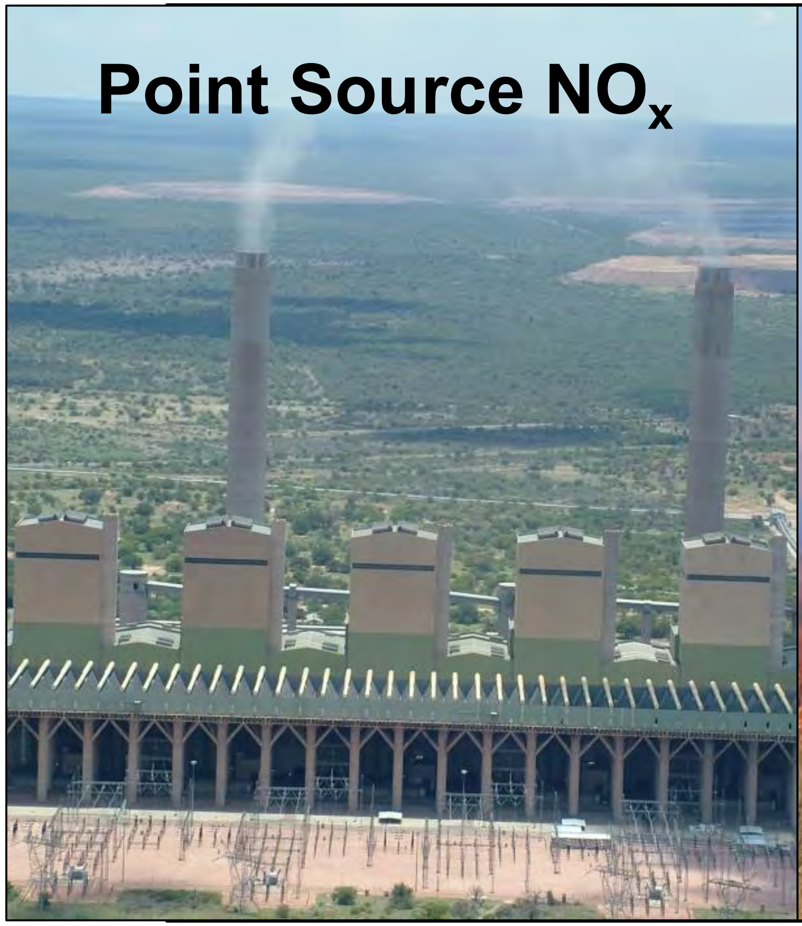
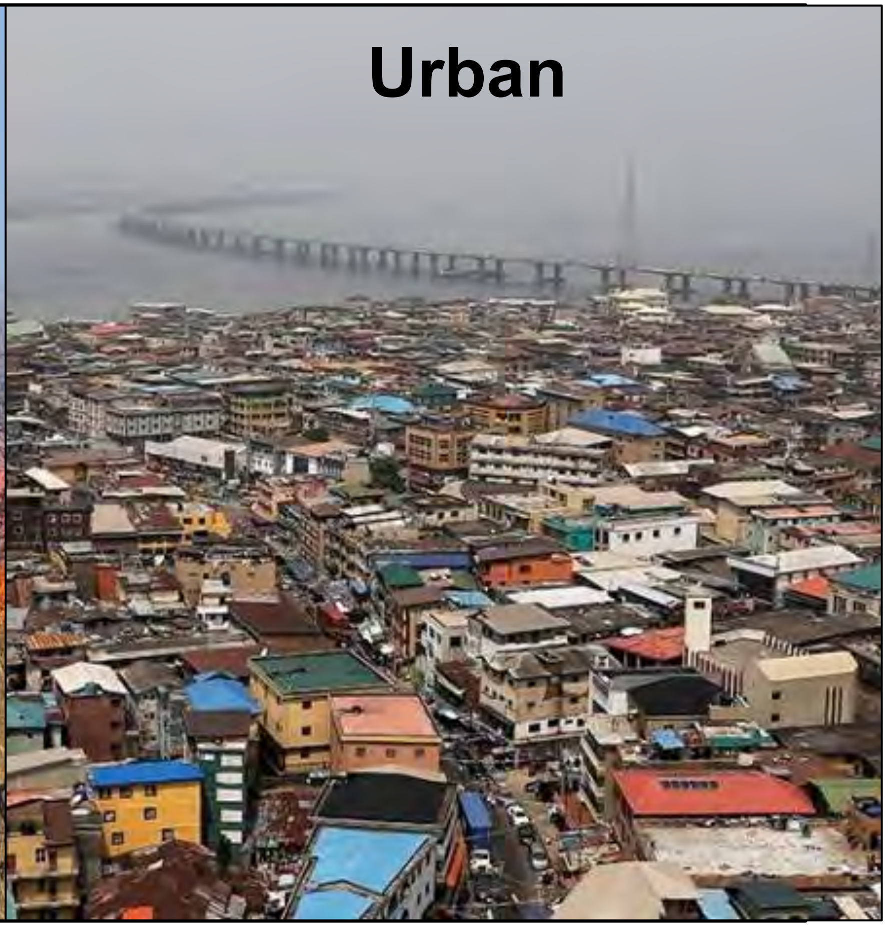
Top-down estimates of nitrogen pollution sources in Sub-Saharan Africa to scrutinize inventories needed for regulation





Eloise Marais (UCL) with Nana Wei, Gongda Lu, Martin Van Damme, Lieven Clarisse, Christine Wiedinmyer, Killian Murphy, Guido van der Werf, Mogesh Naidoo, Rebecca Garland, Keita Sekou

IGAC 2026 **8 September 2026**

Atmospheric Impacts of Launch and Re-entry Emissions

Growing community working on this topic!

