Use of Satellites for Health and Environmental Justice

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ISSI Workshop

21 March 2023

Use of Satellites for Health and Environmental Justice
... and Vertical Profiles and a UK Validation Site

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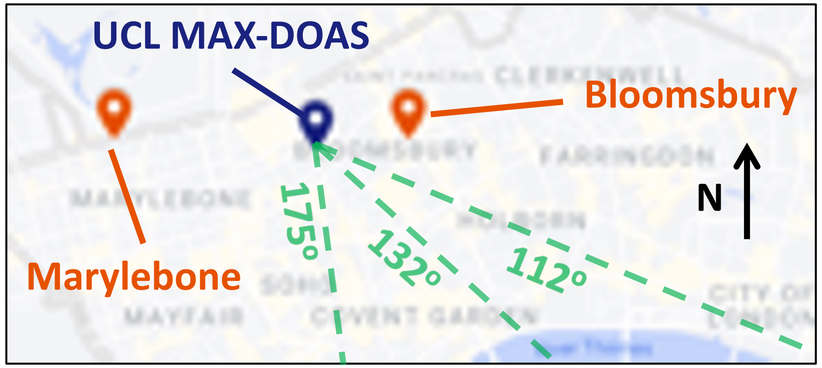
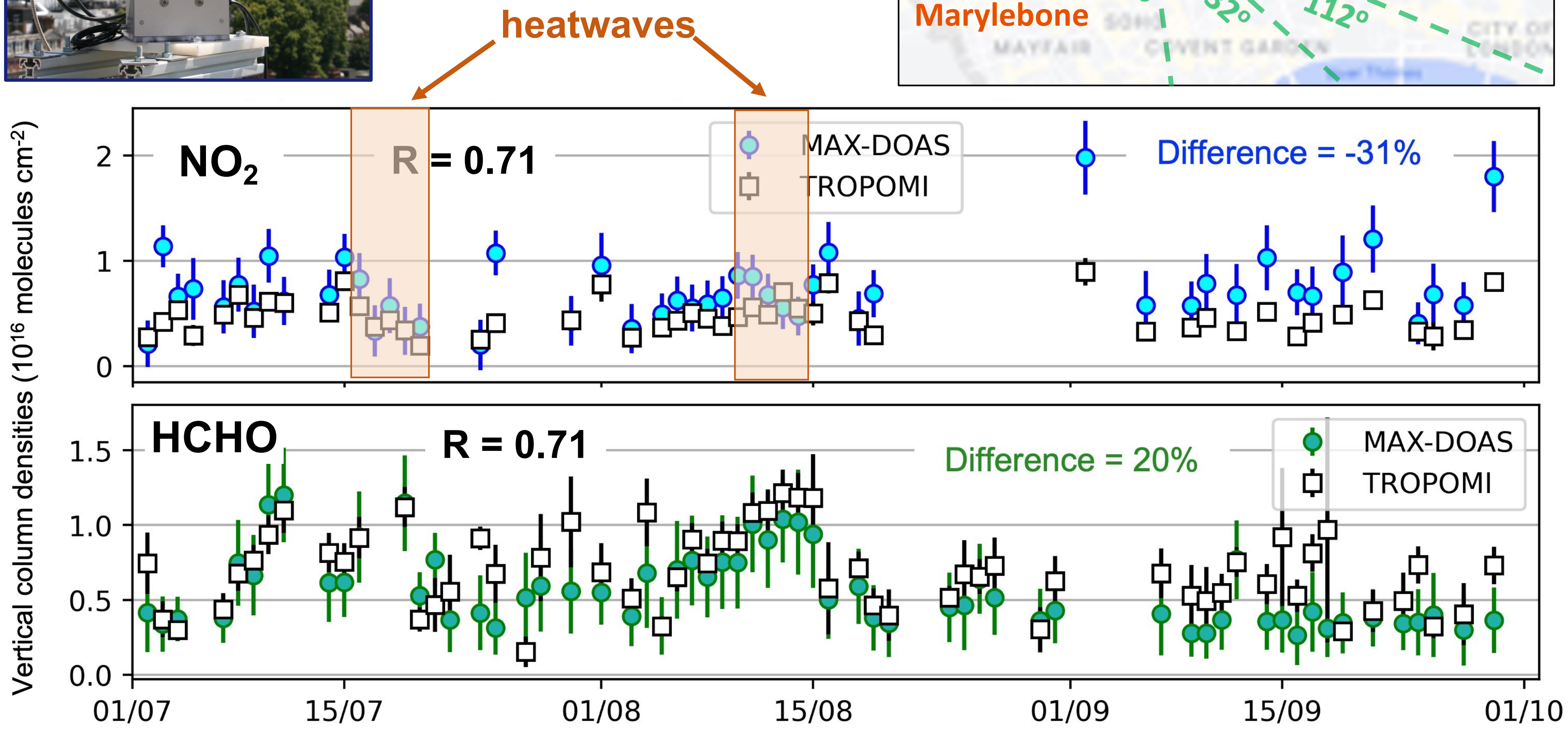
Satellite Instrument Validation Point in Central London



