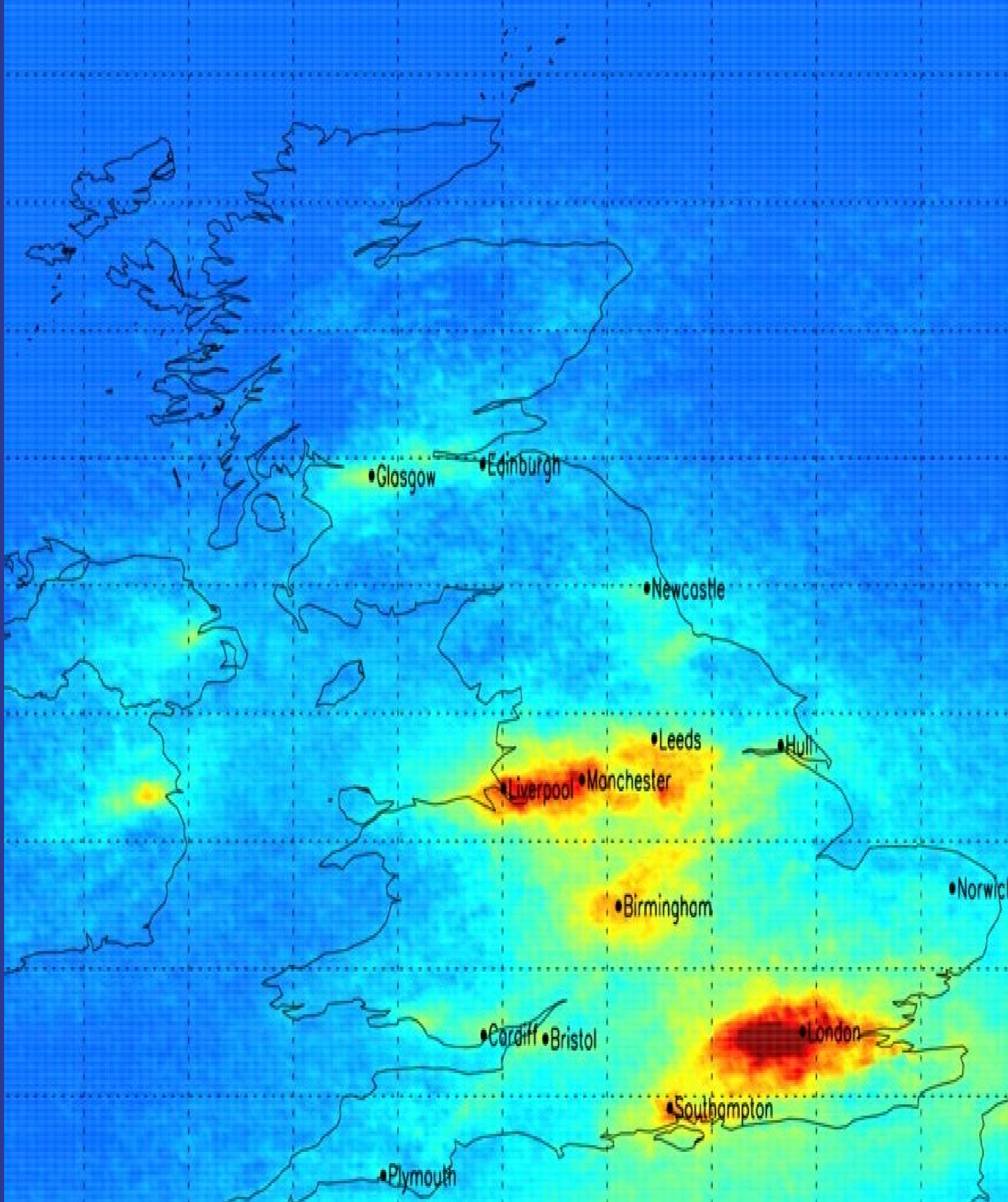
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Satellite Observations of Atmospheric Pollution and Their Value for Informing Policy

Martyn Chipperfield[1], Eloise Marais[2], Richard Pope[1], Chris Wilson[1]

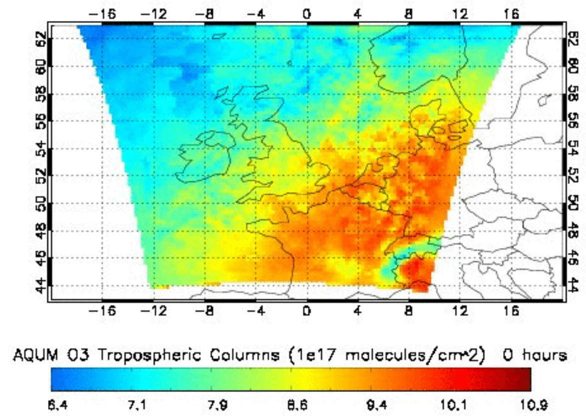
1. NCEO, University of Leeds
2. University College London