At IGAC:

Poster S2_P541 by Connor Barker on (Session 2)

Talk by Kostas Tsigaridis on Thursday afternoon

In Other Ways:

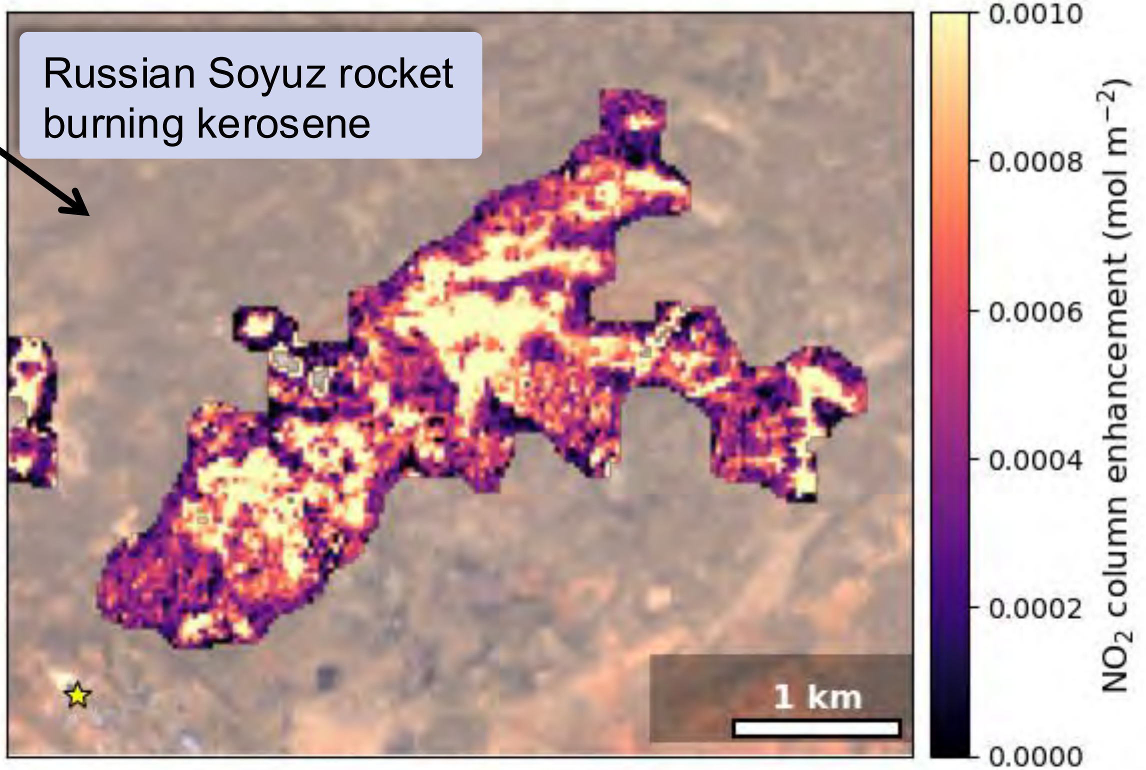
ESA-organized workshops

Dedicated sessions at AGU and EGU

AIRL working group

Experts white paper coordinated by European Space Sciences Committee (ESSC)

Rocket NO_2 plume retrieved from Landsat



Want to find out how to contribute advancing this topic?

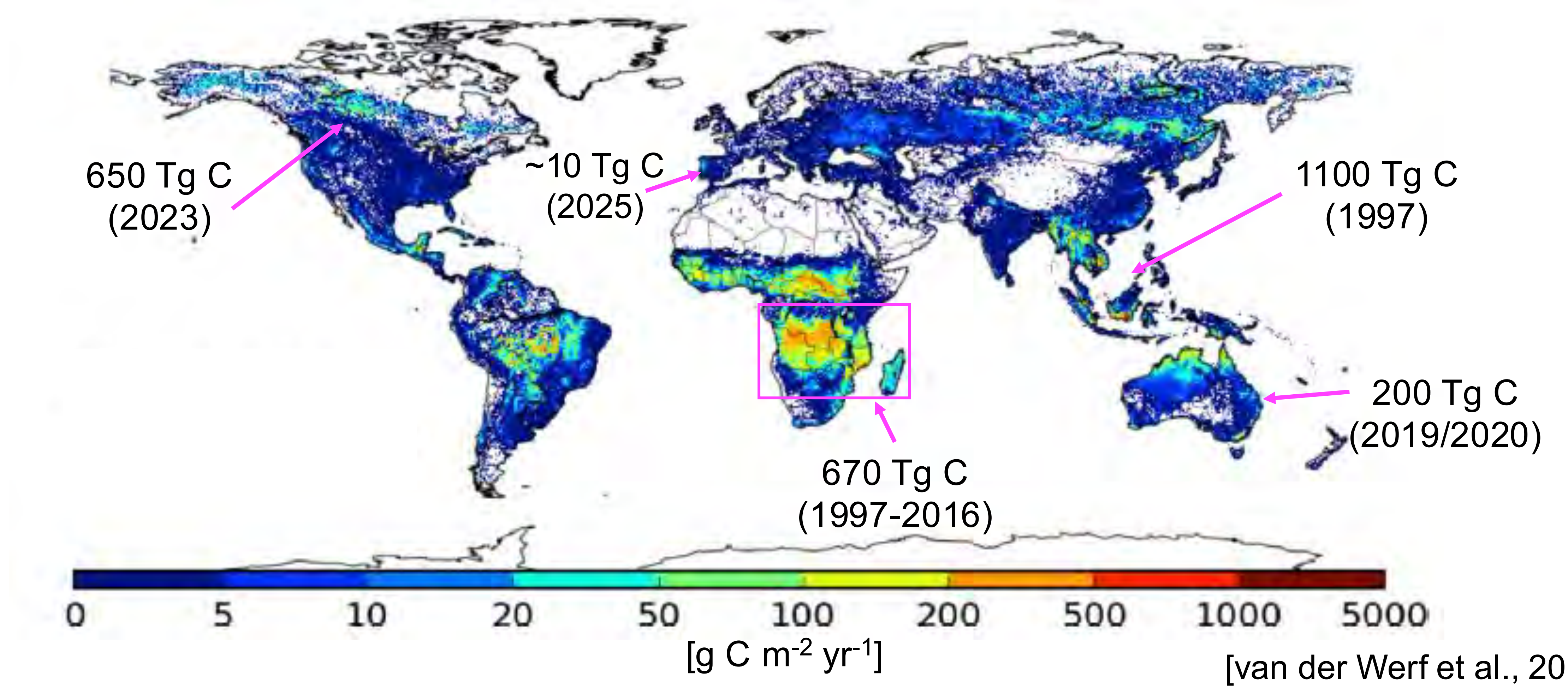
Get in touch: e.marais@ucl.ac.uk

Chat to Connor at his poster!