Capital Equipment Fund



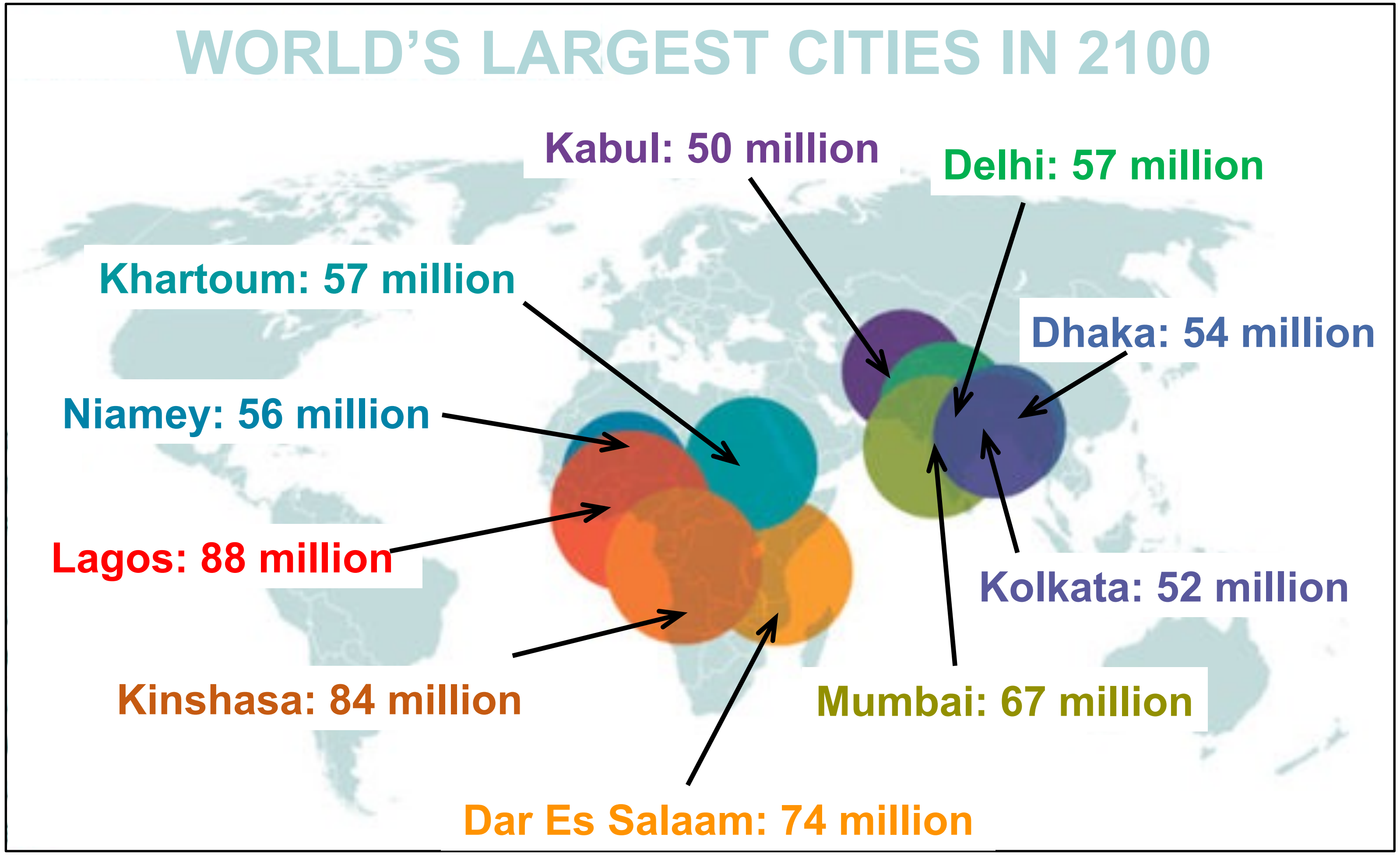
TROPOMI 31% less than MAX-DOAS

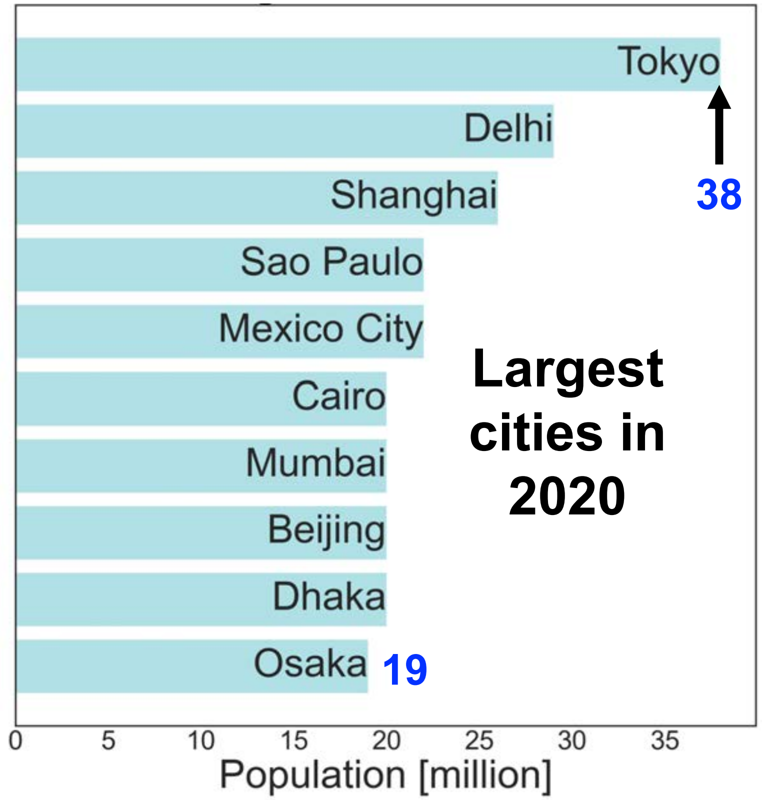
TROPOMI 20% more than MAX-DOAS

[Ryan et al., ACP, in review]

Only UK UV/visible validation point operational since July 2022

Air Pollution in Fast-growing Tropical Megacities





Adapted image: https://medium.com/ensia/here-come-the-megacities-1b0f8a2287f2

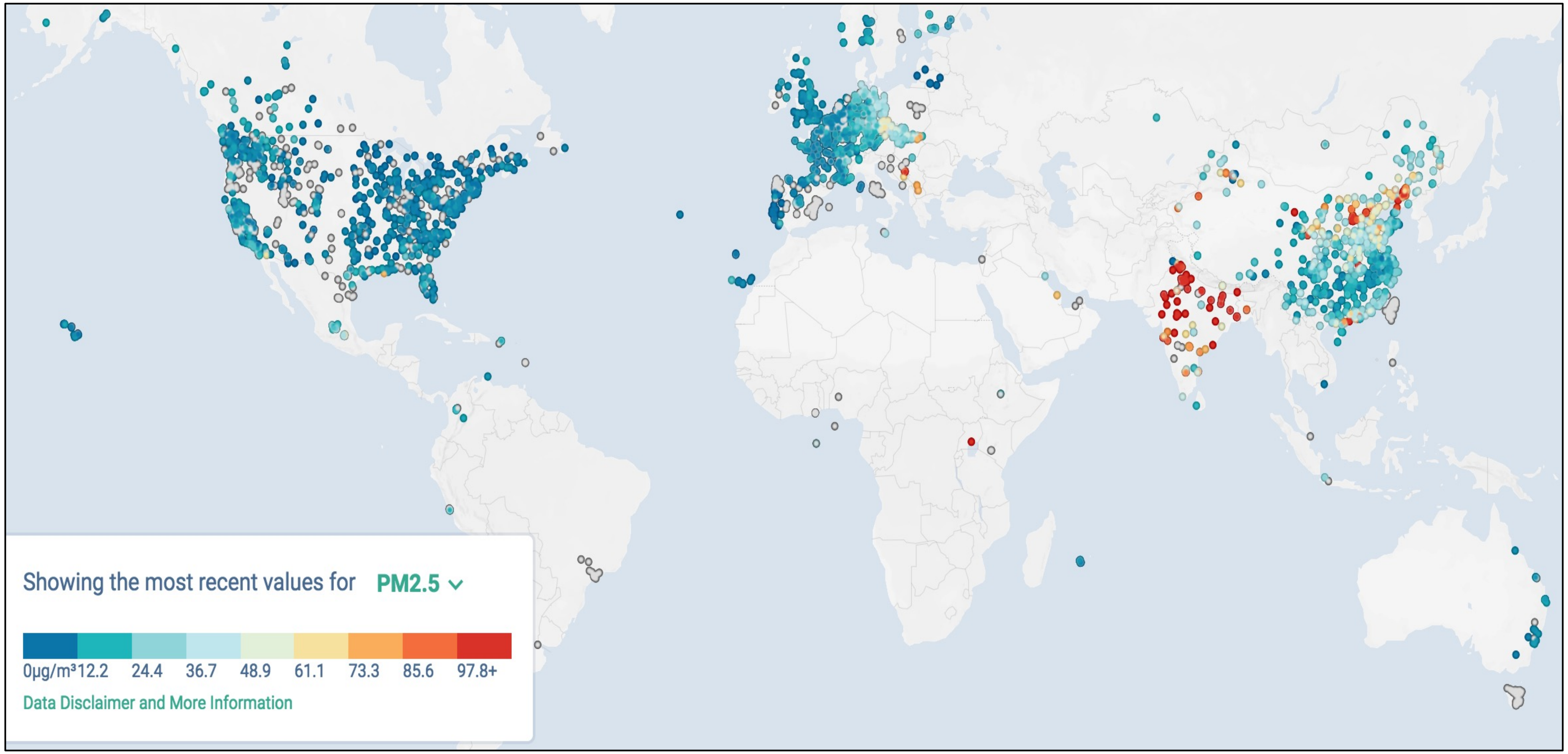
Projections: https://journals.sagepub.com/doi/full/10.1177/0956247816663557

