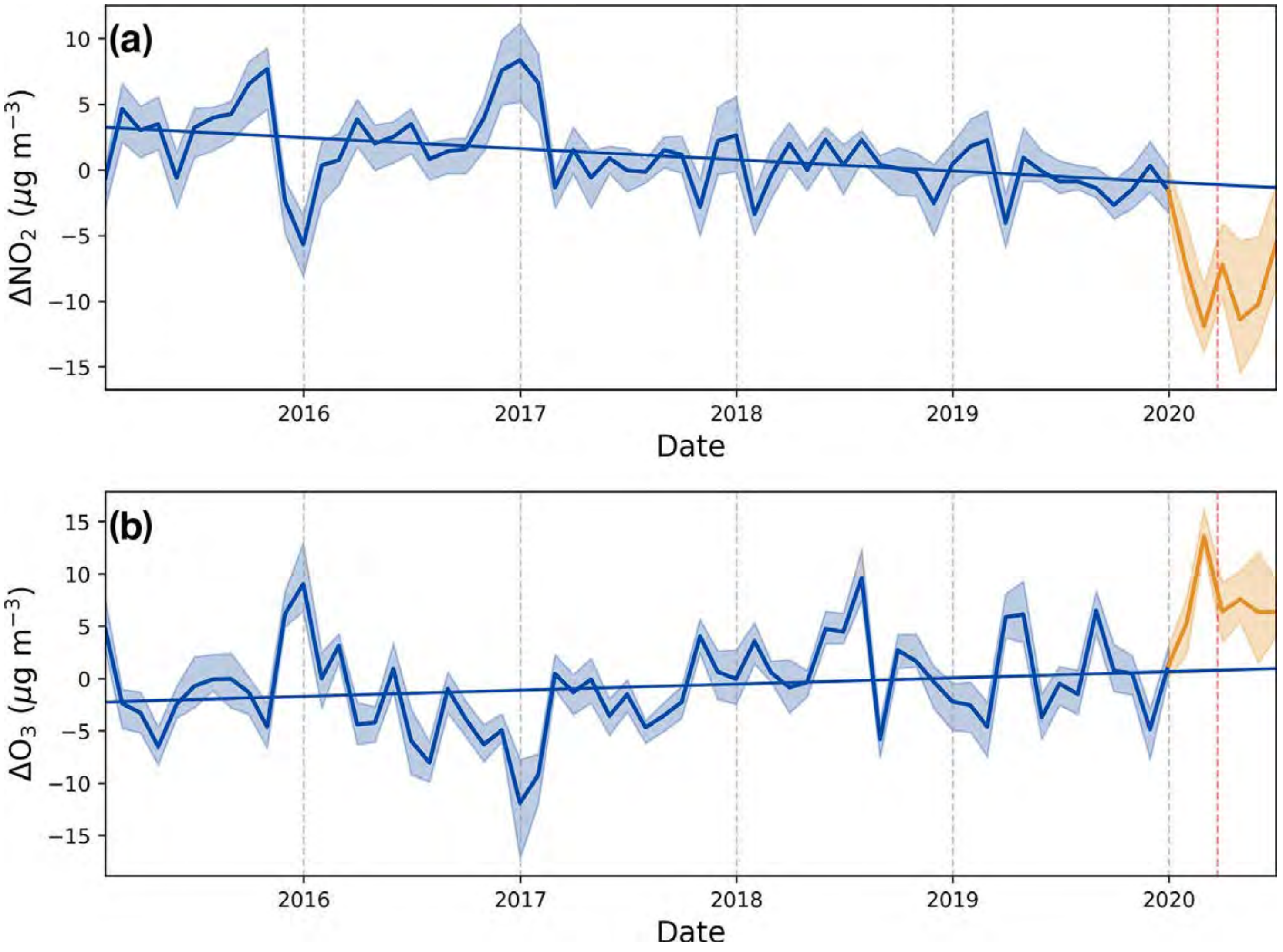
UK lockdown timeline



[Lee et al., 2020, https://doi.org/10.5194/acp-20-15743-2020]

42% decrease in NO_2 during UK lockdown

Deseasonalized surface observations of NO_2 and ozone using long-term mean

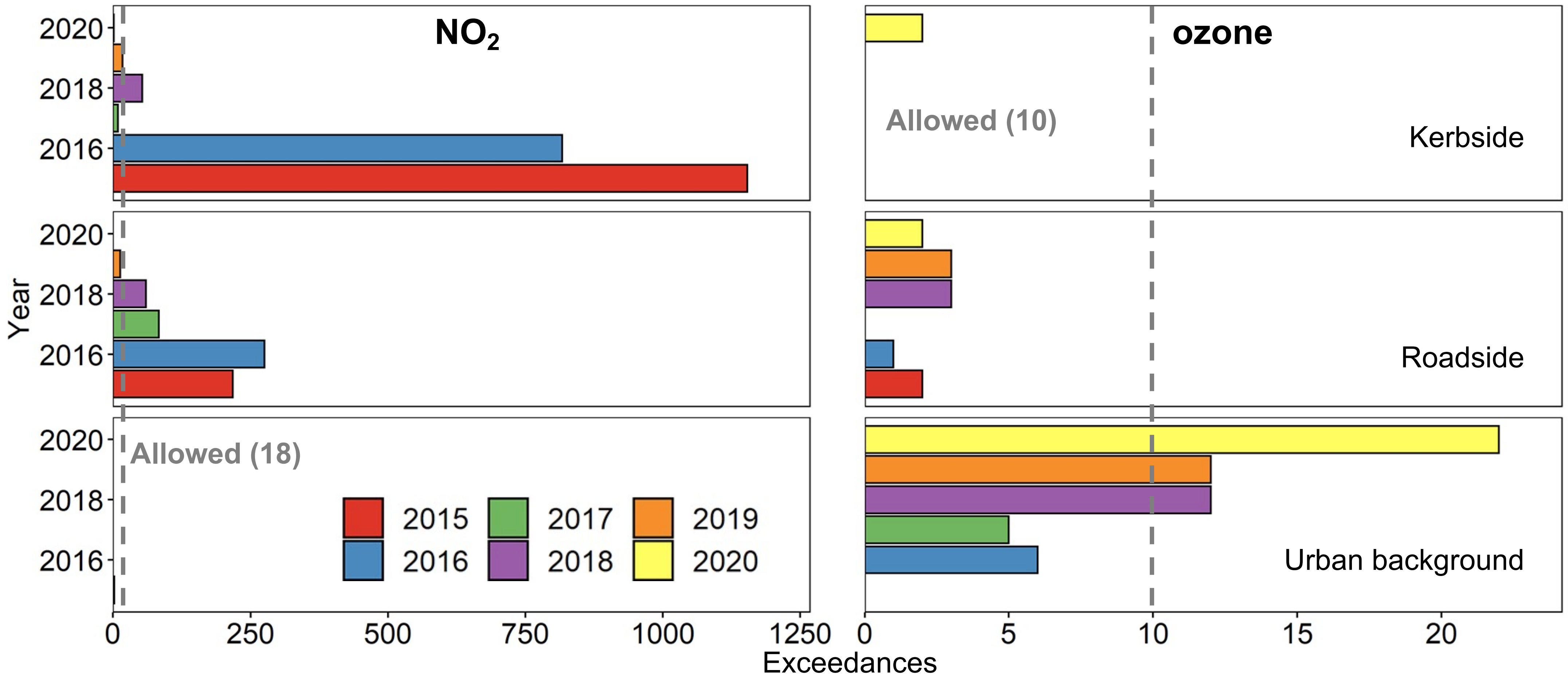


42% decrease in NO_2

11% increase in ozone

[Lee et al., 2020, https://doi.org/10.5194/acp-20-15743-2020]

Decline in air quality standard exceedances in London

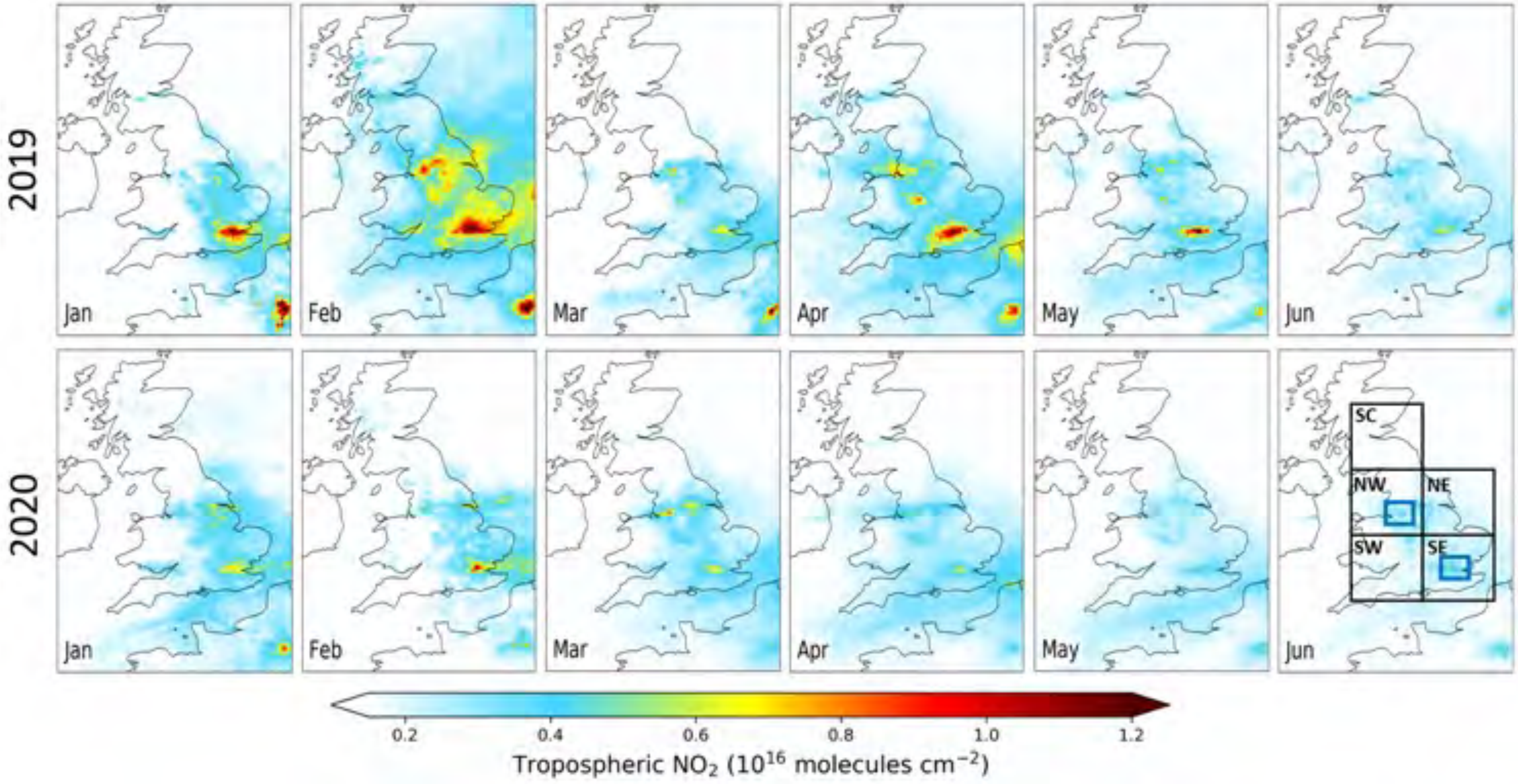


[*Adapted from* Lee et al., 2020, https://doi.org/10.5194/acp-20-15743-2020]

Surface observations have limited spatial coverage

Influence of lockdown measures on UK $PM_{2.5}$ uncertain. Requires regional model.

