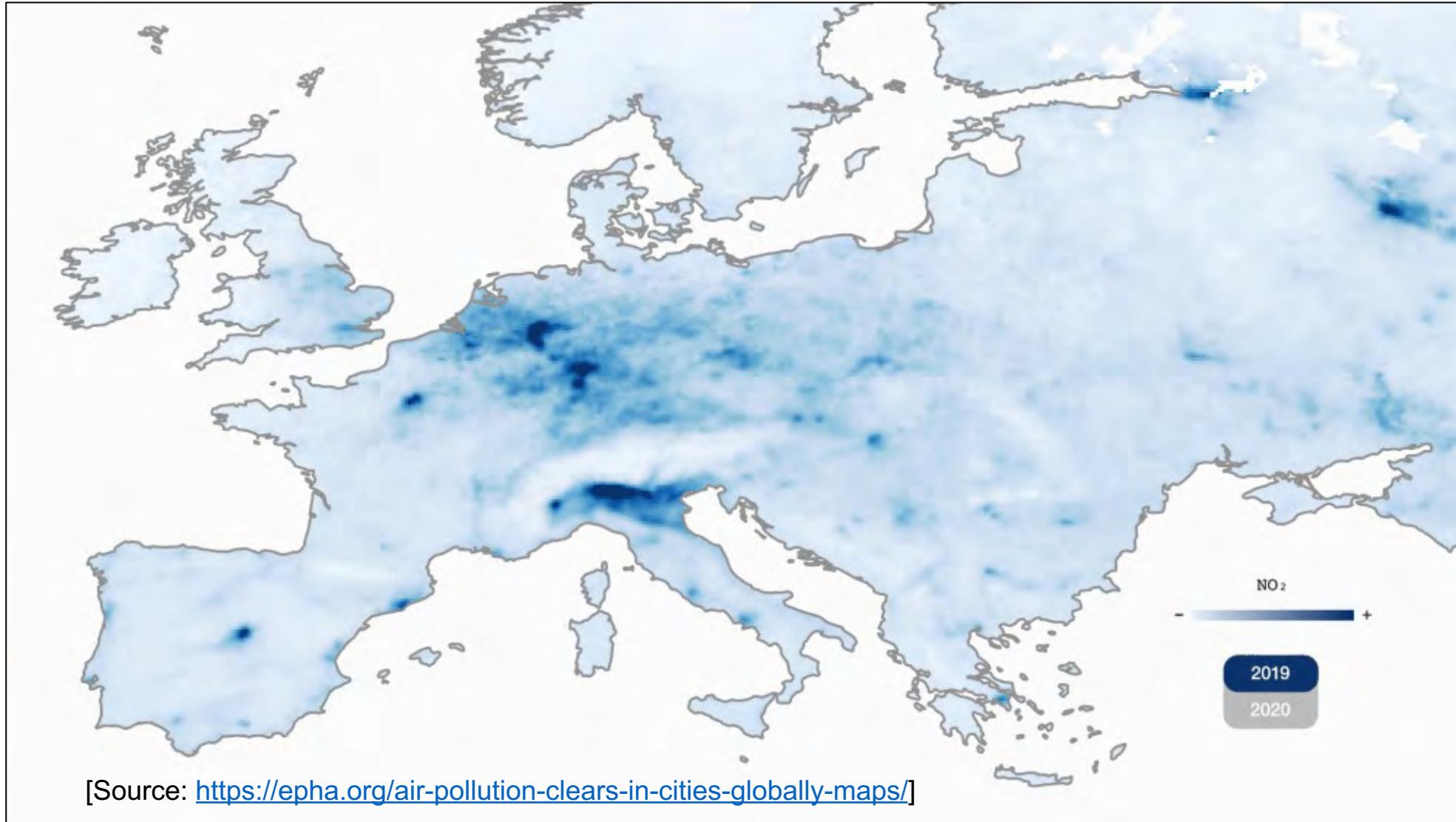


# UK air quality during the Spring 2020 lockdown: relative role of sources and meteorology



# Dramatic improvements in air quality during lockdowns

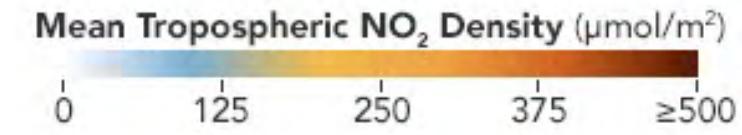
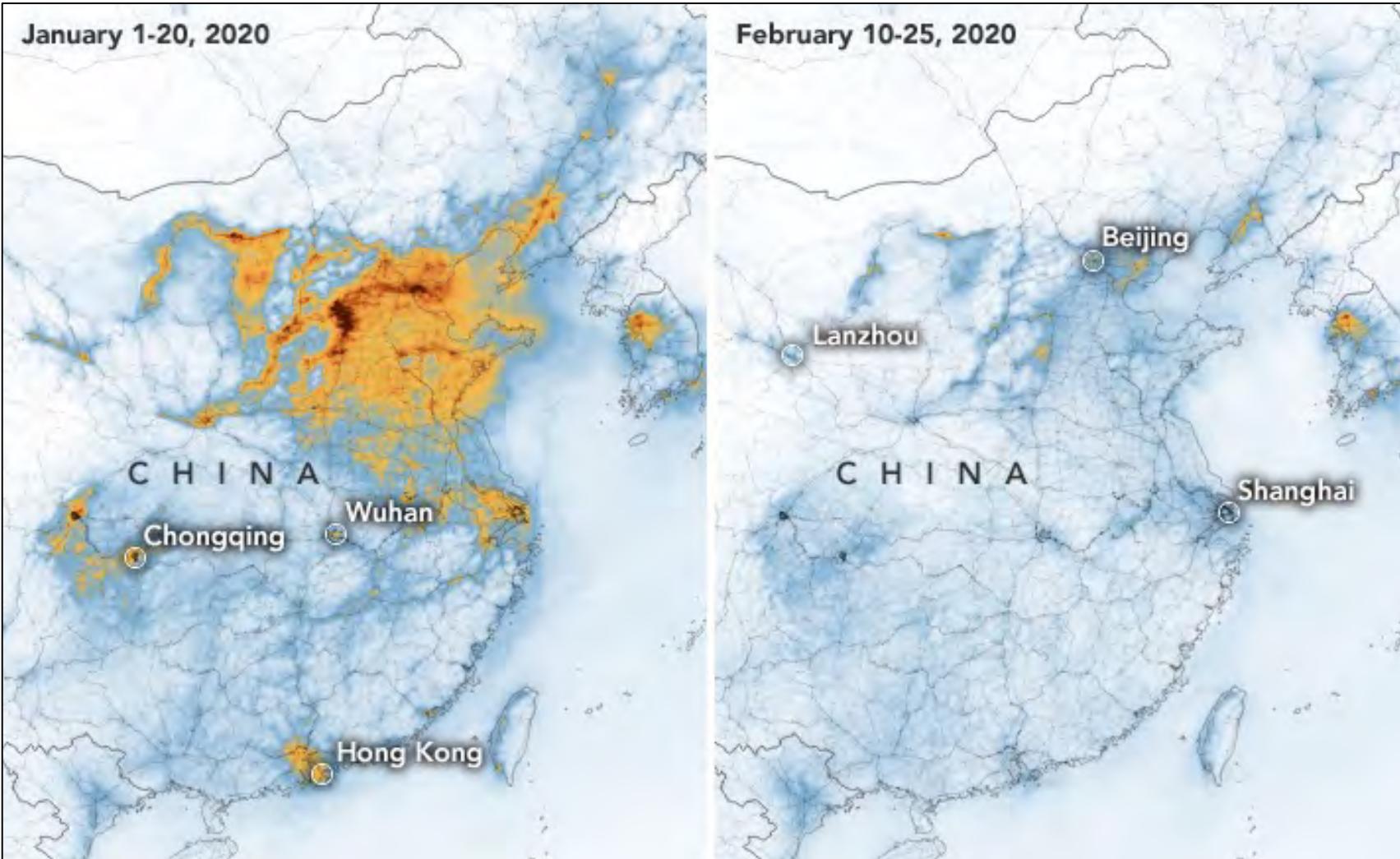


Source: <https://edition.cnn.com/2020/04/23/india/india-air-pollution-coronavirus-nasa-intl/>

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<sub>2</sub> before vs during lockdown



**TROPOMI:**  
TROPOspheric Monitoring  
Instrument

TROPOMI sees NO<sub>2</sub> and provides constraints on NO<sub>x</sub>

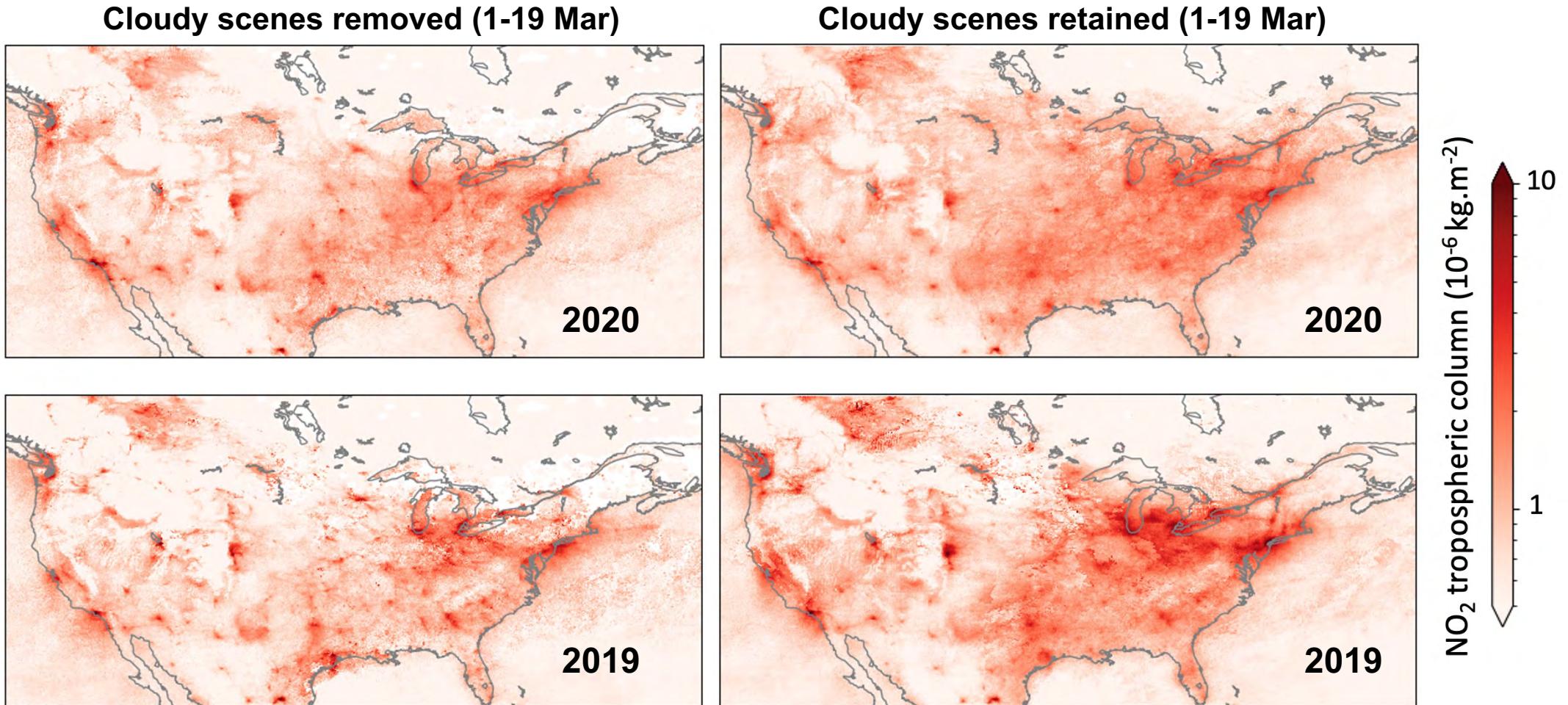
$$\text{NO}_x = \text{NO} + \text{NO}_2$$

[Source: [https://eoimages.gsfc.nasa.gov/images/imageresords/146000/146362/china\\_trop\\_2020056.png](https://eoimages.gsfc.nasa.gov/images/imageresords/146000/146362/china_trop_2020056.png)]

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

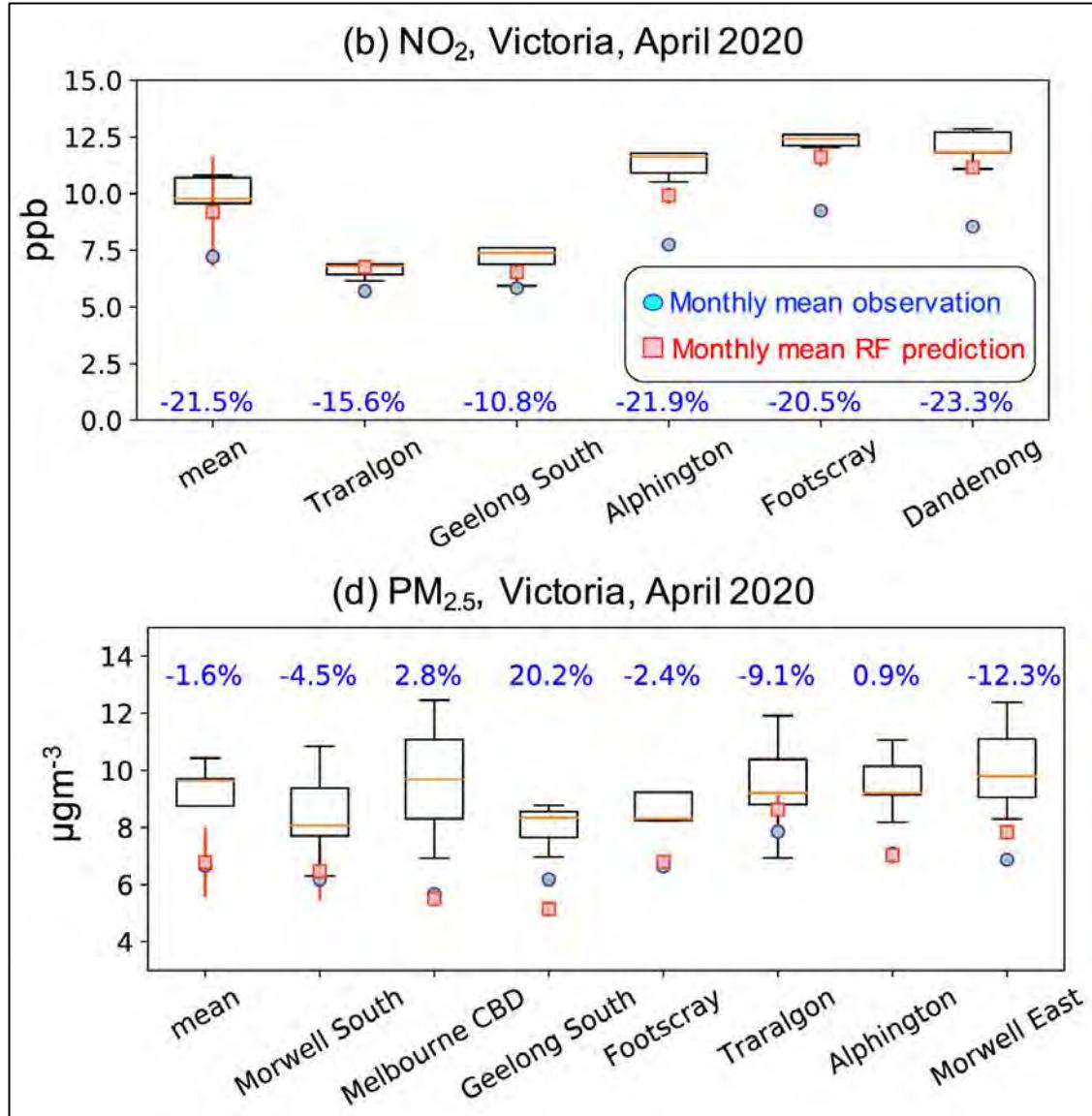
TROPOMI data publicly available for use by experts and novices, but detailed knowledge of this data is crucial!