The largest cities the world has ever seen will be in the tropics

An Unjust Monitoring Network

Surface Measurements Progressed from <u>Severely Limited</u>

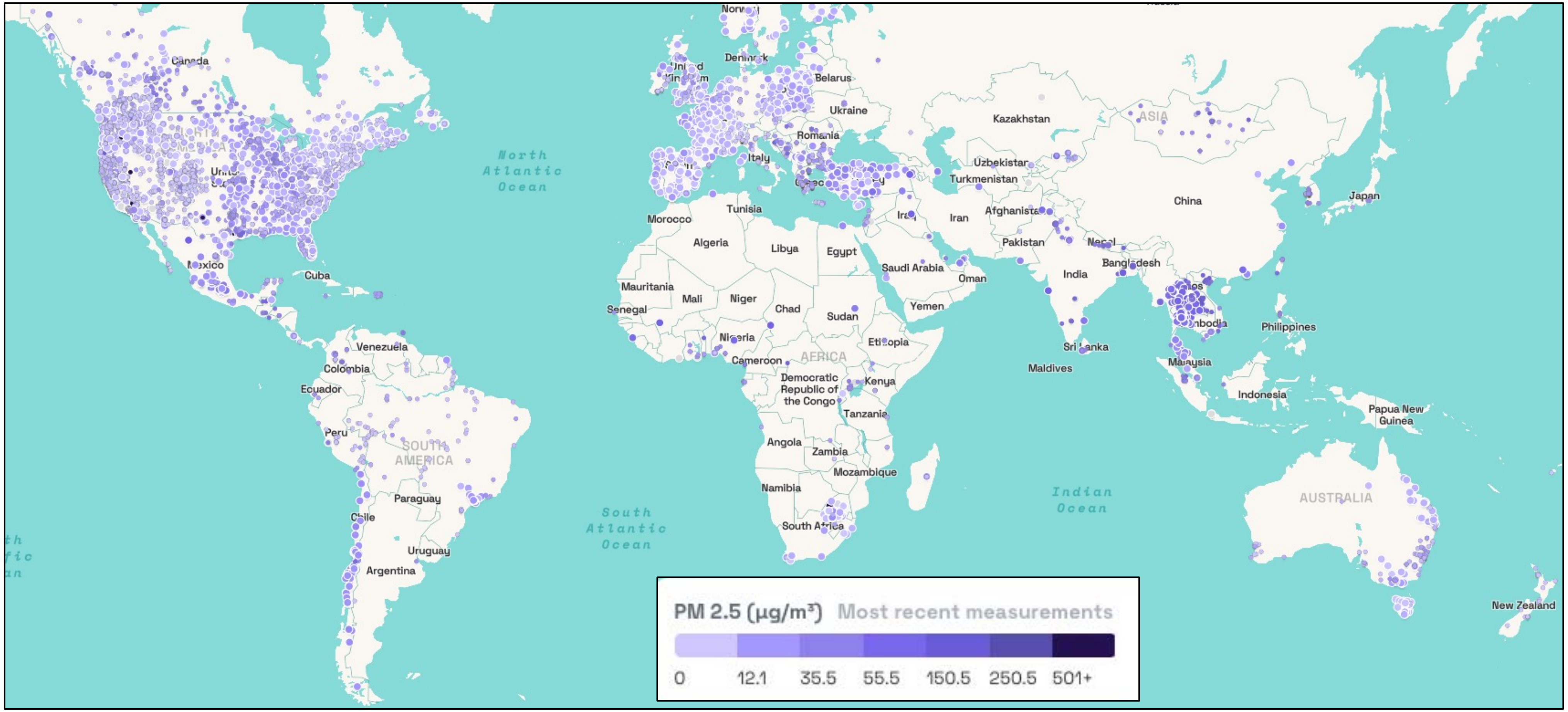
Snapshot in 2018



[OpenAQ, Accessed 7 November 2018]

To <u>Limited</u> Coverage Today

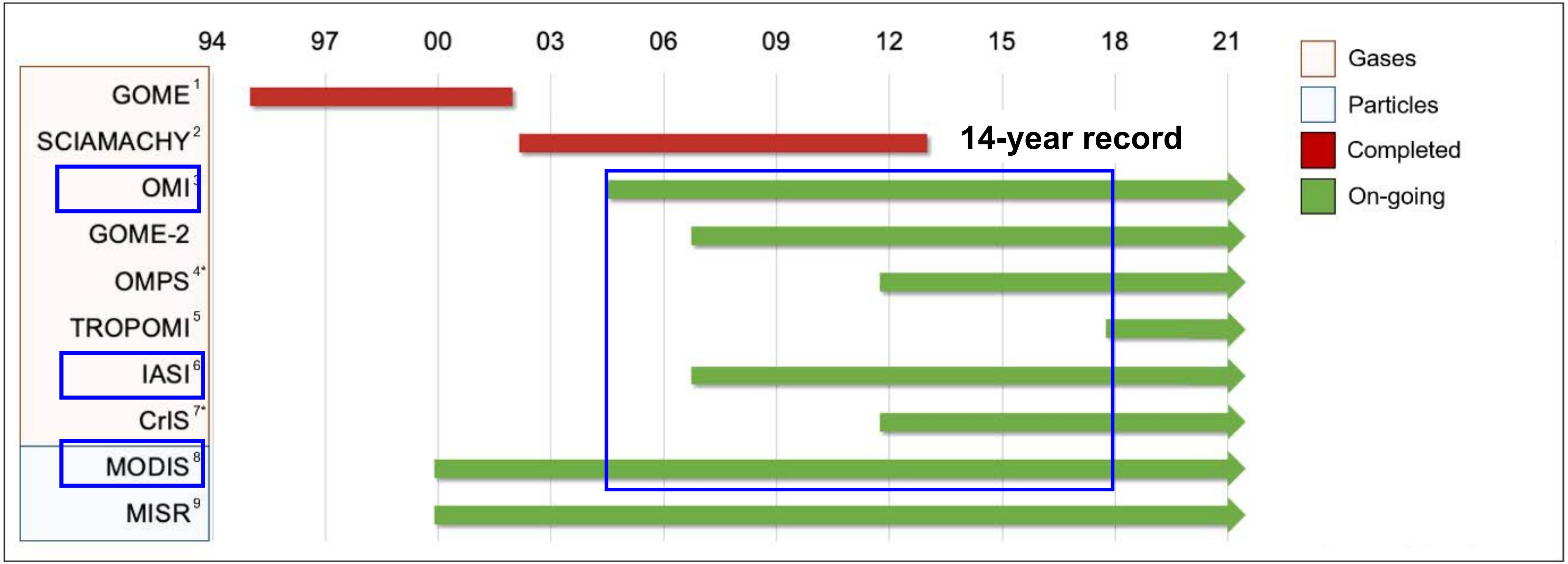
Snapshot in 2023



[OpenAQ, Accessed 15 March 2023]

Increasing data coverage in the tropics due to low-cost sensor technology and data processing revolution and perhaps a shift in data access/sharing culture

Satellite in LEO Offer Daily Global Coverage



OMI NO_2: component of NO_x

OMI HCHO: ubiquitous oxidation product of VOCs

IASI NH_3: agriculture, fires, waste burning and precursor of $PM_{2.5}$

MODIS AOD: proxy for surface $PM_{2.5}$

Combine multiple pollutants to better interpret drivers of air quality degradation

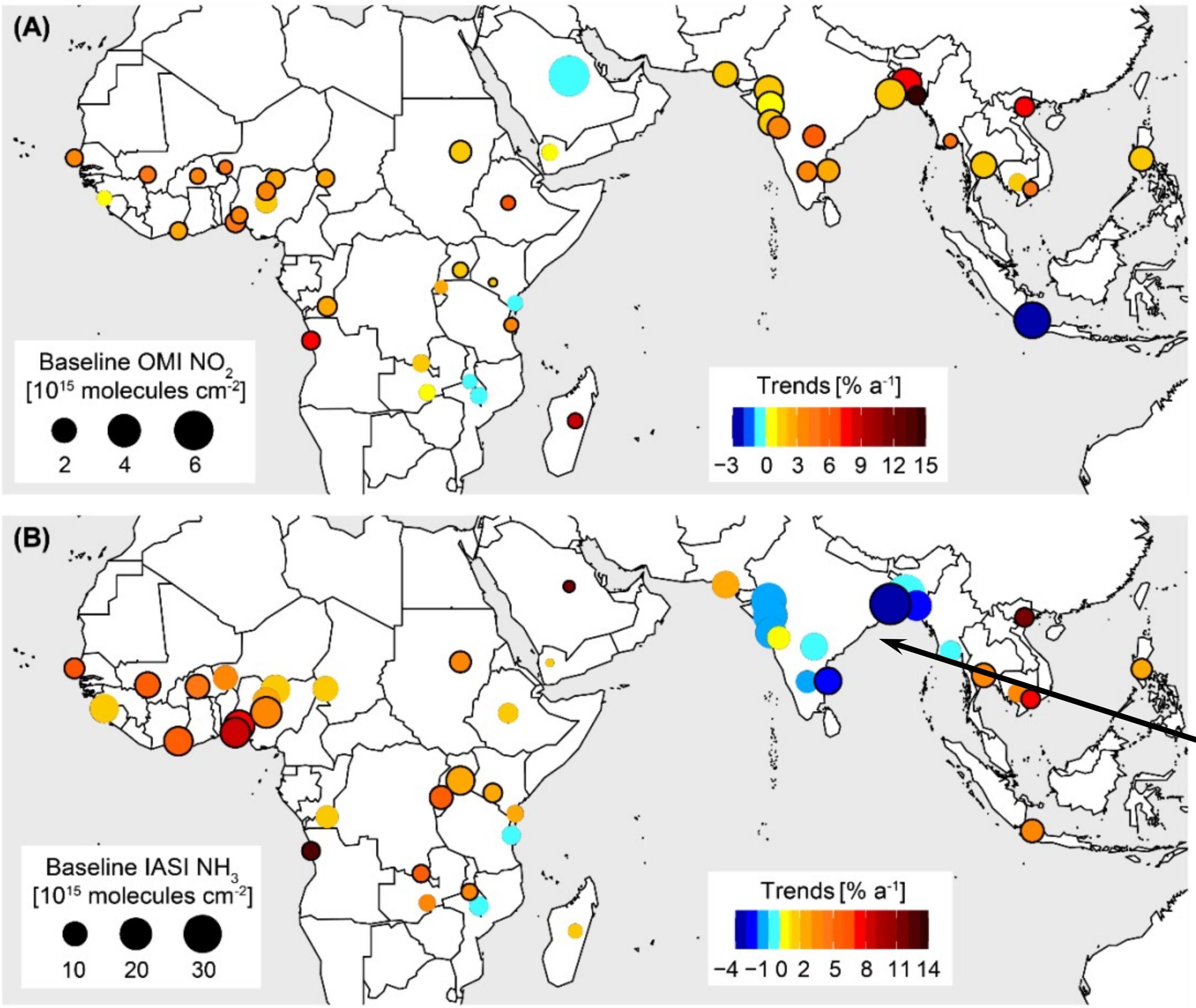
Steep Annual Increases in NO_x and NH_3

NO_2 trends (proxy for **NO_x**) [2005-2018]

