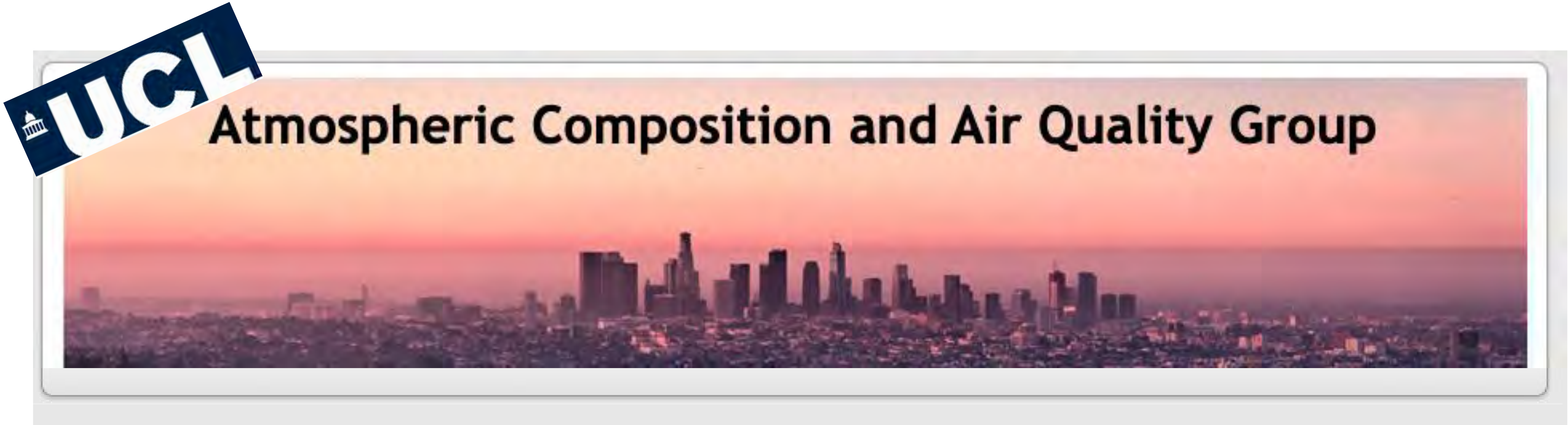
Use of column abundances of ammonia detected from space-based sensors to derive agricultural emissions



https://maraisresearchgroup.co.uk/

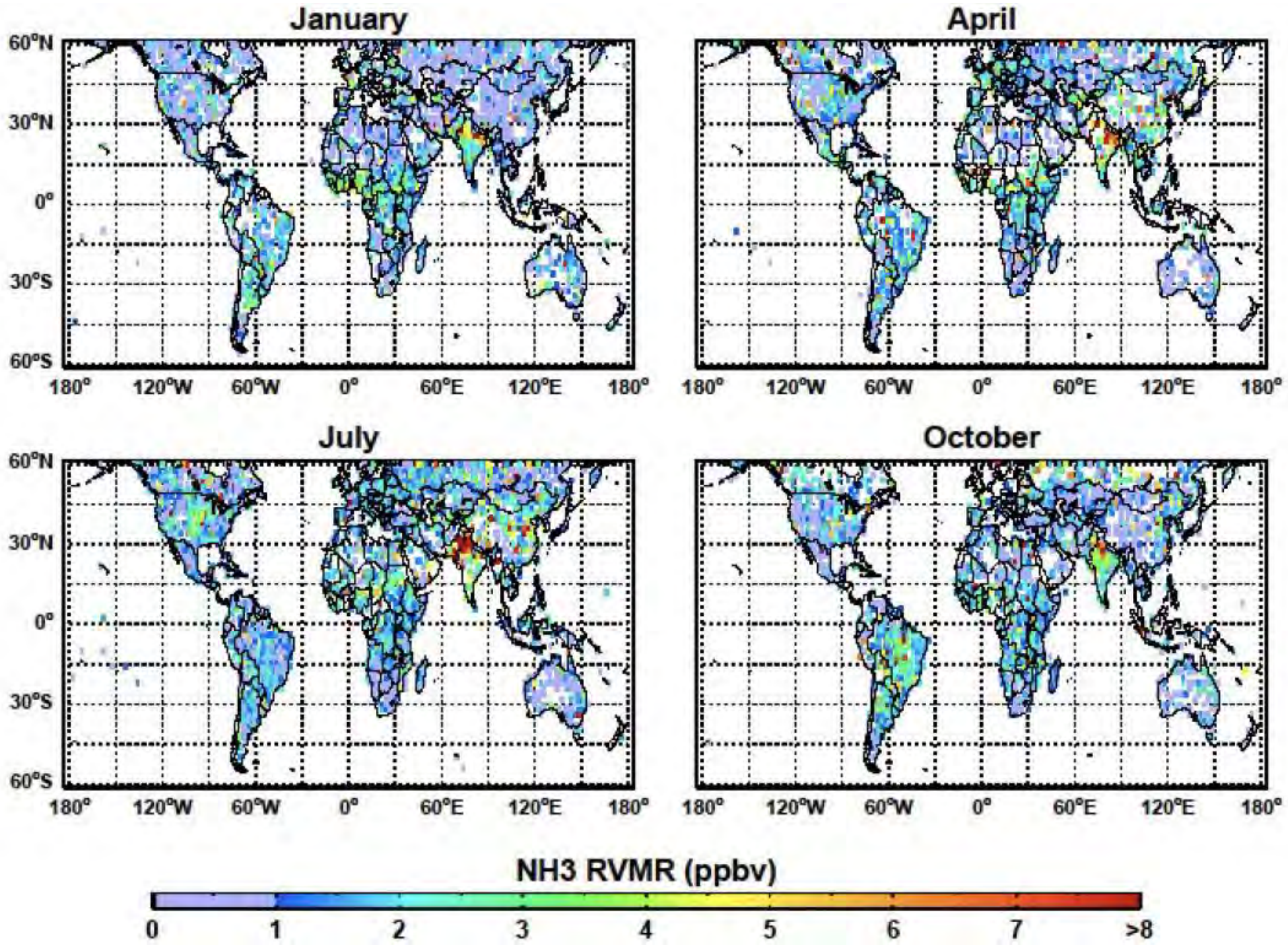
Prof Eloise A. Marais e.marais@ucl.ac.uk

27 Feb 2025

Proof of concept starts with the TES instrument

NASA Tropospheric Emission Spectrometer (TES) instrument on the Aura A-Train

Multiyear (2006-2009) average boundary layer mixing ratios of ammonia



Demonstrates feasibility

Low data density (multiple days to achieve global coverage)