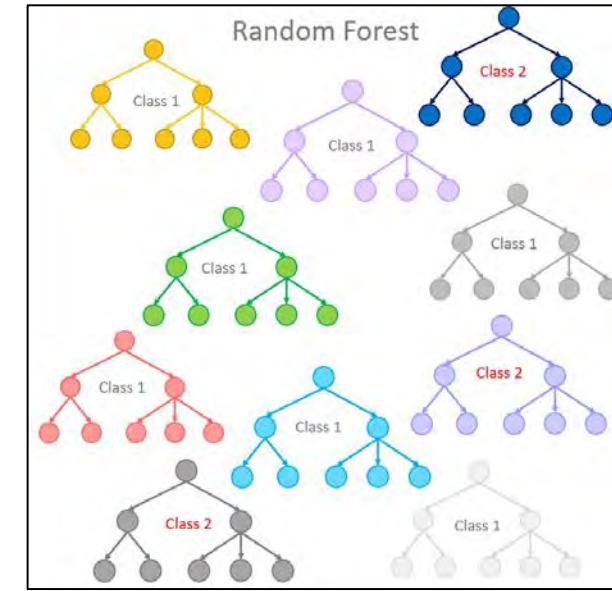
Leads to different conclusions about the magnitude of the decline in  $\text{NO}_x$

[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:

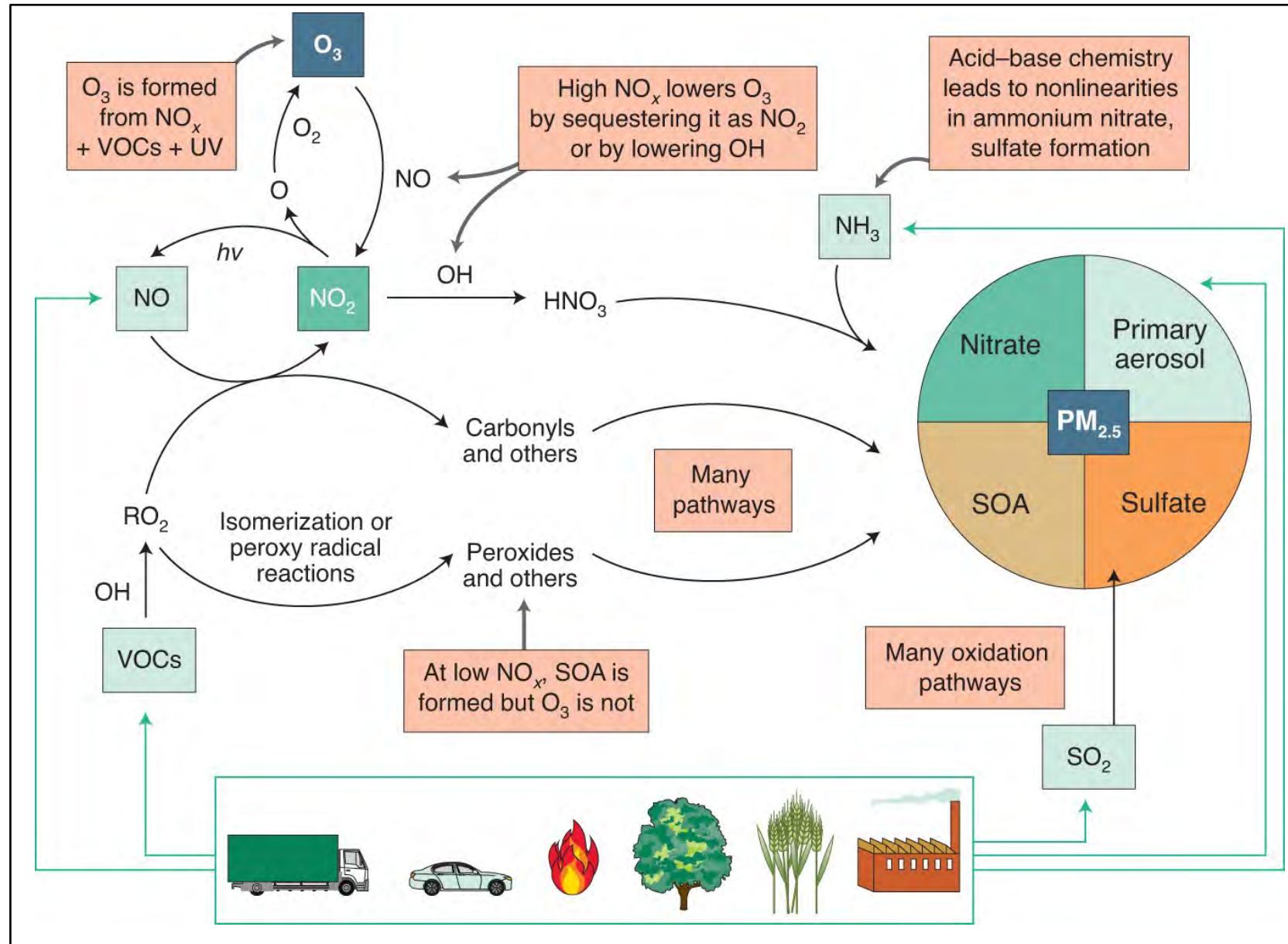
All factors: yellow lines minus blue circles

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.

# 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<sub>x</sub>

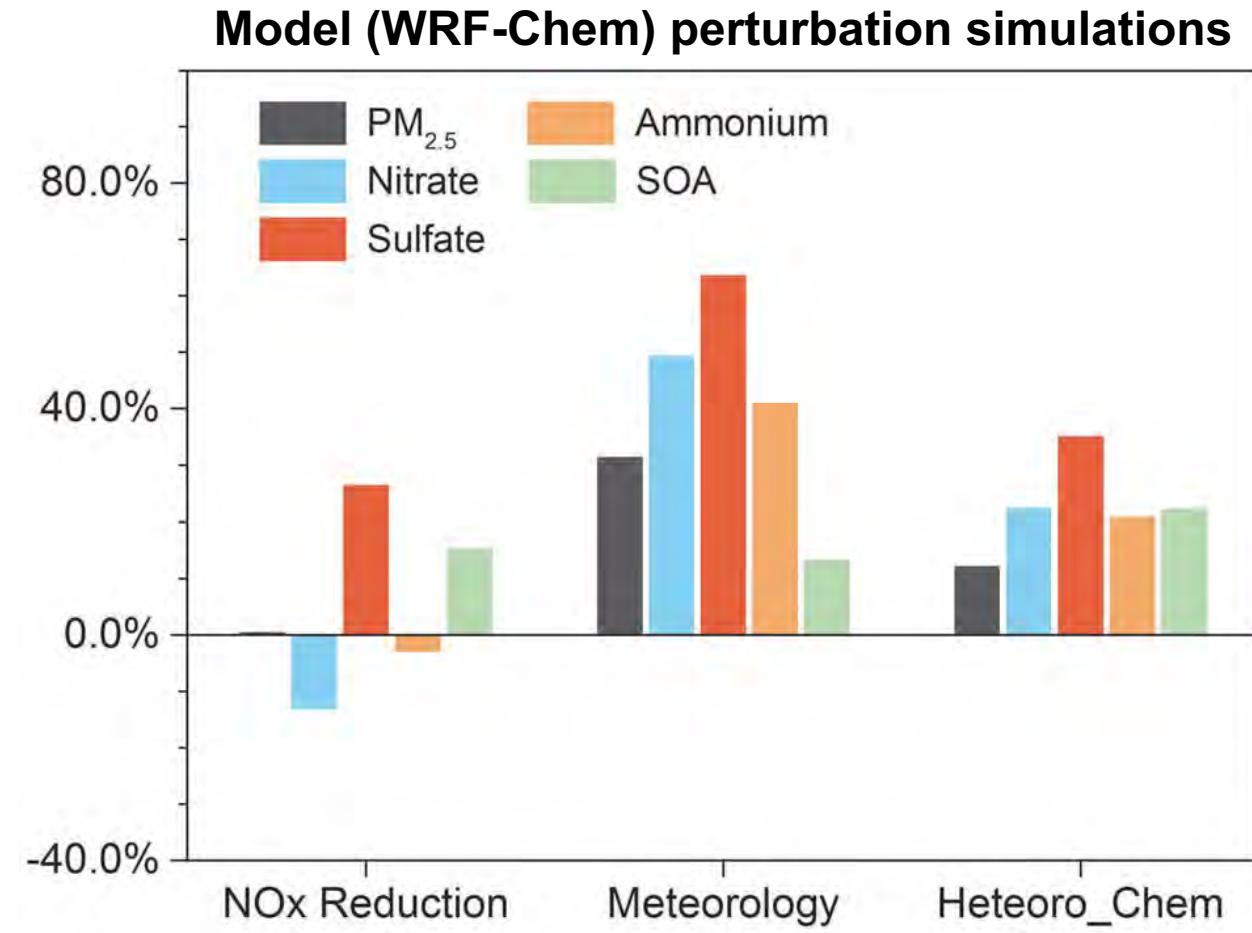
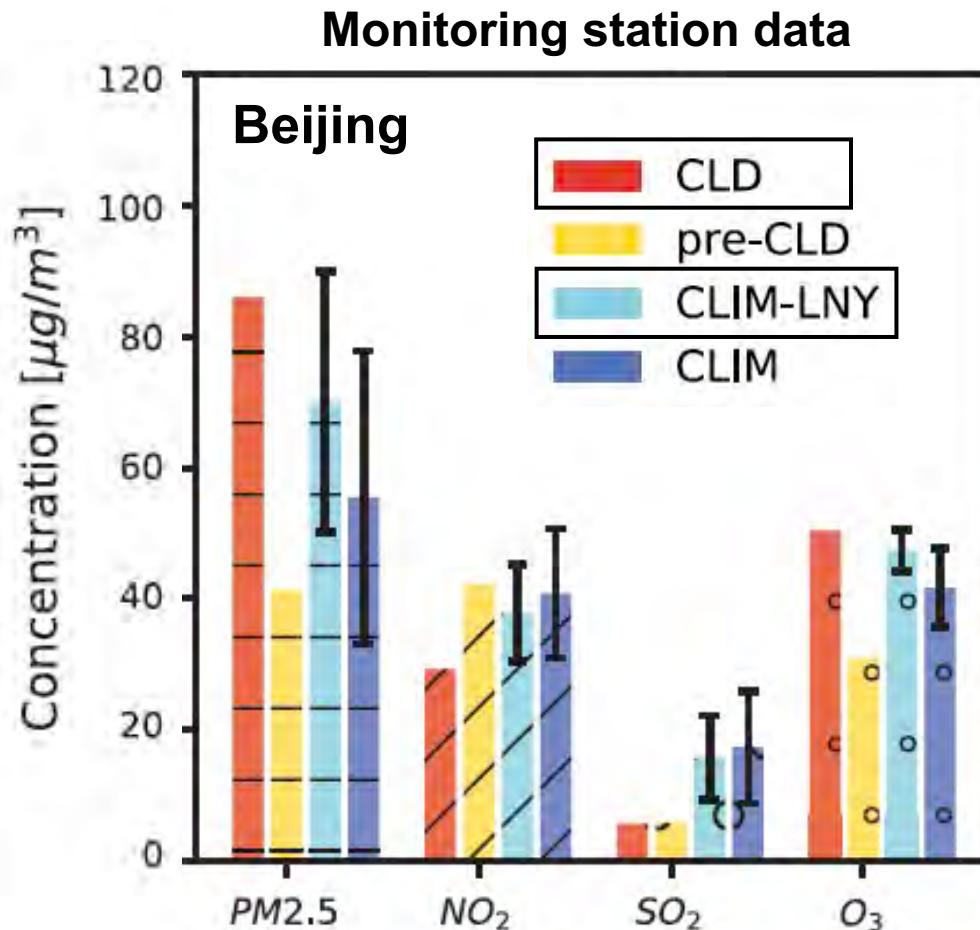
Changes in oxidizing capacity (OH, O<sub>3</sub>)

Aerosols impact availability of light

# Chemical transformations also key factor

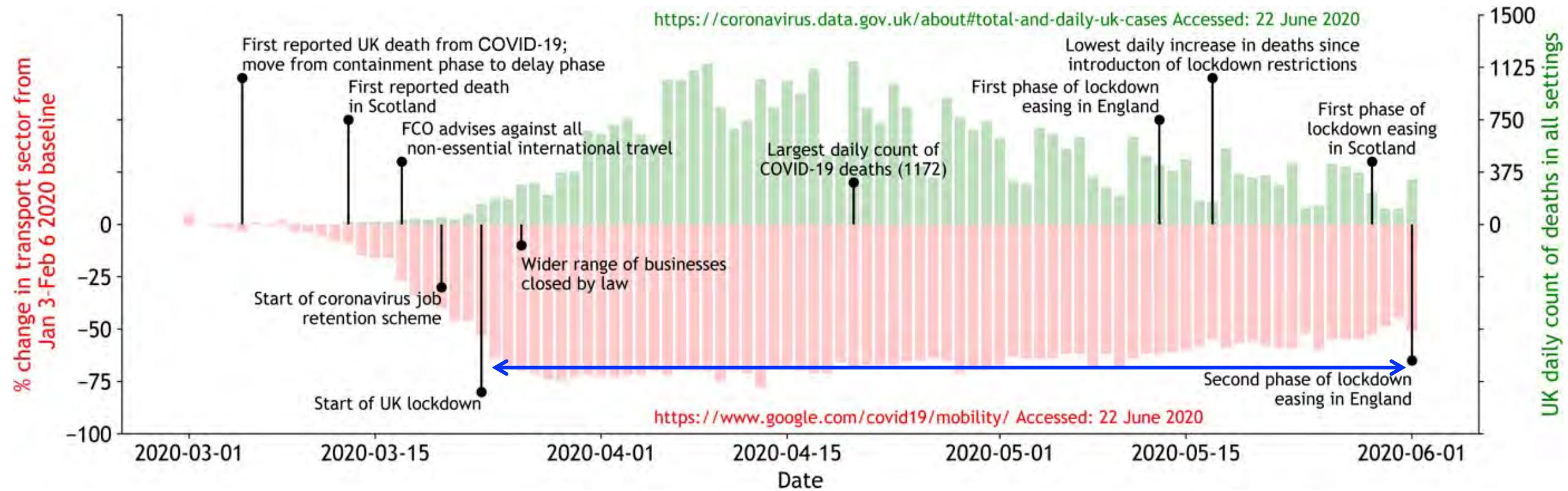
During city lockdowns in China PM<sub>2.5</sub> decreased almost everywhere, except over Beijing.

High relative humidity, stable conditions, positive feedbacks.