www.nceo.ac.uk @NCEOscience

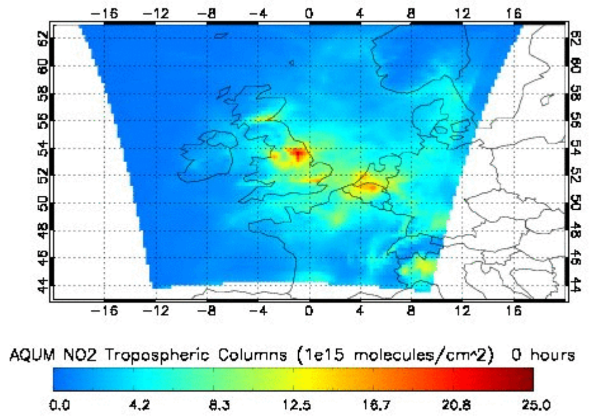


Atmospheric Composition: Science and Policy

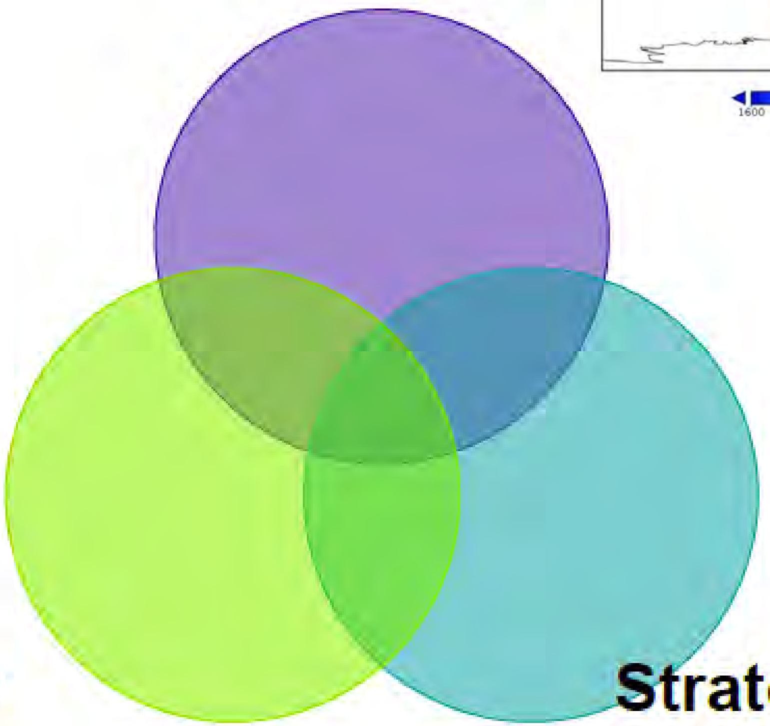
O_3



NO_2

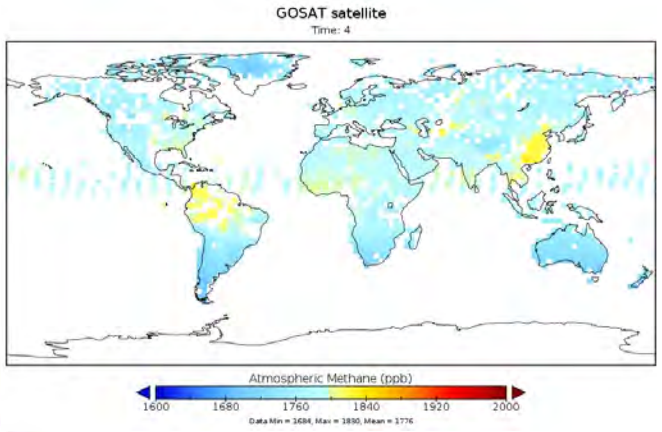


Climate

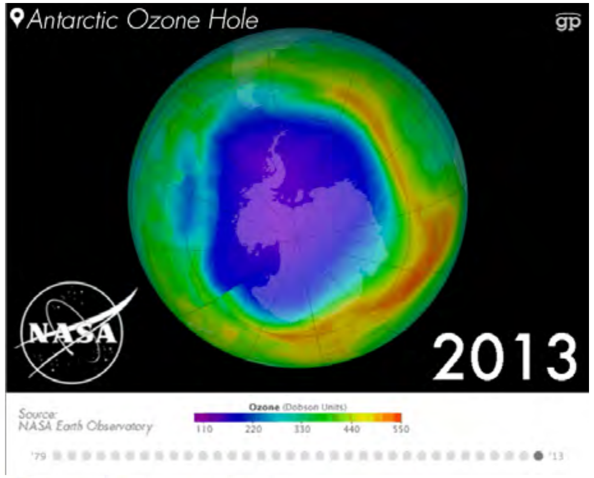


Air Quality

Stratospheric Ozone



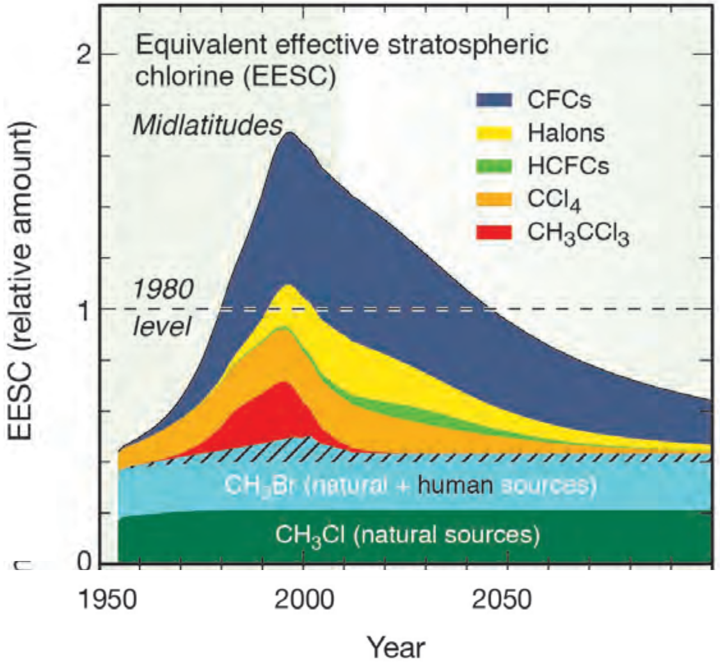
GOSAT CH_4
(R Parker, Leicester)



UK National Atmospheric Emissions Inventory (NAEI)

Montreal Protocol
(Controls production of ozone-depleting halocarbons)

Montreal Protocol: Recent Illegal CFC-11 emissions



Montreal Protocol expectations

LETTER (2018)

https://doi.org/10.1038/s41586-018-0106-2

An unexpected and persistent increase in global emissions of ozone-depleting CFC-11

Stephen A. Montzka[1]*, Geoff S. Dutton[1,2], Pengfei Yu[2,3], Eric Ray[2,3], Robert W. Portmann[3], John S. Daniel[3], Lambert Kuijpers[4], Brad D. Hall[1], Debra Mondeel[1,2], Carolina Siso[1,2], J. David Nance[1,2], Matt Rigby[5], Alistair J. Manning[6], Lei Hu[1,2], Fred Moore[1,2], Ben R. Miller[1,2] & James W. Elkins[1]

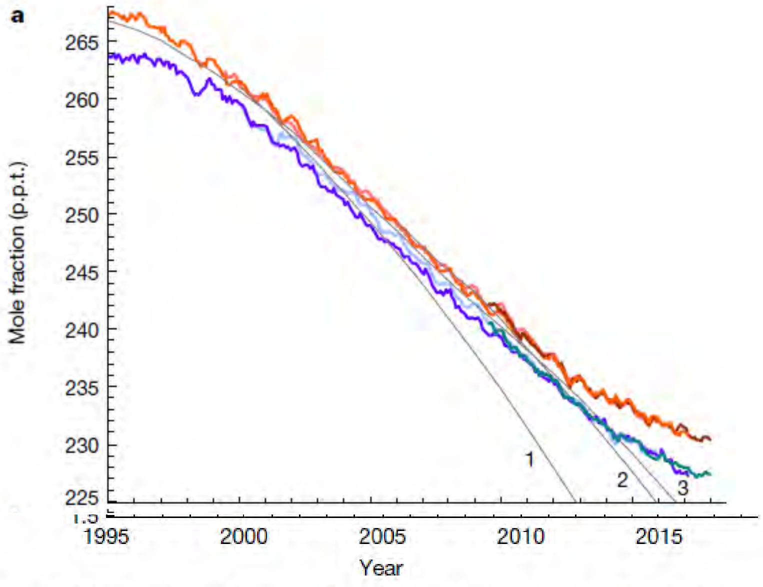


Fig. 1 | Observations of atmospheric CFC-11 over time. a, Hemispheric

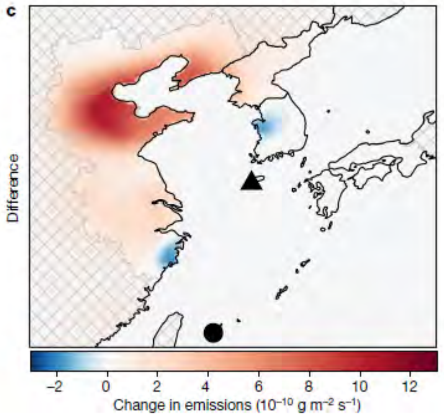
LETTER (2019)

https://doi.org/10.1038/s41586-01

(50%)