5 km x 8 km resolution

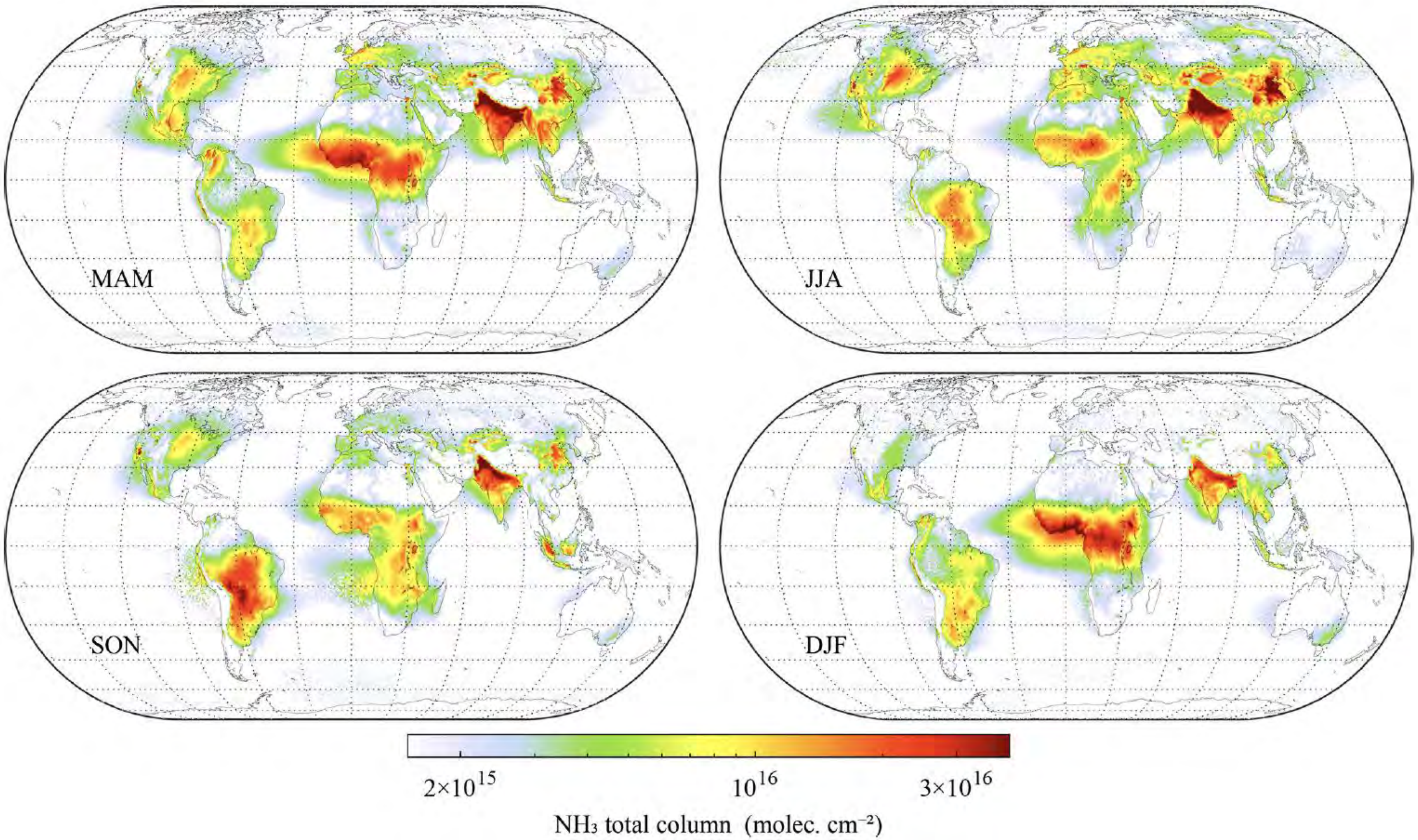
Launched 2004
Midday overpass
No longer operating

[Shephard et al., 2011]

Progressed to IASI instruments

Infrared Atmospheric Sounding Interferometer (IASI) instruments on MetOp-A, -B, and -C satellites

Long-term (Oct 2007 to Sept 2022) seasonal mean total column densities



~12 km resolution elliptical pixels

Daily global coverage

Long-term consistent record since October 2007

Morning overpass

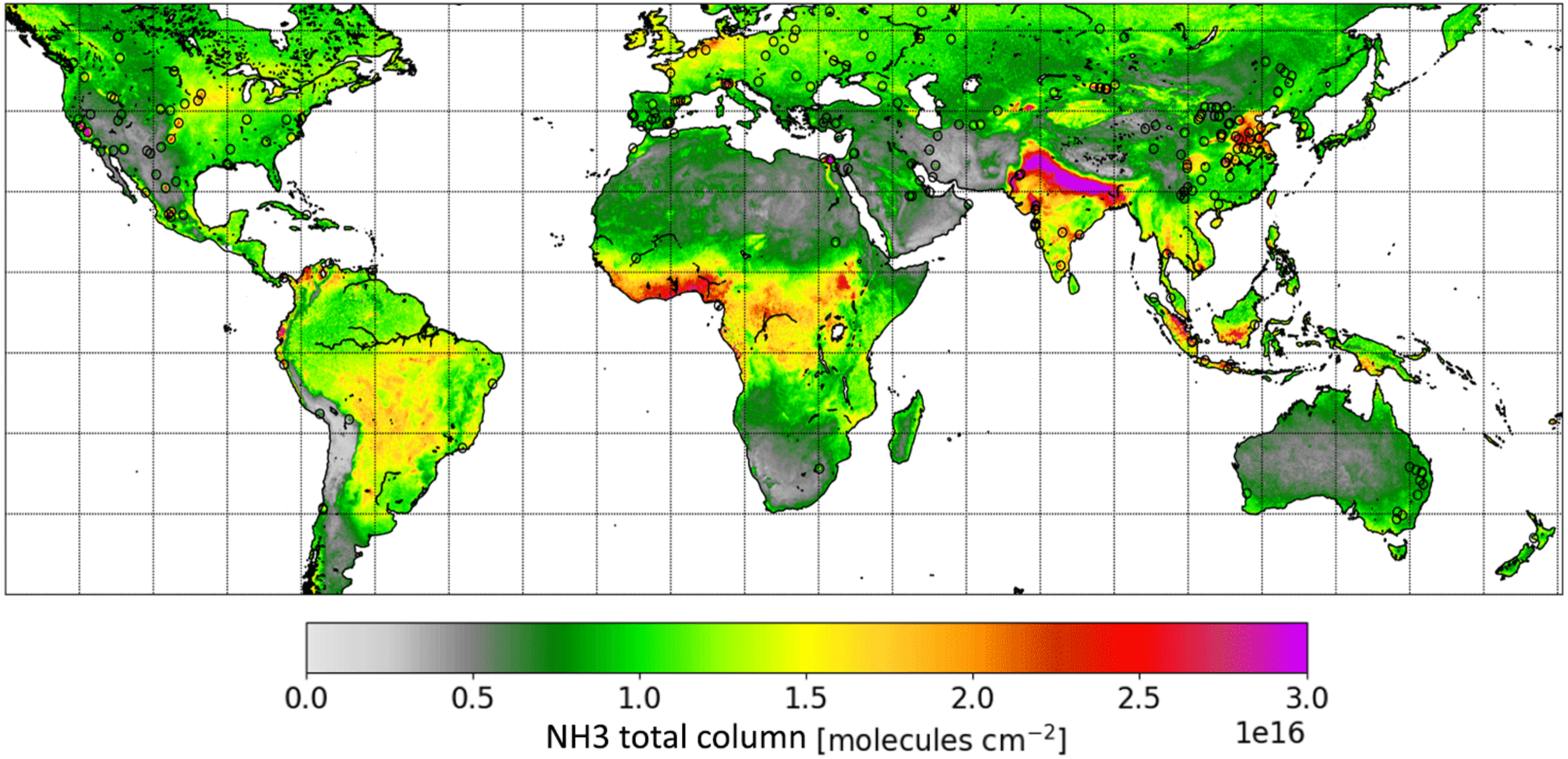
Machine learning retrieval method using model prior