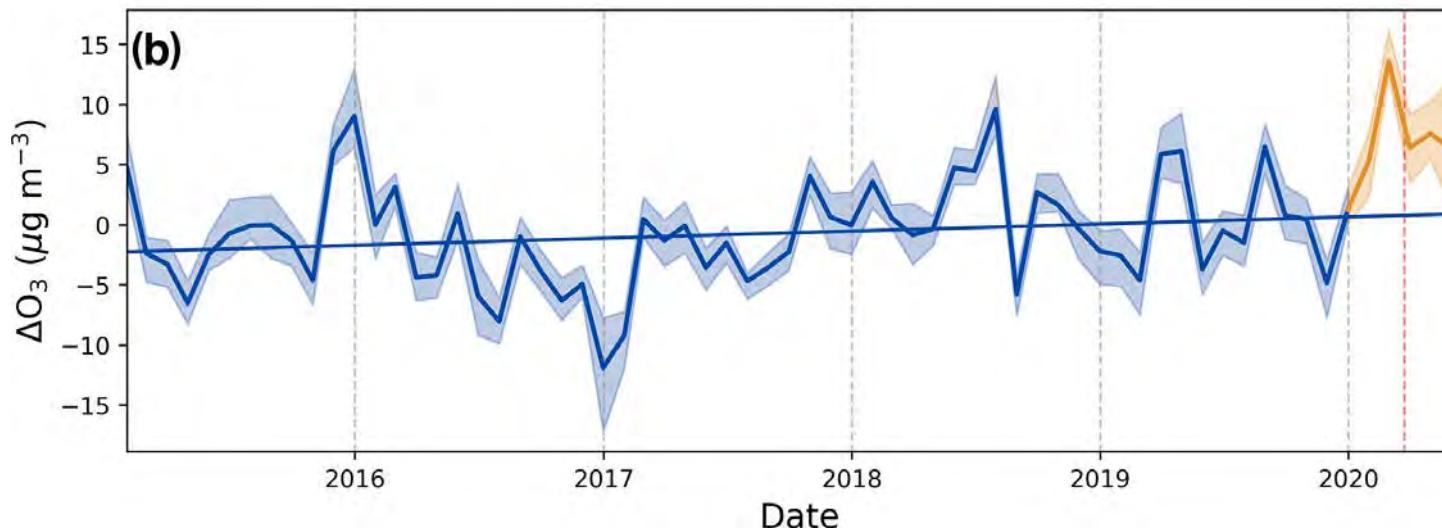
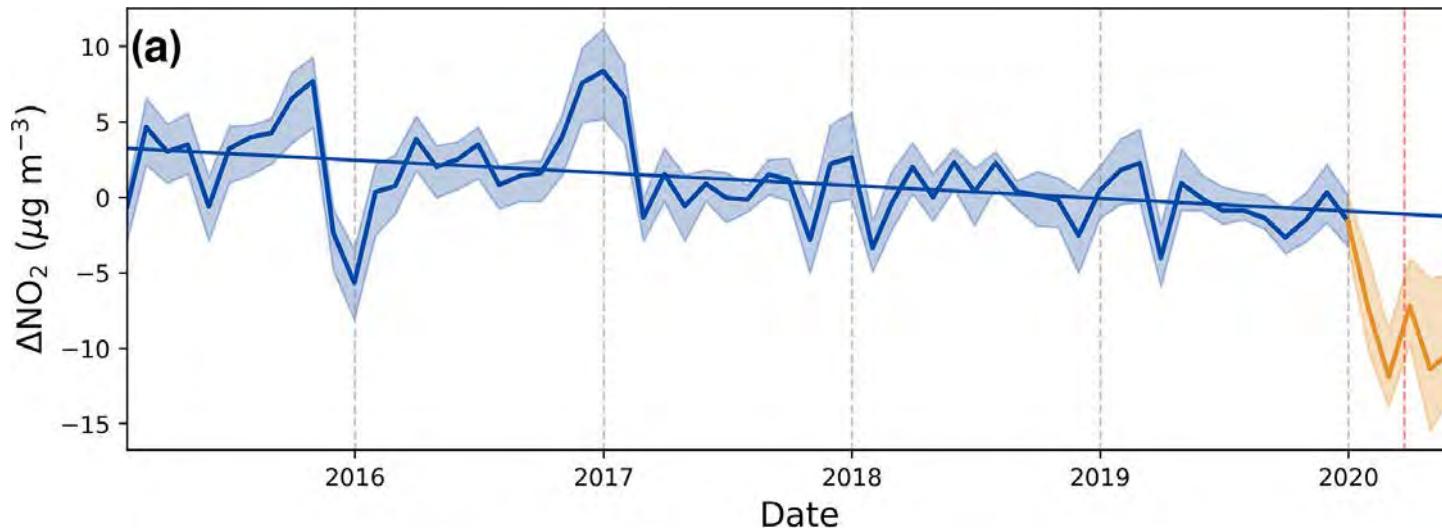
[Source: Le et al., 2020, <https://science.sciencemag.org/content/369/6504/702>]

# UK lockdown timeline

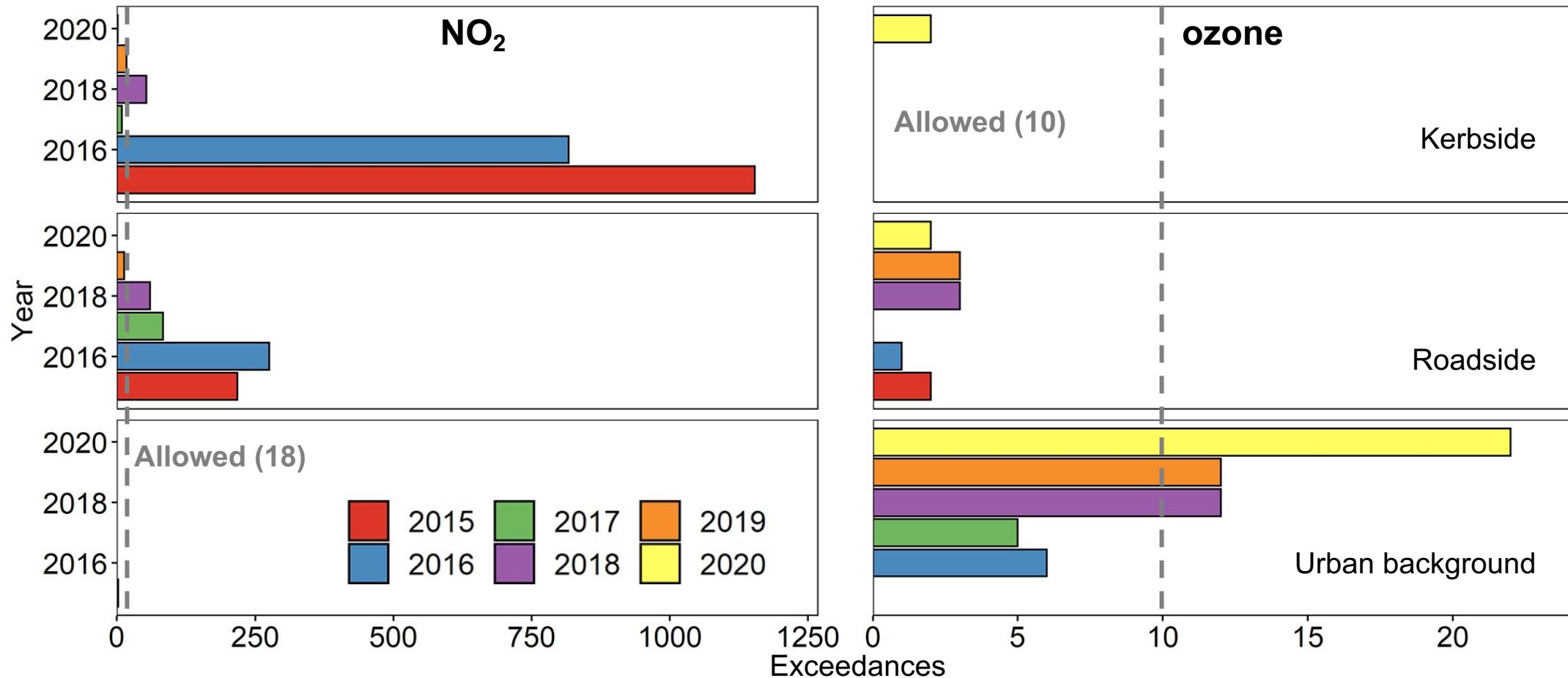


# 42% decrease in NO<sub>2</sub> during UK lockdown

Deseasonalized surface observations of NO<sub>2</sub> and ozone using long-term mean



# Decline in air quality standard exceedances in London

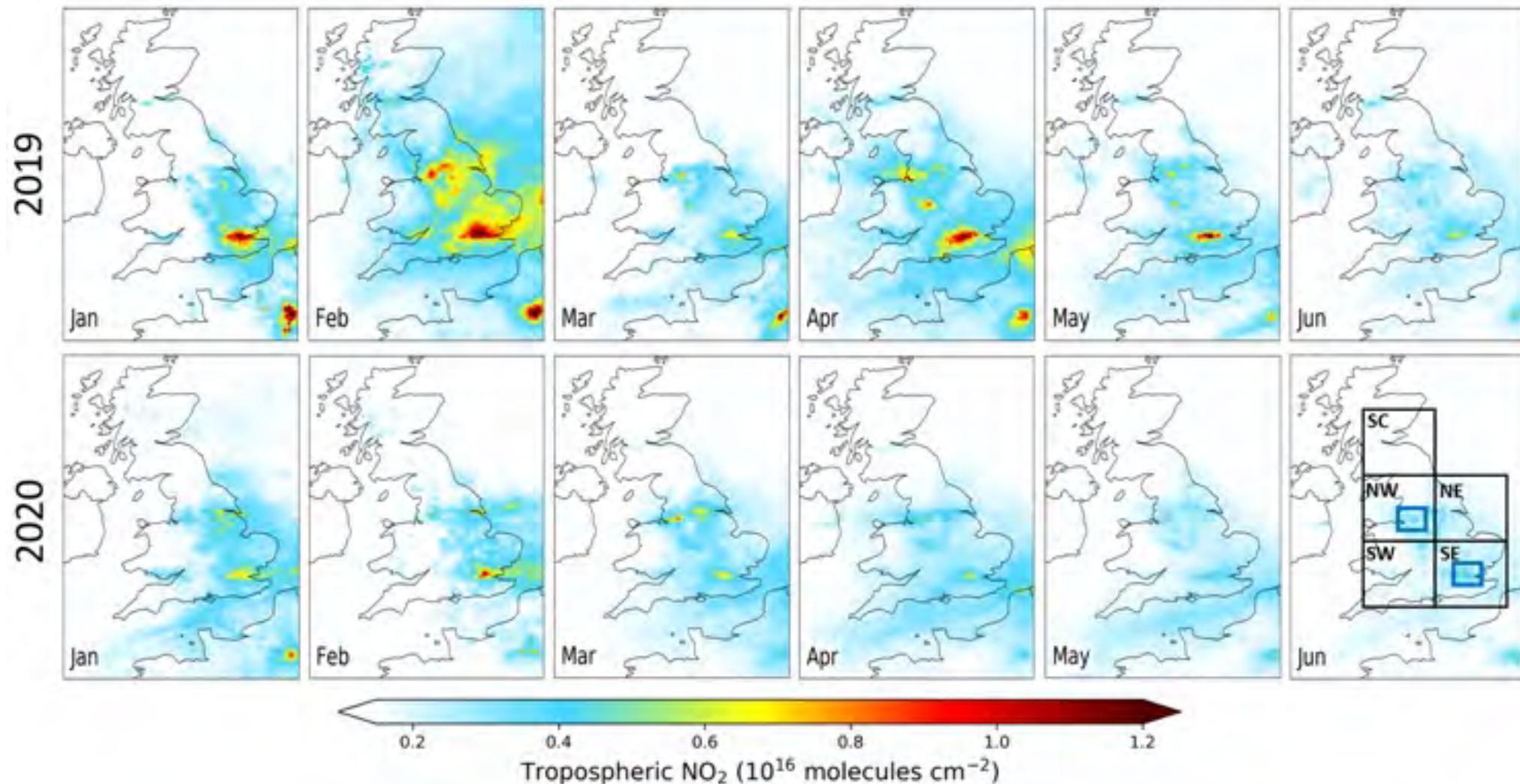


[Adapted from Lee et al., 2020, <https://doi.org/10.5194/acp-20-15743-2020>]

Surface observations have limited spatial coverage

Influence of lockdown measures on UK PM<sub>2.5</sub> uncertain. Requires regional model.

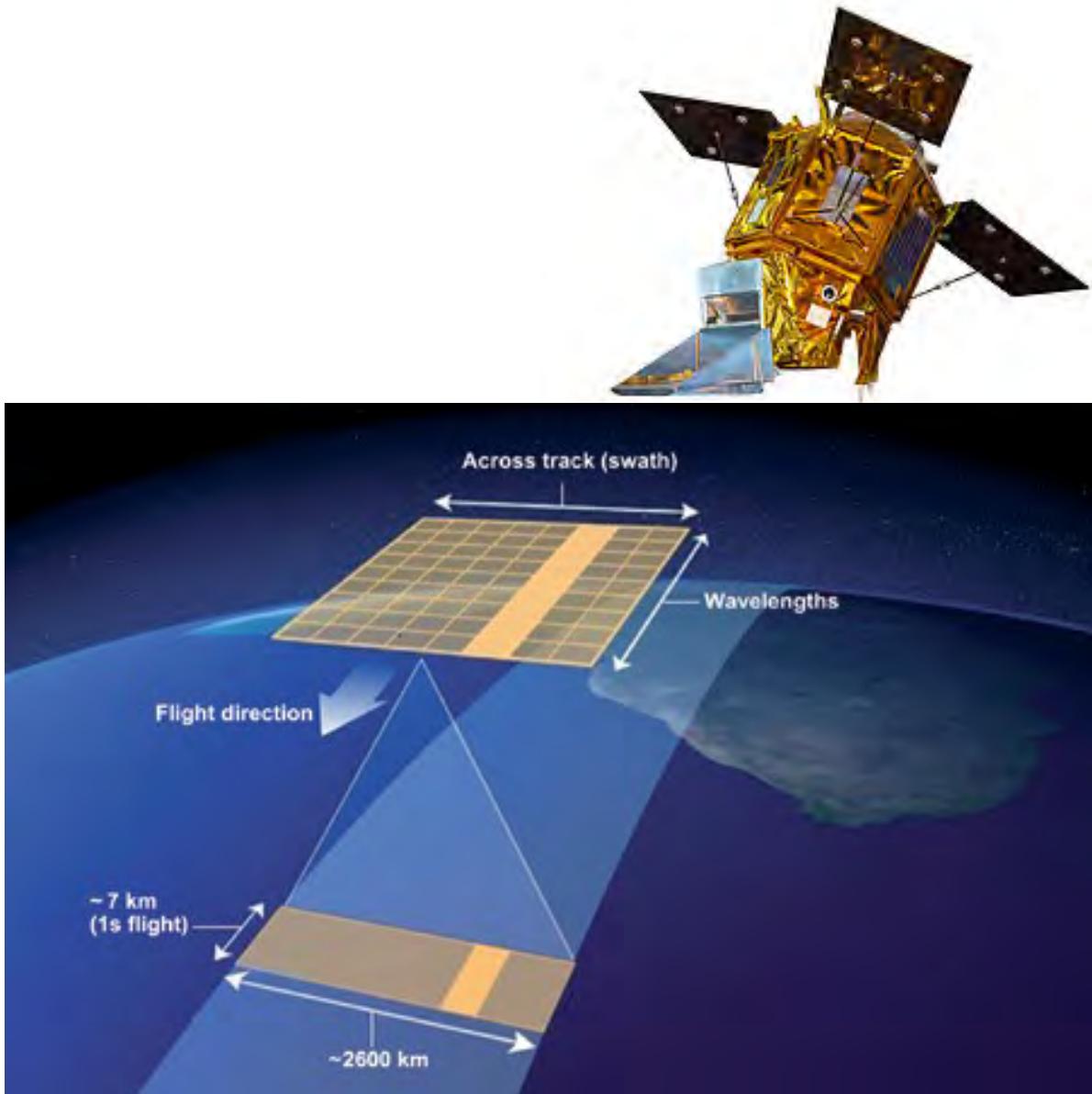
# Regional changes in air quality diagnosed with TROPOMI