OMI: Ozone Monitoring Instrument

NH_3 trends (depends on acidic aerosol abundance) [2008-2018]

IASI: Infrared atmospheric sounding interferometer



Circle Features:

Size: start of record

Color: trend

Outline: significant

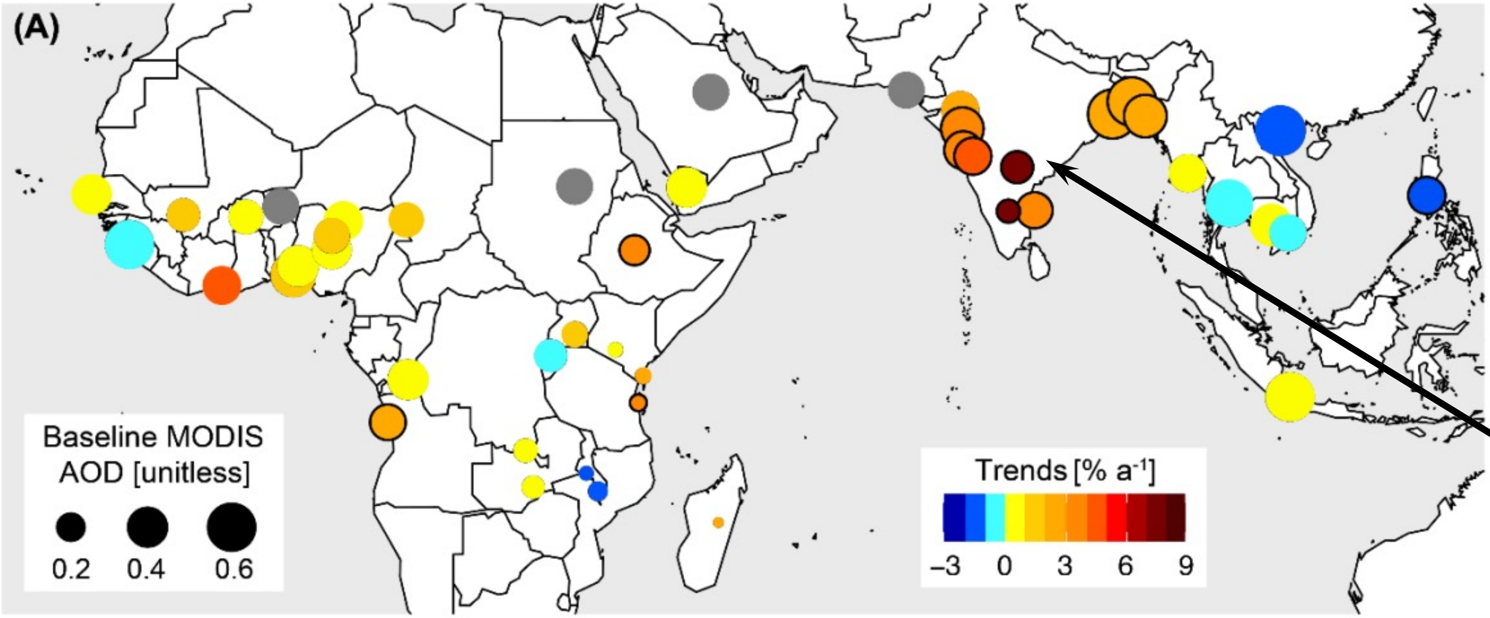
Decline over Indian subcontinent due to increase in uptake to acidic aerosols

NH_3 data from M. Van Damme, L. Clarisse, P.-F. Coheur at ULB

Annual Changes in $PM_{2.5}$ and Ozone Production Regime

AOD trends
(proxy for **$PM_{2.5}$**)
[2005-2018]

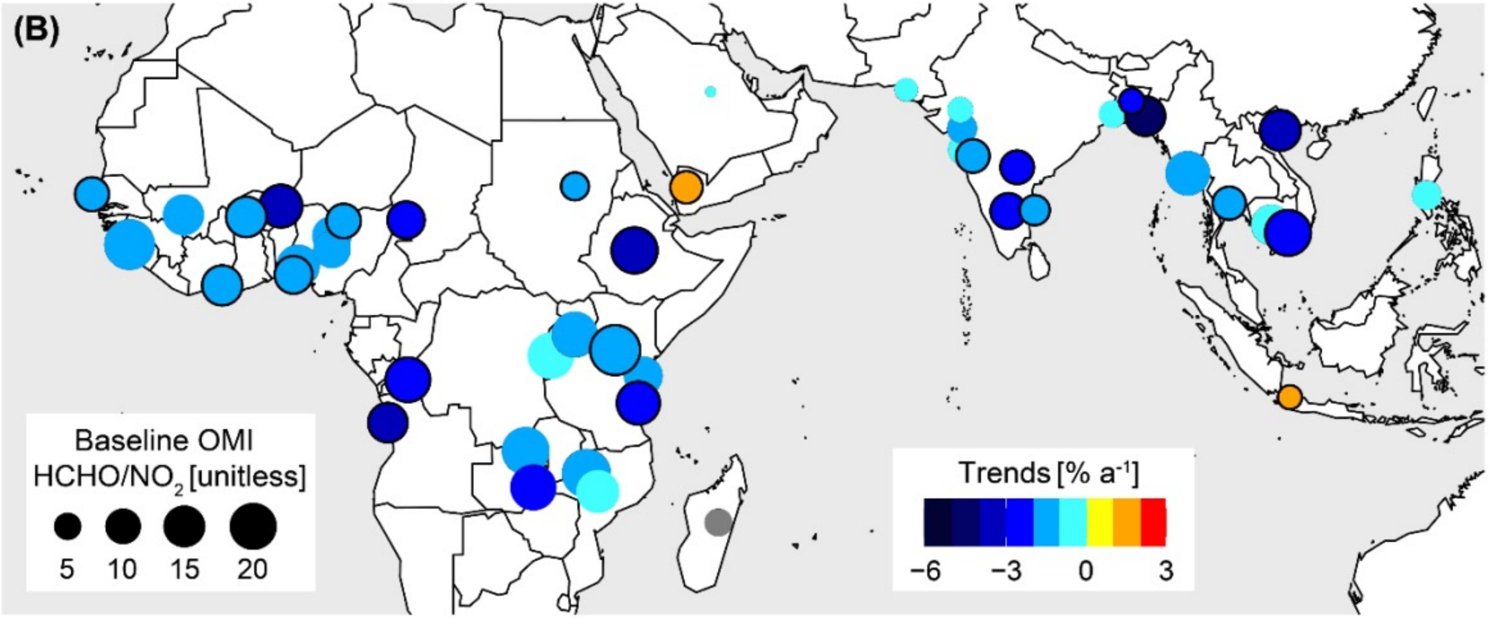
MODIS: Moderate resolution imaging spectroradiometer



Circle Features:
Size: start of record
Color: trend
Outline: significant

Increases in $PM_{2.5}$ precursors SO_2, NH_3, NO_x

$HCHO/NO_2$ trends
(proxy for ozone production regime)
[2005-2018]