[Clarisse et al., 2023]

And to CrIS instruments

Cross-track Infrared Sounder (CrIS) instruments on NOAA satellites

Long-term (2013-2017) annual mean total column densities



Daily global coverage

~14 km elliptical pixel resolution

Data record since 2012

Midday overpass

Traditional optimal estimation retrieval method using model prior

[Dammers et al., 2019]

Case study of UK ammonia emissions:

- The UK National Atmospheric Emission Inventory (NAEI)
- IASI (morning overpass) NH3 observations
- CrIS (midday overpass) NH3 observations
- A state-of-science chemical transport model
- Surface network observations
- Collaboration with NAEI developer and satellite data providers

Part of a Defra-funded research project with collaborators at NCEO

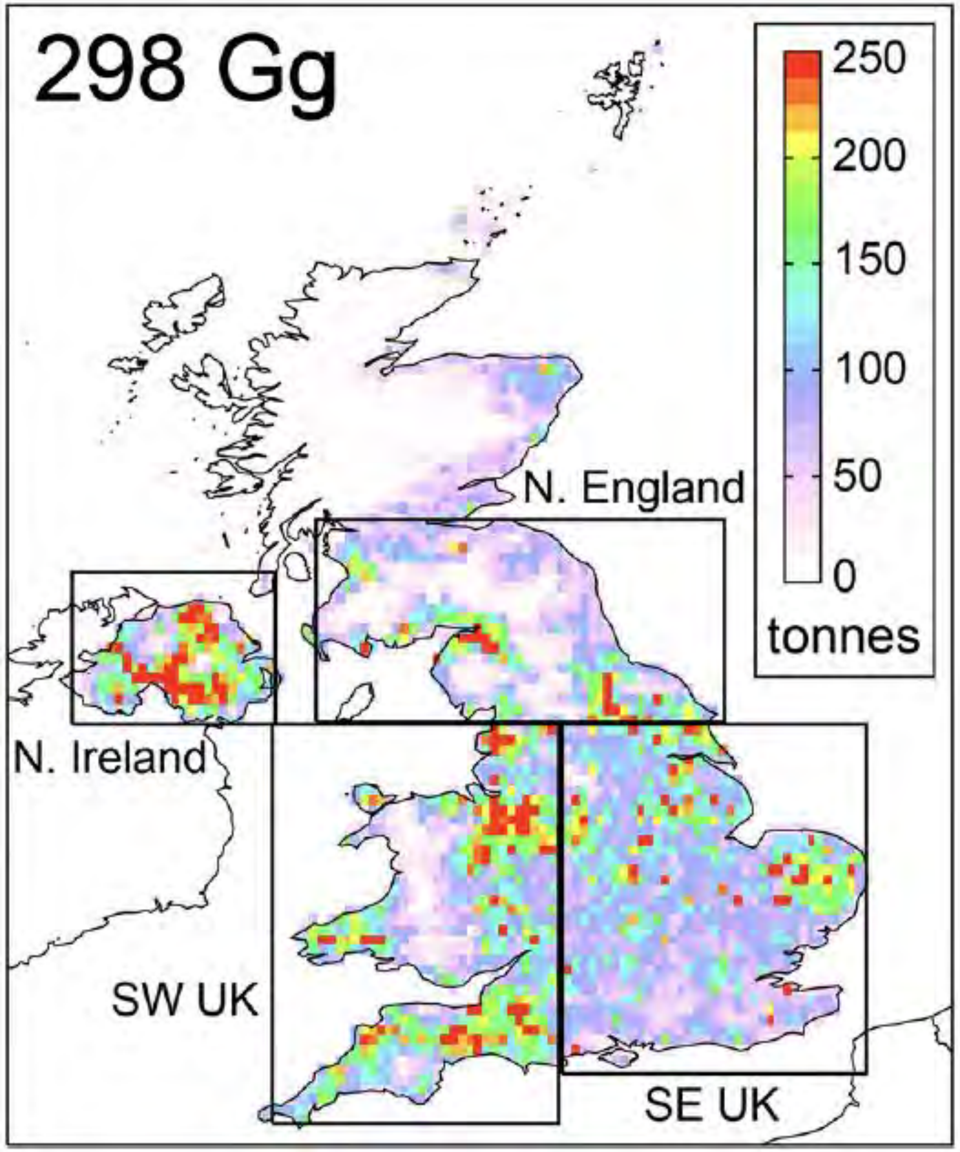
Inventory (Bottom-Up) Emissions

National Atmospheric Emission Inventory (NAEI) annual NH_3 emissions for 2016

Gg = kilotonnes

Mapped to 0.1 degree resolution

Provided at 1 km resolution from 5 km resolution nitrogen flow model



Agriculture most (>80%) of total total anthropogenic emissions

Dominant sources are manure management, fertilizer use, dairy and beef cattle farming