Open Fire Reactive Nitrogen (NO_x and NH_3) Emissions

Global Context for Southern Africa Biomass Burning

Biomass burning carbon emissions from the Global Fire Emissions Database (GFED) inventory

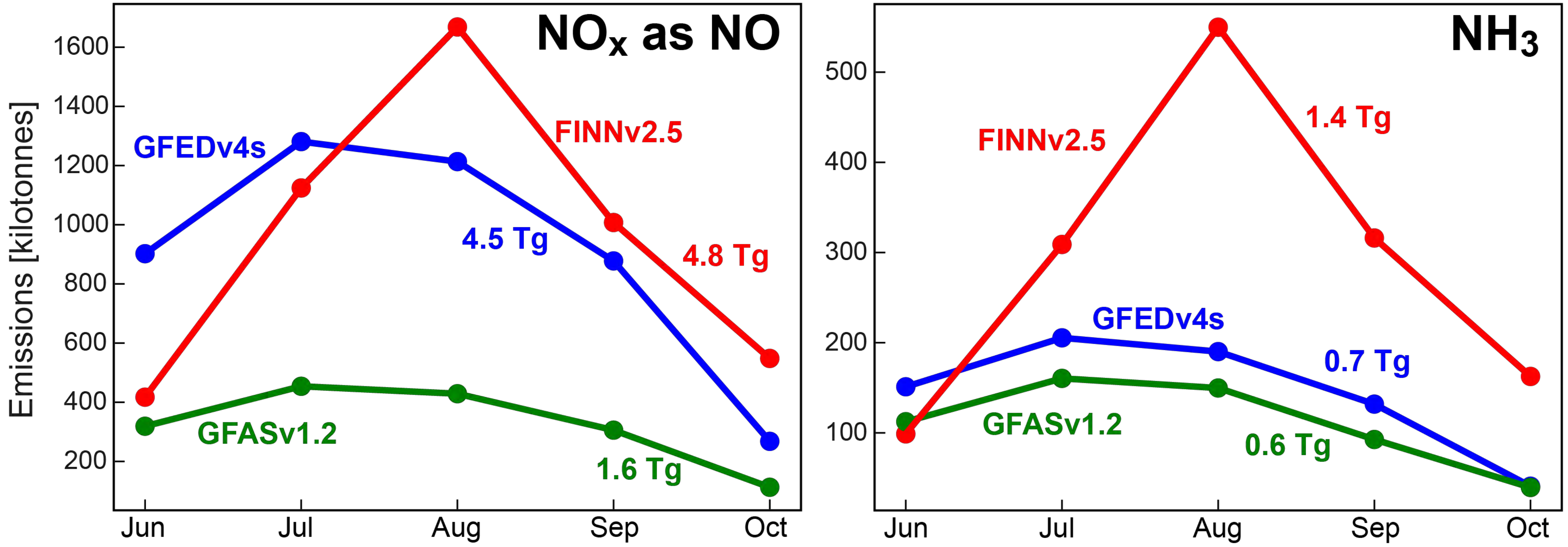


[van der Werf et al., 2017]

Open fire emissions in southern Africa outcompete most anomalous fires in other regions, so is a potentially large global source of reactive nitrogen

Reactive Nitrogen Emissions in Southern Africa

Monthly bottom-up June-October 2019 emissions



Other differences: Time and spatial resolution, injection height, landcover classes

Mostly savanna fires

In FINN, ~20-times more fuel consumed for tropical forest fires (smouldering) than the other inventories

Impact of Different NO_x Emissions on Ozone Formation

Ozone production efficiency (**OPE**) = ozone produced per mass unit NO_x emitted

GFAS: **13 Tg O_3 (Tg NO)$^{-1}$**

FINN: **9.6 Tg O_3 (Tg NO)$^{-1}$**

GFED: **6.9 Tg O_3 (Tg NO)$^{-1}$**

FINN OPE > GFED OPE, as far more VOCs and CO in FINN:

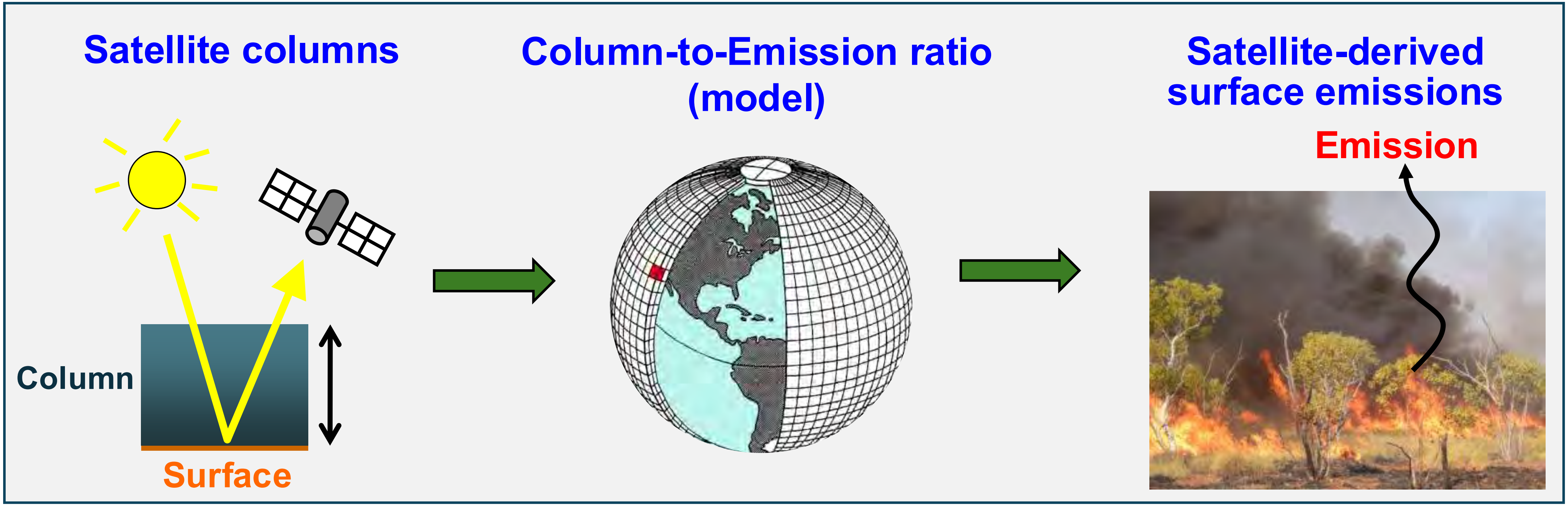
- **FINN**: 108 Tg CO and 13 Tg C for 21 NMVOCs
- **GFED**: 82 Tg CO and 2 Tg C for 13 NMVOCs