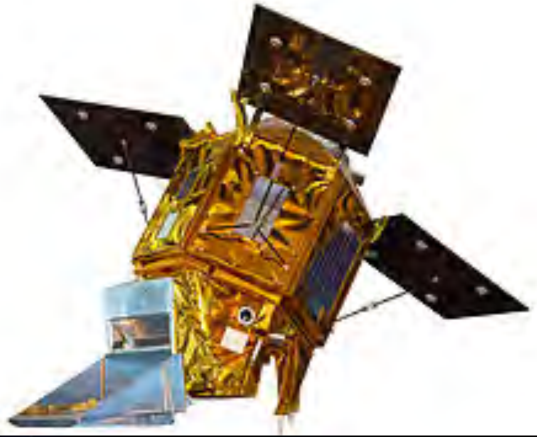
Regional changes in air quality diagnosed with TROPOMI

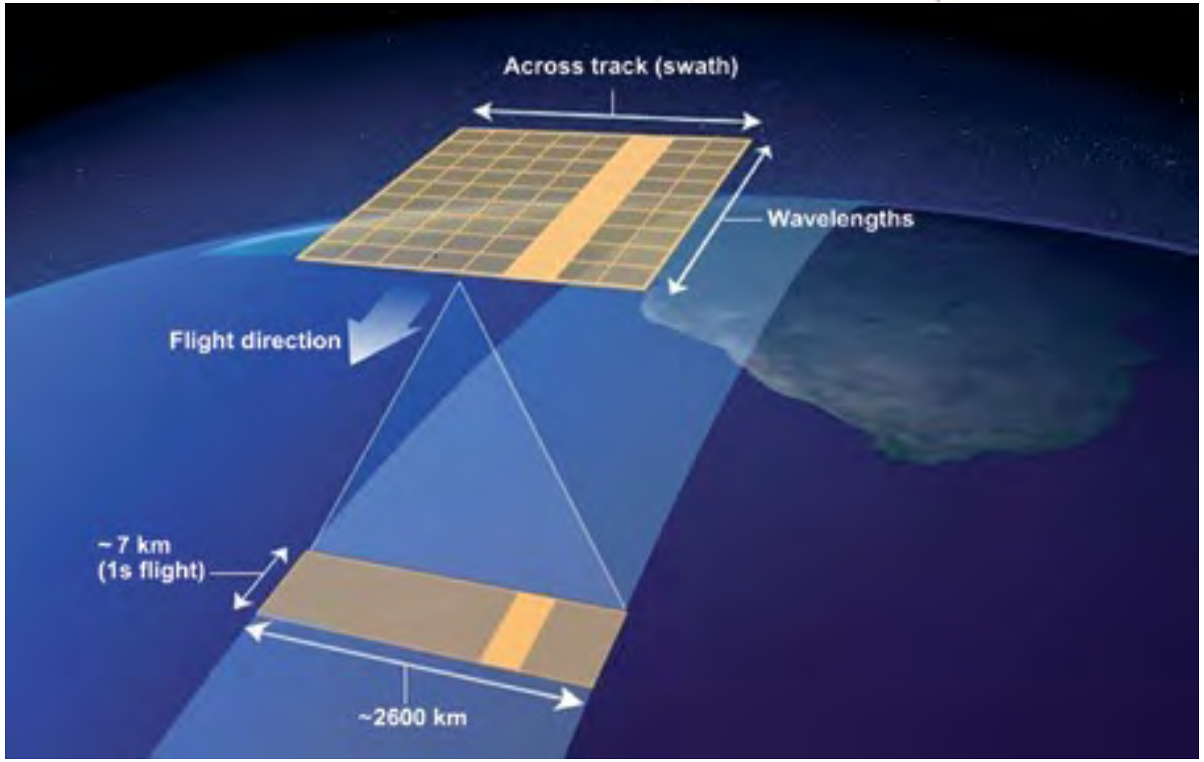


TROPOMI analysis by Dan Potts (UG at U. Leicester) supervised by Hartmut Boesch (U. Leicester)

[Potts et al., in press, https://iopscience.iop.org/article/10.1088/1748-9326/abde5d]

TROPOMI instrument onboard the Sentinel-5P satellite





<u>Overpass:</u> 13:30 local solar time

<u>Spatial resolution:</u> 5.5 km x 3.5 km (nadir)

<u>Swath width:</u> 2700 km

<u>Launch date:</u> 13 October 2017

Data publicly available in multiple locations. Link to S5P Hub: https://s5phub.copernicus.eu/dhus/#/home

Using TROPOMI to investigate ozone production regimes in India

$$\mathrm{VOCs} \xrightarrow{\mathrm{ox}} \mathbf{HCHO}$$

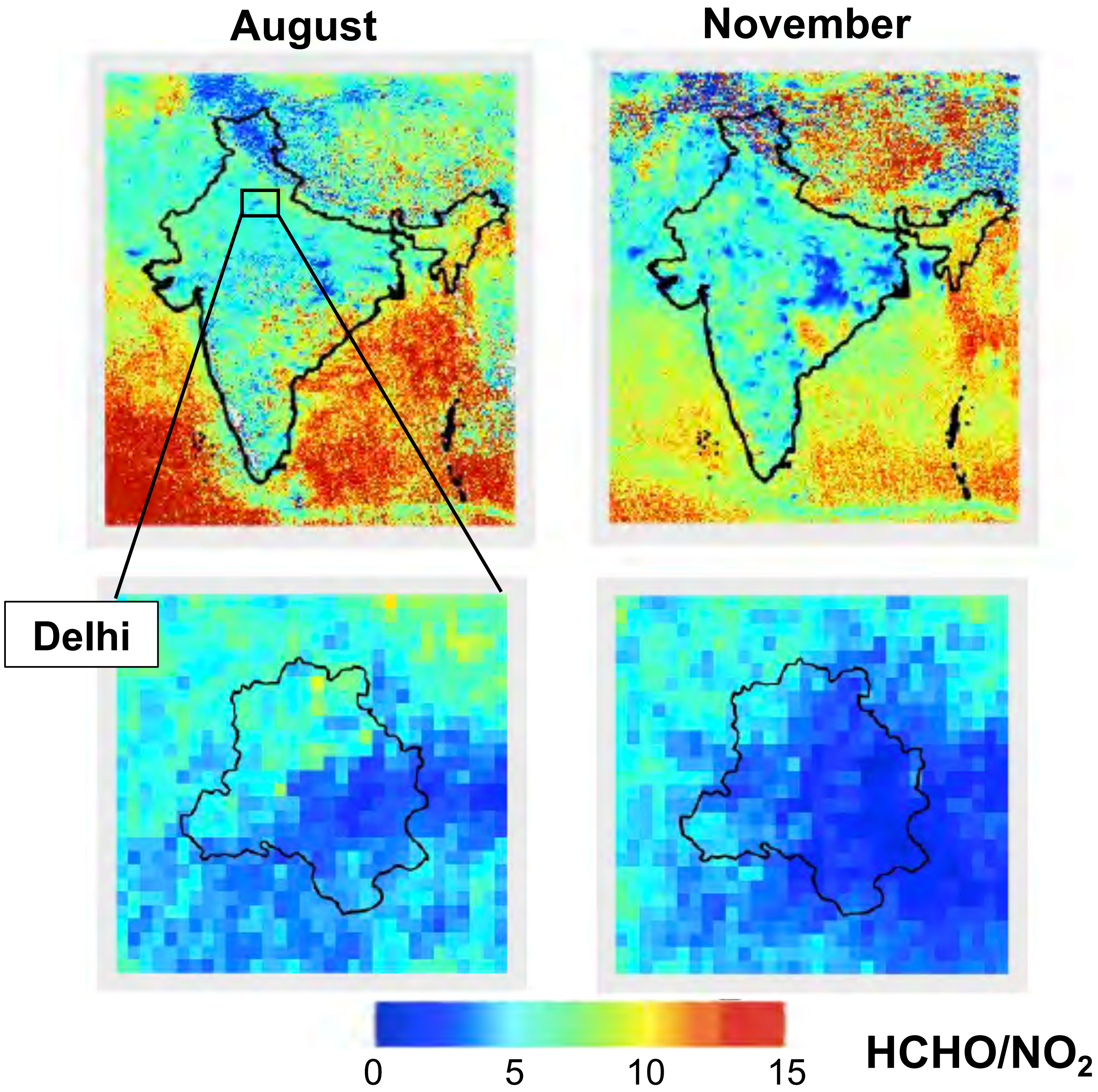
$$NO_x = NO + \mathbf{NO_2}$$

Abundance of VOCs and NO_x determine ozone production rates

$HCHO/NO_2$

< 1 ⇒ NO_X-saturated
> 1 ⇒ NO_X-sensitive

[Martin et al., 2004]



10 km resolution

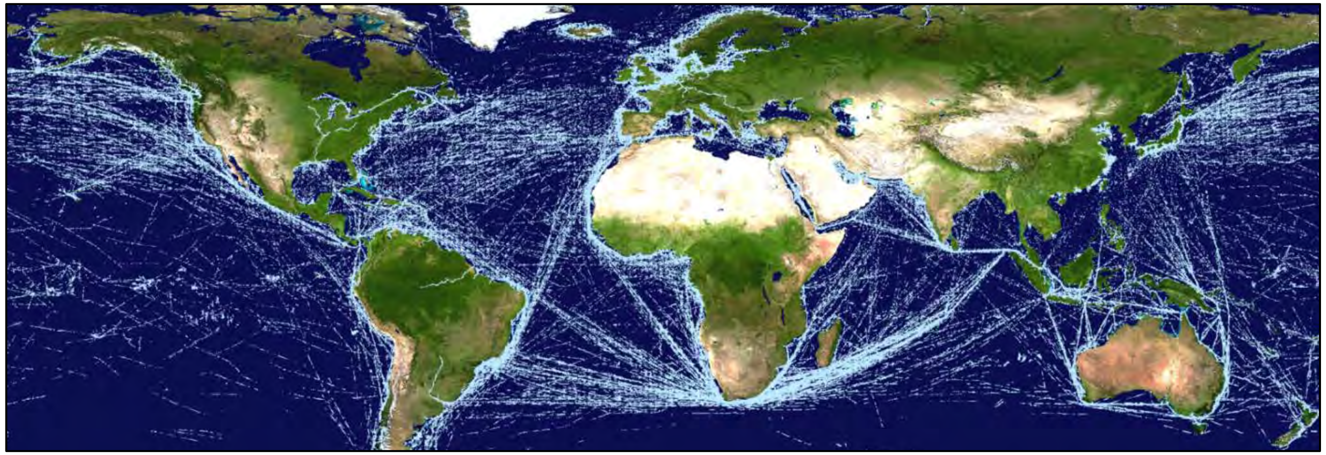
2.5 km resolution

Work by Karn Vohra

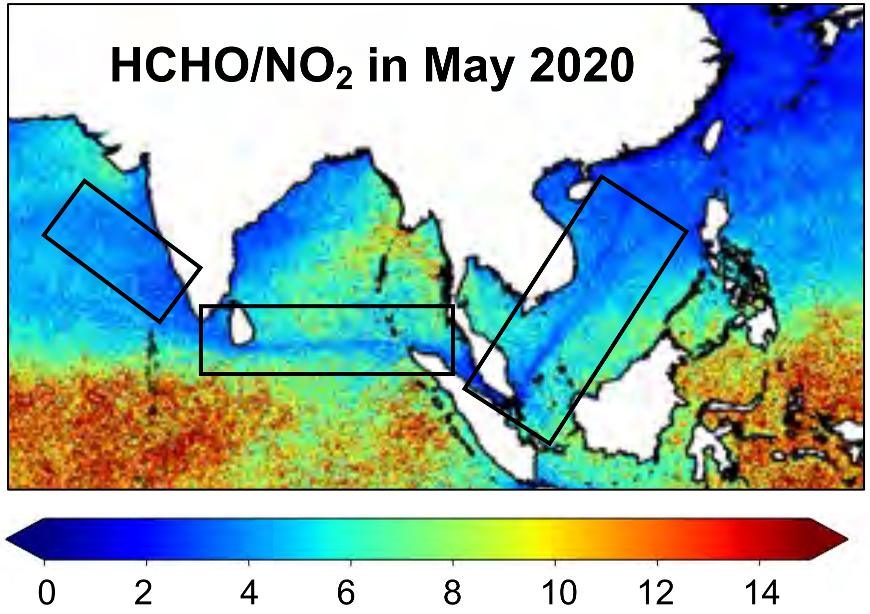
Using TROPOMI to investigate ozone production of busy shipping lanes