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



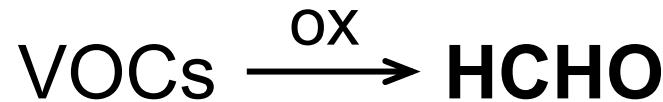
Overpass: 13:30 local solar time

Spatial resolution: 5.5 km x 3.5 km (nadir)

Swath width: 2700 km

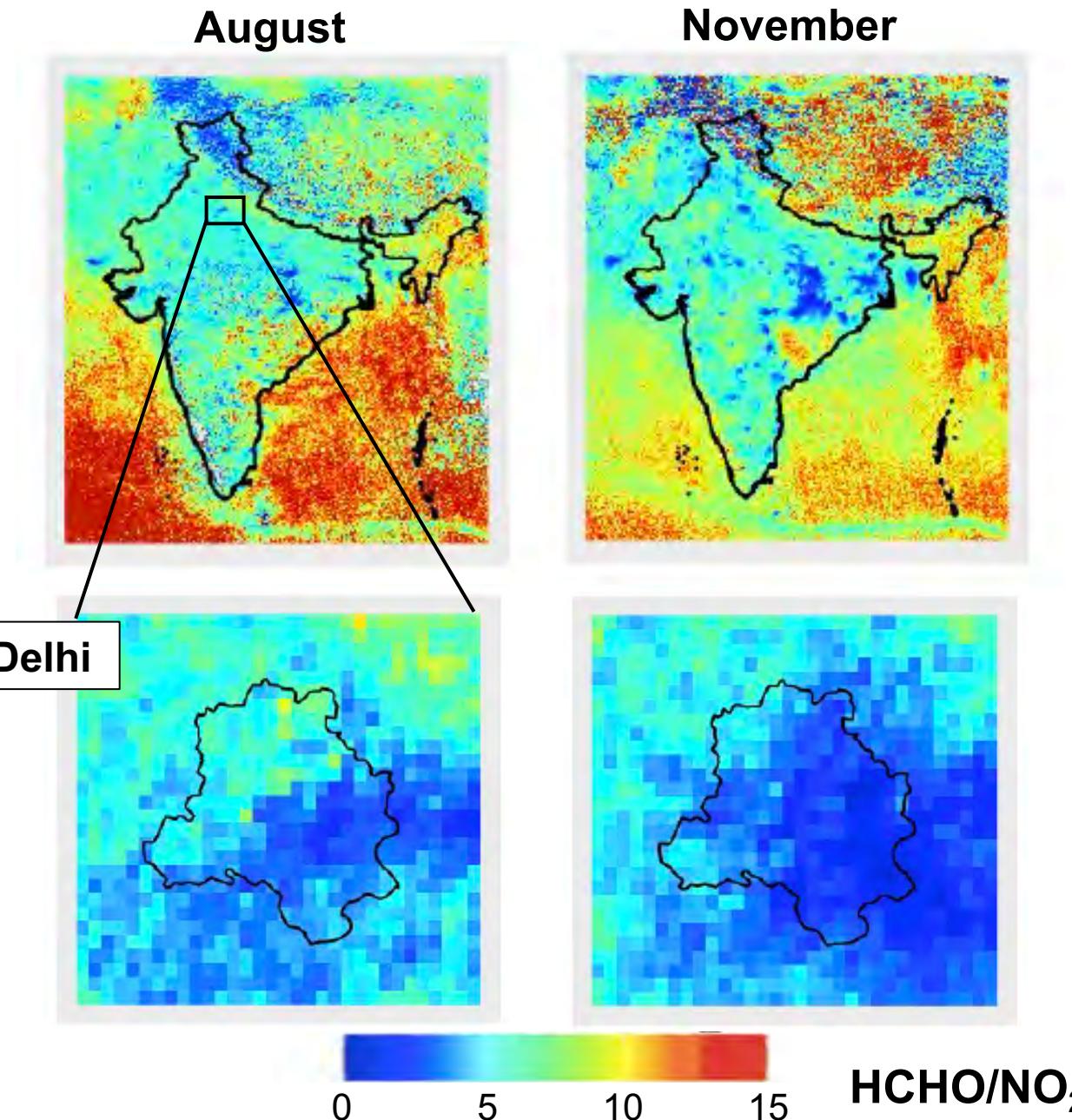
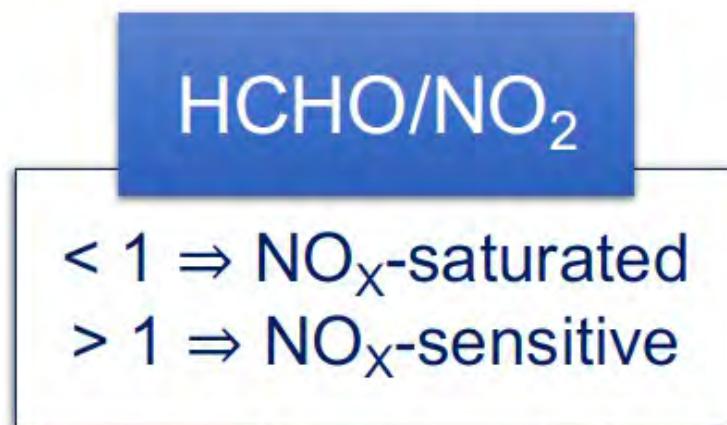
Launch date: 13 October 2017

# Using TROPOMI to investigate ozone production regimes in India



$$\text{NO}_x = \text{NO} + \text{NO}_2$$

Abundance of VOCs and  $\text{NO}_x$  determine ozone production rates



# Using TROPOMI to investigate ozone production of busy shipping lanes

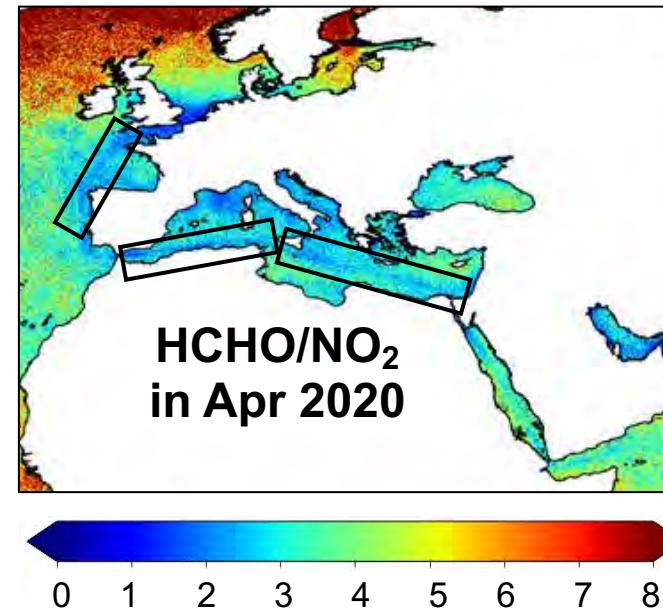
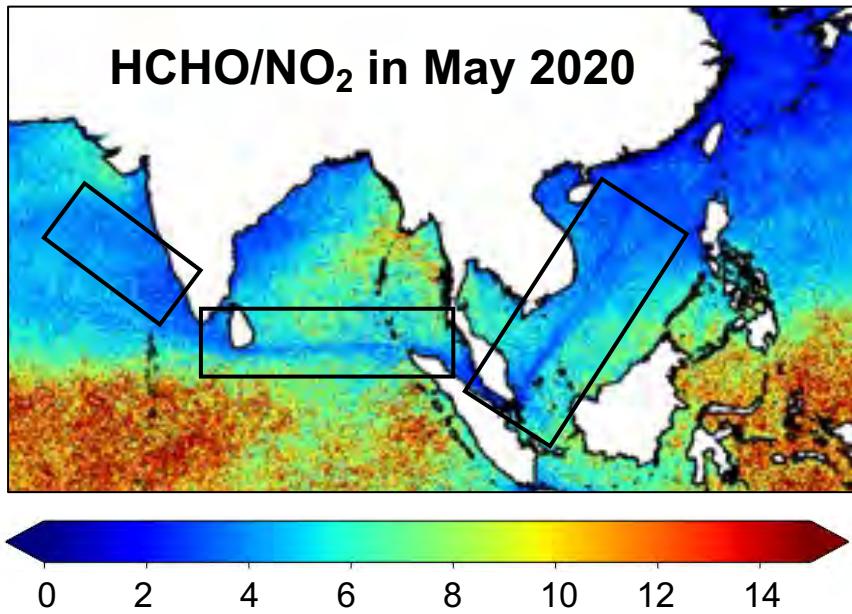
Shipping activity from Automatic Identification System (AIS) data



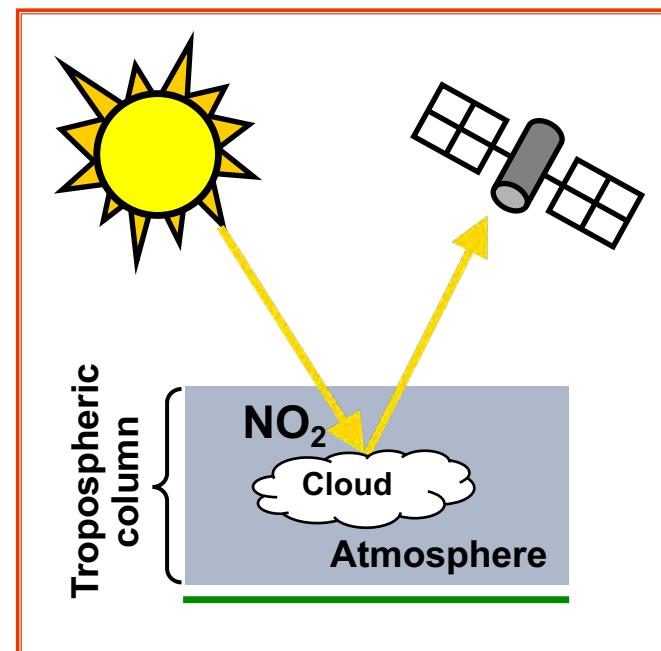
Ships run on  
heavy fuel oil  
(bunker fuel)



[Source: [https://www.esa.int/ESA\\_Multimedia/Images/2016/01/Satellite-AIS-based\\_map\\_of\\_global\\_ship\\_traffic](https://www.esa.int/ESA_Multimedia/Images/2016/01/Satellite-AIS-based_map_of_global_ship_traffic)]

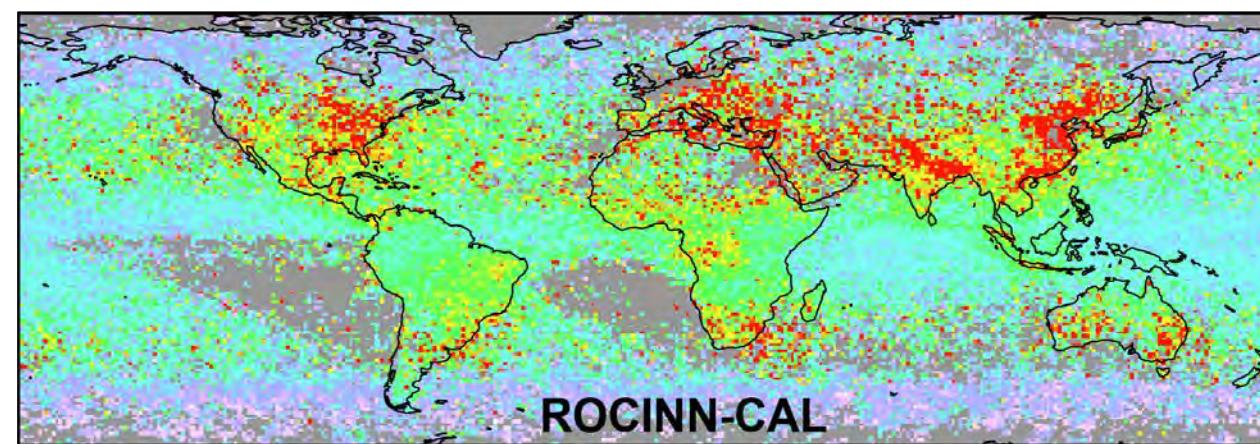
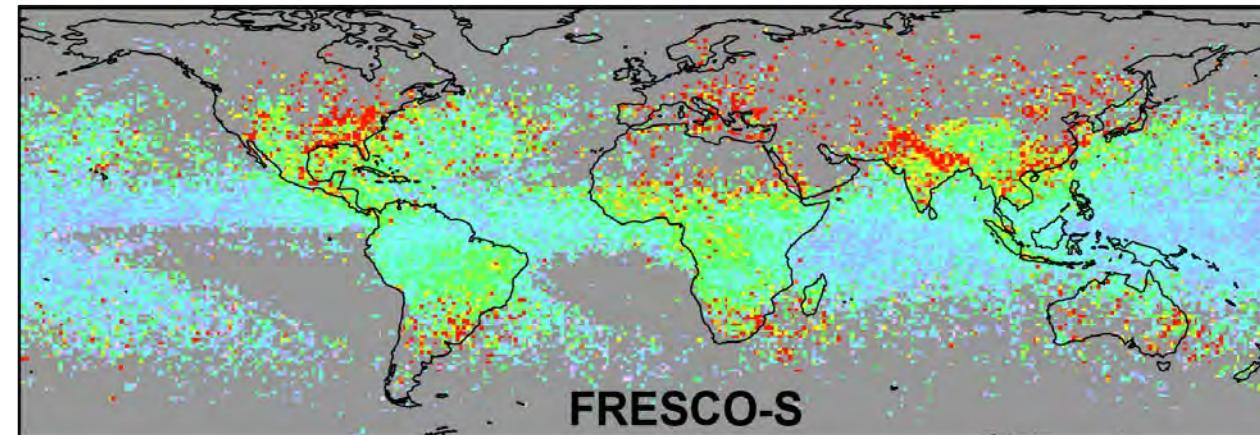


# Developing new products from TROPOMI total columns of NO<sub>2</sub>



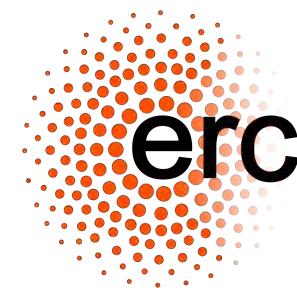
Use, rather than discard,  
observations over optically  
thick clouds

TROPOMI annual mean upper tropospheric NO<sub>2</sub> [pptv]