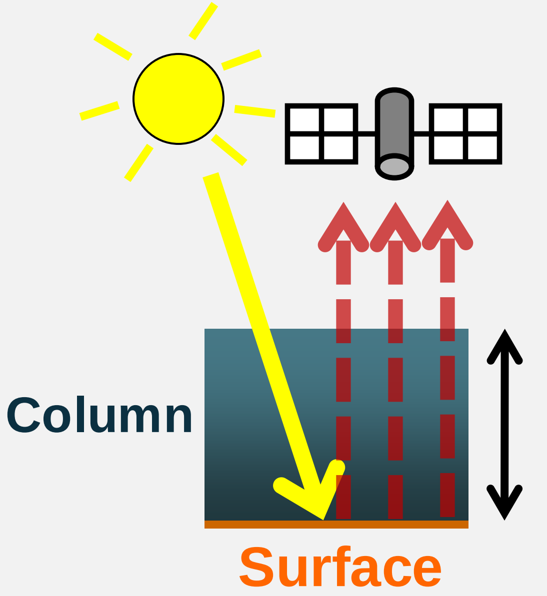
[Marais et al., 2021]

Observationally-derived (Top-Down) Emissions

Convert atmospheric **column concentrations** to surface **emissions** using a **model**

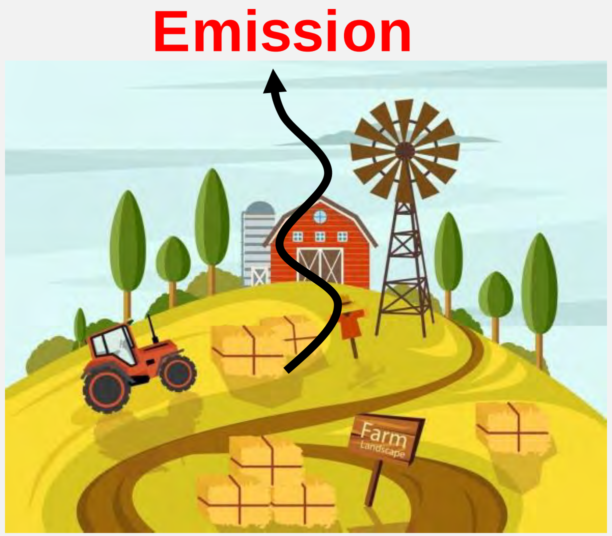
COLUMNS → **Conversion Factor** → **EMISSIONS**

Satellite columns



Column-to-Emission ratio (model)

Satellite-derived Surface Emissions

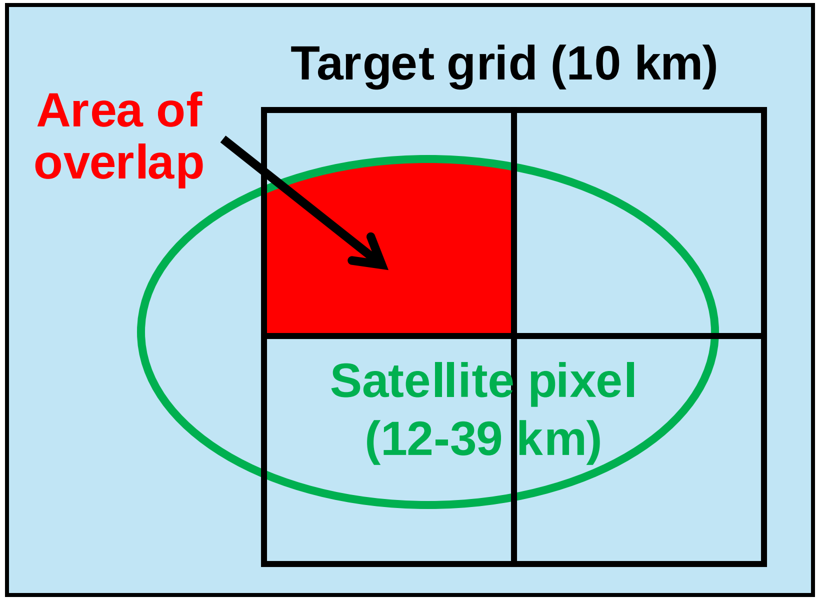


More complex inversion techniques using adjoints, machine learning, Lagrangian models tracking plumes

Preprocess to Finer Resolution than Instrument

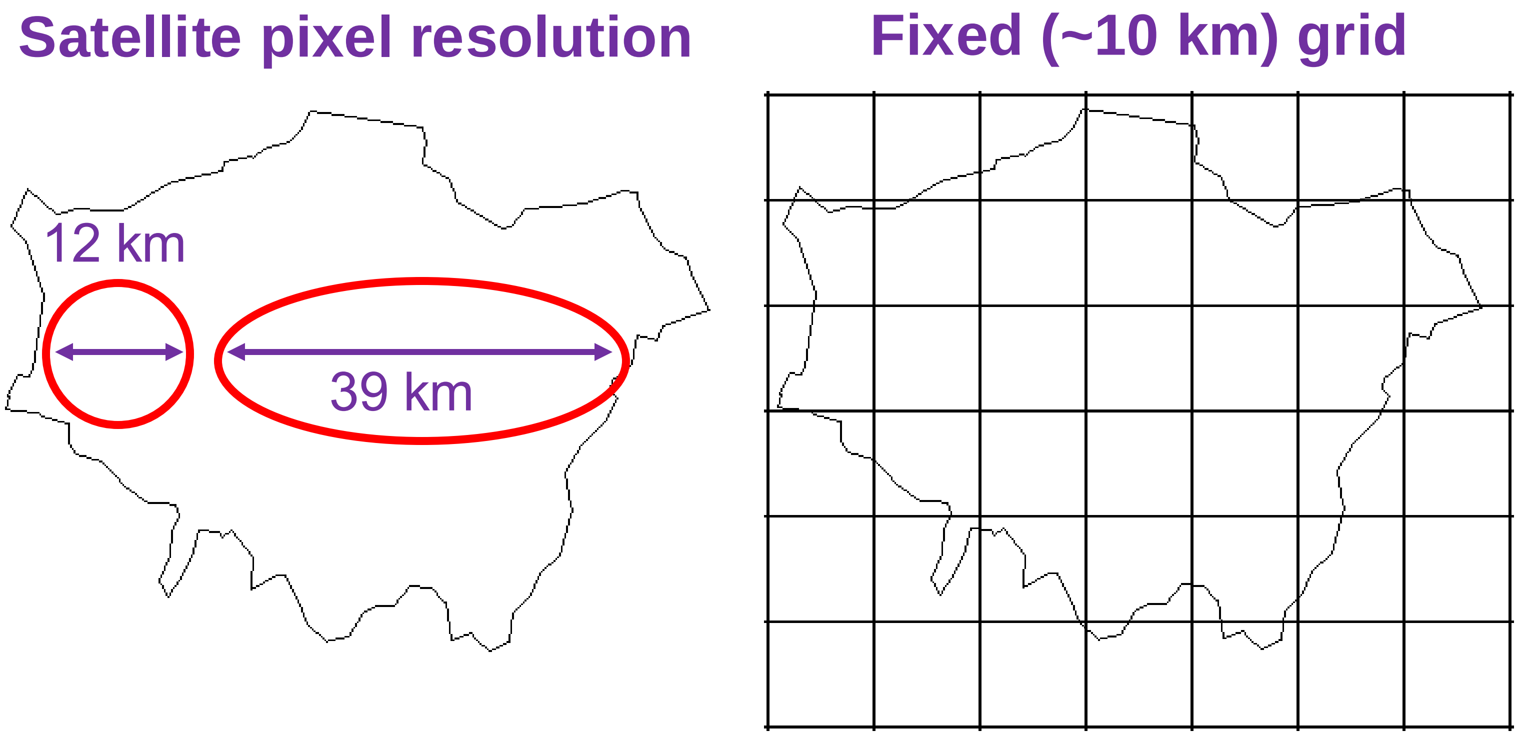
Use so-called oversampling to enhance spatial resolution relative to native resolution of instrument