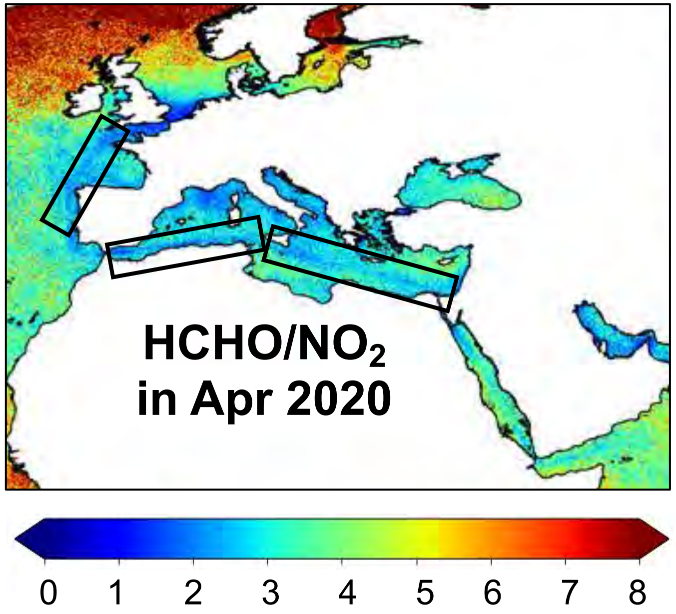
Ships run on heavy fuel oil (bunker fuel)

Shipping activity from Automatic Identification System (AIS) data



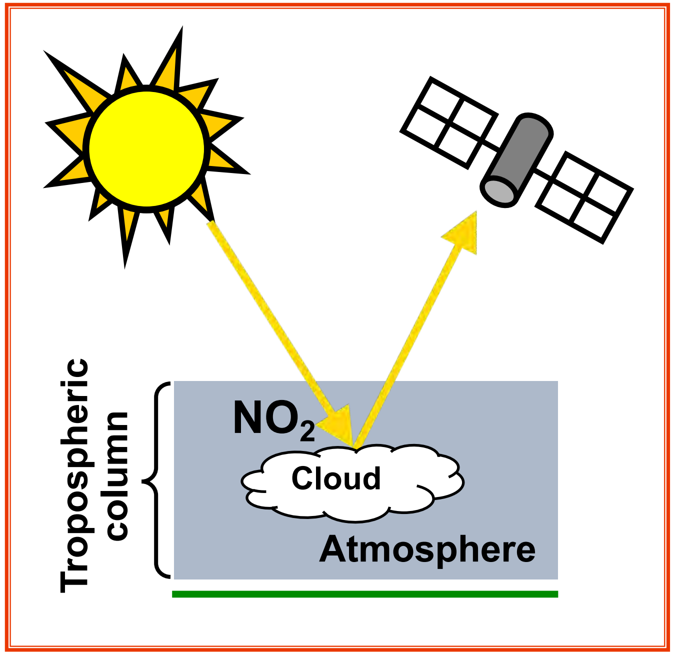
[Source: https://www.esa.int/ESA_Multimedia/Images/2016/01/Satellite-AIS-based_map_of_global_ship_traffic]





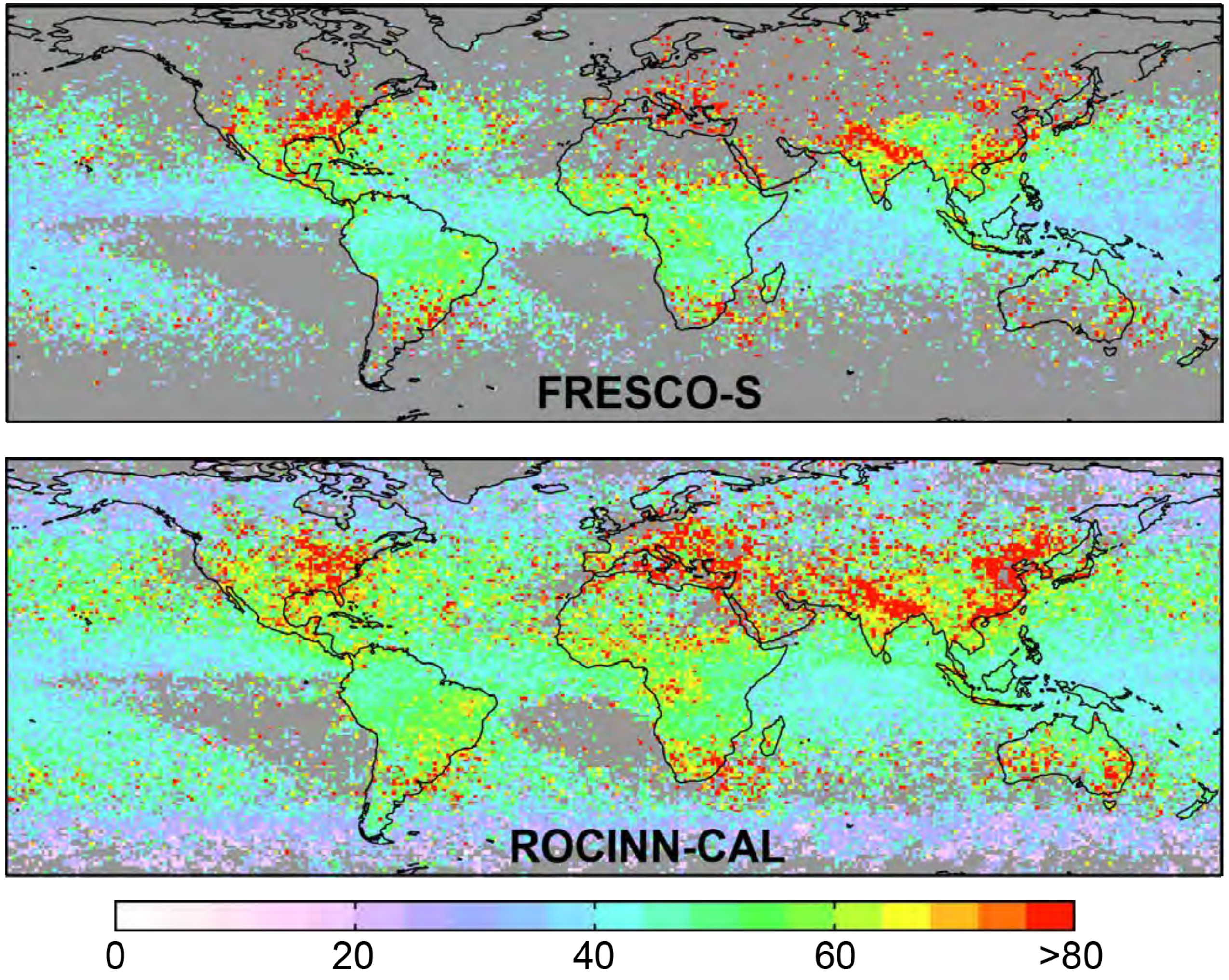
Work by Gongda Lu

Developing new products from TROPOMI total columns of NO_2



Use, rather than discard, observations over optically thick clouds

TROPOMI annual mean upper tropospheric NO_2 [pptv]

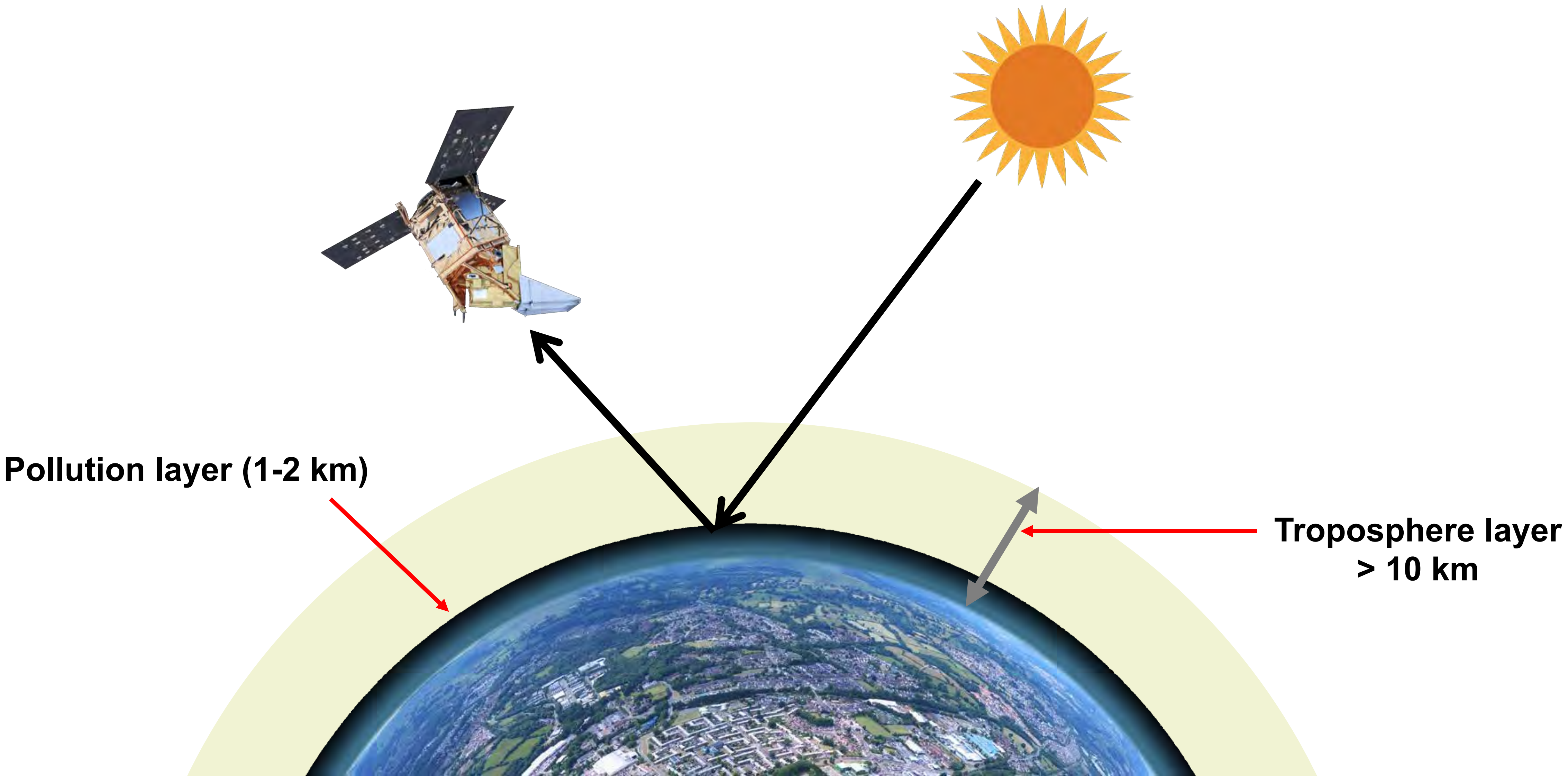


Derive NO_2 mixing ratios in the upper troposphere, where routine, reliable observations are sparse

[Marais et al., 2021, https://amt.copernicus.org/articles/14/2389/2021/]