Less NO_x from GFAS increases OPE, as O_3 more sensitive to NO_x

Top-down emission using IASI NH_3 and TROPOMI NO_2

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

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

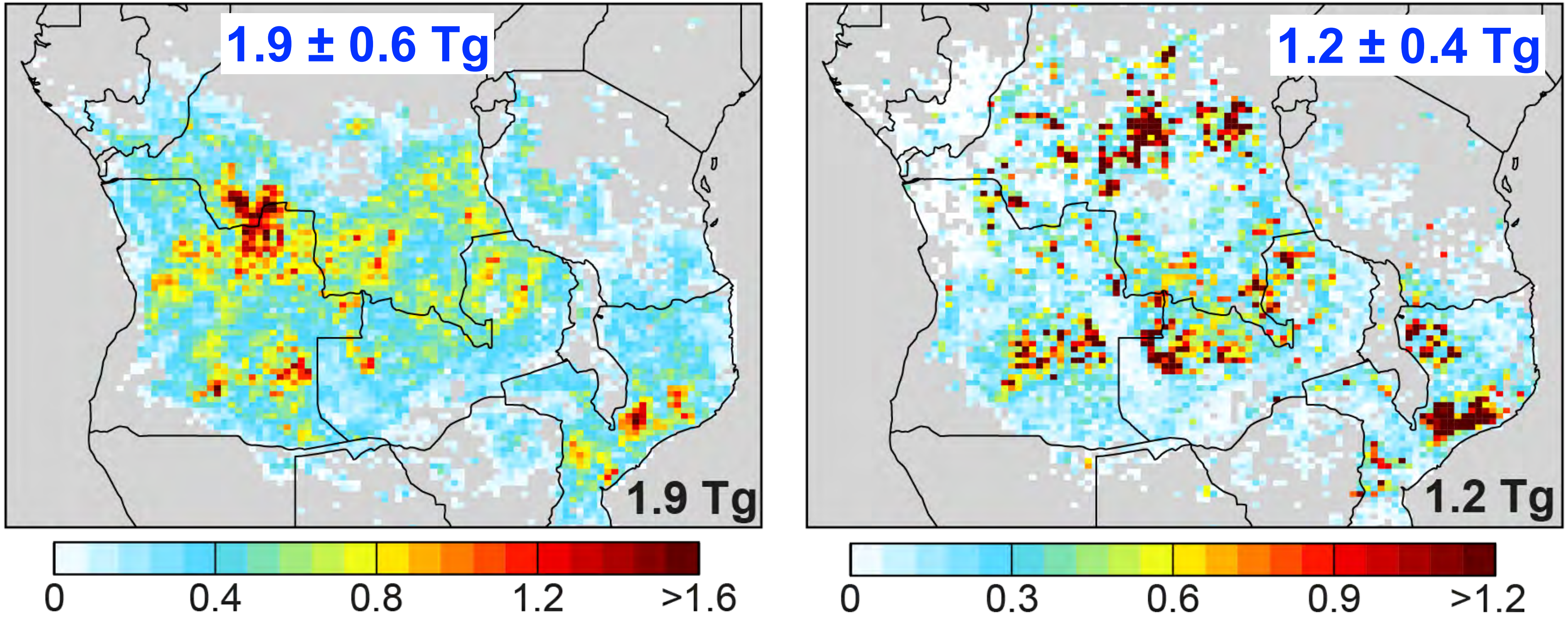


Simple mass balance approach, as it's a first order problem (very large errors)

Use best-performing inventory (**GFAS** for NO_x, **FINN** for NH_3) for gridsquares where open fires > 50% total emissions

Top-down Emissions with Best Performing Inventories

Top-down NO_x emissions [kt NO] — Top-down NH_3 emissions [kt]



Top-down NO_x most similar to GFASv2.1 and top-down NH_3 most similar to FINNv2.5

Emissions peak in similar month to bottom-up: July and August for NO_x and August in NH_3