Increase in CFC-11 emissions from eastern China based on atmospheric observations

M. Rigby[1,15], S. Park[2,15]*, T. Saito[3,15], L. M. Western[1,15], A. L. Redington[4,15], X. Fang[5,15], S. Henne[6], A. J. Manning[4], R. G. Prir
G. S. Dutton[7,8], P. J. Fraser[9], A. L. Ganesan[10], B. D. Hall[7], C. M. Harth[11], J. Kim[11], K.-R. Kim[2], P. B. Krummel[9], T. Lee[2], S. Li[12]
Q. Liang[13], M. F. Lunt[14], S. A. Montzka[7], J. Mühle[11], S. O'Doherty[1], M.-K. Park[12], S. Reimann[6], P. K. Salameh[11], P. Simmond
R. L. Tunnicliffe[1], R. F. Weiss[11], Y. Yokouchi[3] & D. Young[1]



2021 Update

Article

A decline in global CFC-11 emissions during 2018–2019

https://doi.org/10.1038/s41586-021-03260-5

Received: 1 July 2020

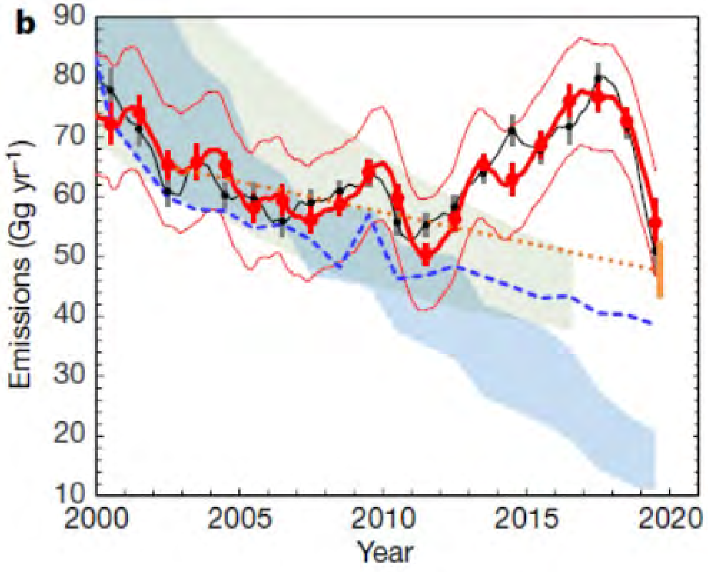
Accepted: 11 December 2020

Published online: 10 February 2021

Check for updates

Stephen A. Montzka[1✉], Geoffrey S. Dutton[1,2], Robert W. Portmann[3], Martyn P. Chipperfield[4,5], Sean Davis[3], Wuhu Feng[4,6], Alistair J. Manning[7], Eric Ray[2,3], Matthew Rigby[8], Bradley D. Hall[1], Carolina Siso[1,2], J. David Nance[1,2], Paul B. Krummel[9], Jens Mühle[10], Dickon Young[8], Simon O'Doherty[8], Peter K. Salameh[10], Christina M. Harth[10], Ronald G. Prinn[11], Ray F. Weiss[10], James W. Elkins[1], Helen Walter-Terrinoni[12] & Christina Theodoridi[13]

Derived CFC-11 emissions (with dynamical correction from TOMCAT CTM)