Oversampling Technique



Weights pixel by area of overlap

Oversampling technique over London

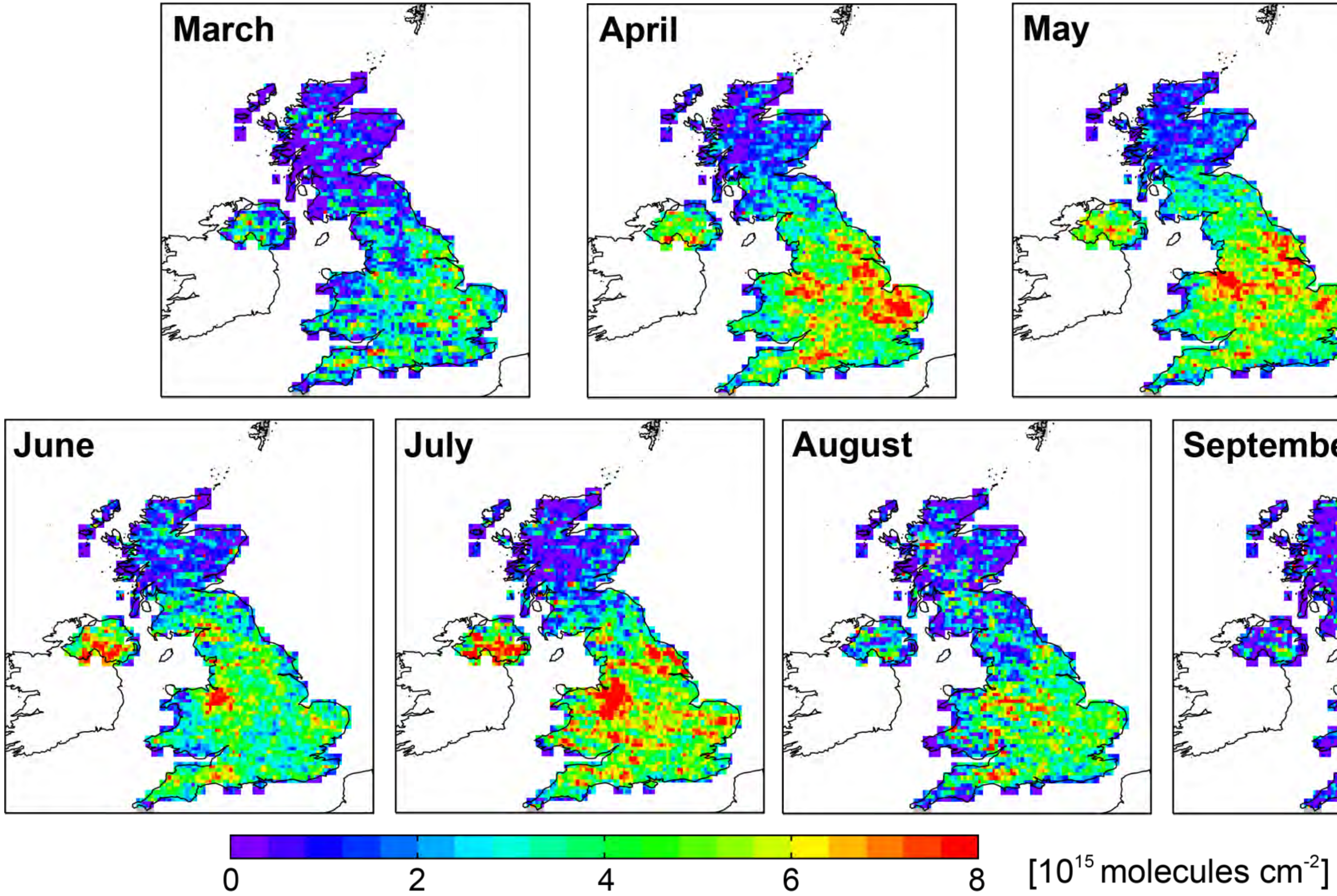


Lose time (temporal) resolution; gain spatial resolution

Improve resolution from 12-40 km to 10 km for an instrument observing ammonia (NH_3)