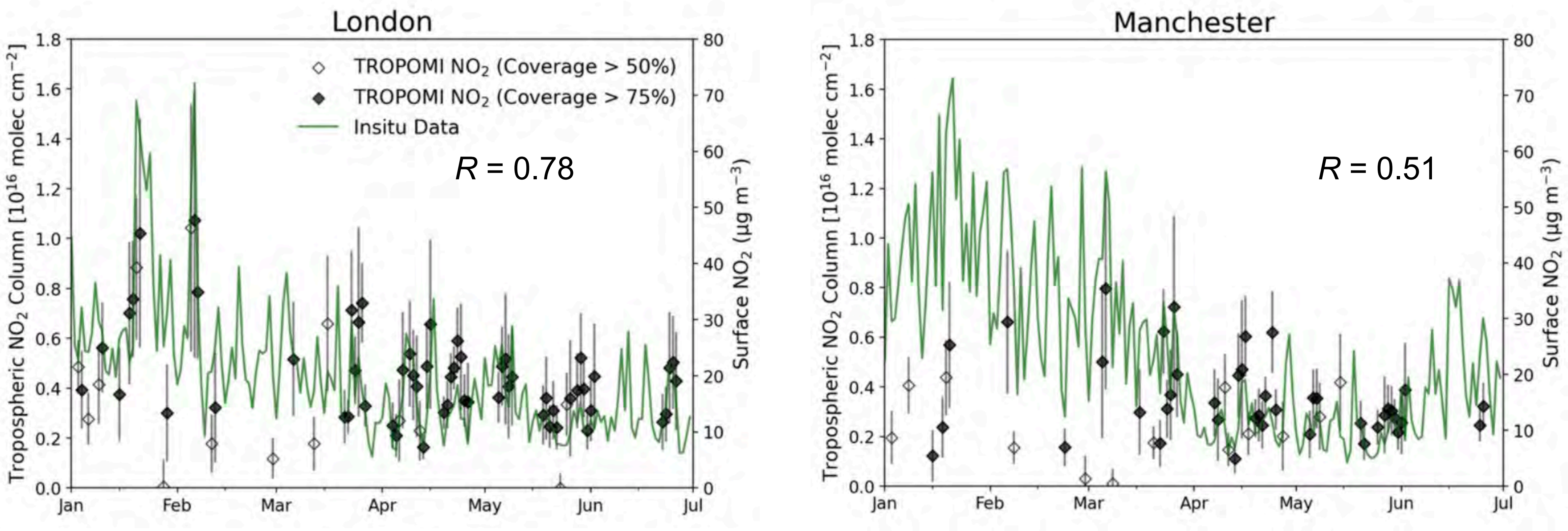
Space-based instruments observe the whole atmospheric column

Requires we assess whether variability in TROPOMI is due to surface air pollution



Determine whether TROPOMI reproduces variability at the surface

Compare TROPOMI daily tropospheric columns to surface measurements in London and Manchester



Surface observations provided by Will Drysdale and James Lee (U. York)

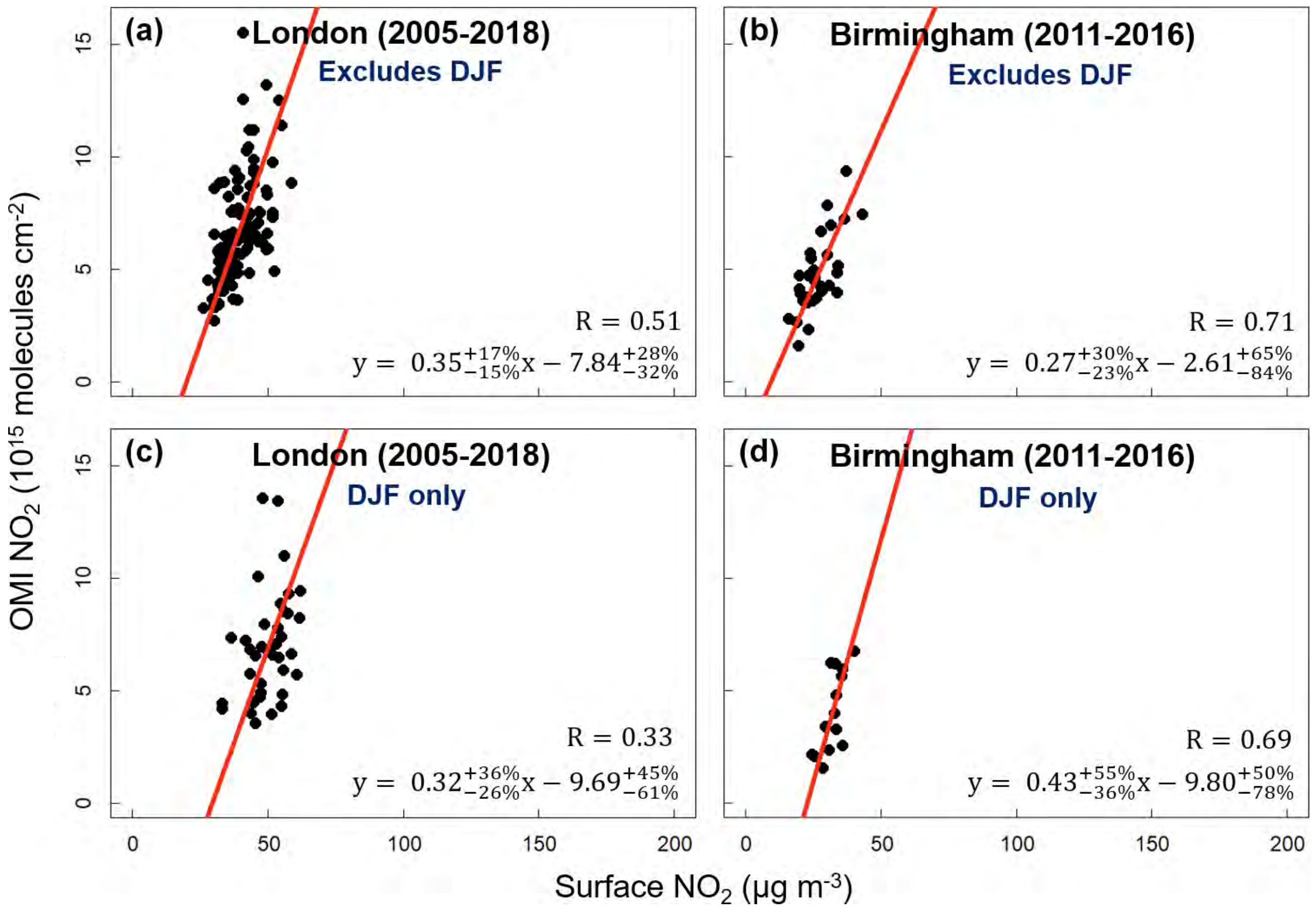
Surface observations sampled during the satellite overpass (midday)

Temporal consistency, though for Manchester this is weaker before than during lockdown

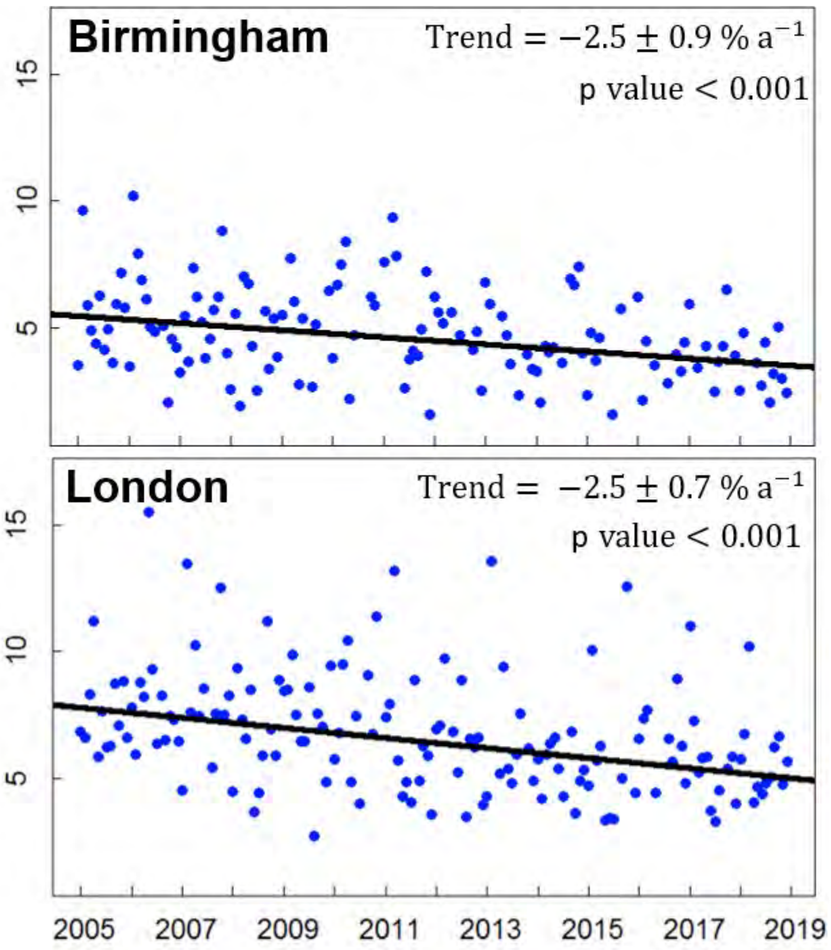
Similar results for TROPOMI predecessor, OMI

The Ozone Monitoring Instrument (OMI) was launched in 2004 and provides 10+ years of observations

Consistency in monthly means over London and Birmingham



Long-term trends



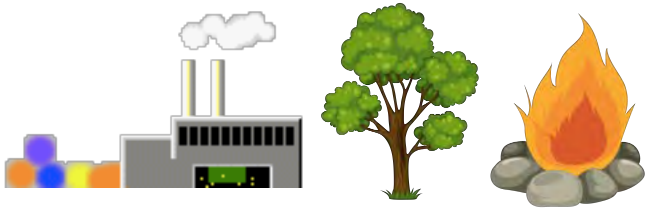
[Vohra et al., in press, 2021, https://acp.copernicus.org/preprints/acp-2020-342/]

Interpret TROPOMI with the GEOS-Chem chemical transport model

GEOS-Chem

3D Atmospheric Chemistry Transport Model

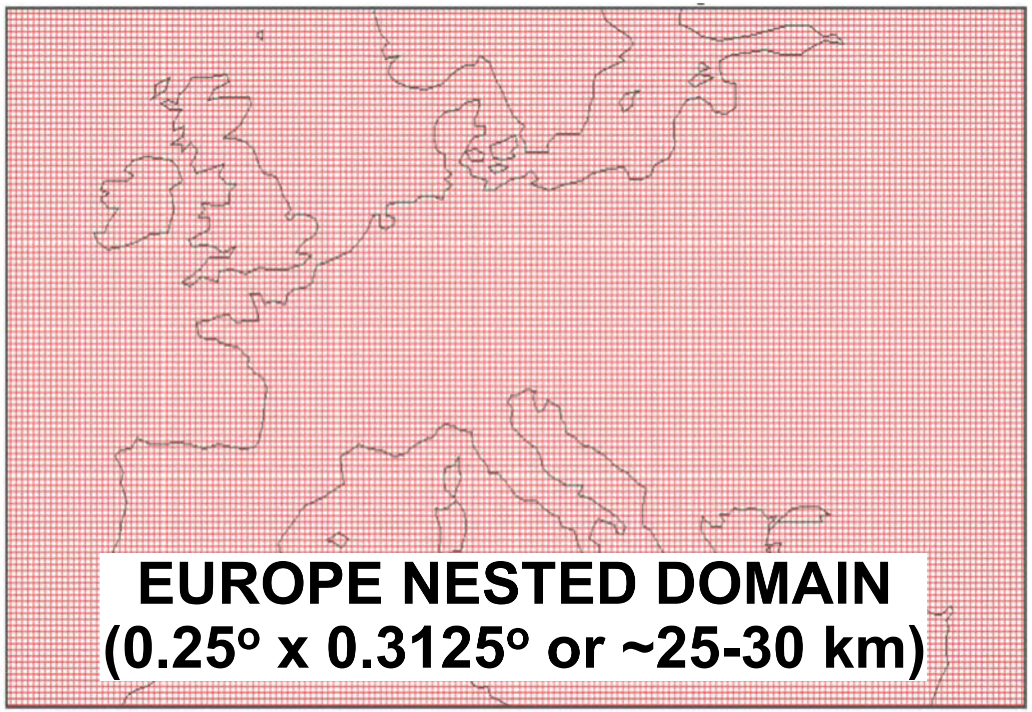
Emissions (natural/human)



EMEP emissions for 2016
with annual scale factors

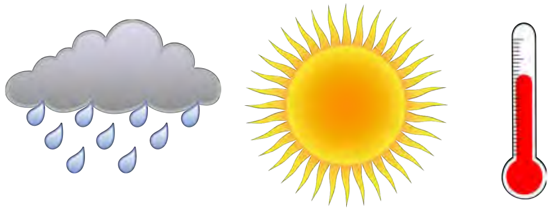
Annual decline in emissions:

NO_x:	2.5%
SO_x:	3.3%
NMVOCs:	2.5%
CO:	2.7%
1º $PM_{2.5}$:	1.9%



Gas phase and heterogeneous chemistry
Transport
Dry/wet deposition

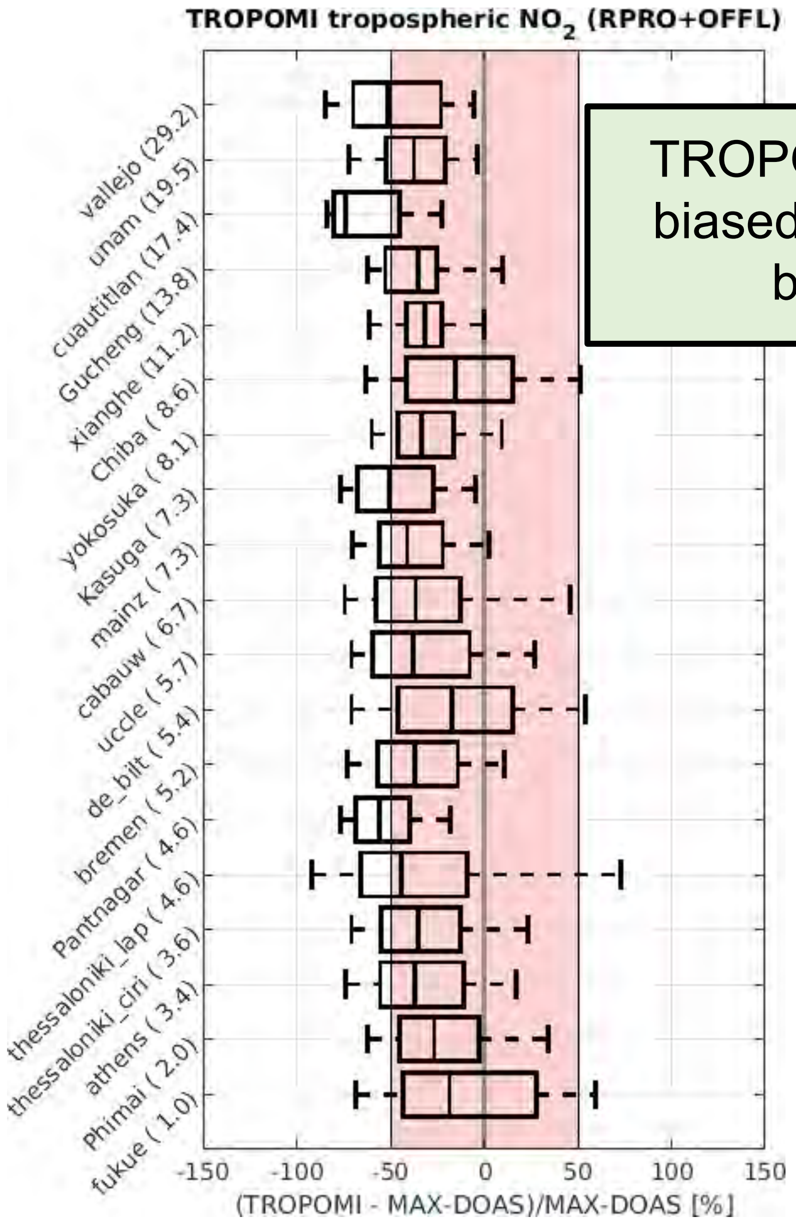
Offline assimilated meteorology



NASA GEOS-FP

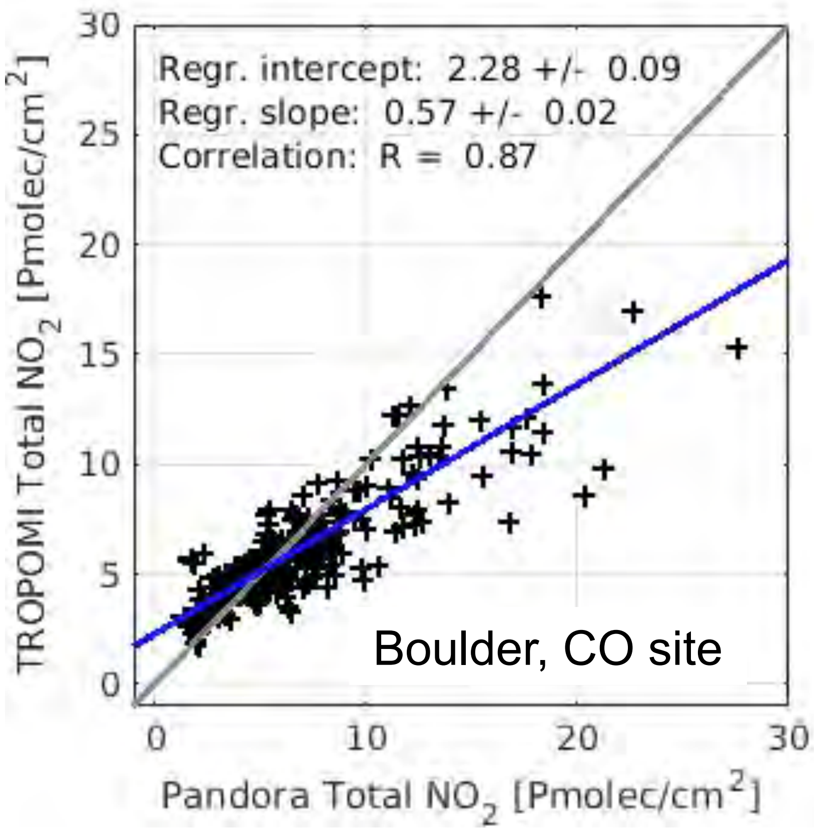
GEOS-Chem **version 12.1.0** (doi:10.5281/zenodo.1553349)

Both tools (TROPOMI, GEOS-Chem) exhibit biases



TROPOMI tropospheric columns biased low compared to ground-based measurements

Caveat: large sampling footprint differences between ground- and space-based instruments

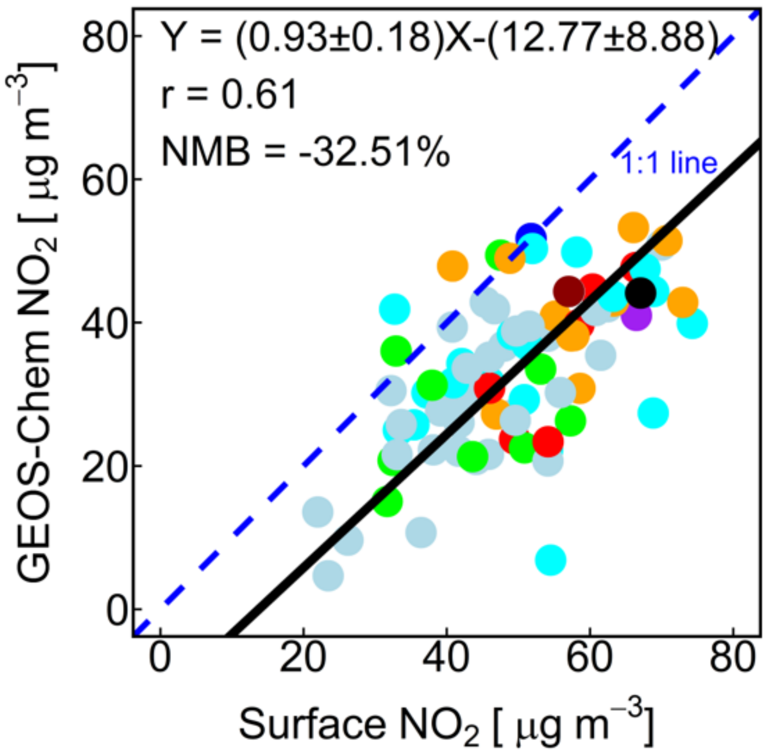


TROPOMI total columns (stratosphere + troposphere) biased high at low concentrations and vice versa

[Both images from Verhoelst et al., 2021, https://doi.org/10.5194/amt-14-481-2021]

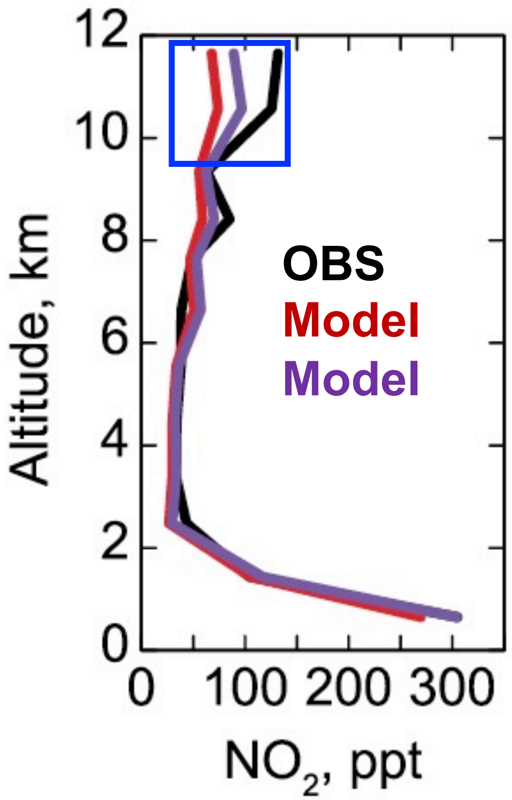
Both tools (TROPOMI, GEOS-Chem) exhibit biases

Model biases at the surface:



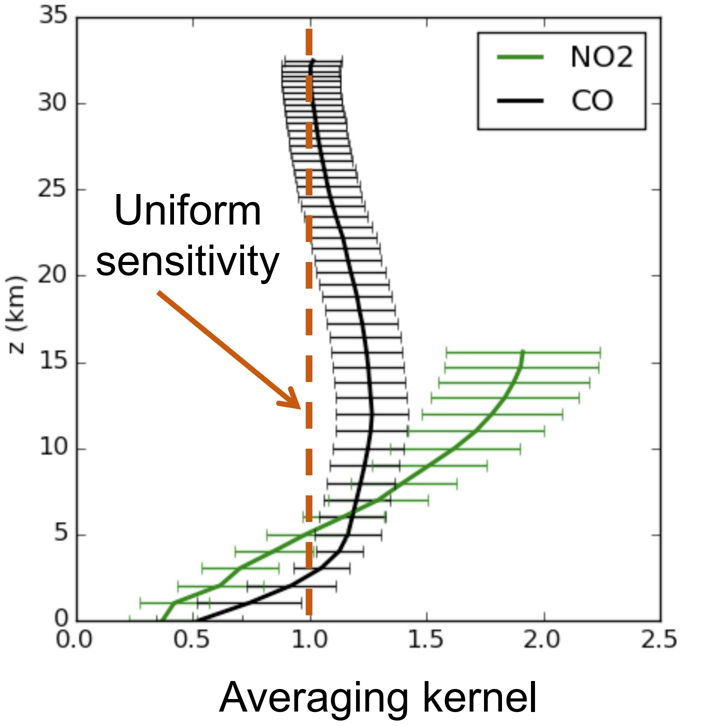
[G. Lu et al., in prep, 2021]

Model biases in upper troposphere:



[Silvern et al., 2018, 10.1029/2018GL077728]