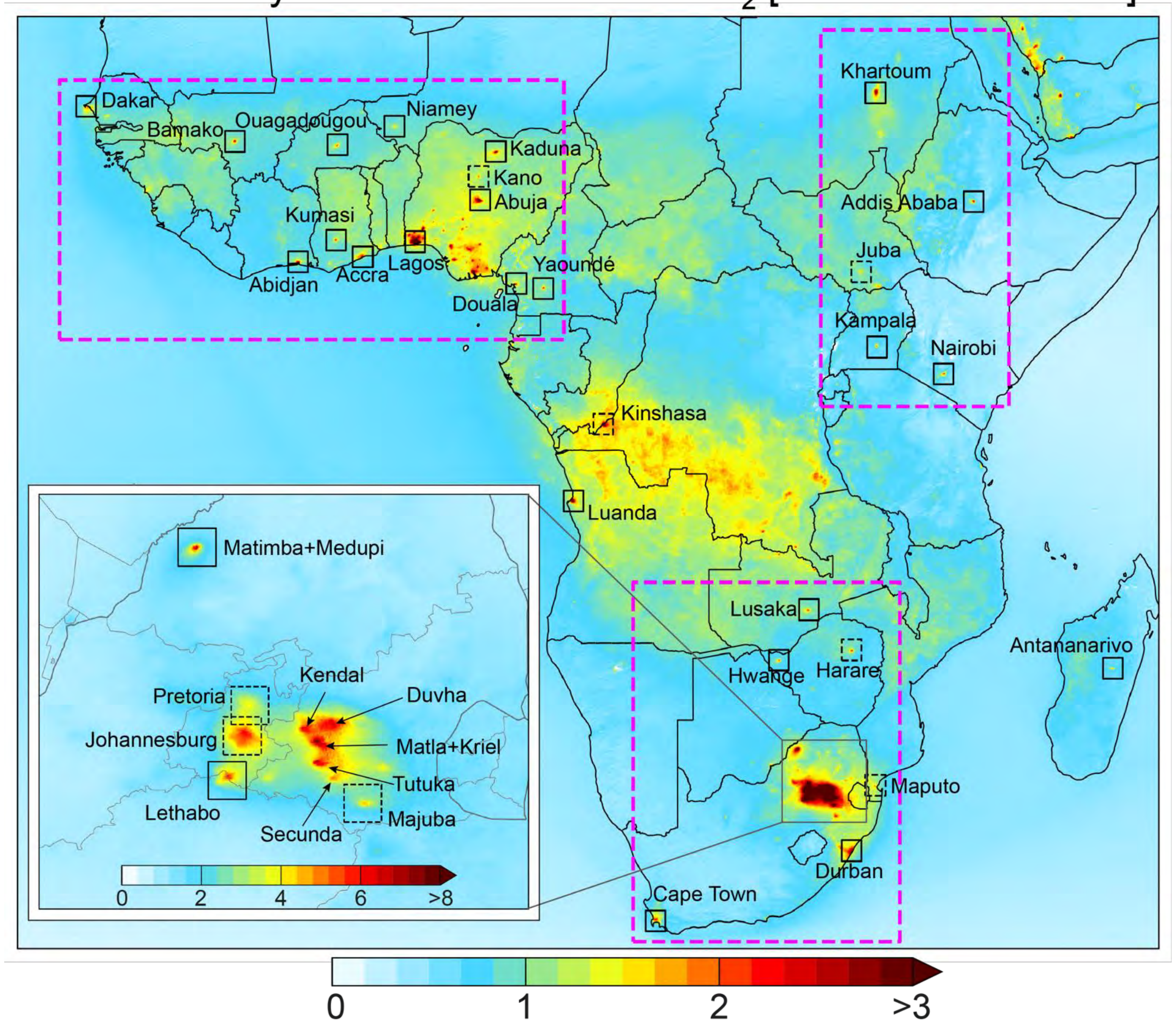
NO_x and NH_3 emissions correlation weak for top-down ($R < 0.4$), but strong for inventories ($R > 0.8$)

Observationally constrained ozone production from biomass burning NO_x: **25 Tg O_3**

Point Source and Urban NO_x

Urban and Point Sources Resolved with TROPOMI

Annual multiyear mean TROPOMI NO_2 [10^{15} molecules cm^{-2}]



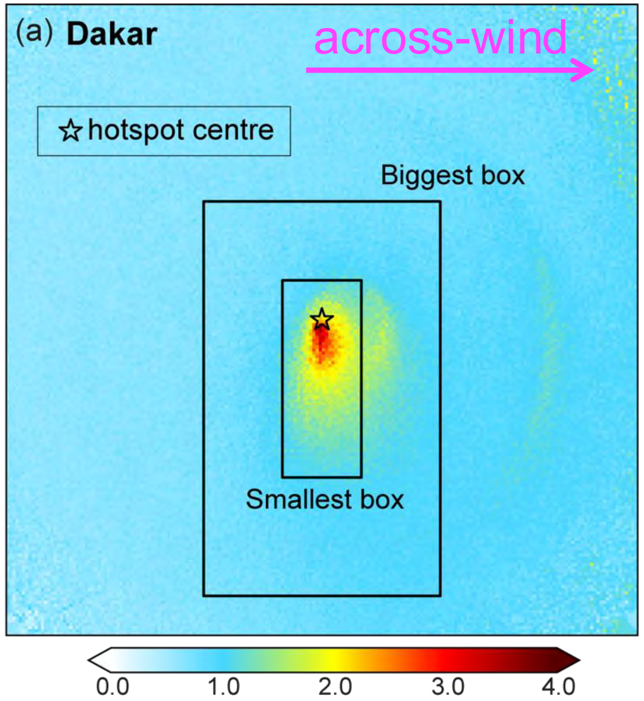
Oversample 4 years of TROPOMI data to finer scale (~2 km) than nadir resolution