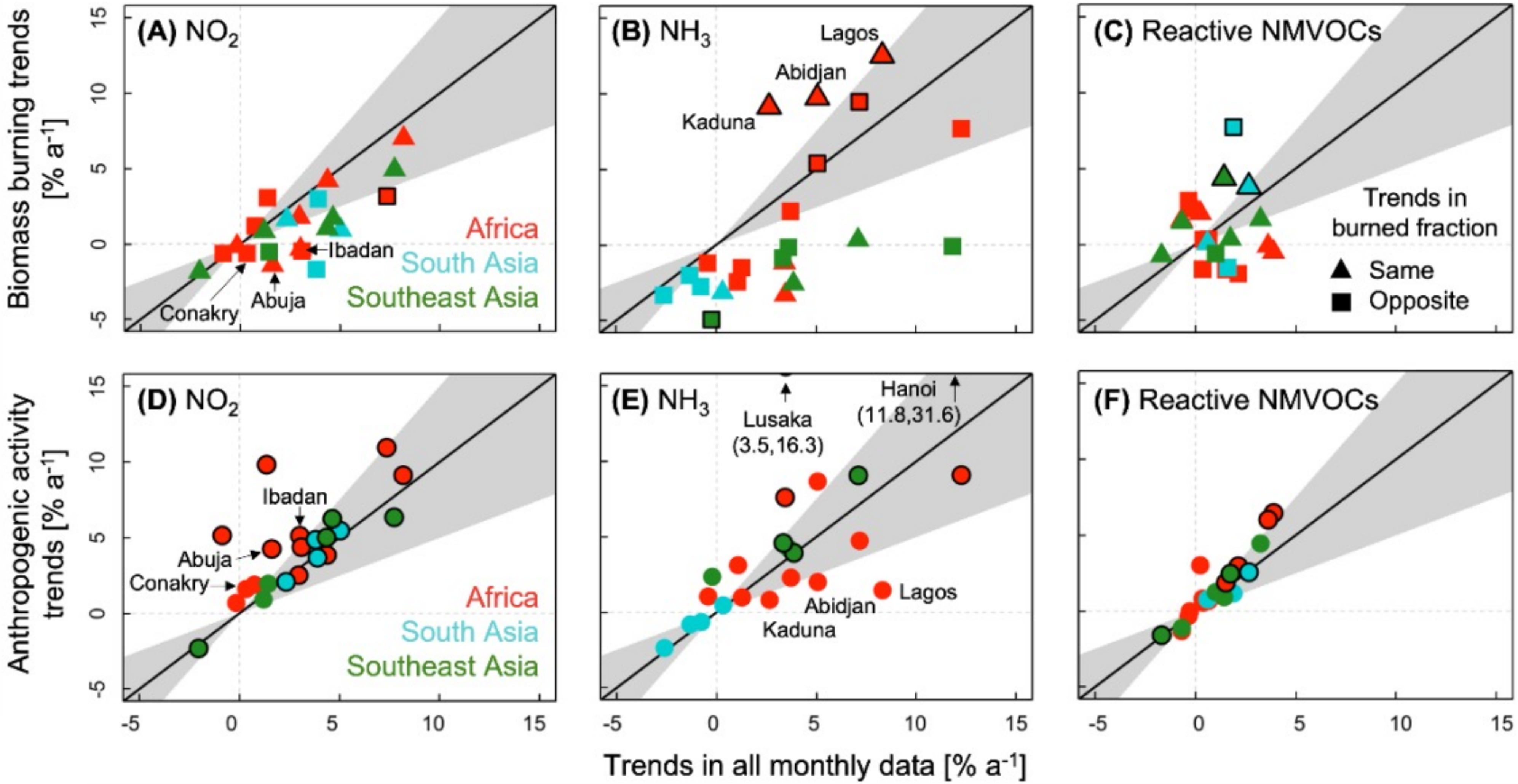


Ratio > 5:
O_3 production sensitive to NO_x

Transitioning to NO_x saturated or VOC sensitive

What's Driving the Observed Trends?

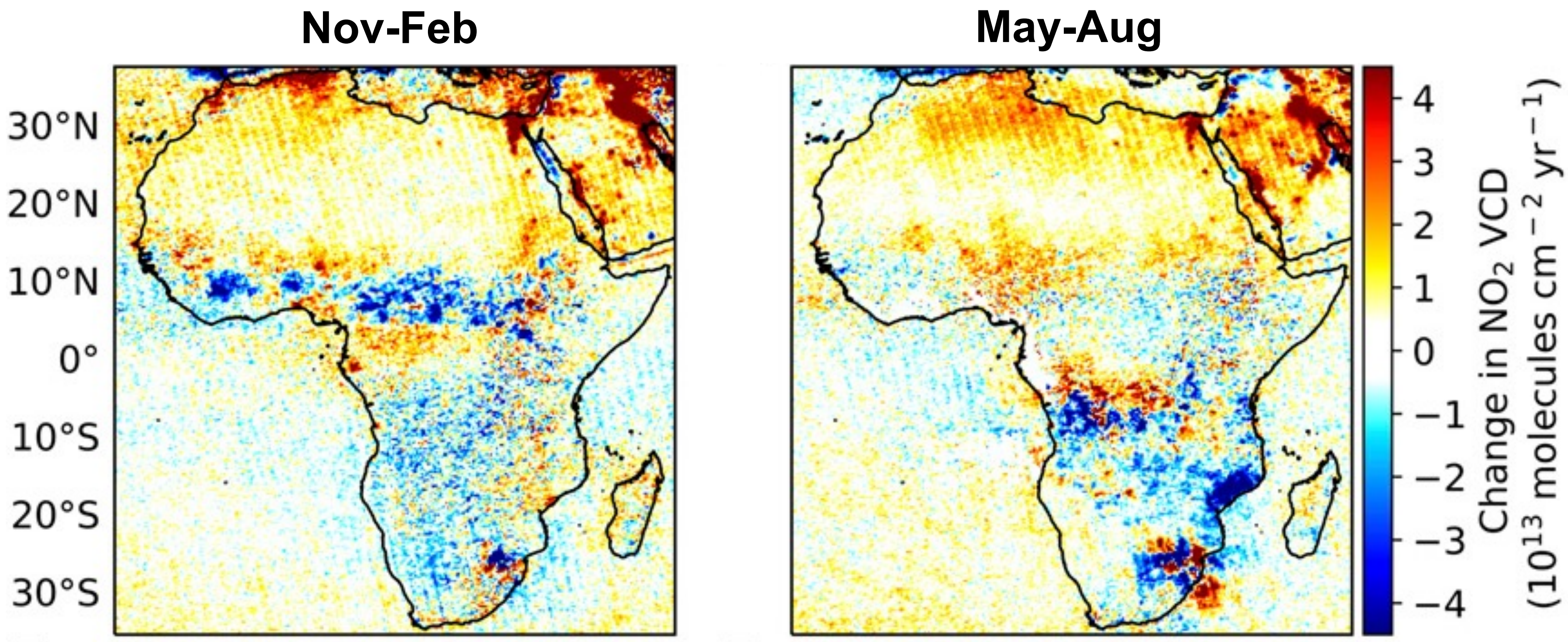
We use a statistical approach and knowledge of seasonality of emissions to assess the relative role of anthropogenic and biomass burning emission



Consistency in trends for anthropogenic influenced months and all data months supports anthropogenic emissions as air pollution trend drivers with some offsetting from decline in agricultural activity

City Drivers and Trends Differ from Regional/National Scale

Well known decline in biomass burning activity in Africa causing regional decline in NO_2



OMI NO_2 trends for 2005 to 2017

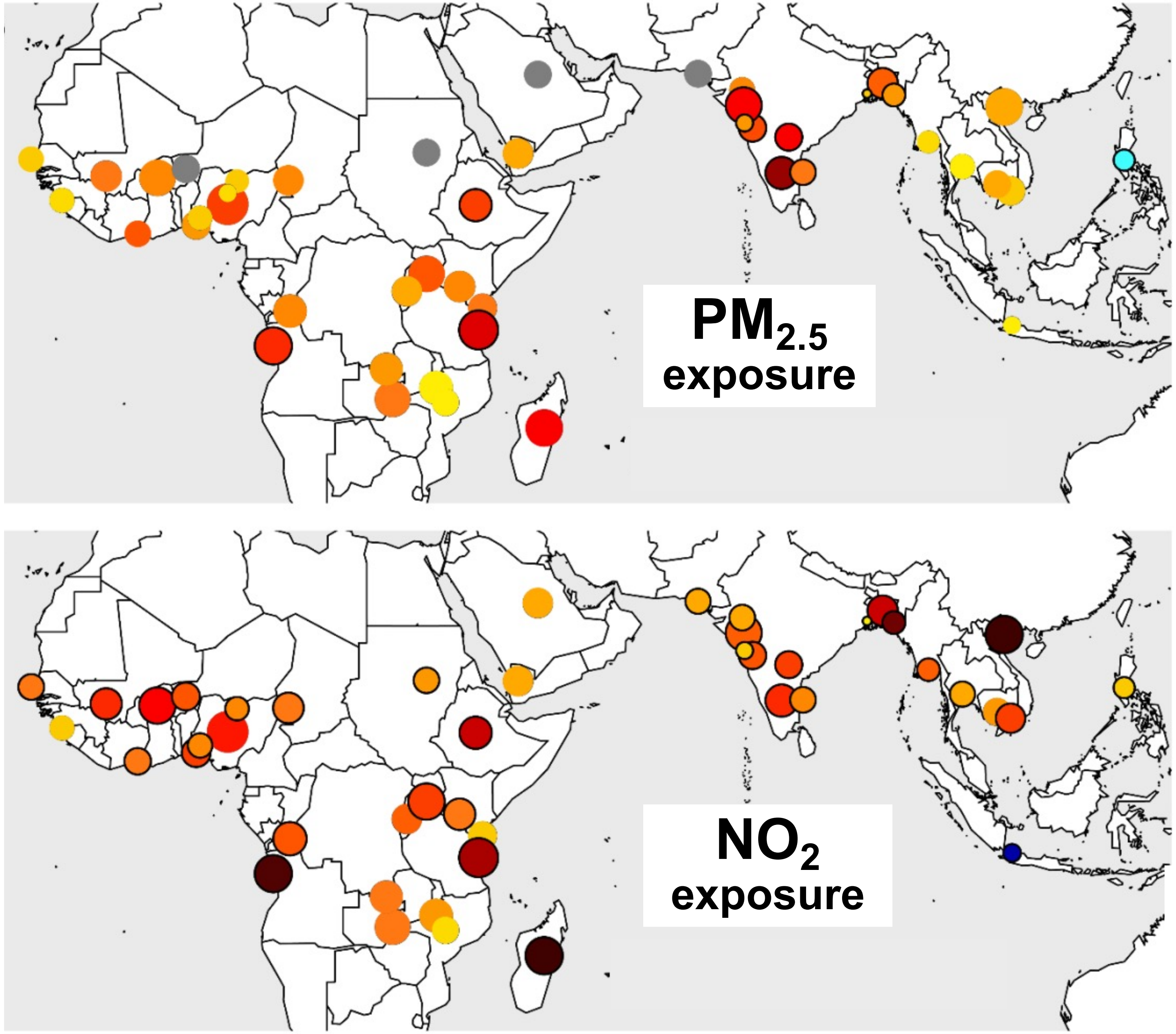
[Hickman et al., PNAS, 2021]