TROPOMI most sensitive to NO_2 in the upper troposphere

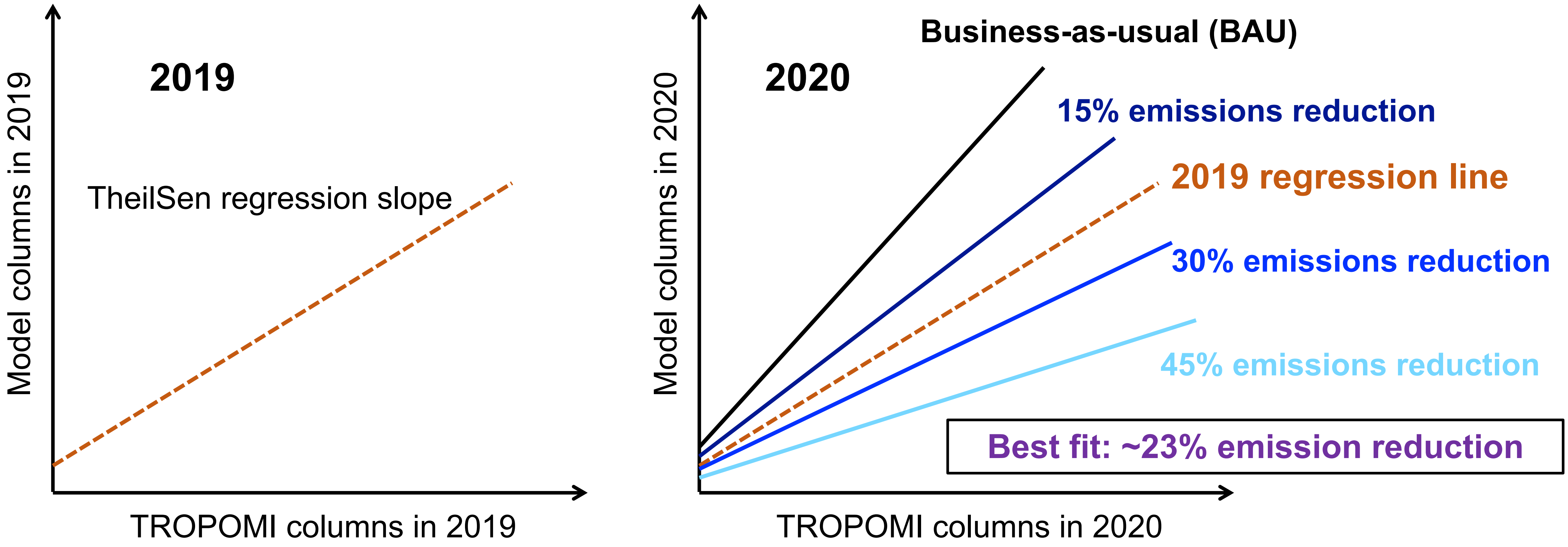


TROPOMI Averaging kernel over Mexico [Lama et al., 2020]

Consider relative change in TROPOMI and GEOS-Chem tropospheric columns

Determine emissions reductions due to lockdown measures

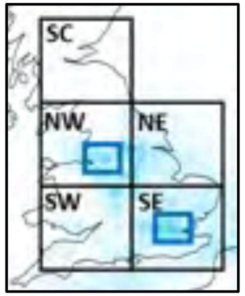
Assuming biases are systematic, TROPOMI and GEOS-Chem should capture the relative change



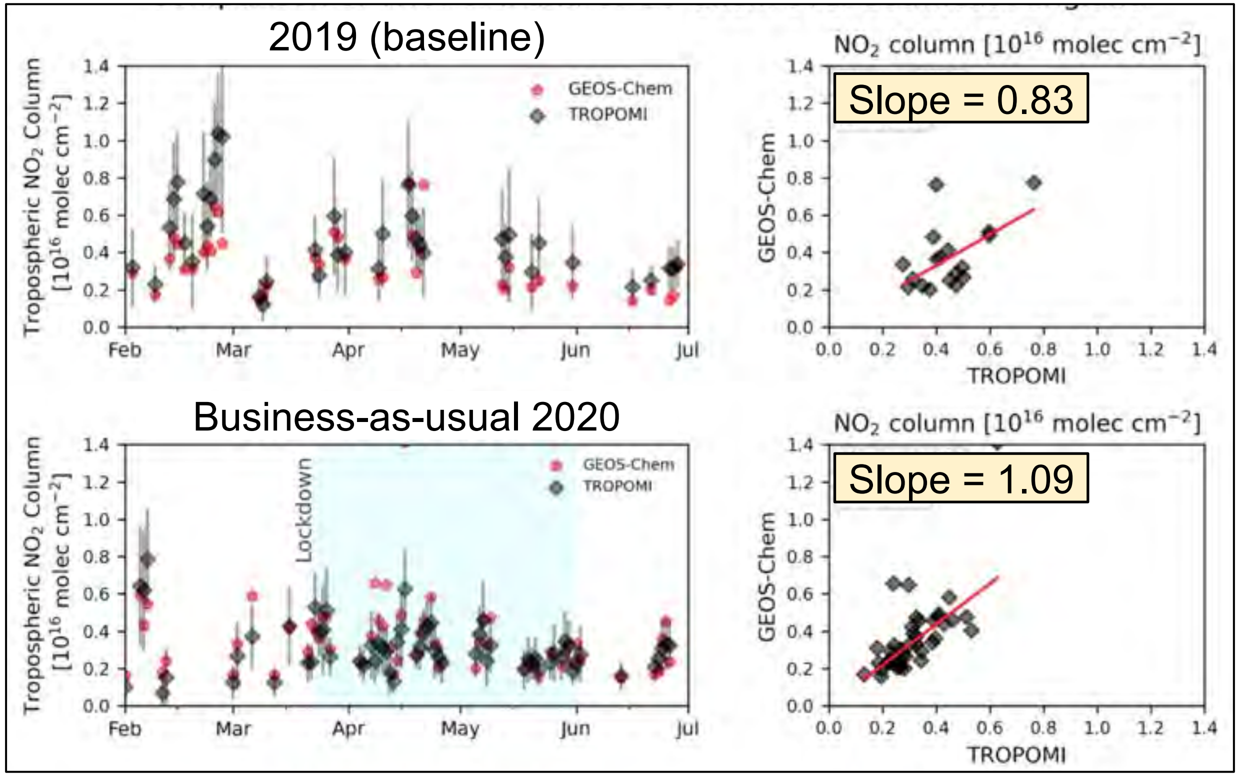
2019 provides **baseline** for statistical consistency between TROPOMI and model

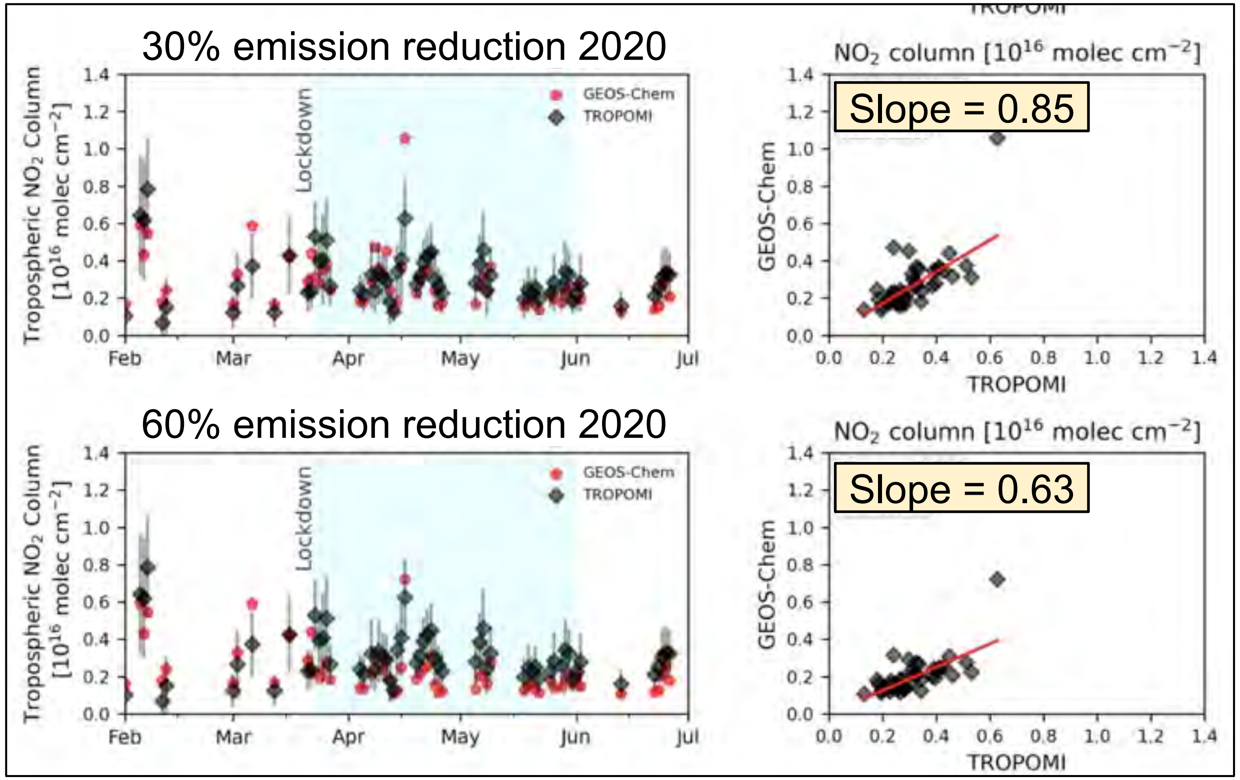
Test multiple emissions scenarios, initially informed by activity data (ONS, Google Activity data)

Emissions reductions at the regional/city scale



TROPOMI vs GEOS-Chem over Southeast England (**SE**)

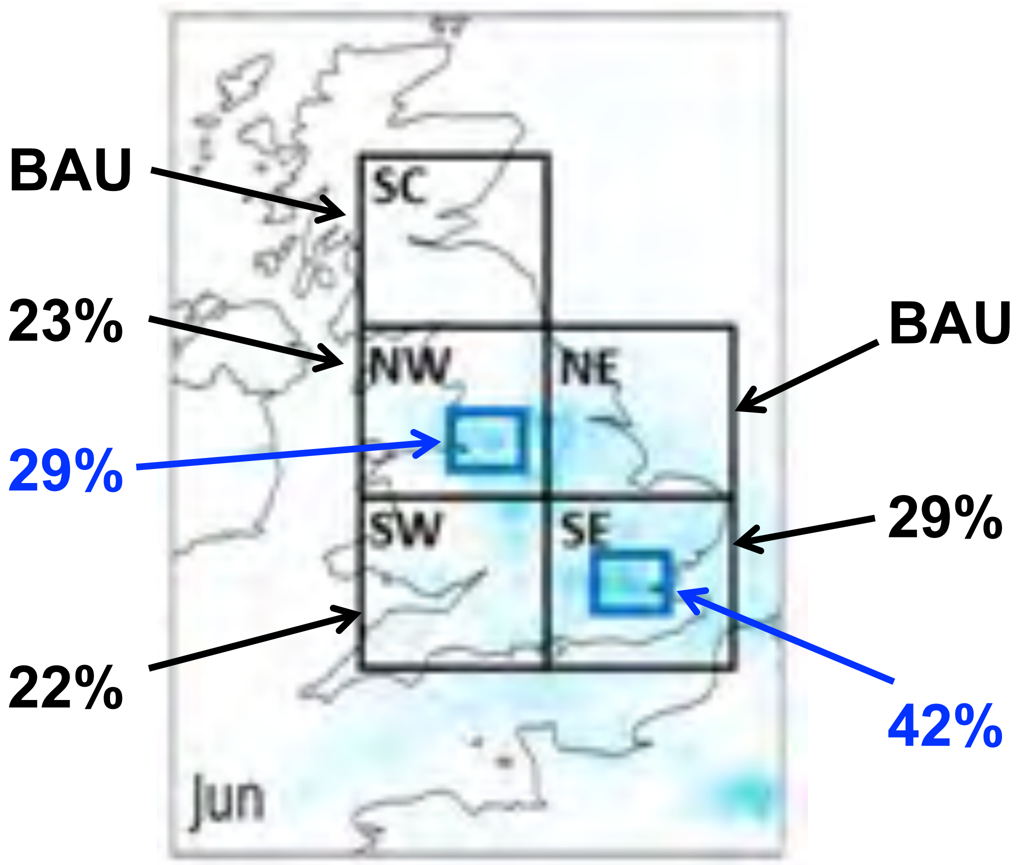




The model business-as-usual scenario only accounts for annual decline in emissions due to air quality policy

Best fit for Southeast England is **~30% reduction** in NO_x emissions due to lockdown measures