32 isolated hotspots: most urban, 4 power plants

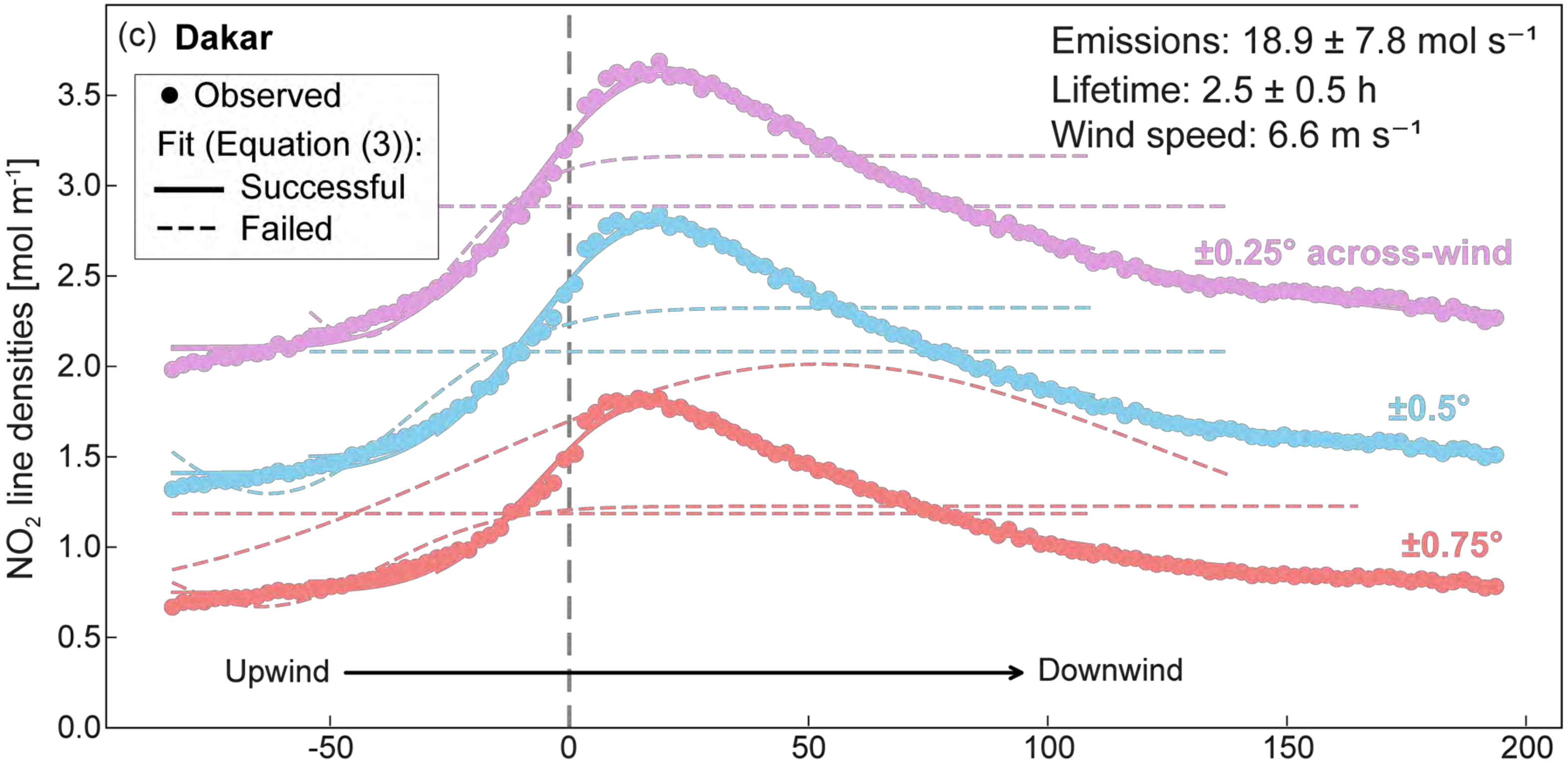
Boxes: solid if approach succeeds; dashed if approach fails

Hotspot NO_x Emissions Inversion Method

Wind rotate TROPOMI NO_2 about the hotspot centre



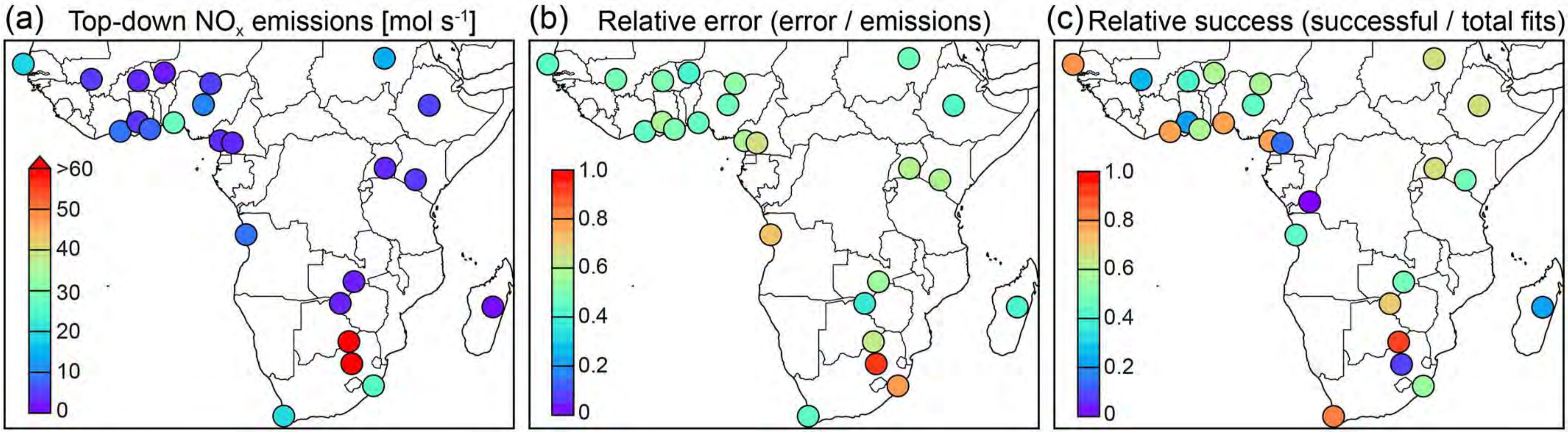
Sum across-wind NO_2 to yield 1D line densities and apply an Exponentially Modified Gaussian (EMG) fit



29 out of 36 fits succeed for Dakar (Senegal) yielding the following quantities:

18.9±7.8 mol NO_x emitted s^{-1}, 2.5±0.5 h effective lifetime, 6.6 m s^{-1} wind speed

NO_x Emissions for All Successful Hotspots



Derived emissions for 24 hotspots compared to at most 5 Sub-Saharan hotspots in past global studies