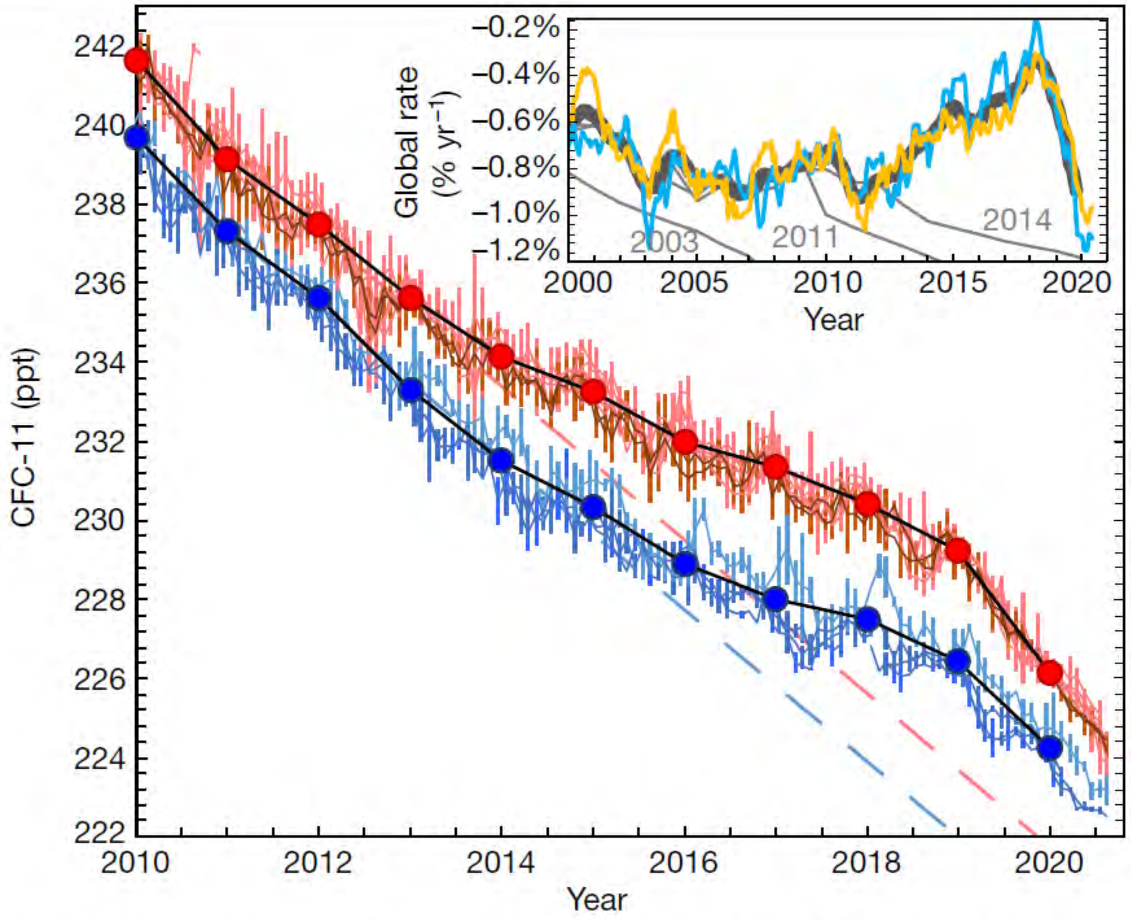
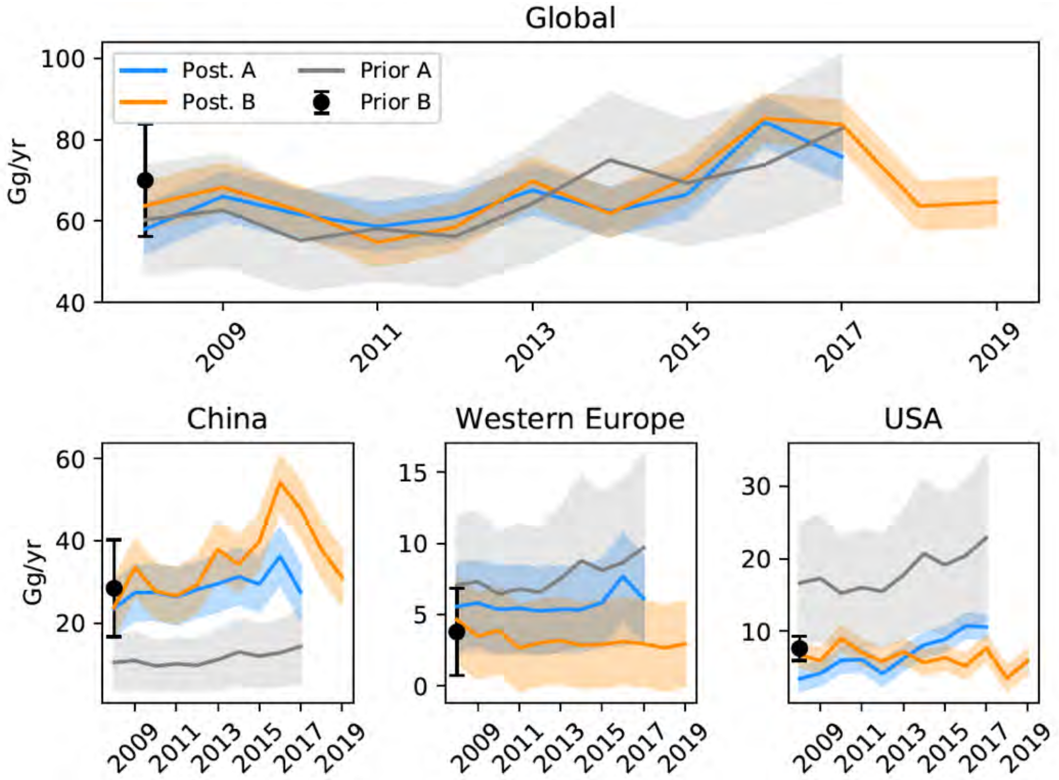
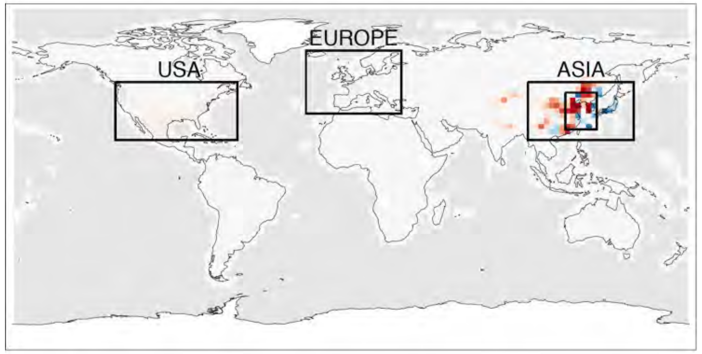
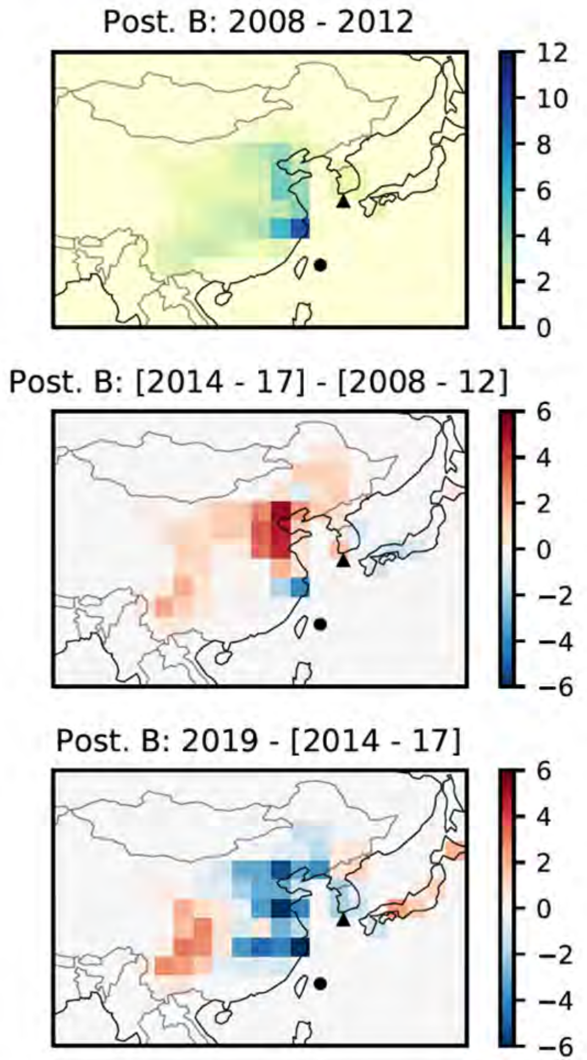


Fig. 1 | Measured atmospheric mole fractions of CFC-11 and global mean rate of change. Monthly mean mole fractions and standard deviations (s.d.) measured at 12 remote sites from NOAA flasks by gas chromatography with

Global Inverse Modelling to find Sources of CFC-11







- Prior B: Global flux increase agrees with Montka et al ~13Gg/yr.
- Change in China is larger than global change, but countered by decreases in the West.
- Most of the increase has gone by 2019 – but not all.