Led to conclusion that socioeconomic development in Africa is not associated with air quality degradation

Not the case if targeted sampling of city

Instead, tropical cities on track to follow the same trajectory as past fast-growing cities

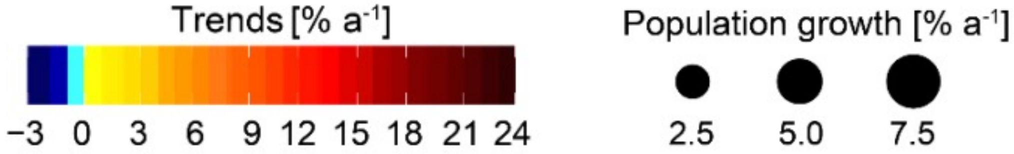
Increase in urban population exposure to air pollution



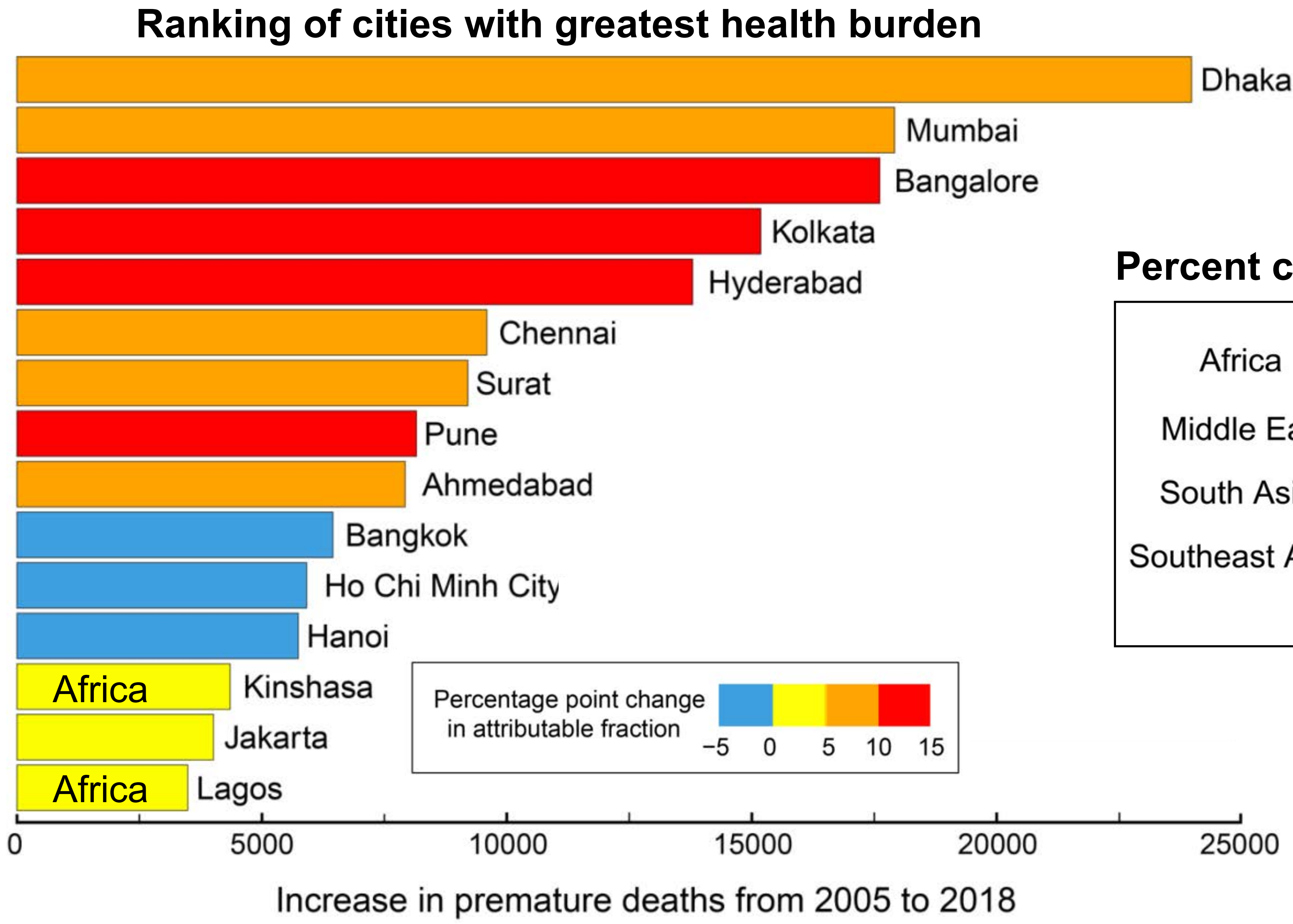
Unprecedented increase in exposure
due to rapid air quality degradation, increase in population and urbanization

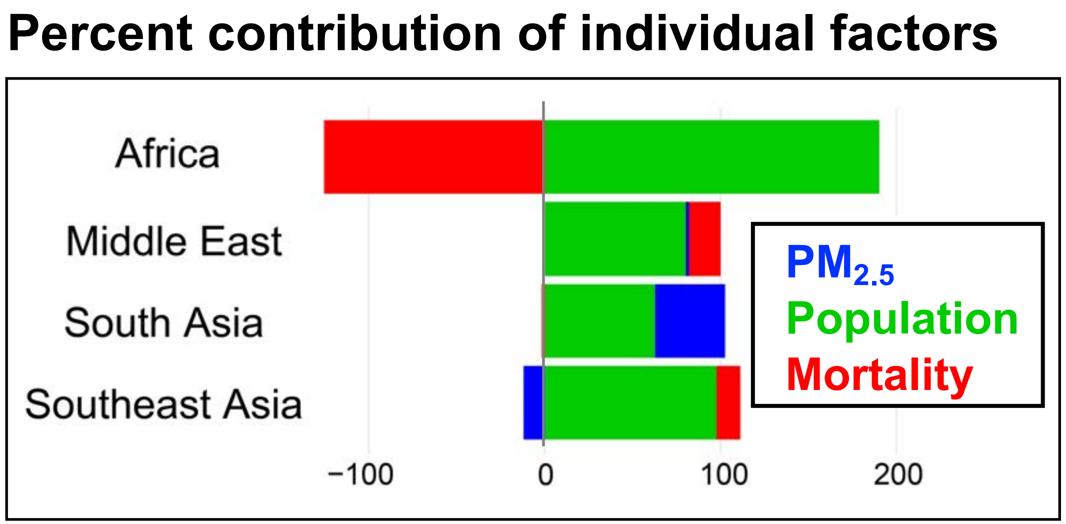
Up to **18 % a^{-1}** increase in $PM_{2.5}$ in India