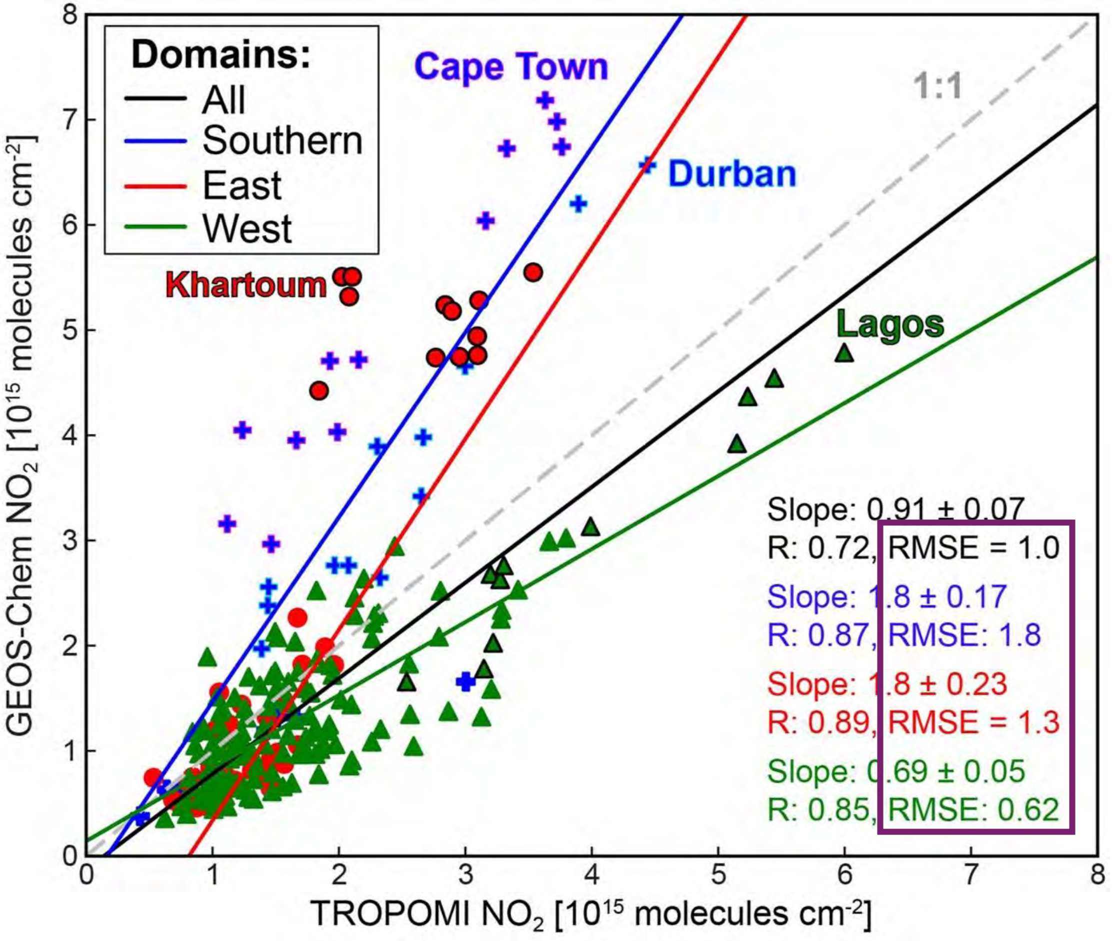
Annual emissions total 312 kilotonnes NO

Most hotspots very small (<10 mol s^{-1}) sources of NO_x compared to urban hotspots in South and Southeast Asia (> 60 mol s^{-1} for Delhi and Dhaka [Lu et al., 2025])

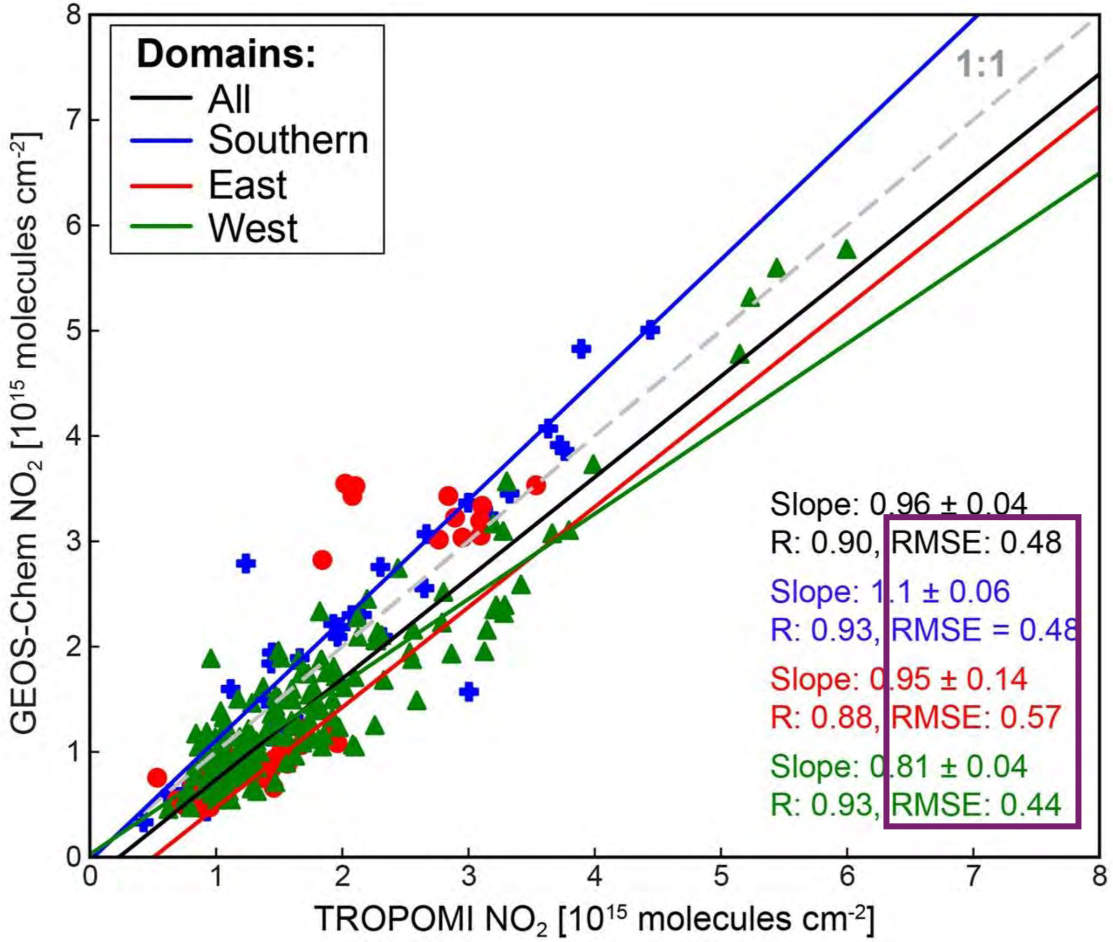
Are Urban Hotspot NO_x Emissions Accurate?