Multiyear means from the IASI (morning overpass) instrument

Multiyear (2008-2018) monthly means for warmer months of the year



Column densities: number of molecules from surface of Earth to top of atmosphere

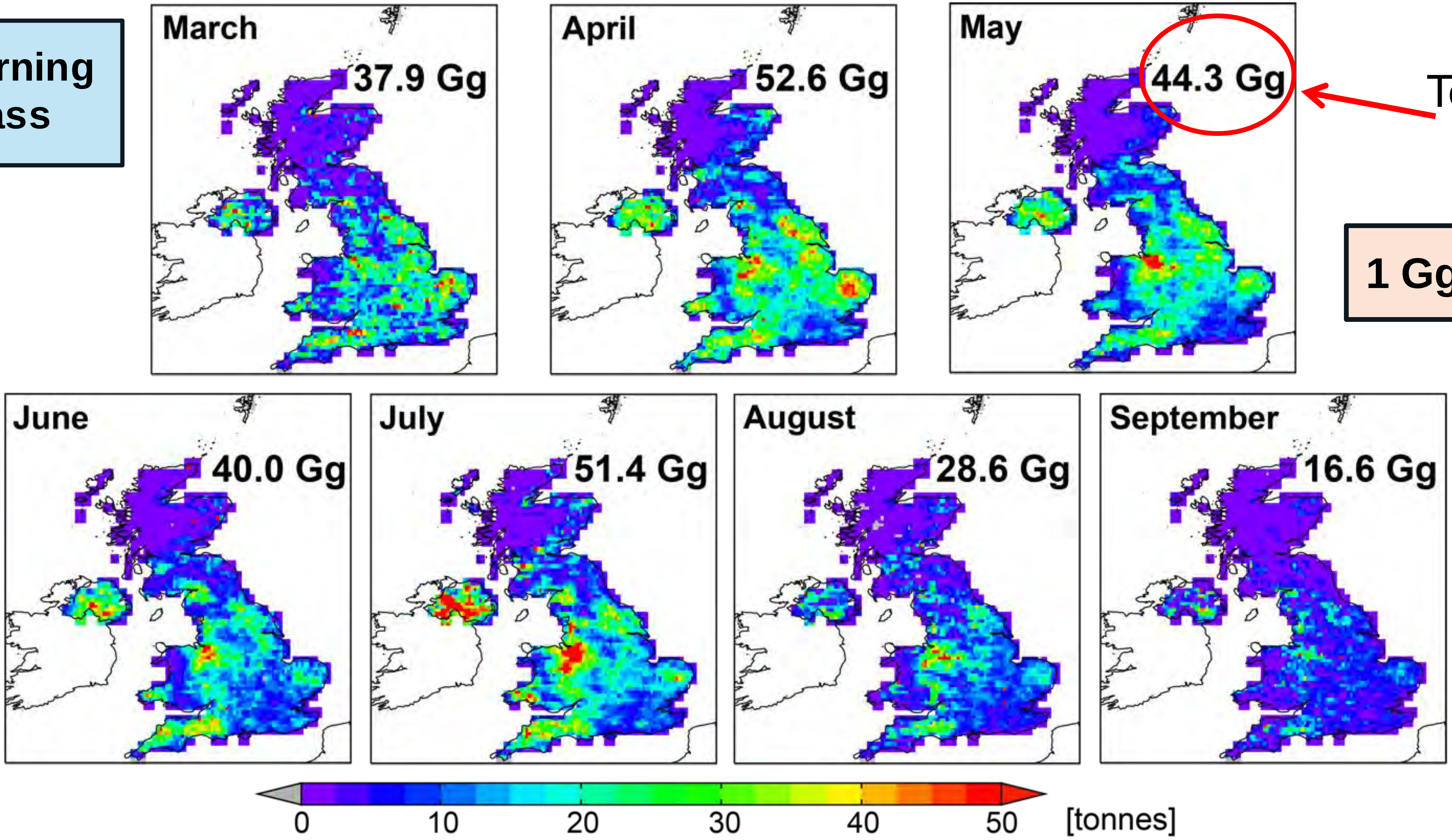
[Marais et al., 2021]

Climatological mean to be consistent with bottom-up ammonia emissions

IASI-derived multiyear (2008-2018) monthly mean NH_3 emissions

Focus on **Mar-Sep** when warm temperatures and clearer conditions increase sensitivity to surface NH_3

IASI: morning overpass



Total monthly emissions

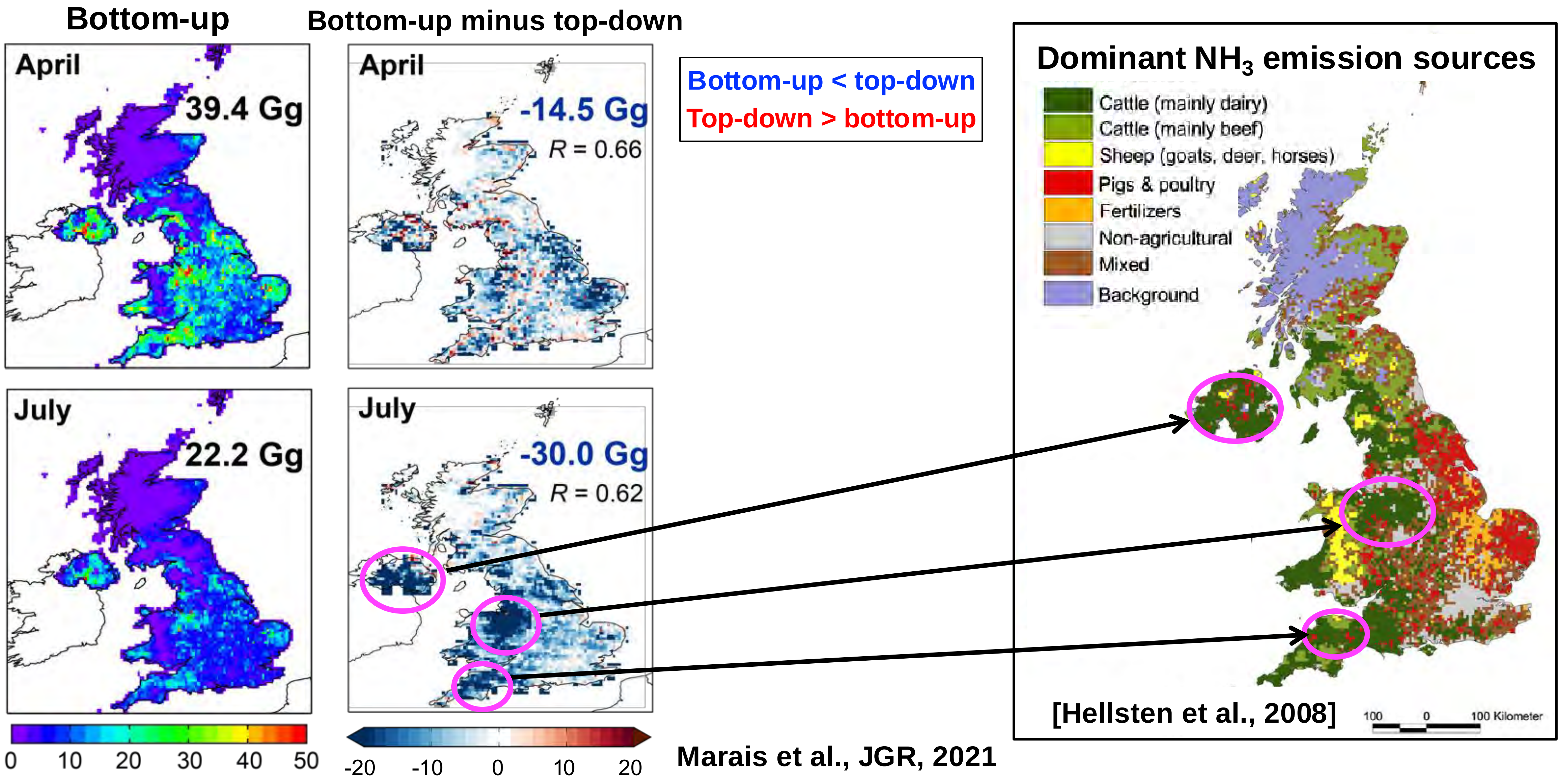
1 Gg = 1 kilotonne

[Marais et al., 2021]