Testing UK Emissions Inventory Using EO Data

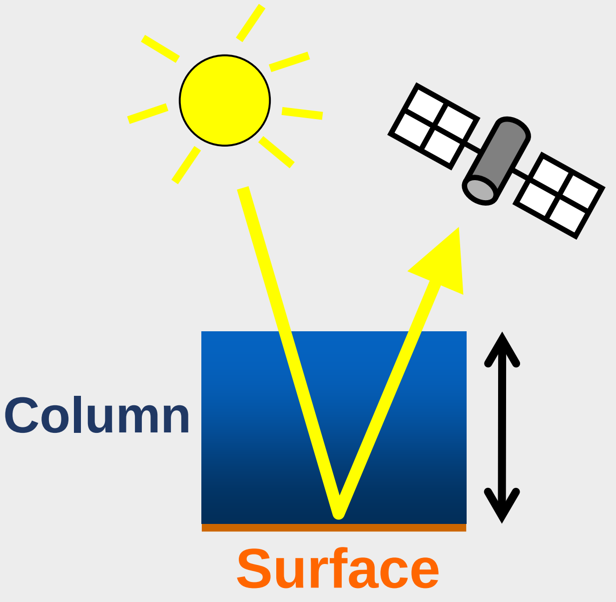
- UK National Atmospheric Emissions Inventory (NAEI, https://naei.beis.gov.uk/) is database of best estimates of UK emissions of air quality pollutants and greenhouse gases.
- ‘Bottom-up’ emissions which use surface observations (e.g. Automated Urban and Rural Network - AURN). Precise observations but a sparse network…
- Can satellite data be used to help constrain uncertainties in NAEI with ‘top-down’ emissions?
- NH_3 and NO_2 are air quality pollutants with (i) important emission uncertainties and (ii) good satellite observations.

Martyn Chipperfield | M.Chipperfield@leeds.ac.uk | NCEO University of Leeds

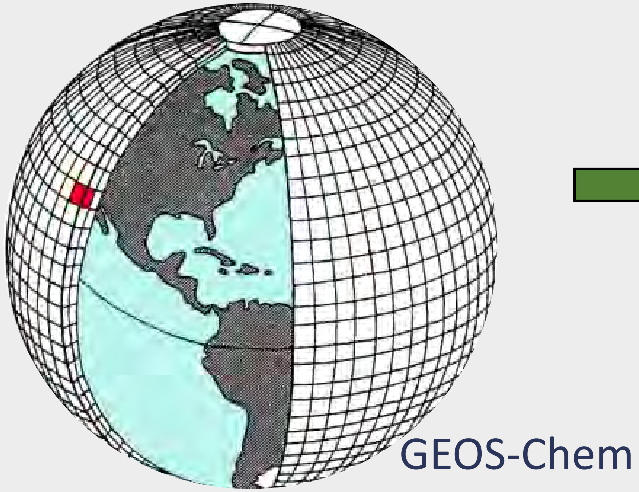
Top-down NH_3 Emissions From IASI, CrIS and 3-D Model

ABUNDANCES → Conversion Factor → EMISSIONS

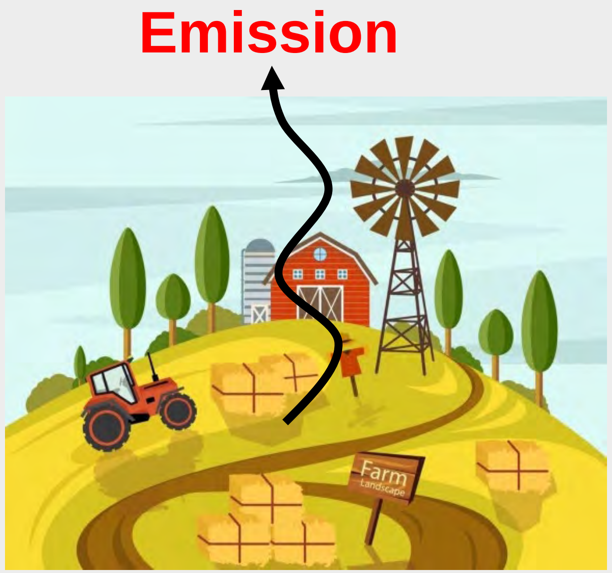
Satellite column densities



Model Concentration-to-Emission Ratio



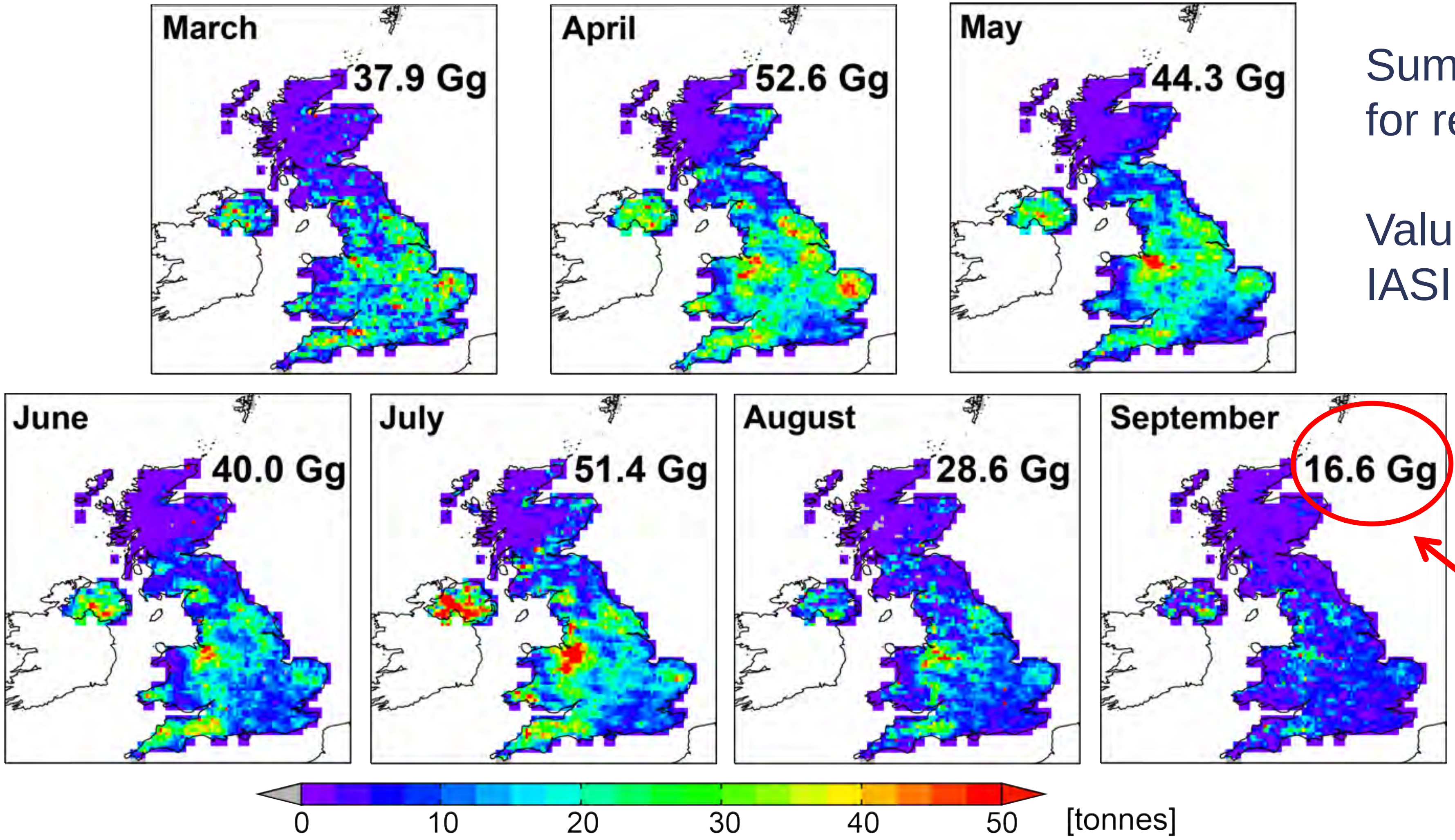
Satellite-derived Surface Emissions



Marais et al., *J. Geophys. Res.*, accepted, 2021.