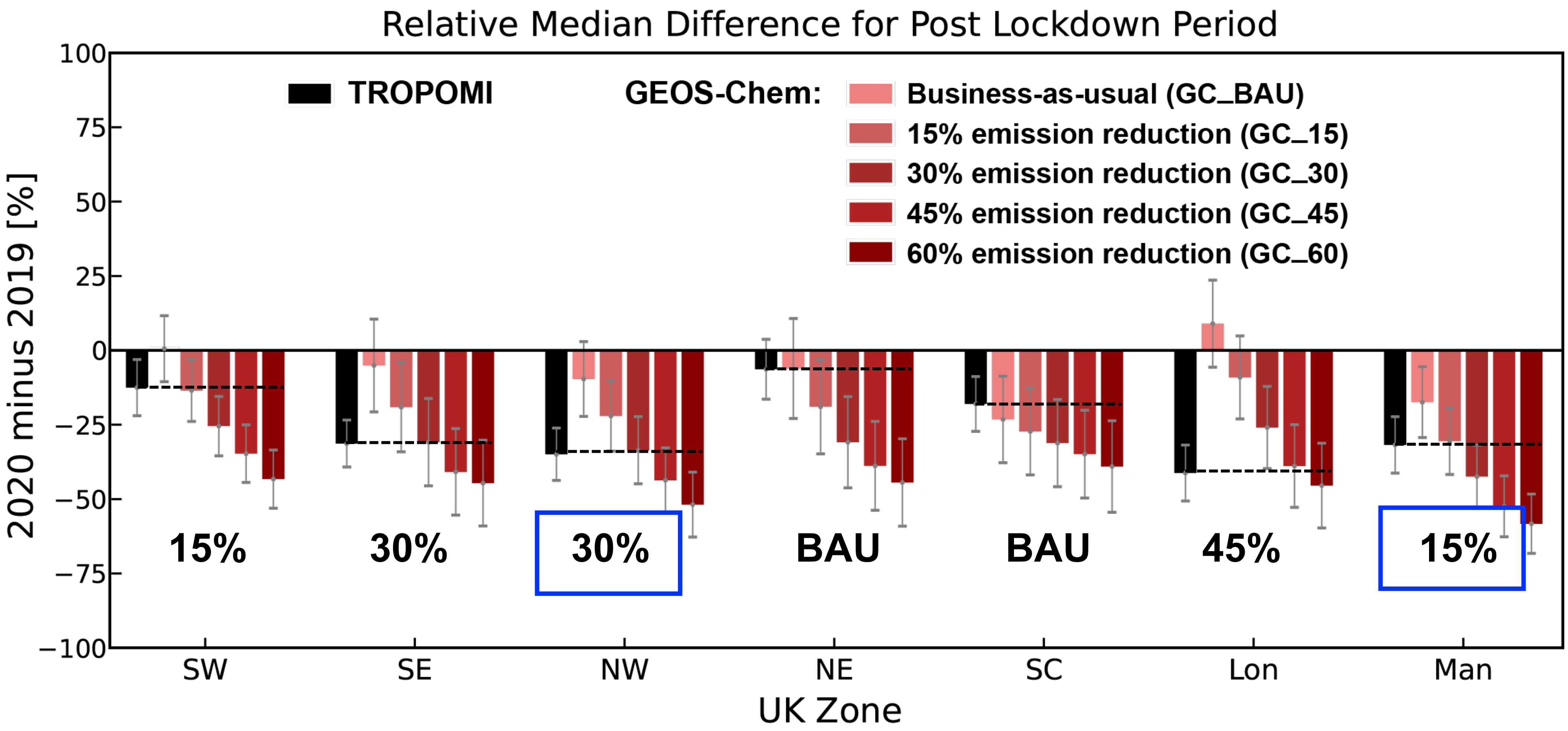
Summary of emissions reductions at the regional/city scale

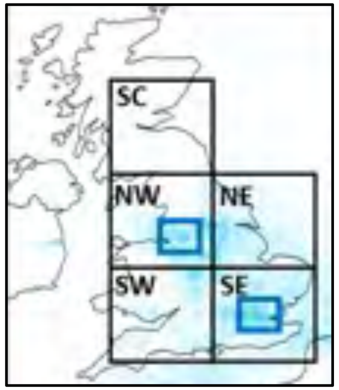


As expected, greater emissions reductions in heavily populated areas with dense road traffic

April 2020 road traffic was 35% of typical values and May 2020 was 50% typical values (ONS)

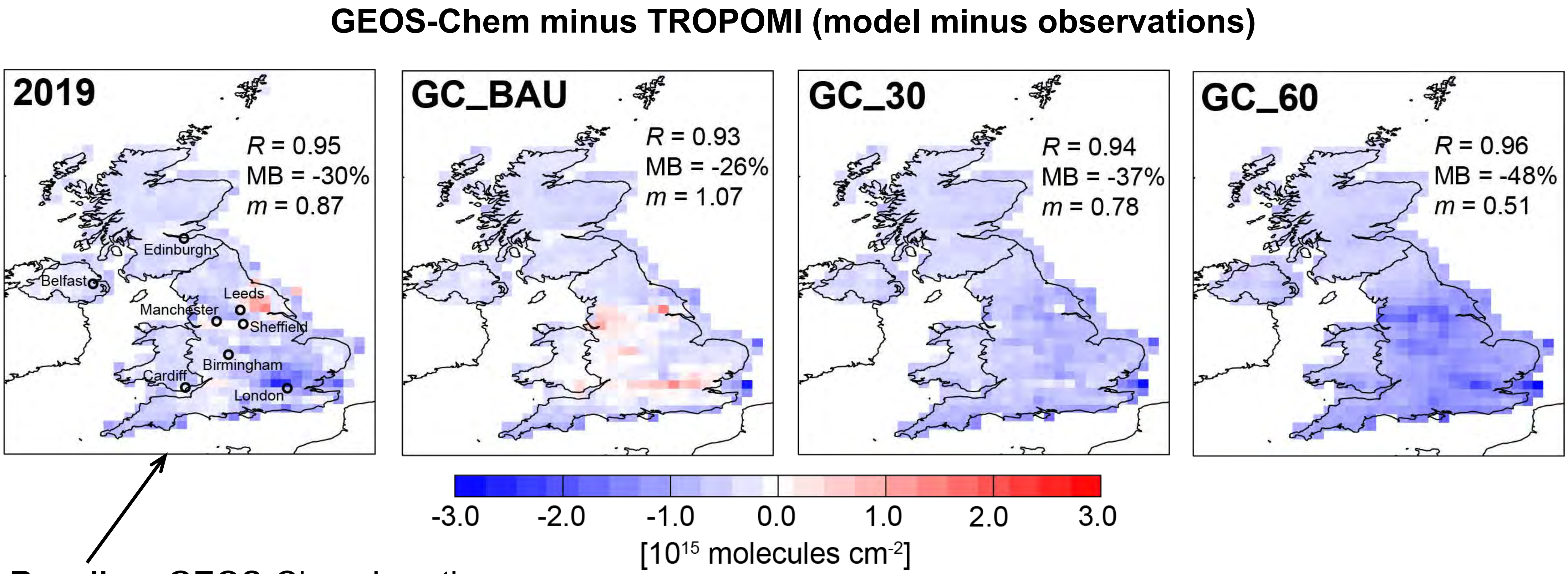
Also assess using median relative difference





Generally consistent with slope approach, except for Northwest and Greater Manchester.

Emissions reductions at the national scale



Baseline: GEOS-Chem less than TROPOMI, except over Drax

National mean decline of **~20%**

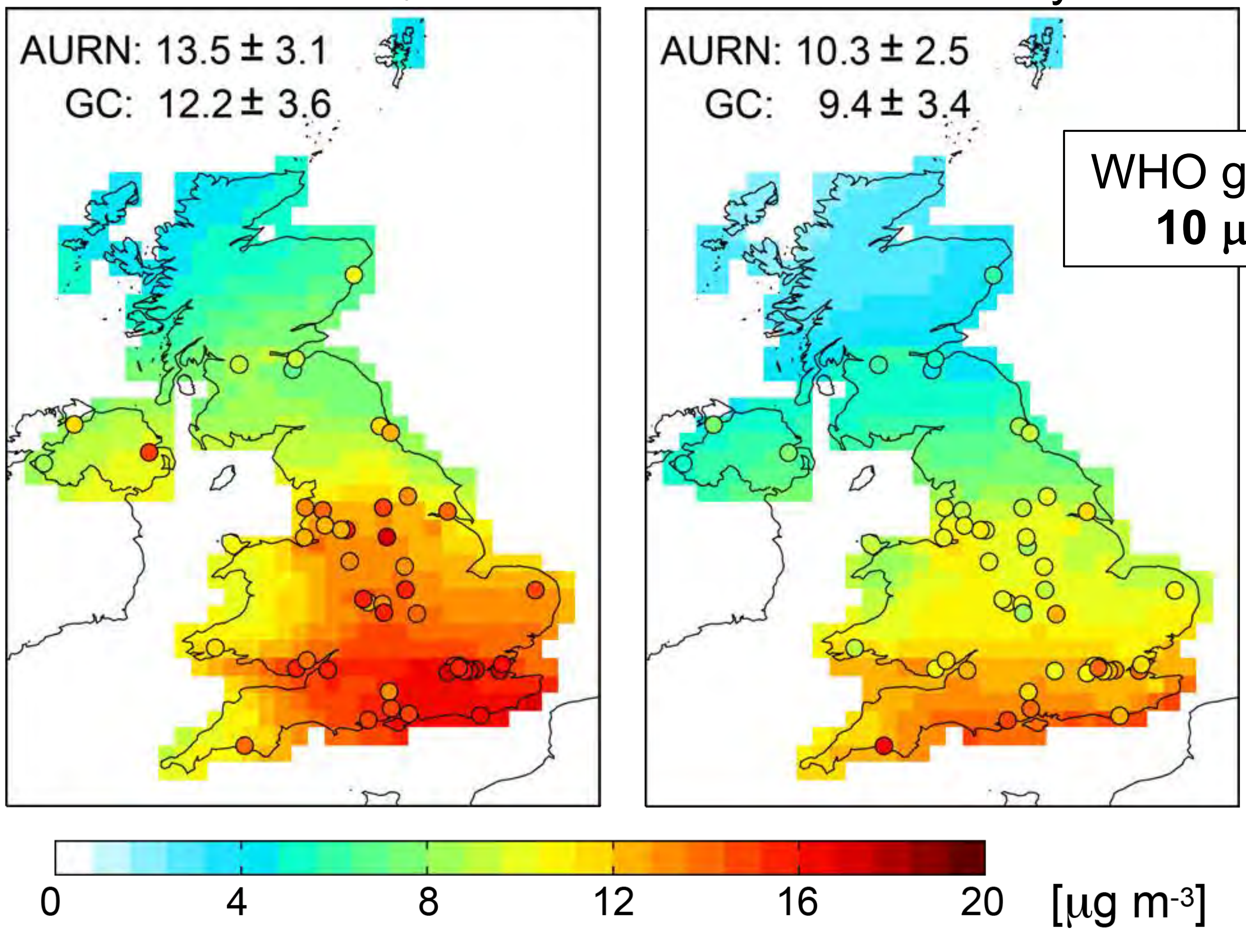
Effect of lockdown measures on surface $PM_{2.5}$

Apply **20% reduction** in all UK non-agricultural anthropogenic emissions during the lockdown

Assess GEOS-Chem against surface observations of $PM_{2.5}$ from the AURN network