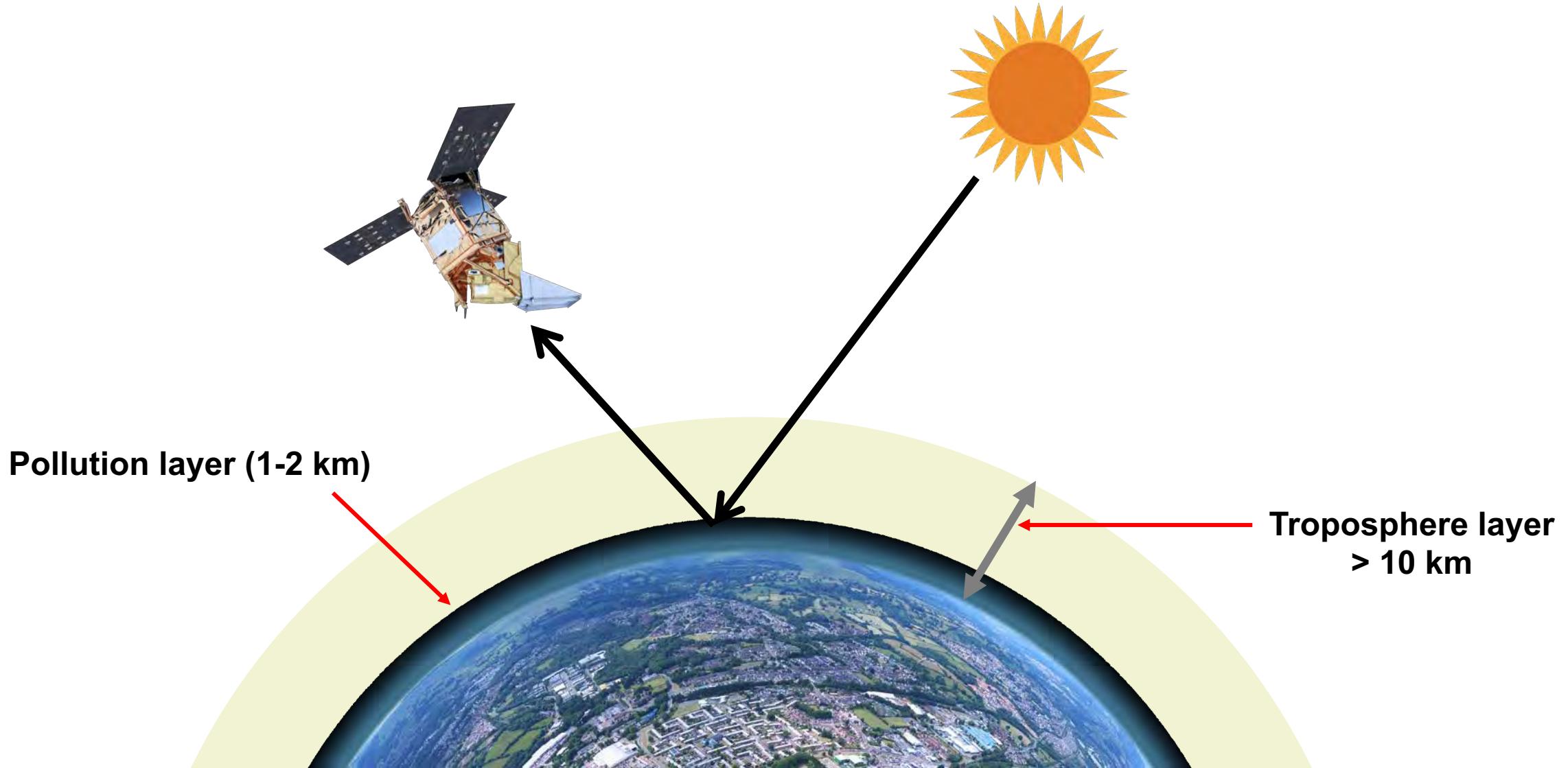
Derive NO<sub>2</sub> mixing ratios in the upper troposphere, where routine, reliable observations are sparse

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



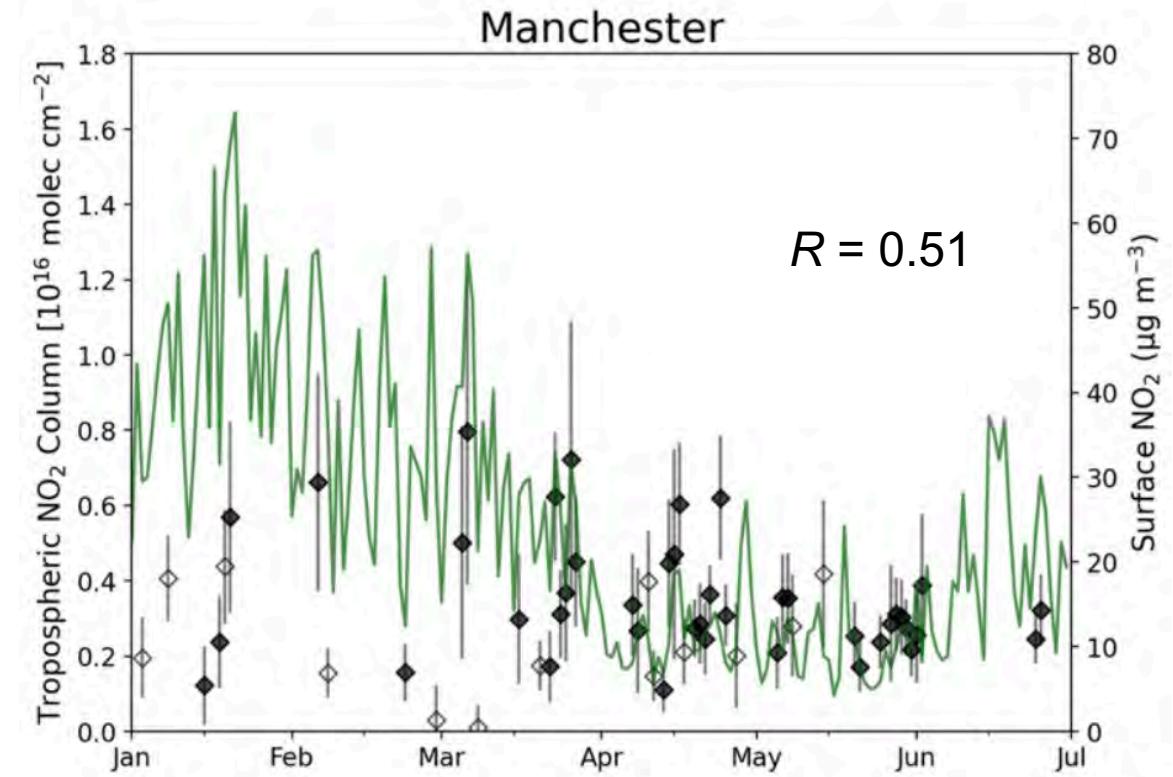
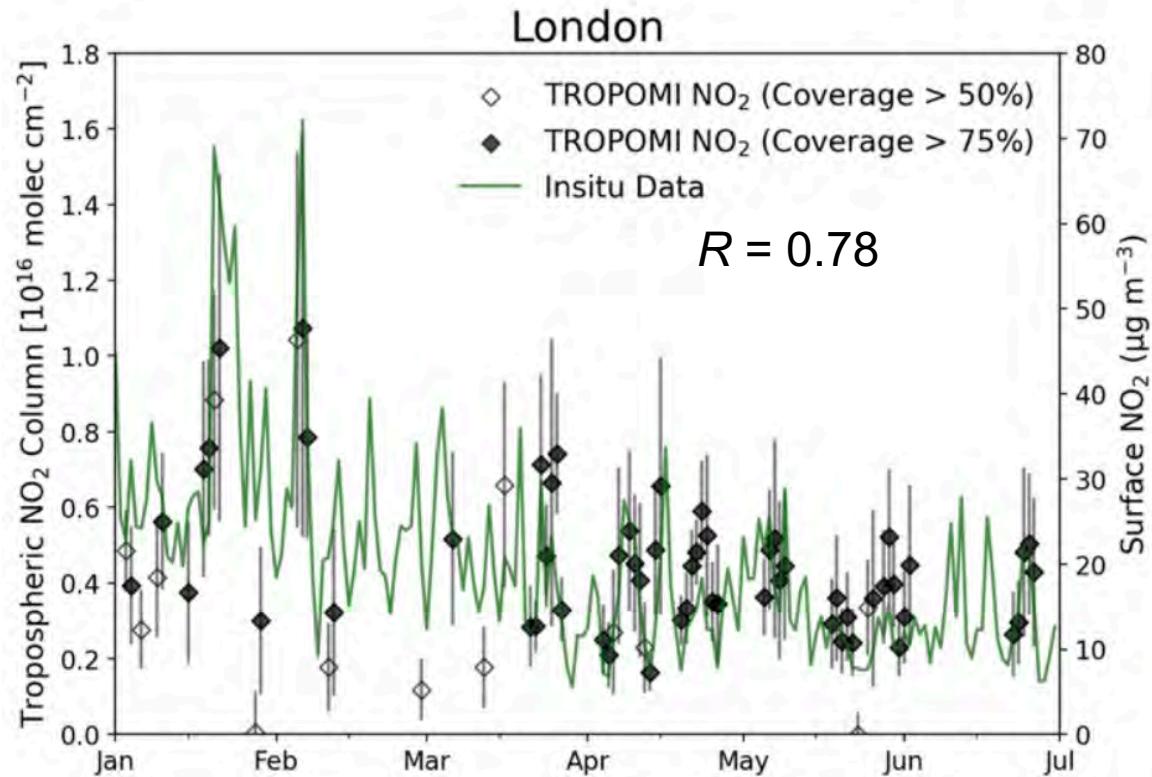
# Space-based instruments observe the whole atmospheric column

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)

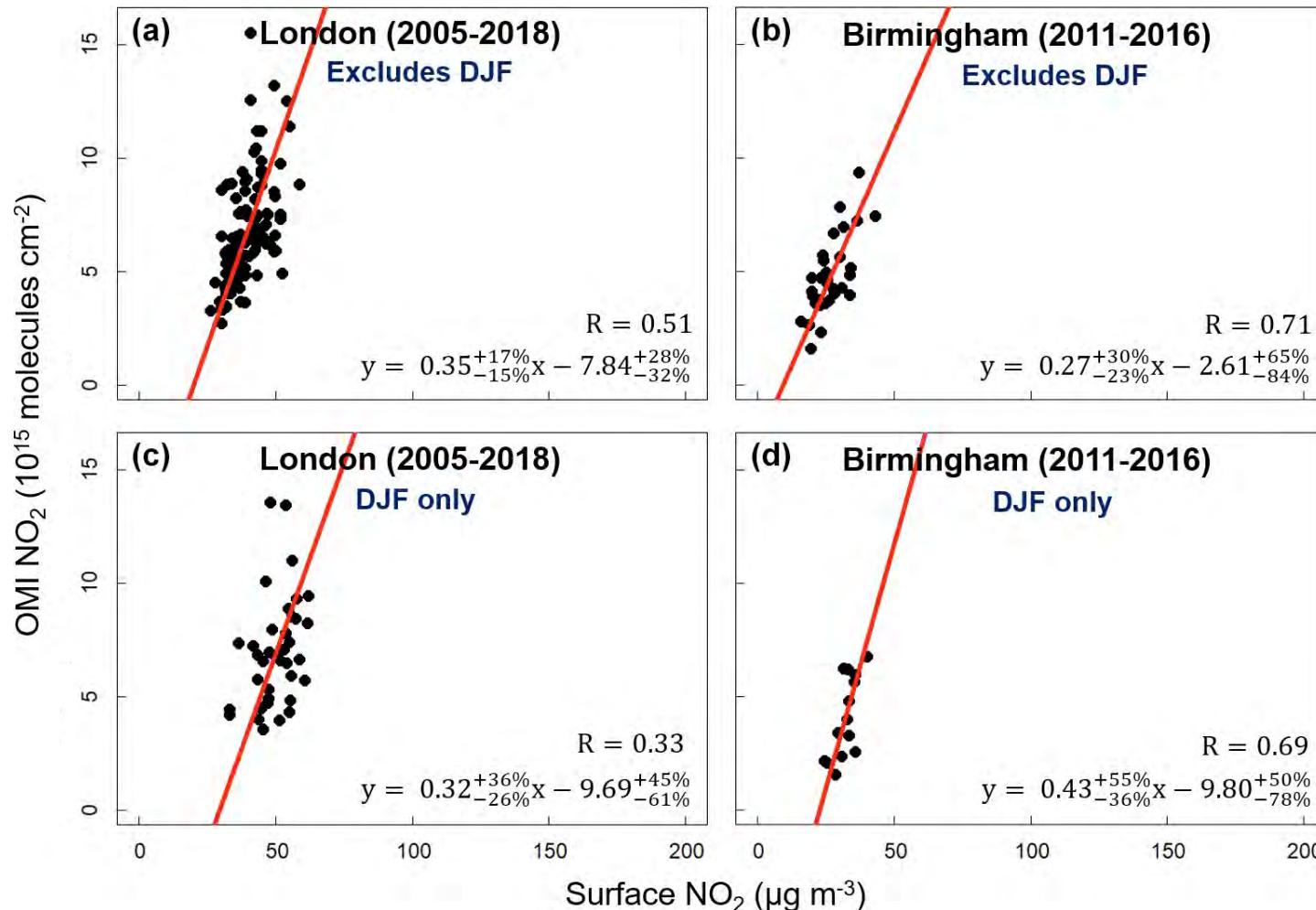
Surface observations sampled during the satellite overpass (midday)

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

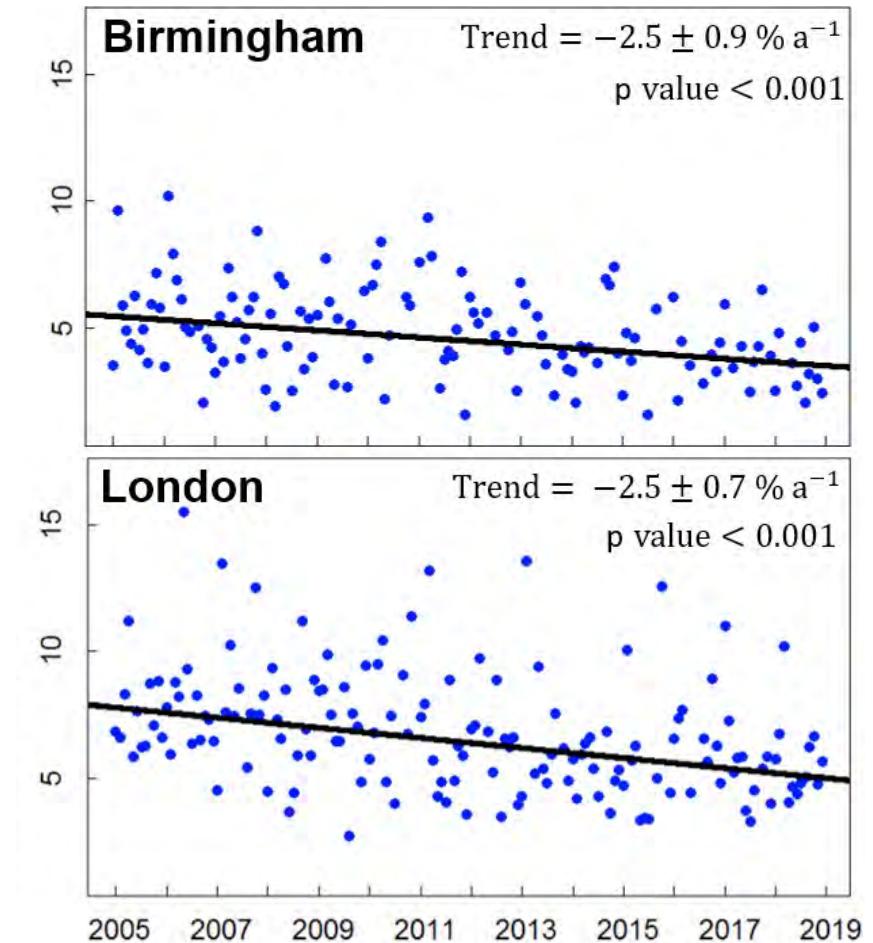
# Similar results for TROPOMI predecessor, OMI