Eloise Marais | E.Marais@ucl.ac.uk | UCL

IASI-derived NH_3 Emissions at 0.1° × 0.1° (~10 km)



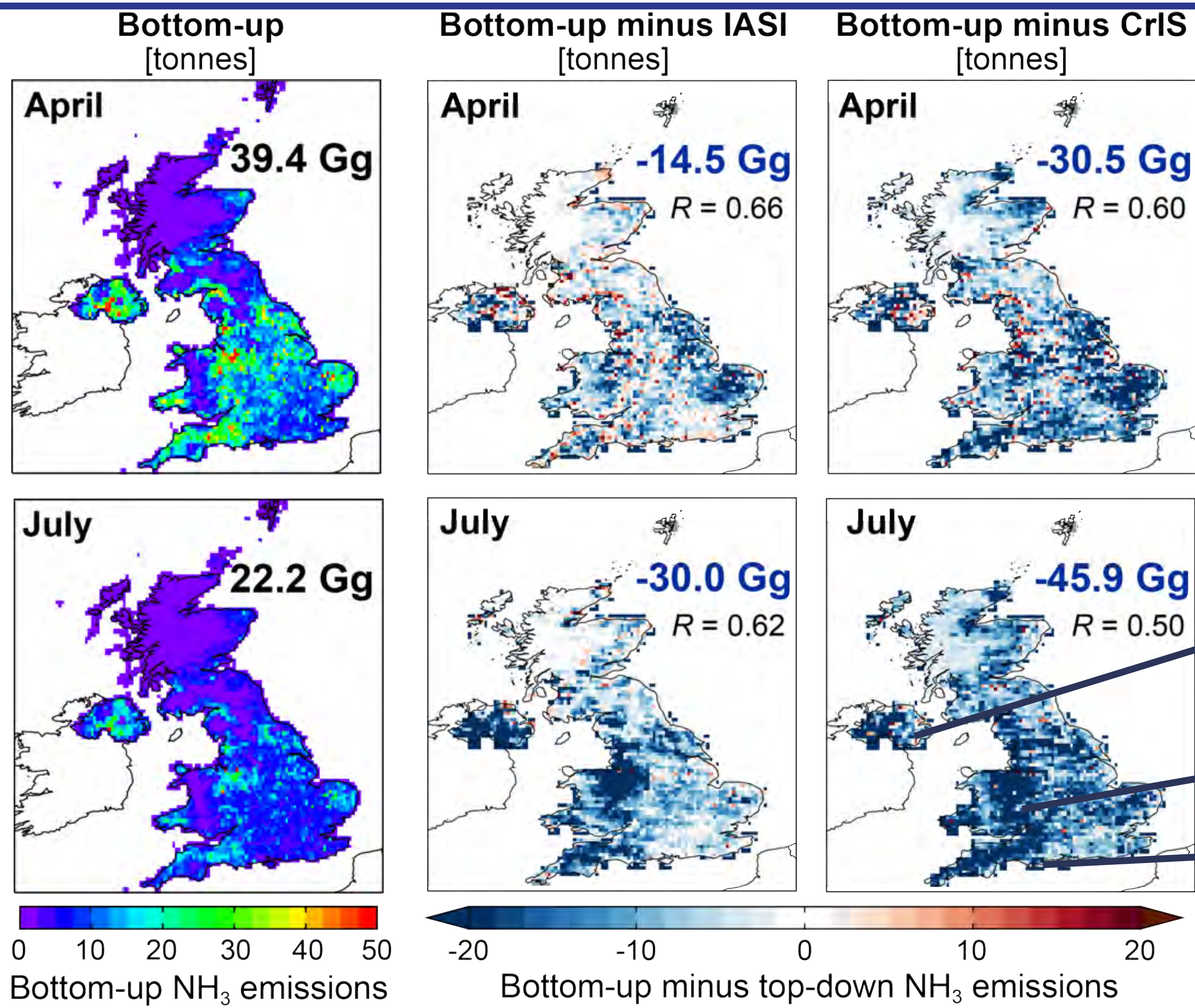
Sum of IASI-derived emissions for retained grids: **272 Gg**

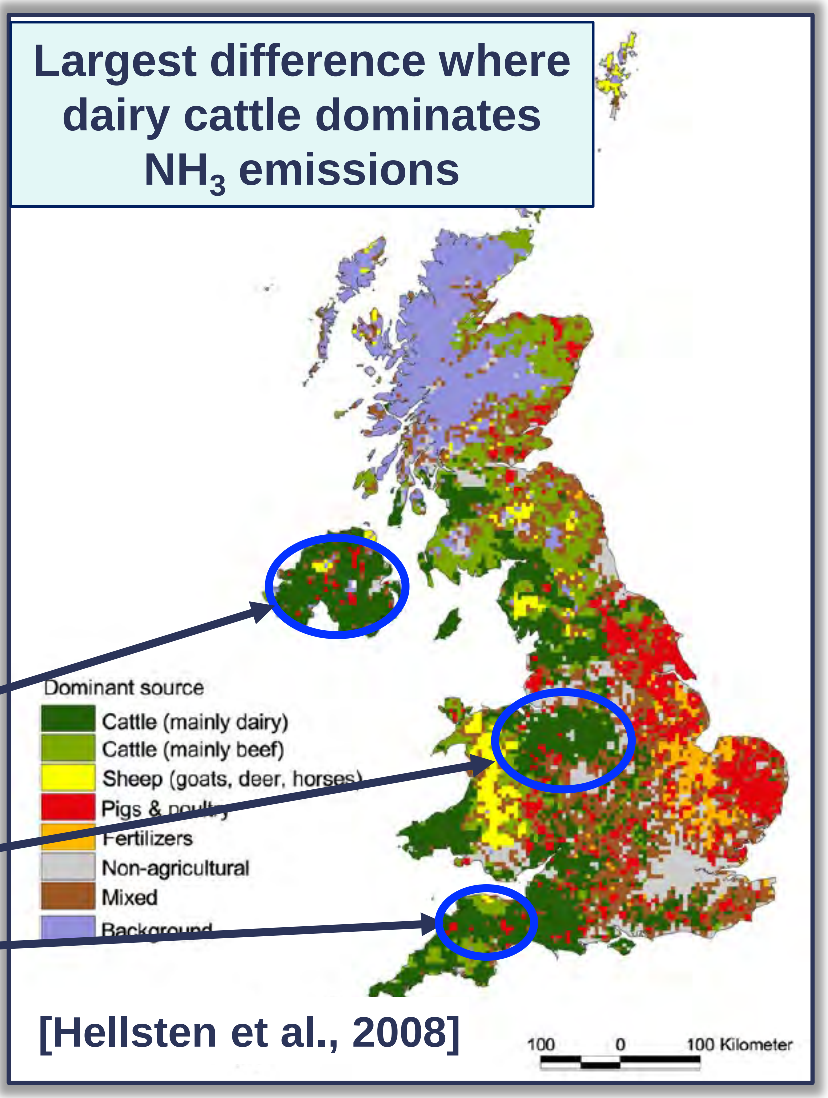
Value for CrIS is 43% more than IASI: **389 Gg**