Up to **23% a^{-1}** increase in NO_2 in many cities



Premature Mortality Attributable to Rise in $PM_{2.5}$ Exposure



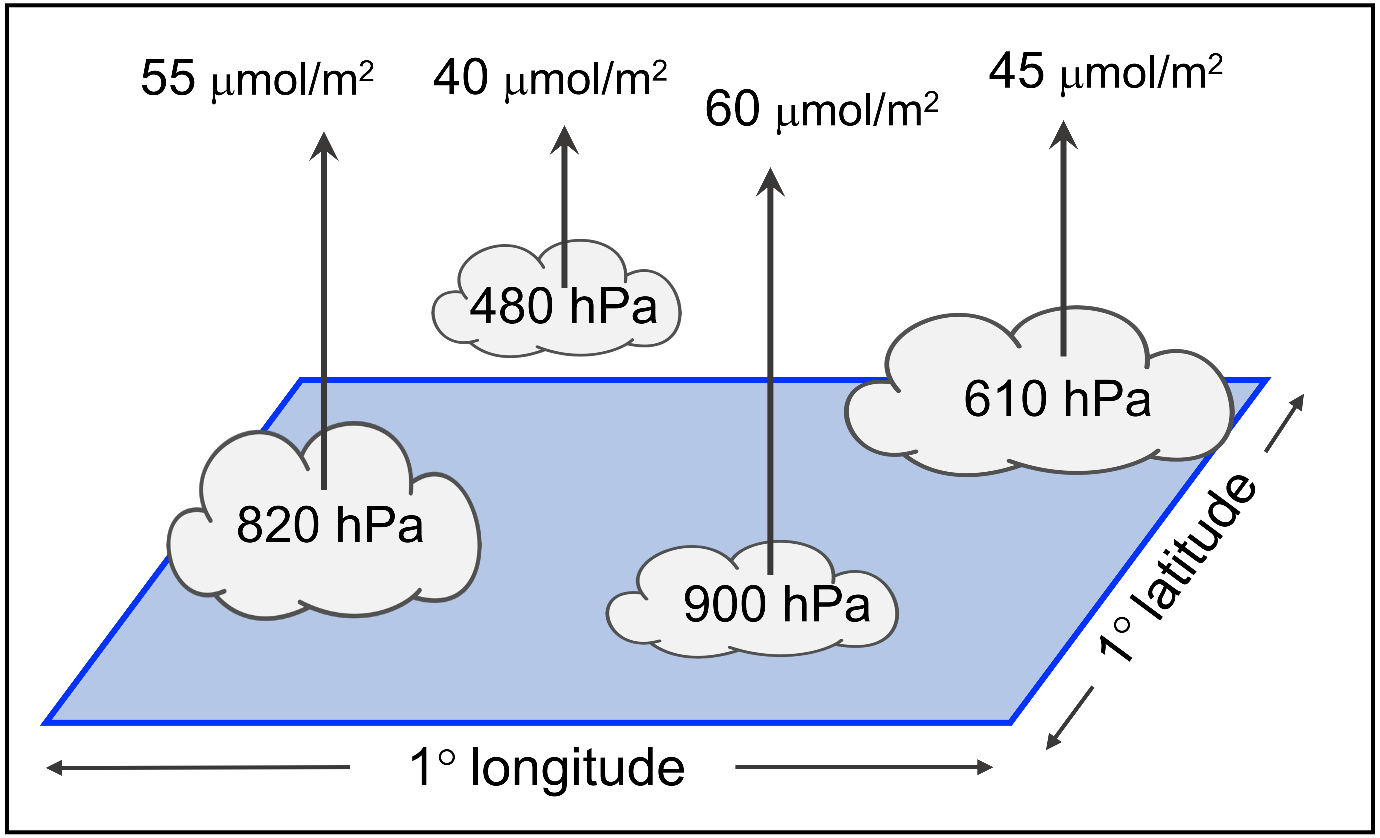


Total: 179,550
[95% CI: -227,131 to 586,231]

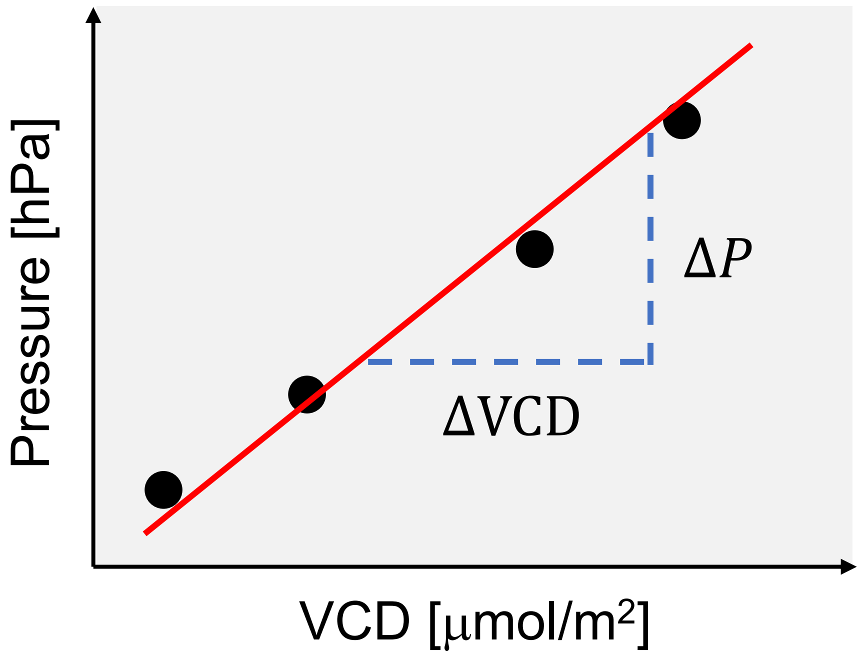
Highest ranked are almost all in Asia. Worst effects in Africa buffered by improvements in healthcare.

Slicing the Atmosphere with Clouds to Map NO_2 Profiles

Clusters of partial columns above optically thick clouds:



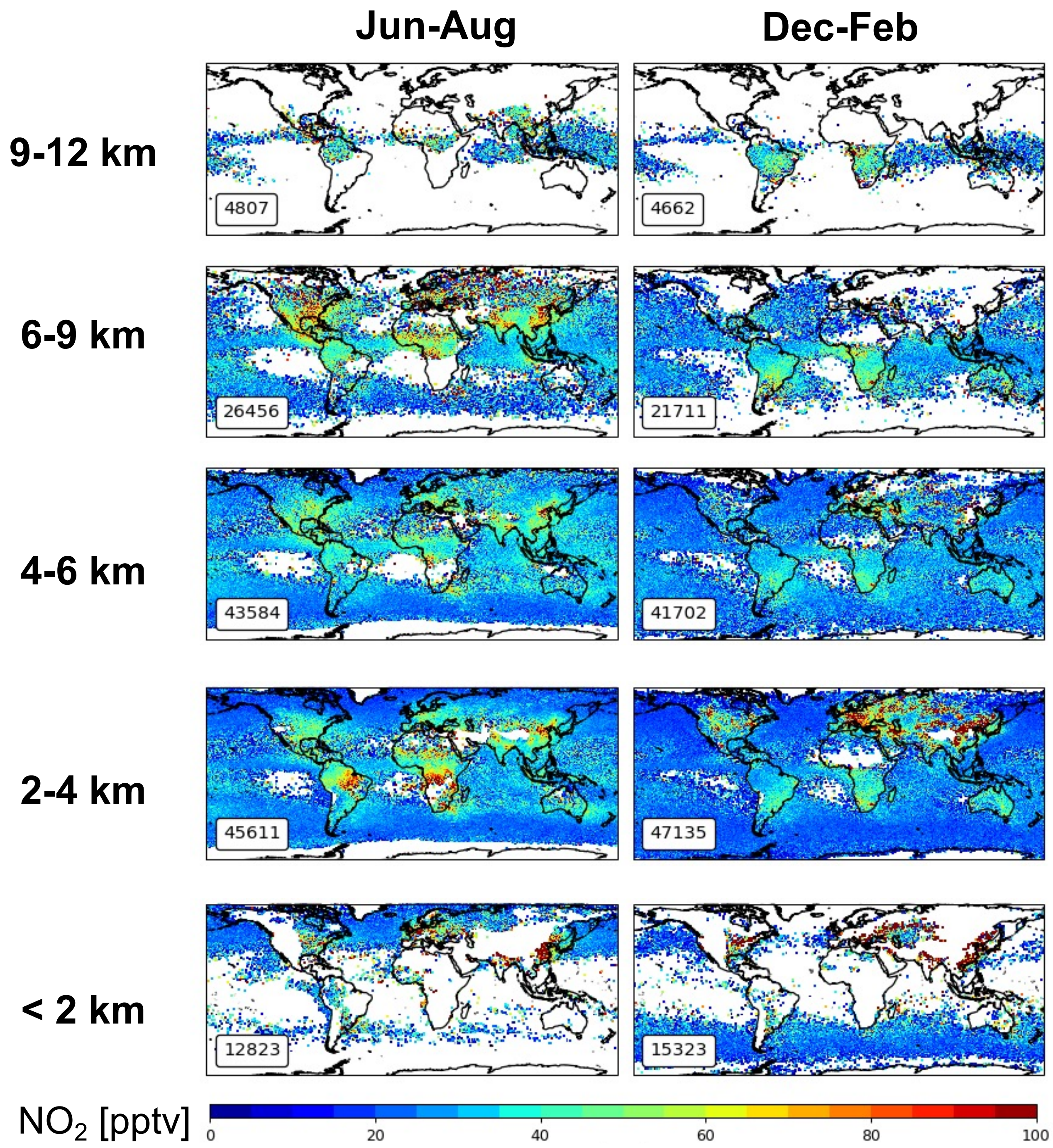
Regress cloud top pressures against partial vertical column densities (VCDs):