Monthly emissions for March-September from **IASI**-derived estimates sum to **271.5 Gg**

Satellite vs inventory NH_3 emissions: spatial distribution

Comparison of months with peak emissions according to IASI (April and July)

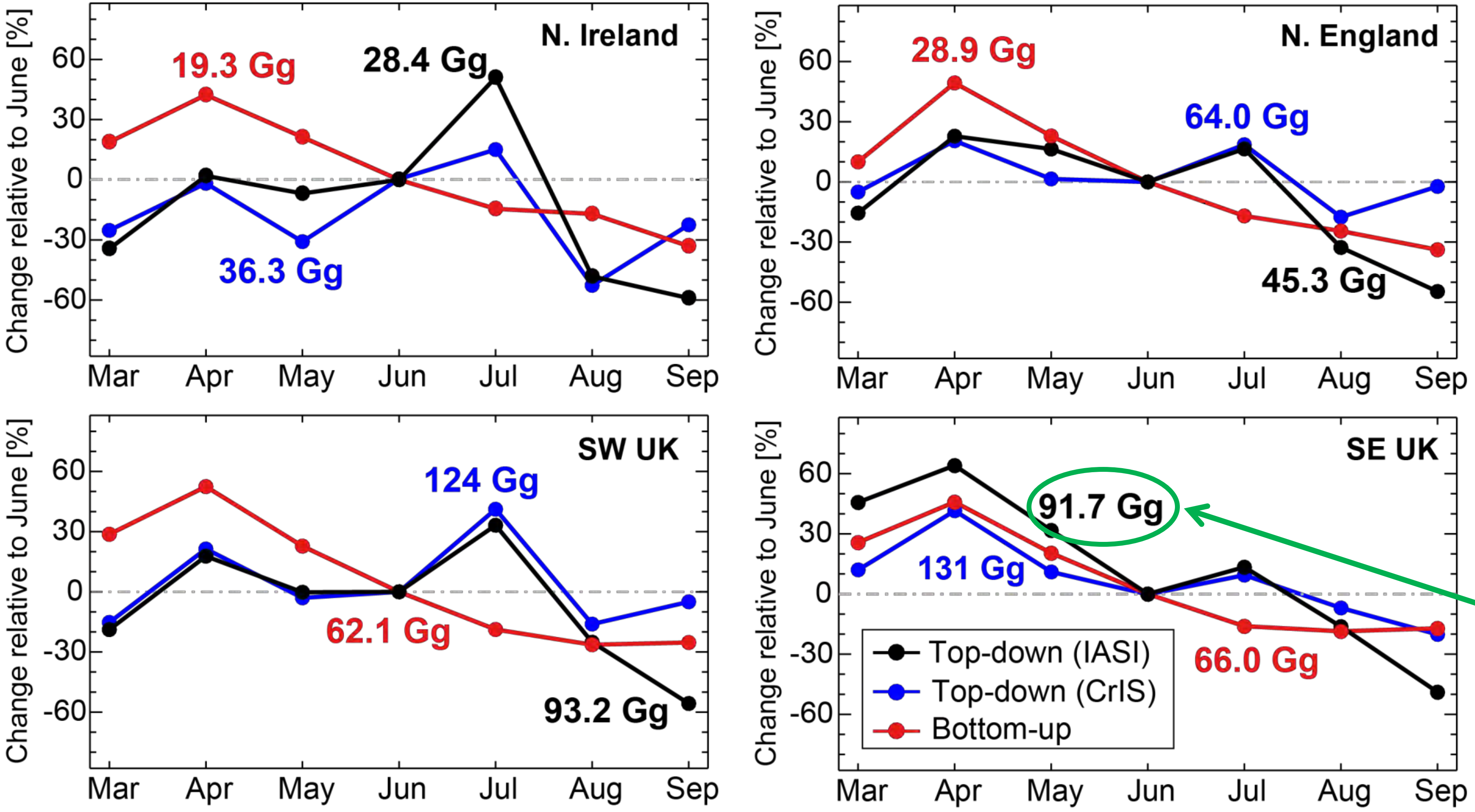


Marais et al., JGR, 2021

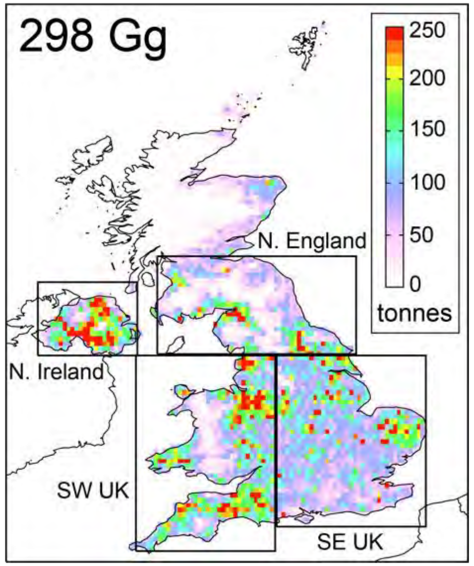
Large July difference over locations dominated by dairy cattle. Inventory is 27-49% less than the satellite values.