23 Mar to 31 May **2019**

23 Mar to 31 May **2020**

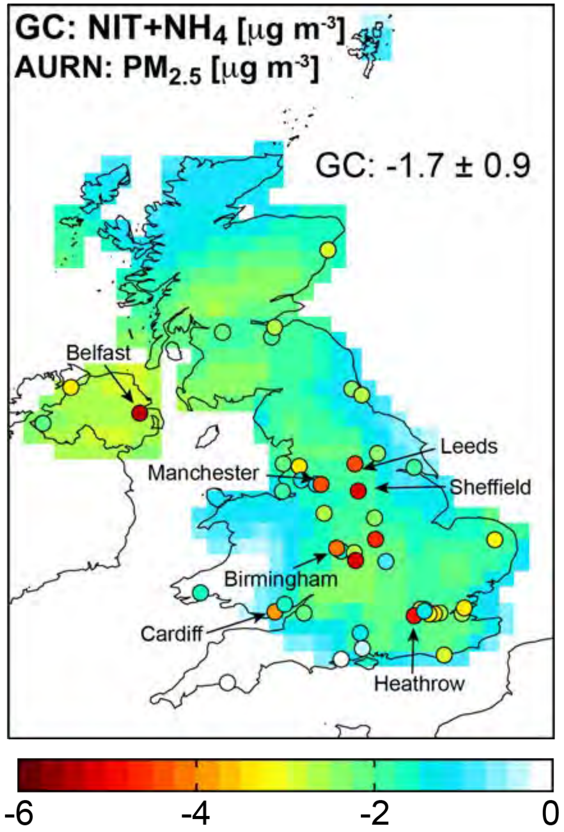


WHO guideline:
10 μg m^{-3}

Decline in $PM_{2.5}$: 3.2 μg m^{-3} (AURN); 2.7 μg m^{-3} (GEOS-Chem)

Model decline dominated by nitrate (NIT) and ammonium (NH_4)

2020 minus 2019 for 23 Mar to 31 May



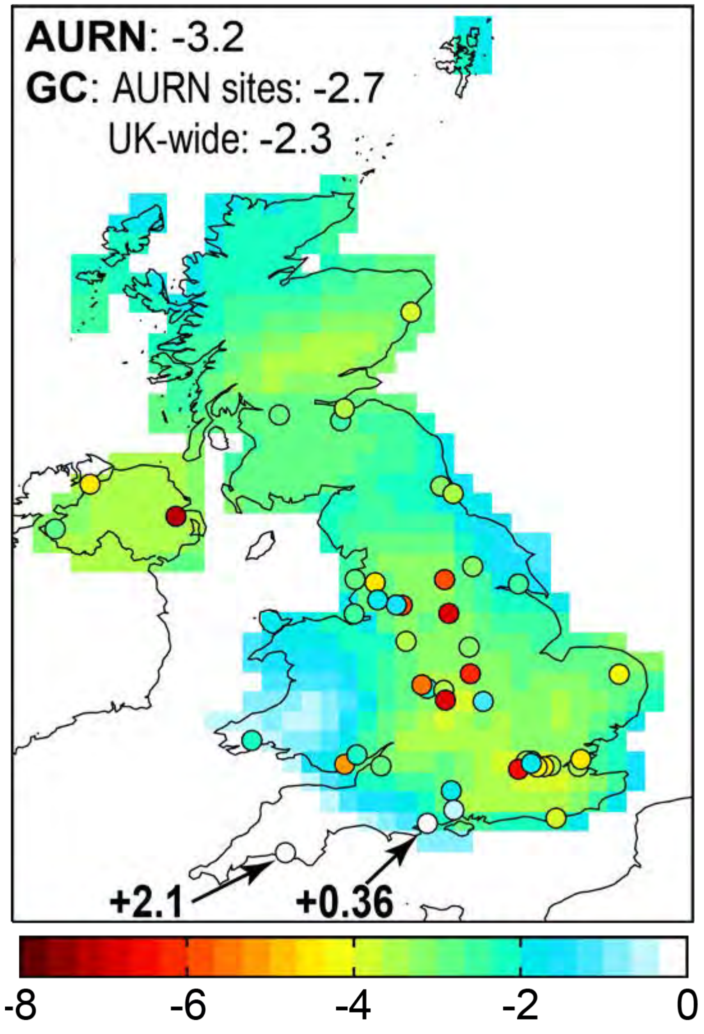
Model misses the decline in primary $PM_{2.5}$ in cities

Effect of lockdown measures on surface $PM_{2.5}$

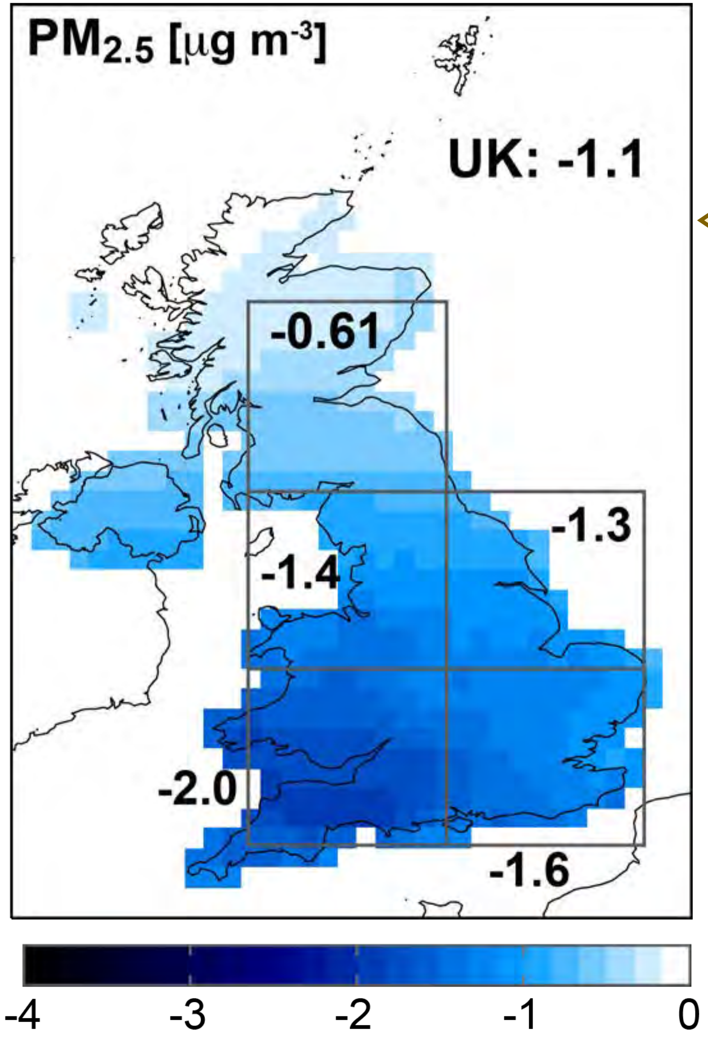
Modelled (and observed) $PM_{2.5}$ in 2020 relative to 2019

Change in $PM_{2.5}$ due to **all factors**

2020 minus 2019

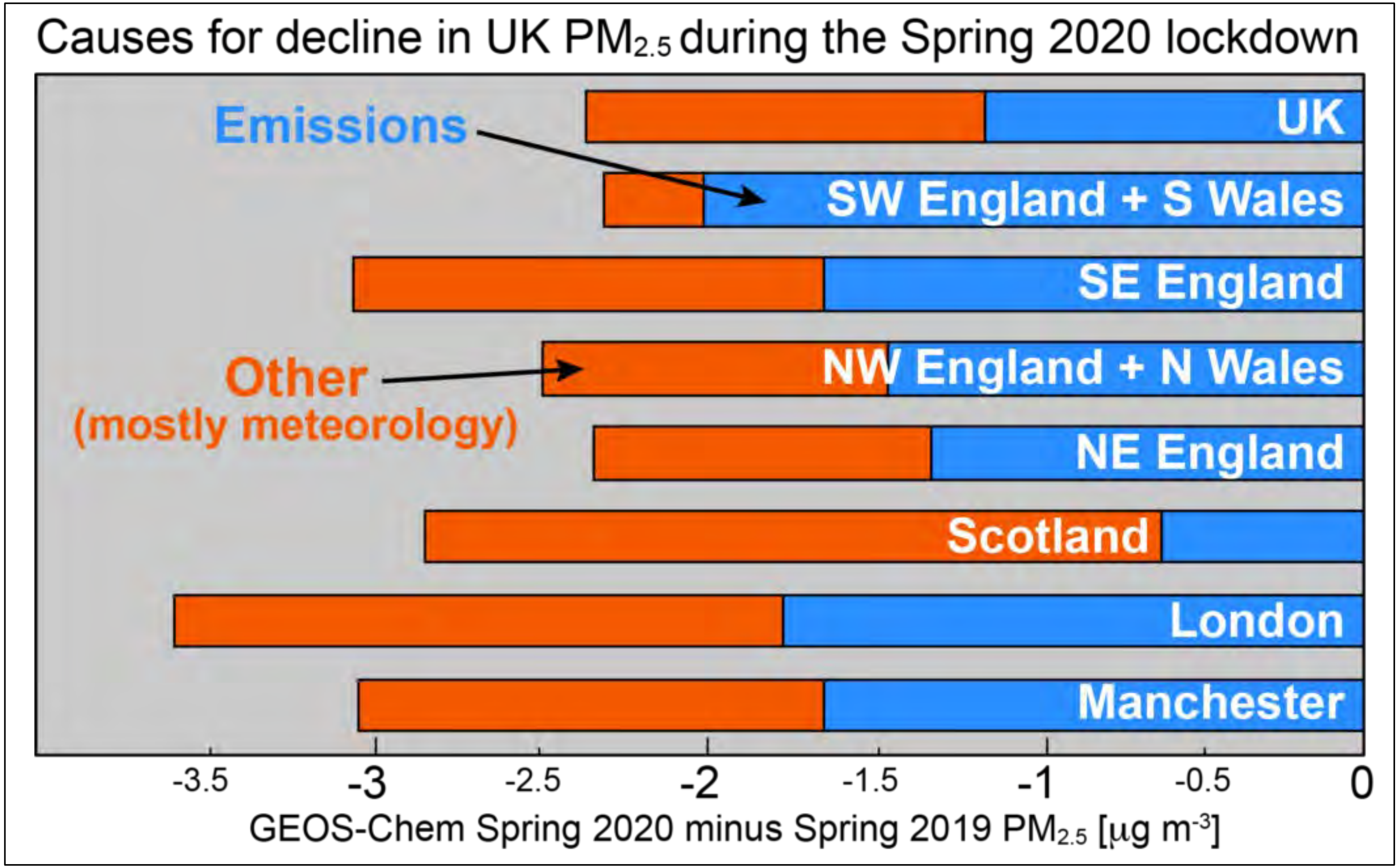


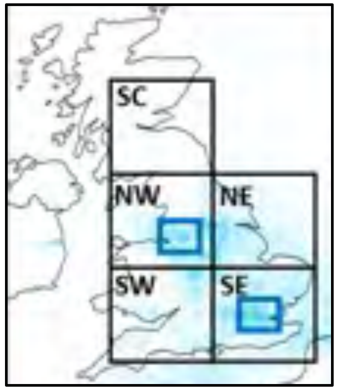
GC_20 minus GC_BAU



Change in $PM_{2.5}$ due to **emissions only**

Changes in $PM_{2.5}$ due to emissions and other factors





Lower $PM_{2.5}$ in 2020 than in 2019 was due in equal measure to interannual variability in meteorology and emissions reductions

Webinar next week on the COVID-19 pandemic, air quality and health:

HEI Annual Conference

Webinar 4: The COVID-19 Pandemic, Air Pollution, and Health: Lessons from Around the Globe

Apr 27, 2021 - 10:00am **(EST; 3pm BST)**

Chairs: Jeff Brook, University of Toronto, HEI Research Committee, and Barbara Hoffmann, University of Düsseldorf, HEI Research Committee

The COVID-19 pandemic has led to widespread disruptions of society, including closures of businesses, schools, and industrial activities, and there have been unprecedented restrictions on travel at all scales. All of this has led to reductions in emissions of air pollution and changes in air quality in locations around the world. Relatedly, there is emerging evidence that exposure to air pollution may be associated with increased susceptibility to infection from COVID-19, with increased adverse symptoms and duration of the disease, as well as increased risk of mortality. This session will discuss these potential linkages, along with evidence of racial inequalities in exposures to air pollution and in COVID-19 outcomes, and discuss challenges in studying these issues. Lastly, the session will bring in the "One Health" approach, recognizing the interconnections between people, animals, and plants and their shared environment.

For more details and to register: https://www.healtheffects.org/annual-conference