Value for bottom-up NAEI much smaller: **199 Gg**

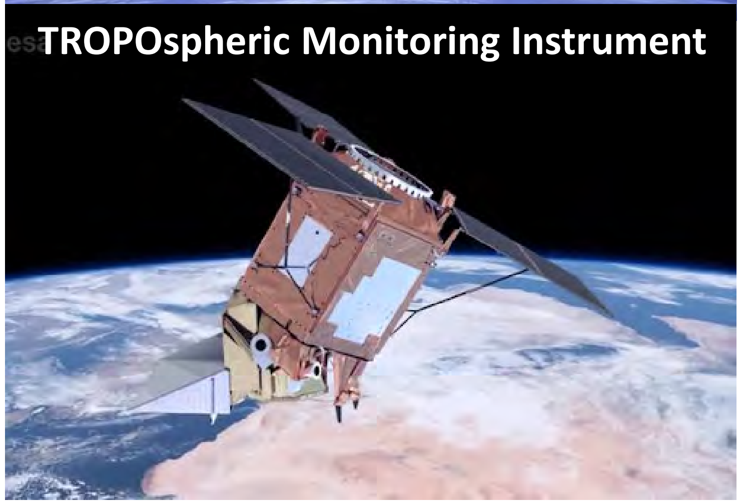
Total monthly emissions

NAEI (bottom up) minus EO-derived NH_3 emissions





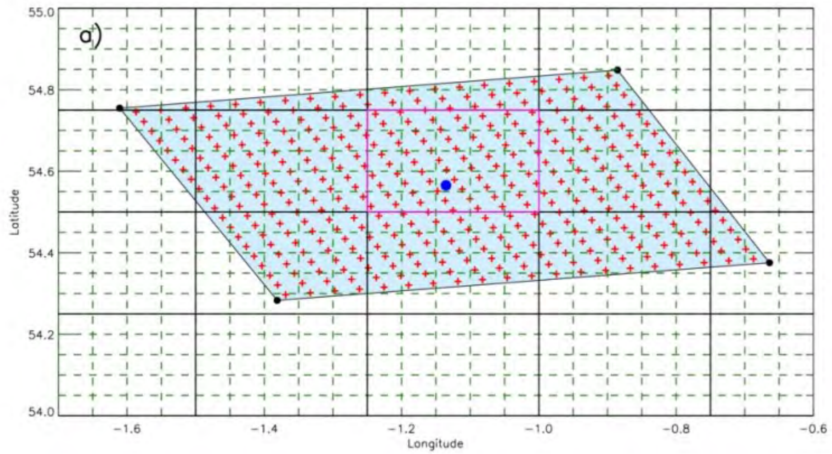
Tropospheric Column NO_2



Satellite Instruments: OMI & TROPOMI

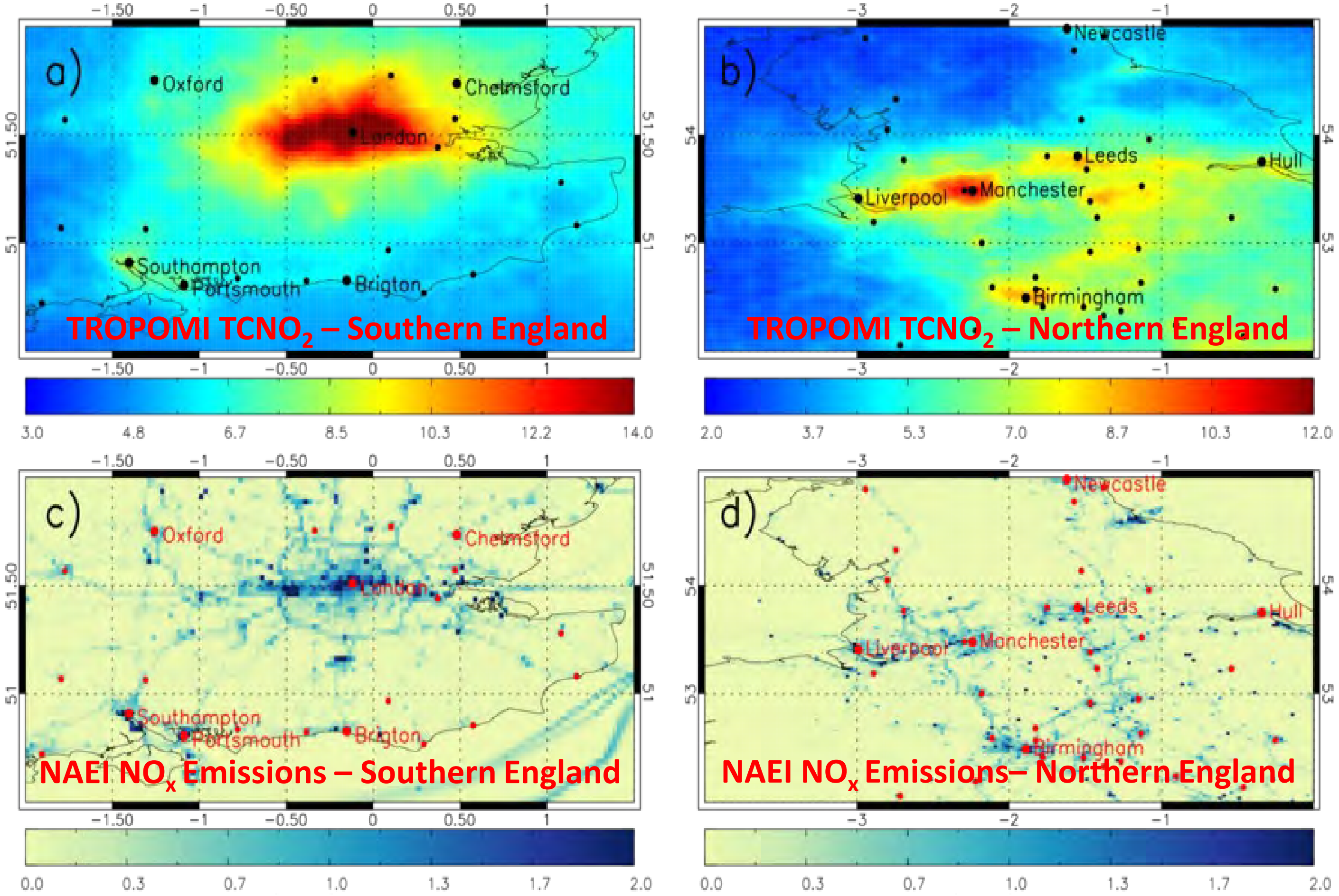
Host Satellites: Aura & Sentinel 5 – Precursor
Launch Date: 15th July 2004 & 13th October 2017
Overpass Time: 13.30 LT & 13.45 LT
Resolution at Nadir: 7 km × 7 km & 13 km × 24 km
Spectral Viewing: UV-Vis & UV-Vis-NIR-SWIR