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

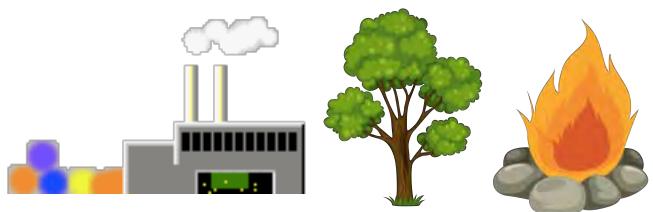


# Interpret TROPOMI with the GEOS-Chem chemical transport model



3D Atmospheric Chemistry Transport Model

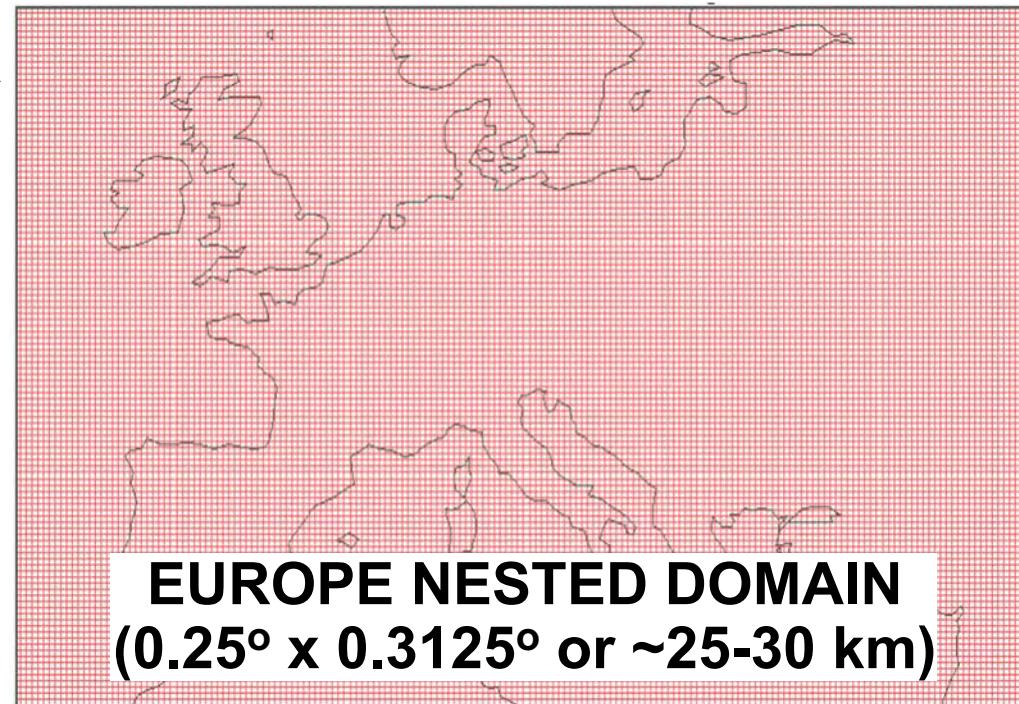
Emissions  
(natural/human)



EMEP emissions for 2016  
with annual scale factors

Annual decline in emissions:

NO <sub>x</sub> :	2.5%
SO <sub>x</sub> :	3.3%
NMVOCs:	2.5%
CO:	2.7%
1° PM <sub>2.5</sub> :	1.9%



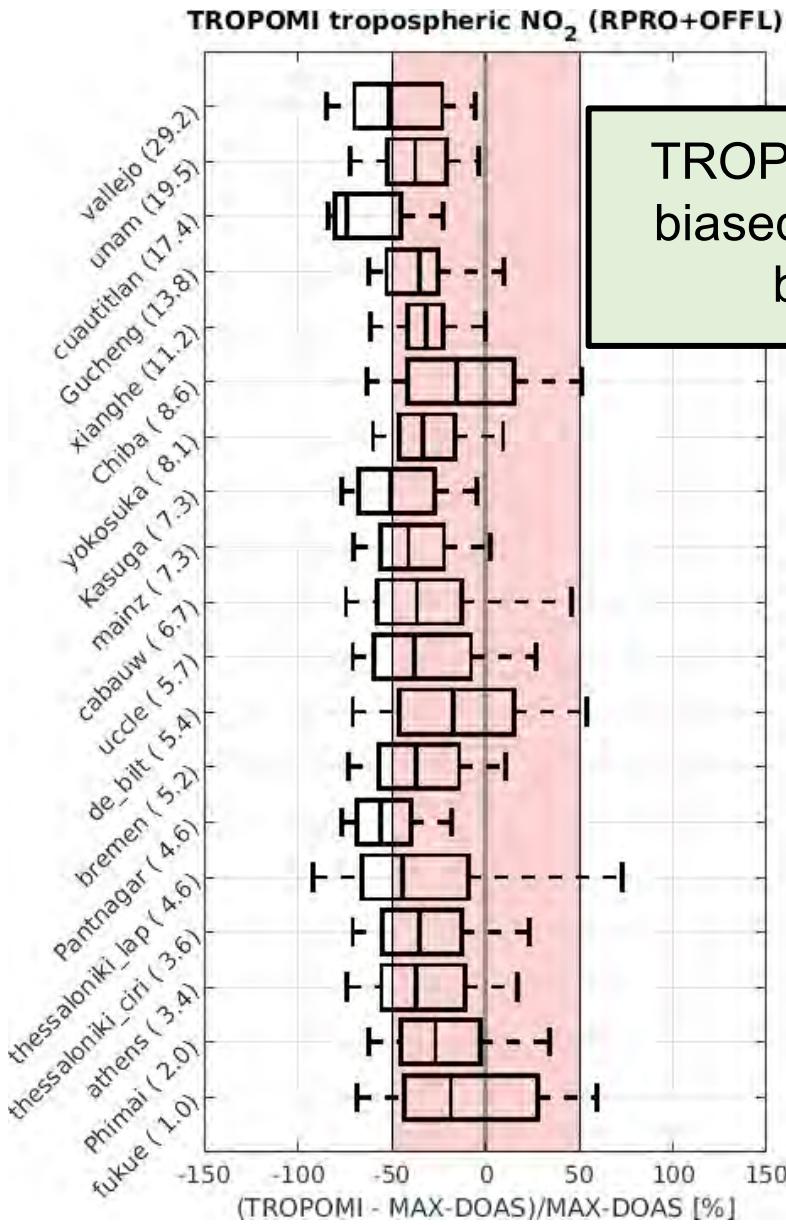
Offline assimilated  
meteorology



NASA GEOS-FP

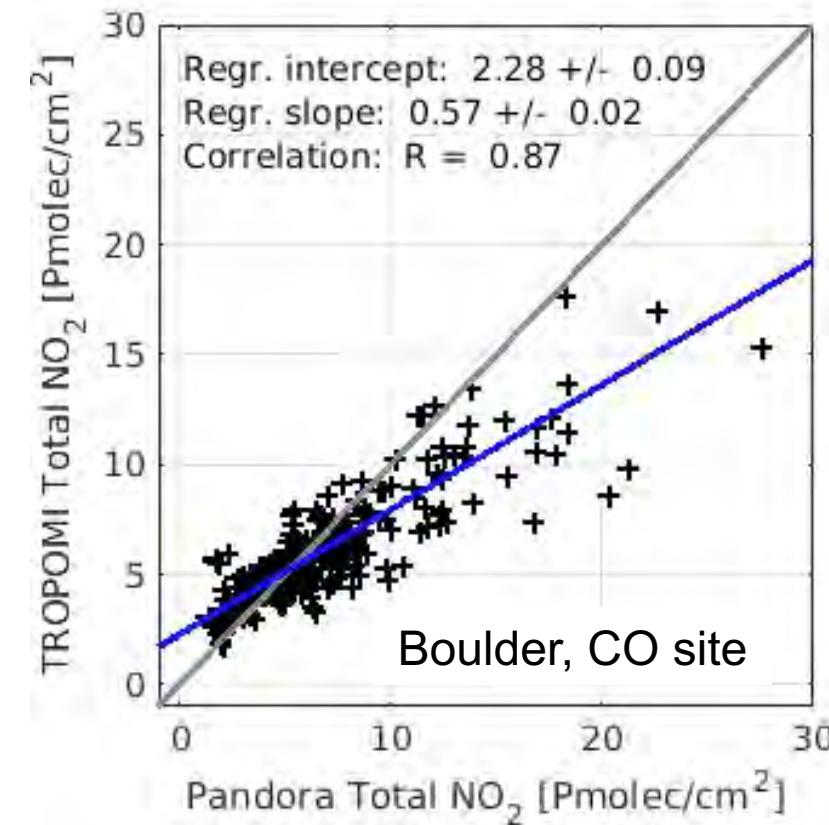
Gas phase and heterogeneous chemistry  
Transport  
Dry/wet deposition

# Both tools (**TROPOMI**, GEOS-Chem) exhibit biases



TROPOMI tropospheric columns biased low compared to ground-based measurements

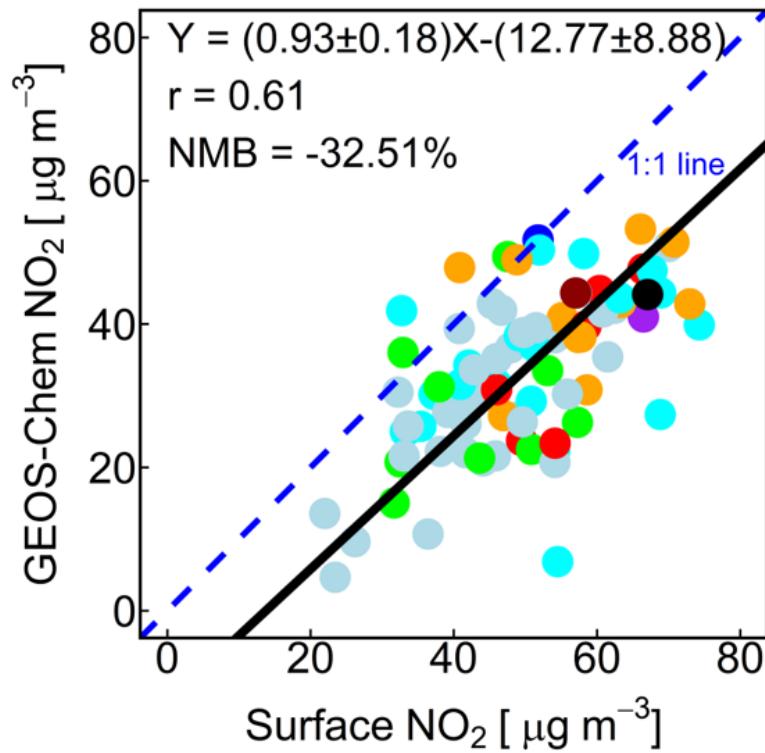
**Caveat:** large sampling footprint differences between ground- and space-based instruments



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

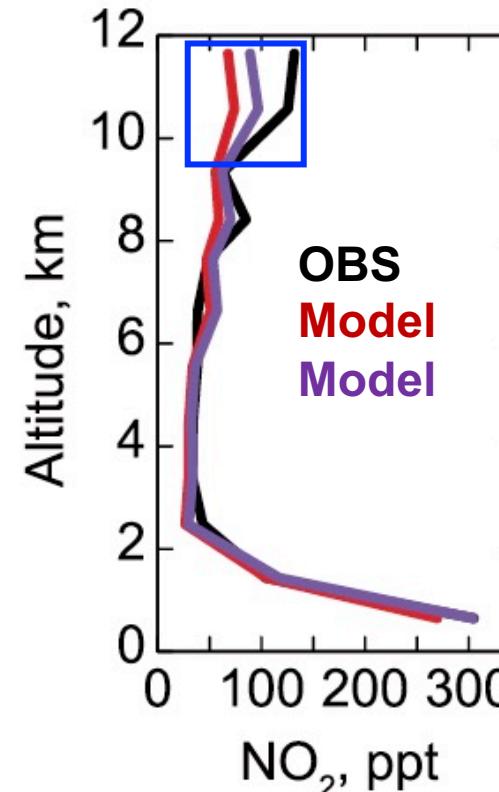
# Both tools (**TROPOMI**, **GEOS-Chem**) exhibit biases

Model biases at the surface:



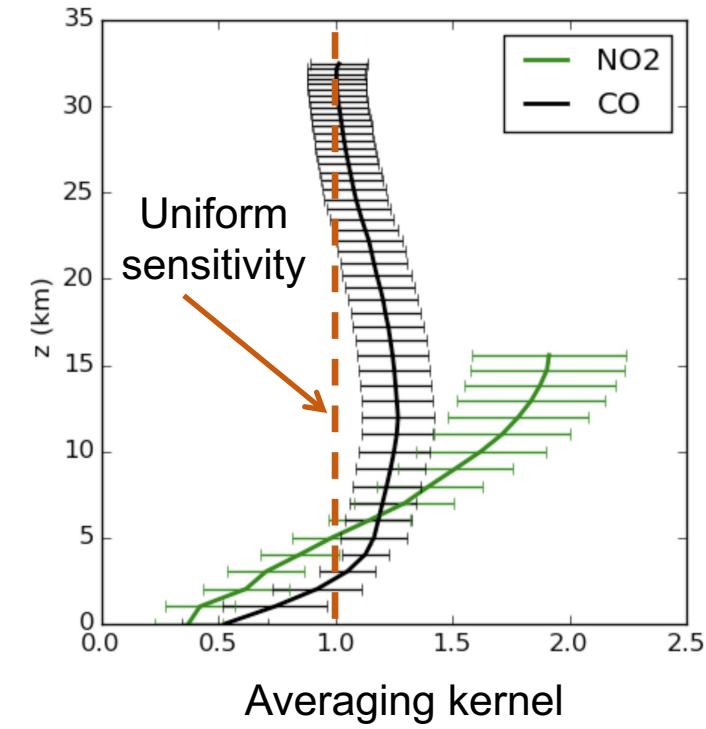
[G. Lu et al., in prep, 2021]

Model biases in upper troposphere:



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

TROPOMI most sensitive to NO<sub>2</sub> in the upper troposphere

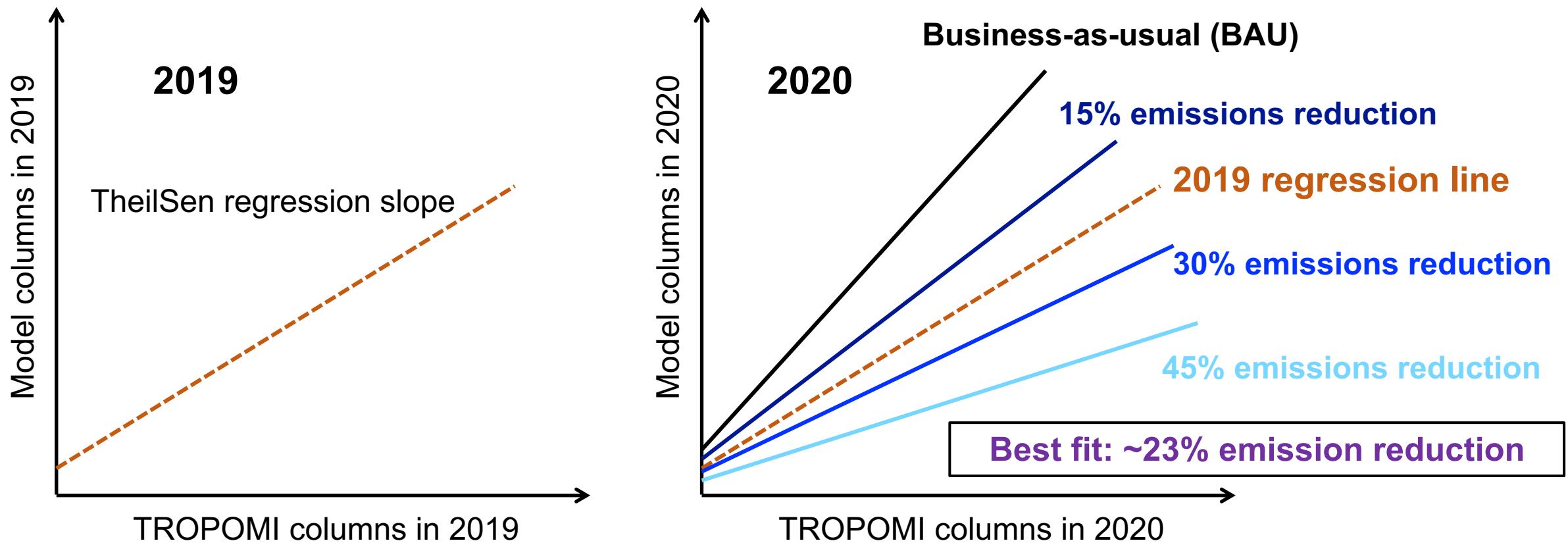


TROPOMI Averaging kernel over Mexico  
[Lama et al., 2020]

Consider relative change in TROPOMI and GEOS-Chem tropospheric columns

# Determine emissions reductions due to lockdown measures

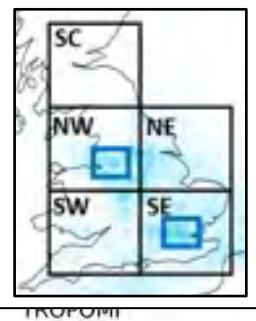
Assuming biases are systematic, TROPOMI and GEOS-Chem should capture the relative change



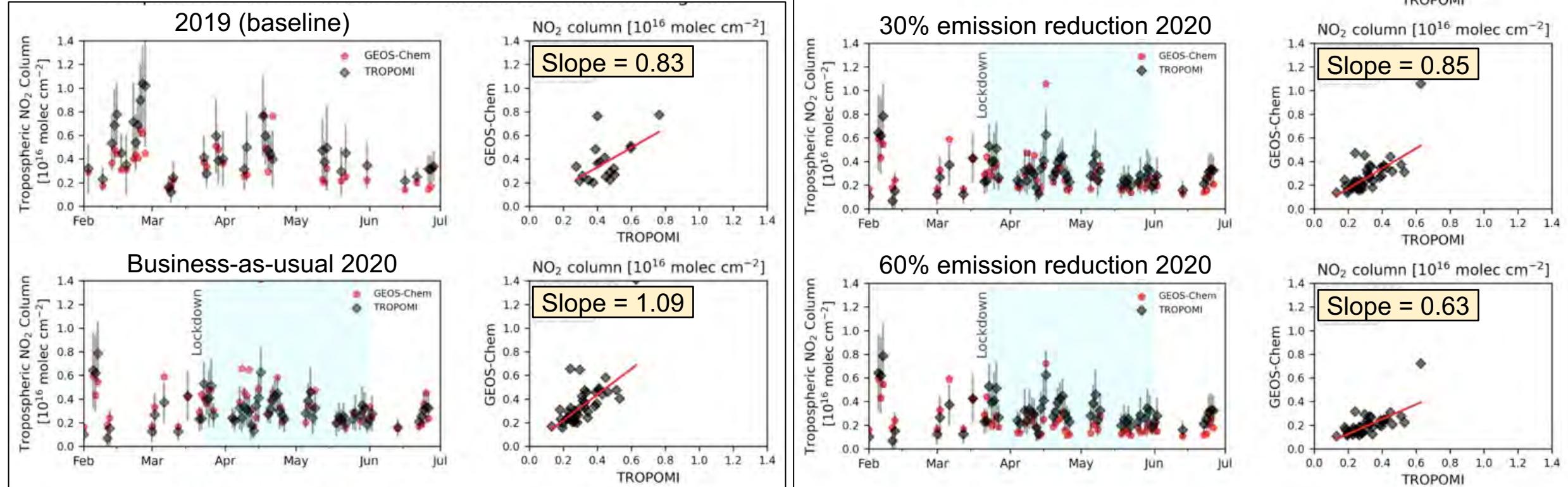
**2019** provides **baseline** for statistical consistency between TROPOMI and model

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

# Emissions reductions at the regional/city scale



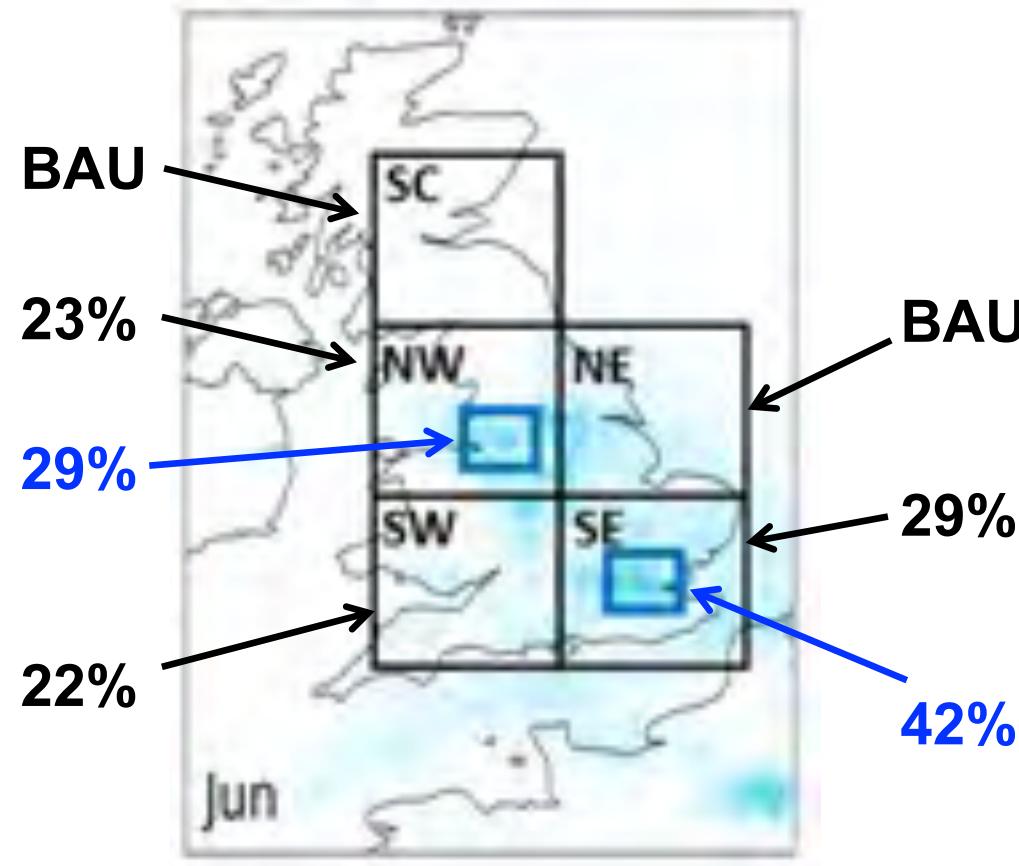
TROPOMI vs GEOS-Chem over Southeast England (SE)



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<sub>x</sub> emissions due to lockdown measures

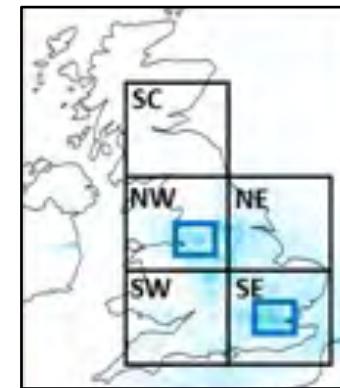
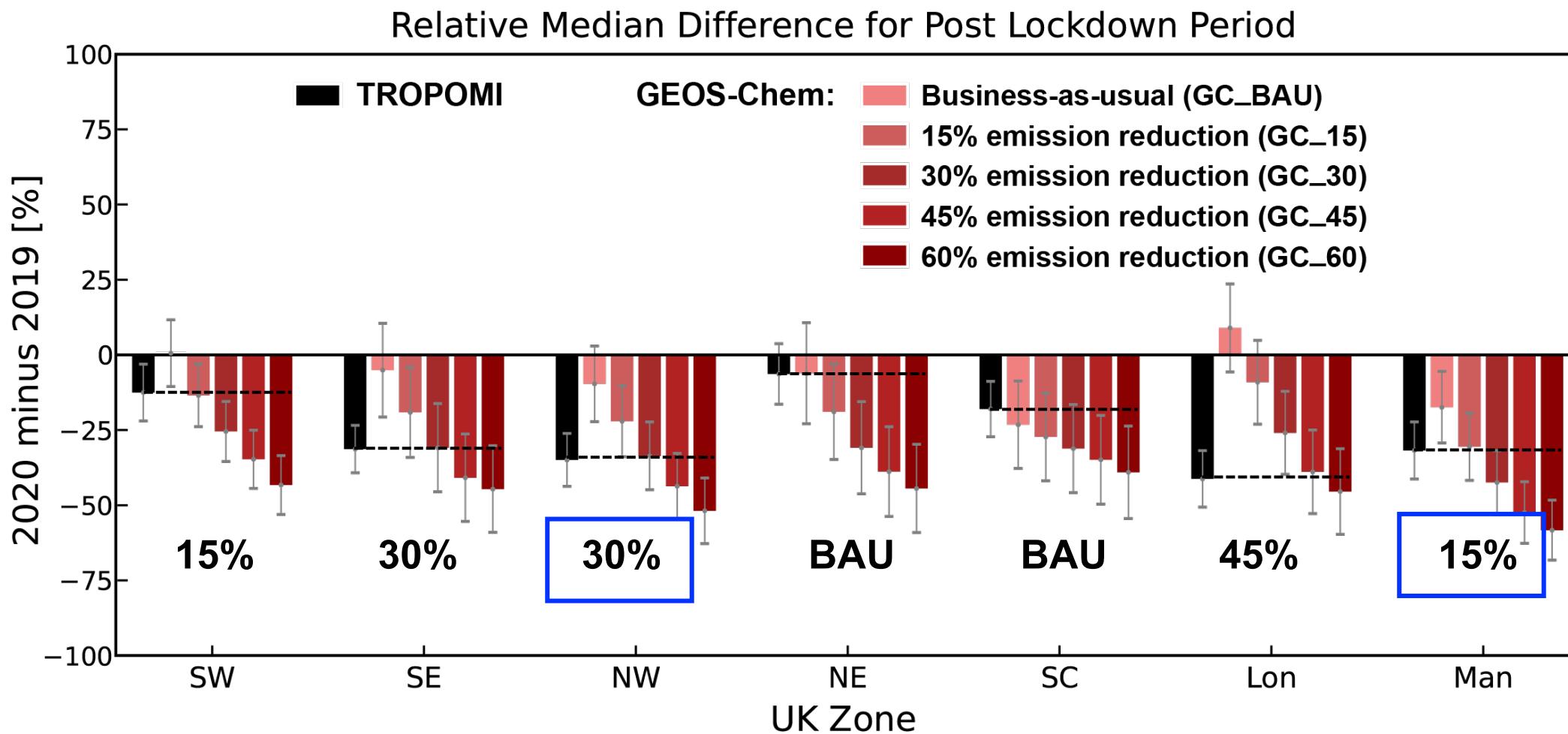
# Summary of emissions reductions at the regional/city scale



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)

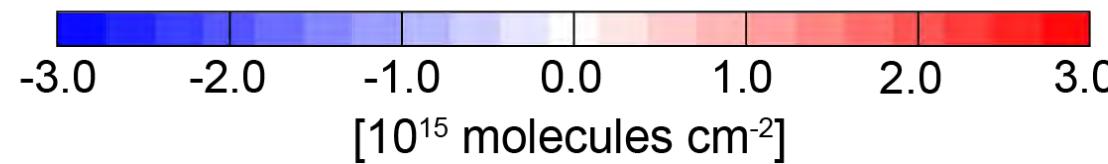
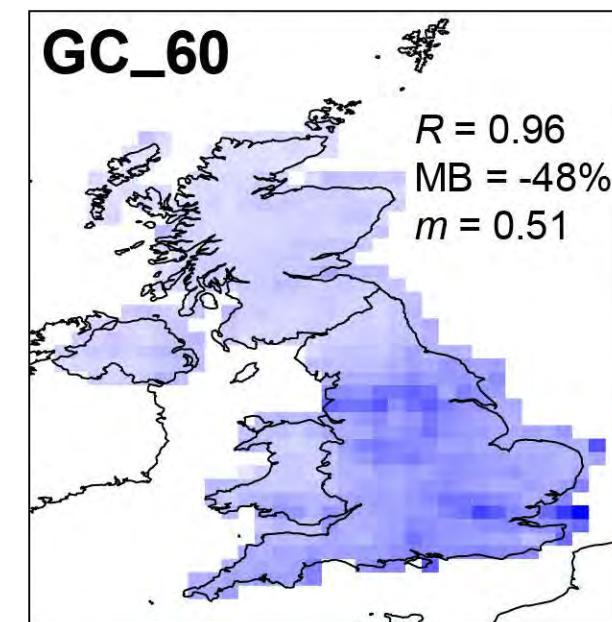
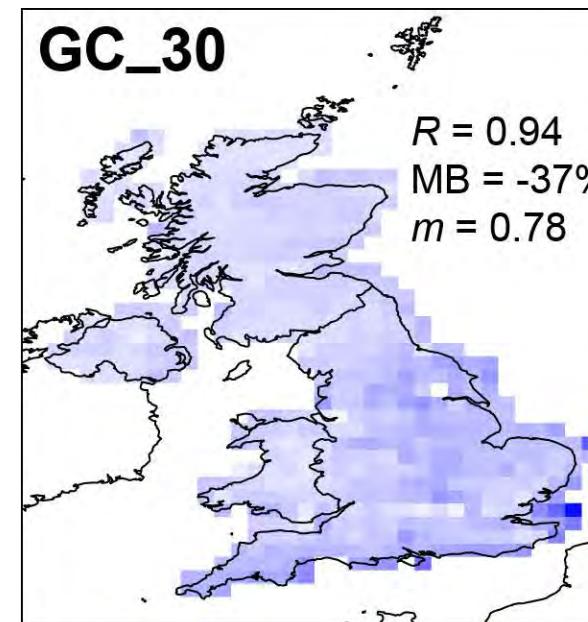
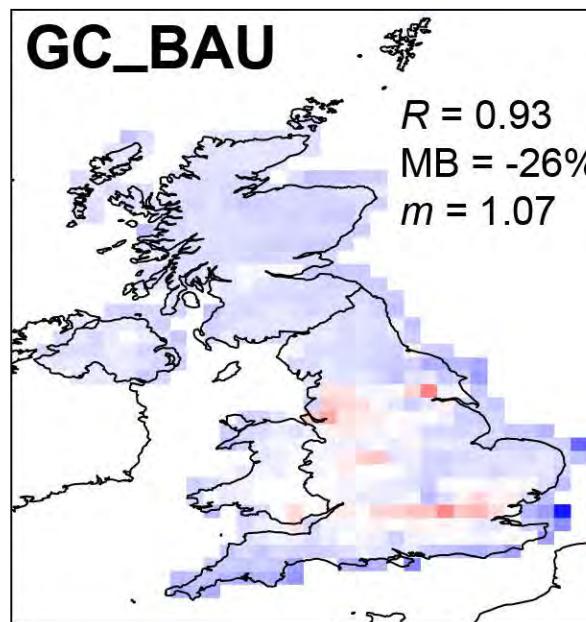
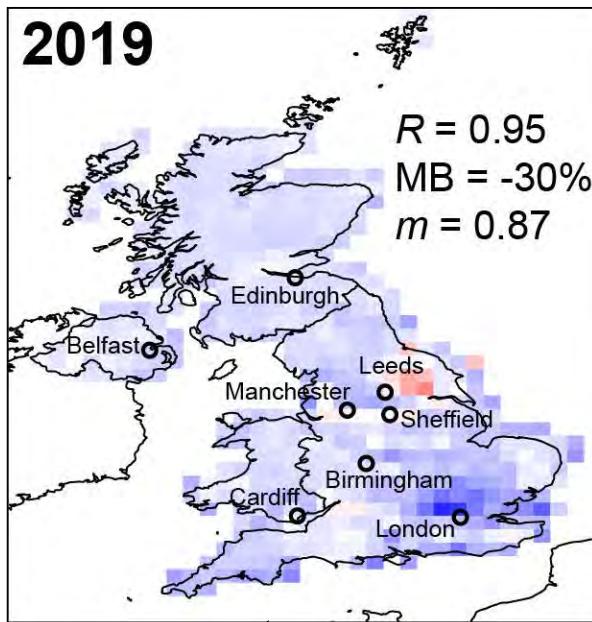
# Also assess using median relative difference