Satellite vs inventory NH_3 emissions: seasonality

Seasonality shown as emissions in each month relative to June



Regions and annual inventory emissions



Mar-Sep emission totals in each region

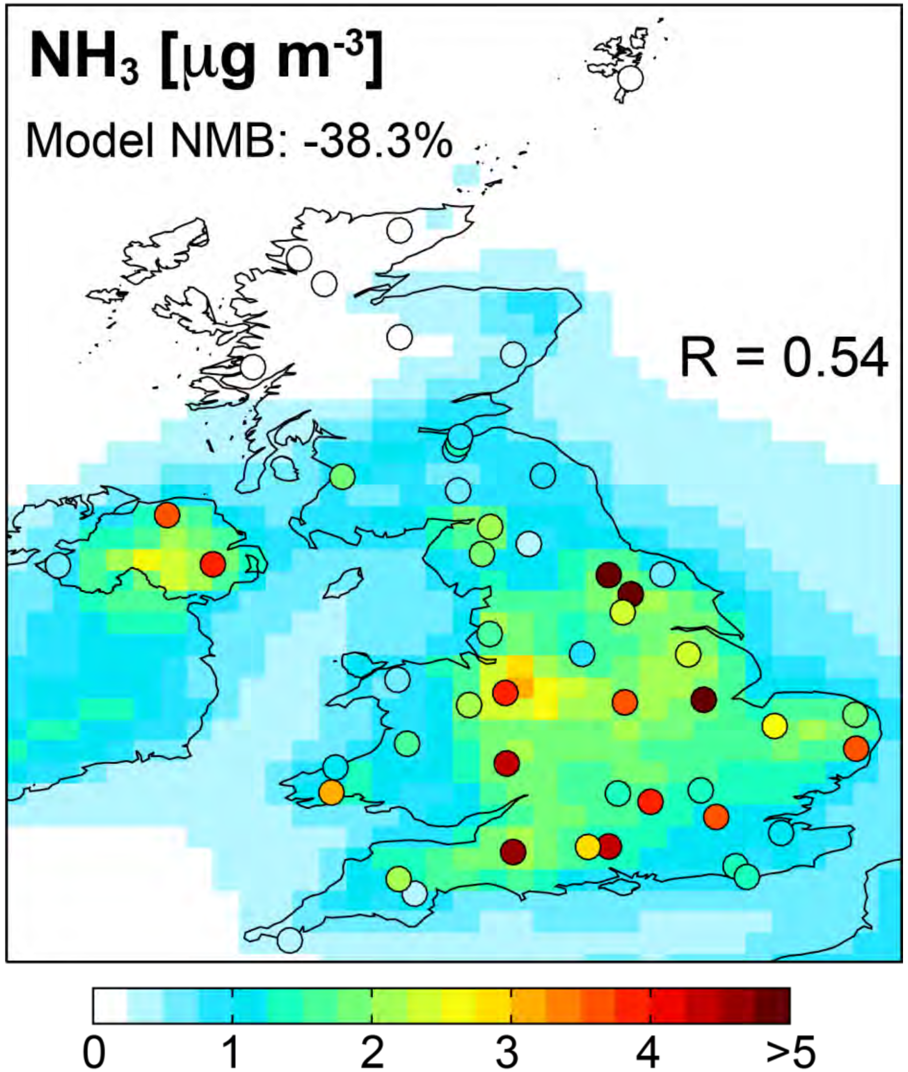
1 Gg = 1 kilotonne

All reproduce spring April peak (fertilizer & manure use). Only the satellite show summer July peak (dairy cattle?).

The increase in emissions in September in CrIS is spurious.

Ground-truthing Requires Abundant, Suitable Surface Observations

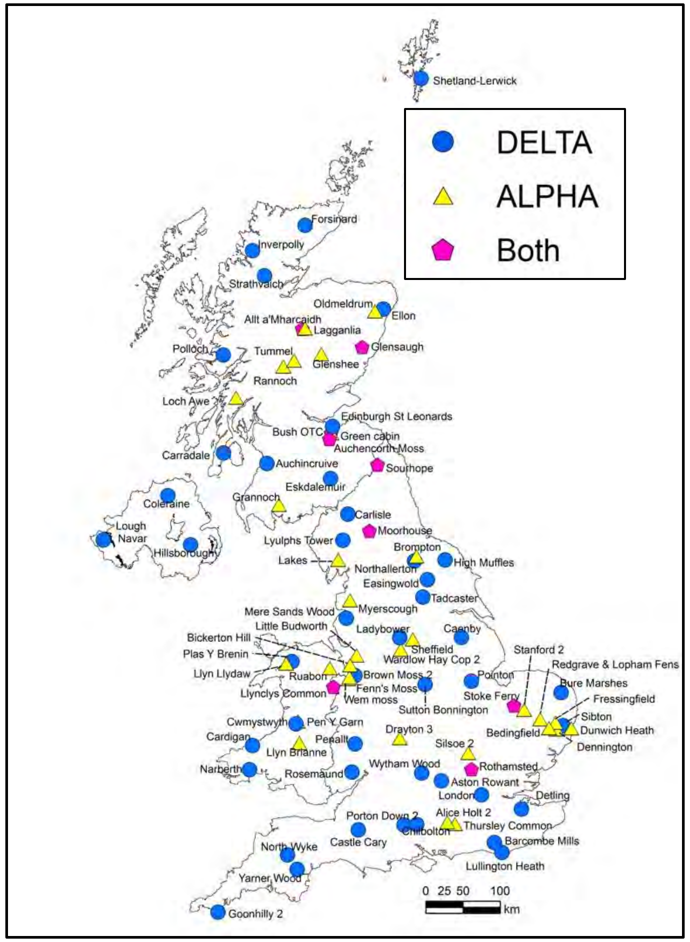
Network (points) and model (background) surface NH_3 in Mar-Sep



Points are for DELTA instruments (blue circles)

DELTA instruments support model underestimate (**NMB = -38%**)

So do passive low-cost ALPHA instruments (yellow triangles) (**NMB = -41.5%**)



GEOS-Chem underestimate in surface NH_3 driven with the NAEI corroborates results from IASI

Leads to reluctance to uptake by inventory developers and integration in policy decisions

In Summary

- Sustained space-based sensor record of ammonia from instruments in low-Earth orbit
- Spatial resolutions of ~12-14 km enhanced by oversampling, but lots of data needed
- Ammonia short-lived, so relate column abundances to surface emissions using a model
- Application to the cloudy UK even feasible!
- Estimate emissions that are consistent with spring fertilizer application location and timing
- Identify large bottom-up and top-down emissions discrepancies in summer over cattle farming intensive regions that requires further investigation
- Bottom-up and top-down inconsistencies confirmed with surface network observations of ammonia (crucial for ground truthing!)
- Geostationary infrared instrument soon to launch over Europe to observe ammonia every 30 min (including over Africa)

Links to Cited Peer-reviewed Studies

- Shephard et al., 2011: www.atmos-chem-phys.net/11/10743/2011/
- Clarisse et al., 2023: https://doi.org/10.5194/amt-16-5009-2023
- Dammers et al., 2019: https://doi.org/10.5194/acp-19-12261-2019
- Marais et al., 2021: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021JD035237
- Hellsten et al., 2008: https://doi.org/10.1016/j.envpol.2008.02.017