Emissions ⟶ **GEOS-Chem** ⟶ **NO_2 column densities**

Default (CEDS) emissions



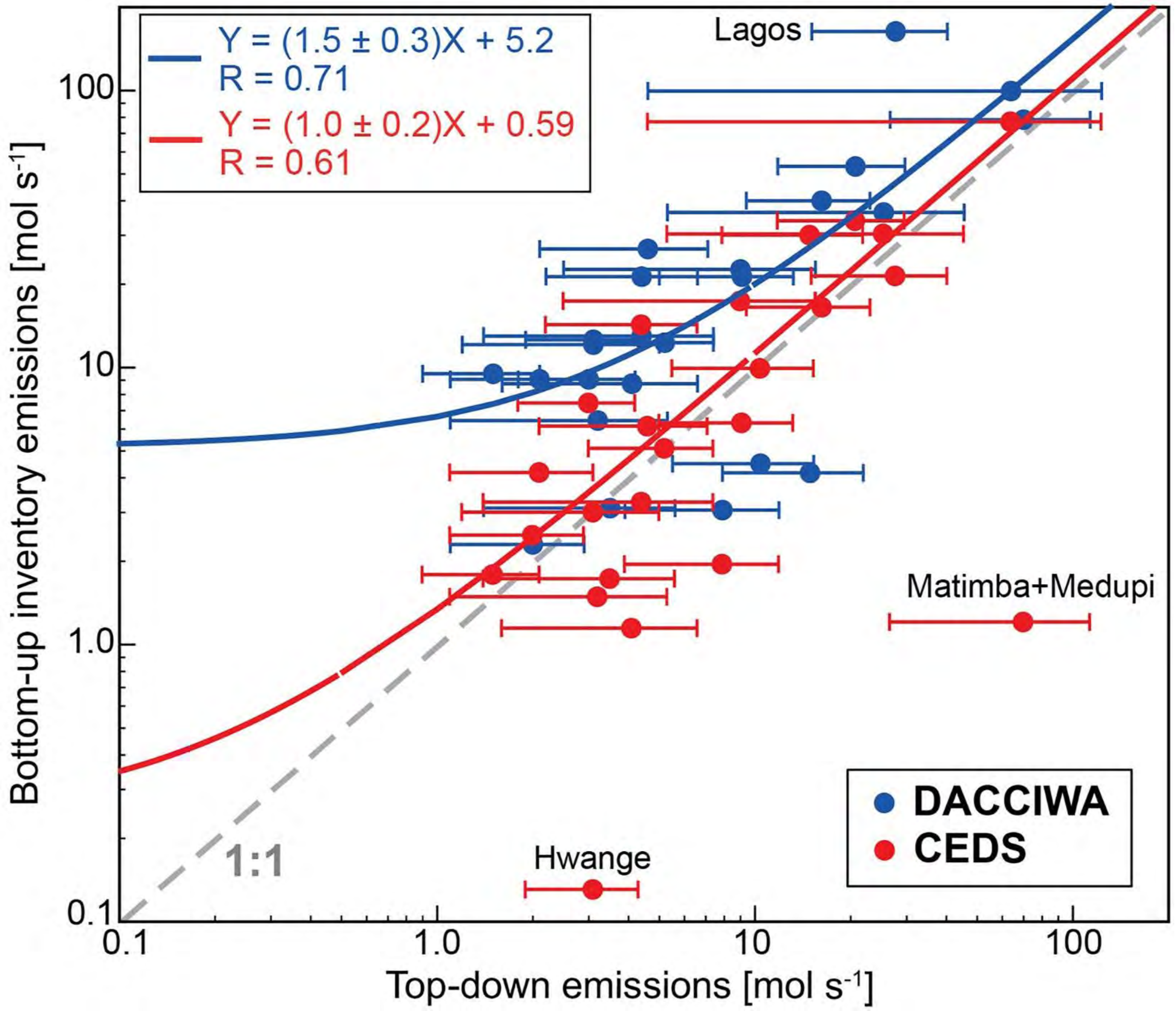
Updated (top-down) emissions



Urban CEDS emissions total 176 kilotonnes NO, whereas top-down total 133 kilotonnes NO

South Africa top-down power plant NO_x 8-20% less than CEMS measurements

Evaluation of a global and a regional inventory



DACCIWA: Africa (regional) inventory
CEDS: global inventory

Global inventory slope of unity, but missing sources (Hwange and combined Matimba and Medupi)

Regional inventory on average ~50% more than top-down estimates and almost 6-times more for Lagos

Inventories are bedrock of policy decisions, so discrepancies should instigate research to resolve these

Summary

Large disparities between top-down and bottom-up emissions

Inventories collocate NH_3 and NO_x open fire emissions, but are separate in the top-down estimates

Hybrid inventory could be viable way forward: FINN for smouldering; GFAS or GFED for flaming

Top-down emissions support burning season O_3 production of 25 Tg from southern Africa fires

Annual hotspot NO_x emissions obtained for a record-breaking 24 hotspots (21 urban, 3 power plants) totalling 207.3 kt NO

Urban NO_x range: < 2 mol s^{-1} (Antananarivo, Madagascar) to ~28 mol s^{-1} (Lagos, Nigeria)

Coal-fired power plant emissions are 2.7 ± 0.9 mol s^{-1} for Hwange in Zimbabwe and similar (~70 mol s^{-1}) for Lethabo and combined plumes of Medupi and Matimba in South Africa

Quasi-validation of the top-down estimates support their use in identifying opportunities for improving global and regional inventories

Links to Papers, Datasets, and Other Resources

Open fire nitrogen emissions:

Paper: https://pubs.rsc.org/en/content/articlelanding/2025/ea/d5ea00041f

Data: https://doi.org/10.5522/04/28712444

Point source NO_x emissions paper:

Paper: https://doi.org/10.1029/2025JD045870

Data: https://doi.org/10.5522/04/30530147

Launch and Re-entry emissions:

Launch and re-entry emissions tracker: https://orbitalemissions.org/

ARIA funded project: https://maraisresearchgroup.co.uk/rocket_emis.html