Oversampling Methodology (Pope et al, 2018)



Increased resolution:
OMI = 5 km × 5 km
TROPOMI = 2.5 km × 2.5 km

High Resolution Column NO_2 versus NAEI



TROPOMI (S5P) provides the highest horizontal resolution measurements of air pollutants.

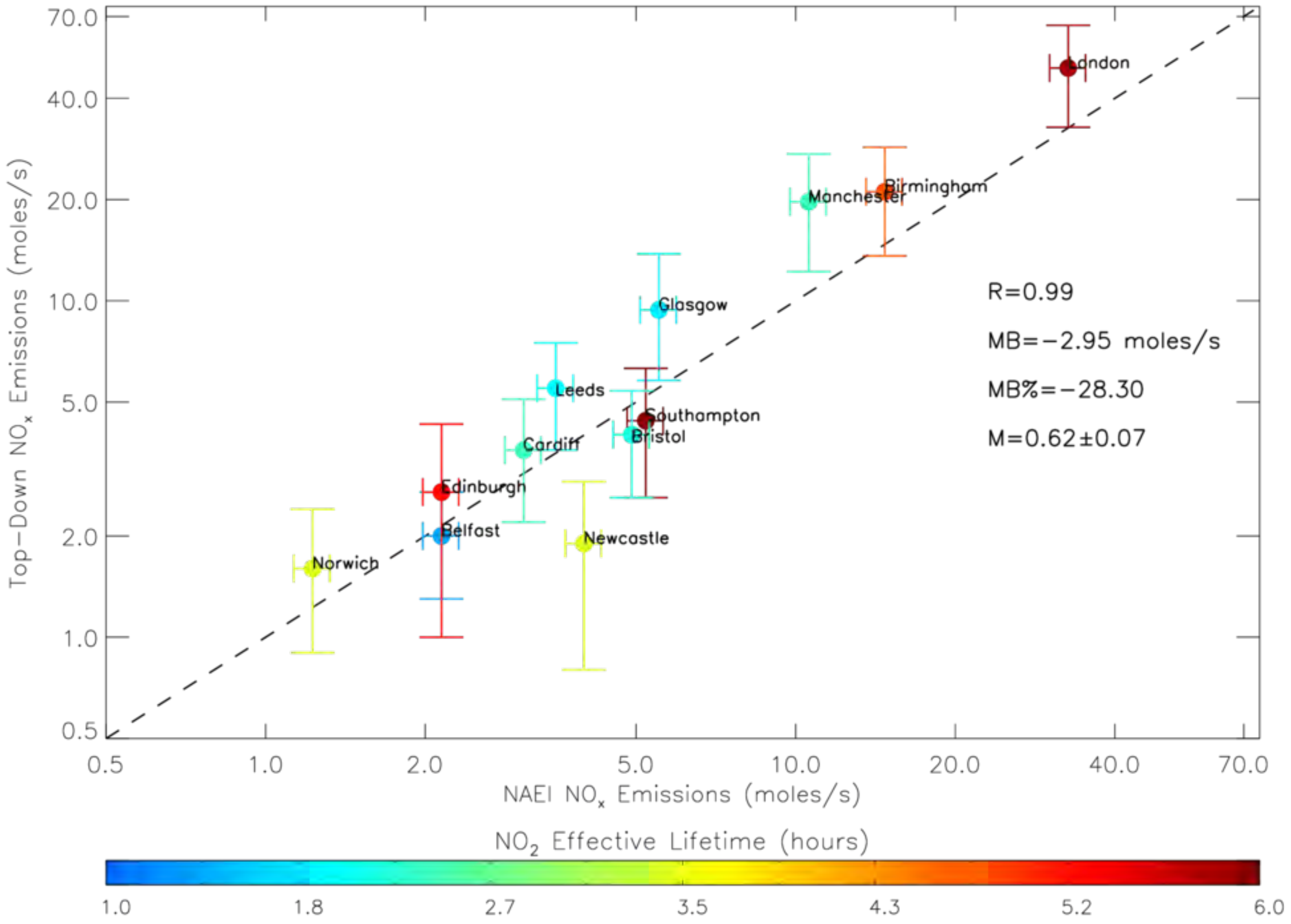
TROPOMI tropospheric column NO_2 ($TCNO_2$) data is mapped onto 0.025° × 0.025° (~2-3 km) grid for comparison with NAEI NO_x emissions.

Despite representing different quantities, for UK cities we find significant spatial correlations of ~0.5-0.6 between $TCNO_2$ and NO_x emissions.

Gives confidence in the spatial representativeness of the emission sources.

TROPOMI $TCNO_2$ (Feb 2018 – Jan 2020) : $\times 10^{-5}$ moles/m^2
NAEI NO_x Emissions (2016): µg/m^2/s

Satellite (top-down) v NAEI NO_x Emissions



Simple mass balance approach to downwind TROPOMI plumes from 12 UK cities.

Low bias in NAEI of ~28%, driven by NAEI underestimates at large cities such as London and Manchester - outside of uncertainty range in the satellite estimates.

GEOS-Chem 3-D model run for 2019 with the NAEI emissions (2016 scaled to 2019) shows consistent underestimation in simulated column NO_2 compared with TROPOMI.

Conclusion: NAEI may underestimate NO_x emissions in e.g. London and Manchester.

Summary

- **Earth observation data** has been essential in the creation of the Montreal Protocol (detection/attribution of ozone depletion) and verifying it's success so far (ozone recovery).
- Ground-based data detected the global, non-Protocol-compliant (illegal), increased emissions. **Inversion-modelling / flux attribution** has been essential for assigning the source of the emissions. Alarm/global
- **EO data** can be used to improve uncertainties in national-scale, 'bottom-up' emissions inventories for certain important pollutants, again with some form of **flux estimation**.
- UK NAEI: May underestimate NH_3 (dairy farming) and NO_2 (large cities) emissions.