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

# Emissions reductions at the national scale

GEOS-Chem minus TROPOMI (model minus observations)



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

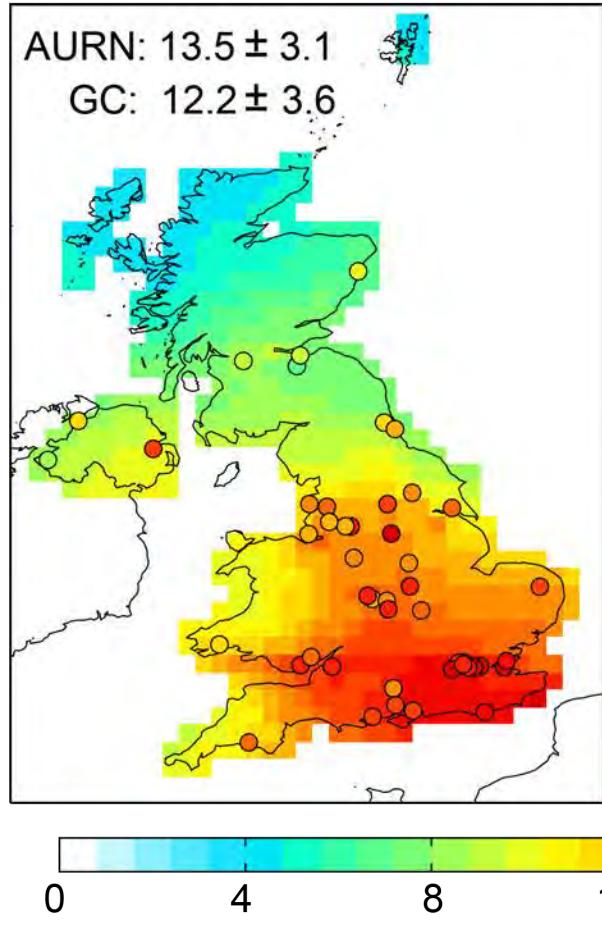
National mean decline of ~20%

# Effect of lockdown measures on surface PM<sub>2.5</sub>

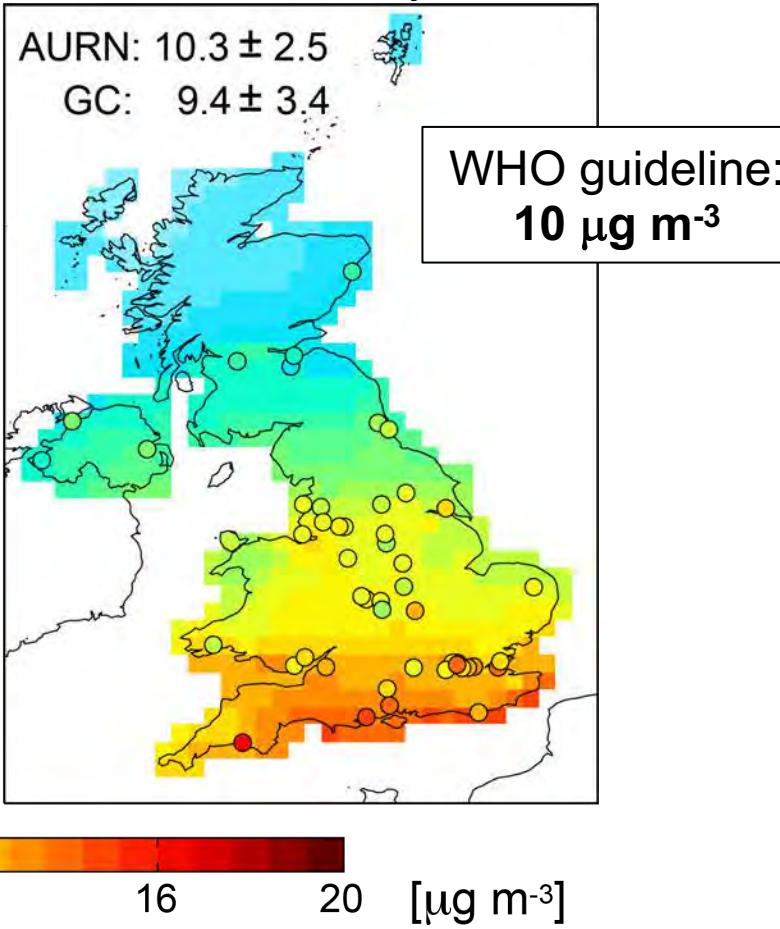
Apply **20% reduction** in all UK non-agricultural anthropogenic emissions during the lockdown

Assess GEOS-Chem against surface observations of PM<sub>2.5</sub> from the AURN network

23 Mar to 31 May 2019

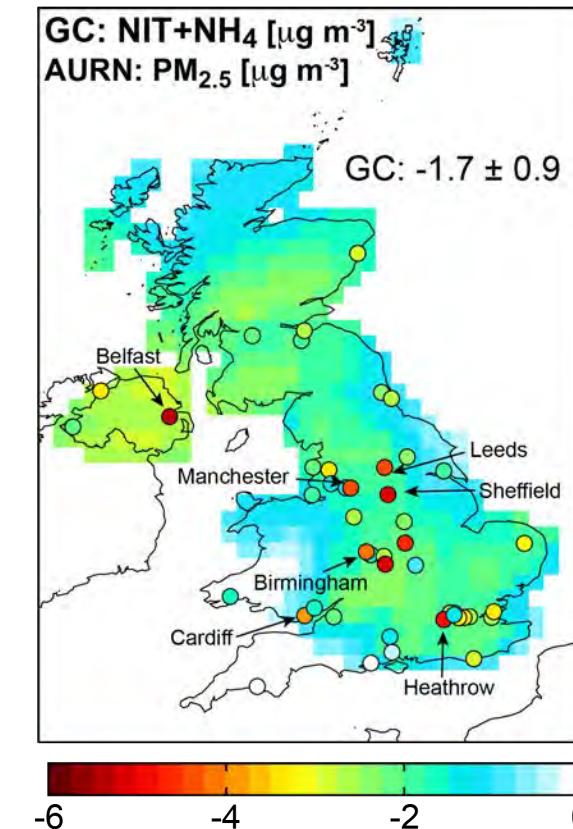


23 Mar to 31 May 2020



Model decline dominated by nitrate (NIT) and ammonium (NH<sub>4</sub>)

2020 minus 2019 for 23 Mar to 31 May



Model misses the decline in primary PM<sub>2.5</sub> in cities

Decline in PM<sub>2.5</sub>:  $3.2 \mu\text{g m}^{-3}$  (AURN);  $2.7 \mu\text{g m}^{-3}$  (GEOS-Chem)

# Effect of lockdown measures on surface PM<sub>2.5</sub>

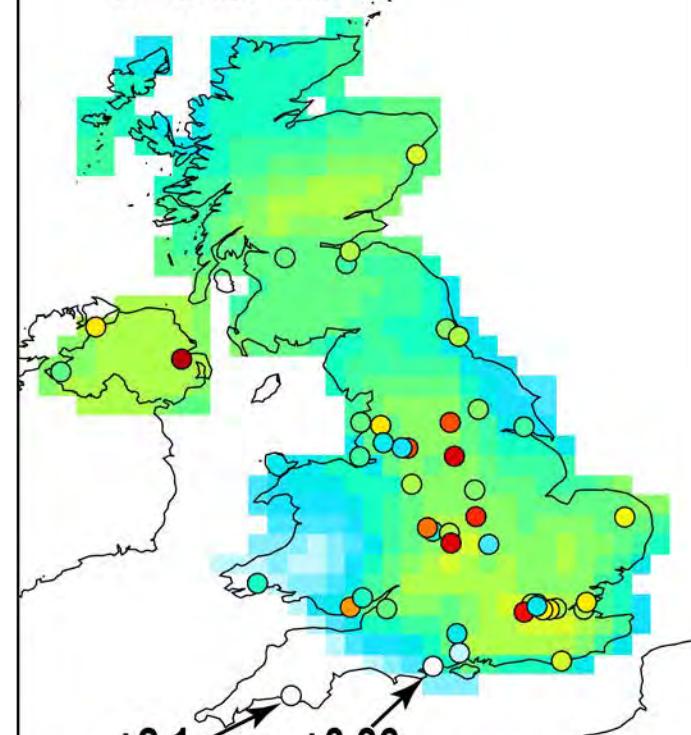
Modelled (and observed) PM<sub>2.5</sub> in 2020 relative to 2019

2020 minus 2019

AURN: -3.2

GC: AURN sites: -2.7

UK-wide: -2.3



-8      -6      -4      -2      0

GC\_20 minus GC\_BAU

PM<sub>2.5</sub> [ $\mu\text{g m}^{-3}$ ]

UK: -1.1

-0.61

-1.3

-2.0

-1.6

-1.4

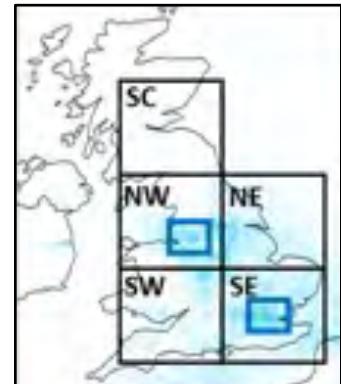
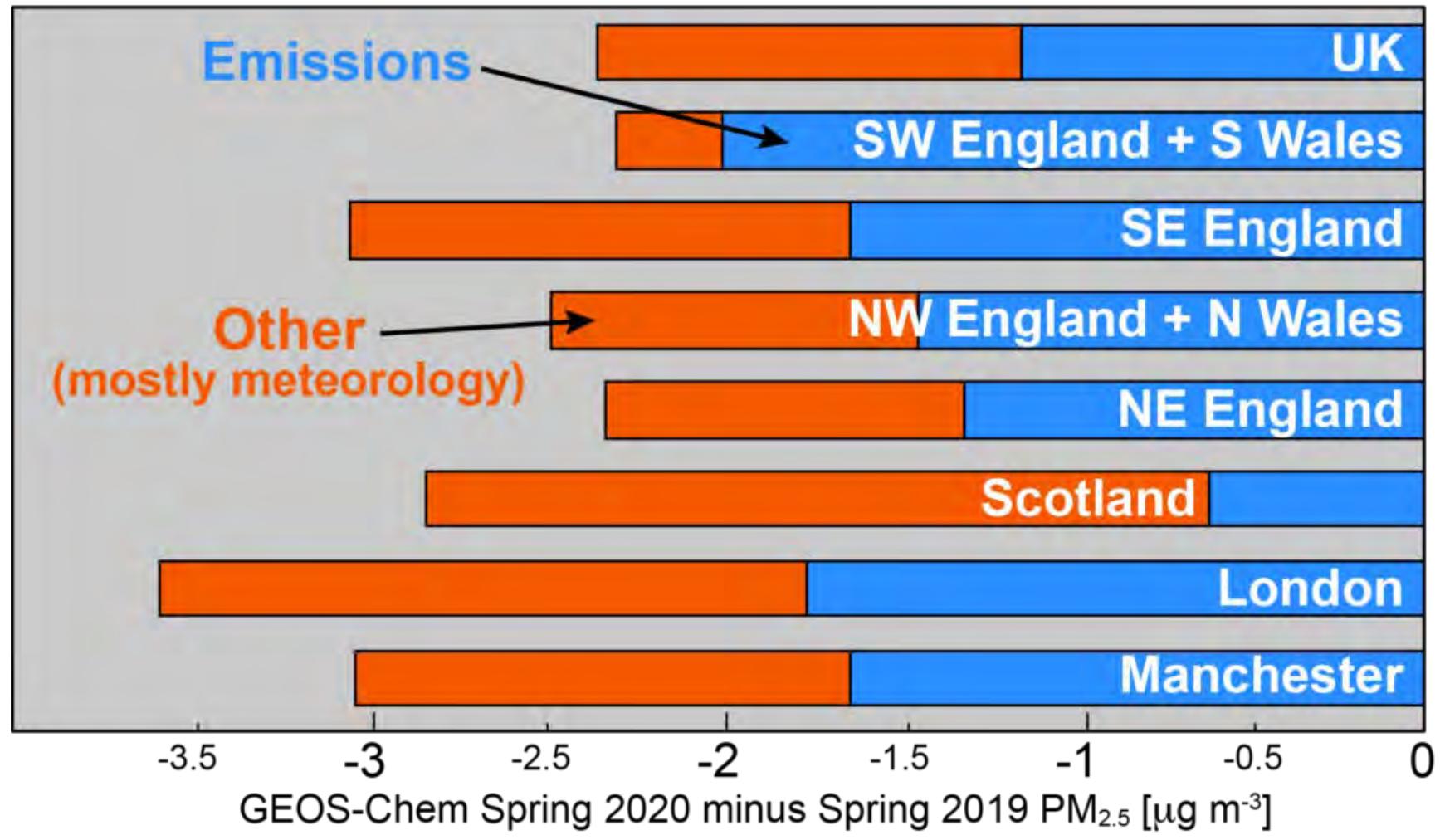
-4      -3      -2      -1      0

Change in PM<sub>2.5</sub>  
due to all factors

Change in PM<sub>2.5</sub> due  
to emissions only

# Changes in PM<sub>2.5</sub> due to emissions and other factors

Causes for decline in UK PM<sub>2.5</sub> during the Spring 2020 lockdown



Lower PM<sub>2.5</sub> 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>