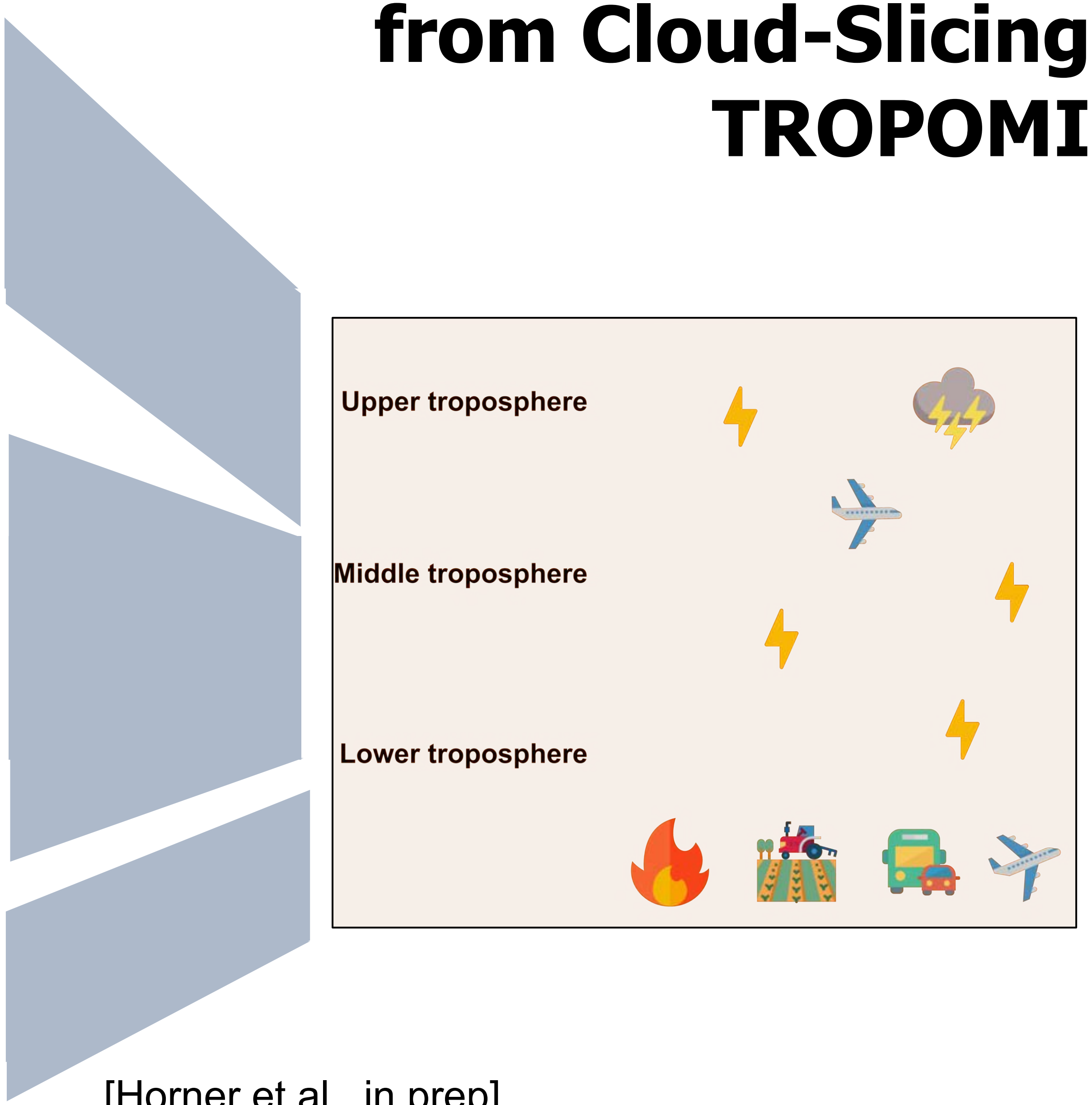


Calculate average mixing ratio between target pressure ranges:

$$\mathrm{NO_2\ VMR} = \frac{\Delta \mathrm{VCD}}{\Delta P} \times \mathrm{const}$$

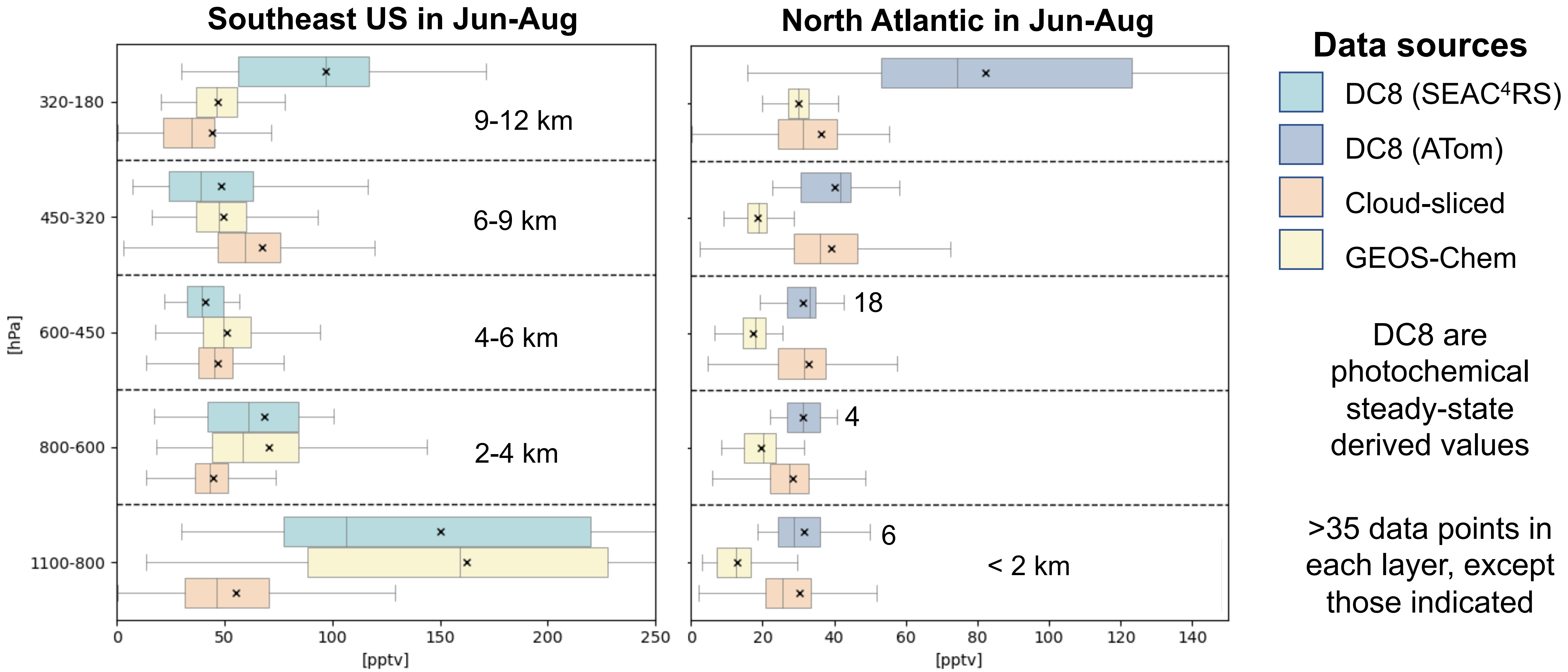
NO_2 Vertical Profiles from Cloud-Slicing TROPOMI





[Horner et al., in prep]

Comparison to NASA DC8 Campaign Observations



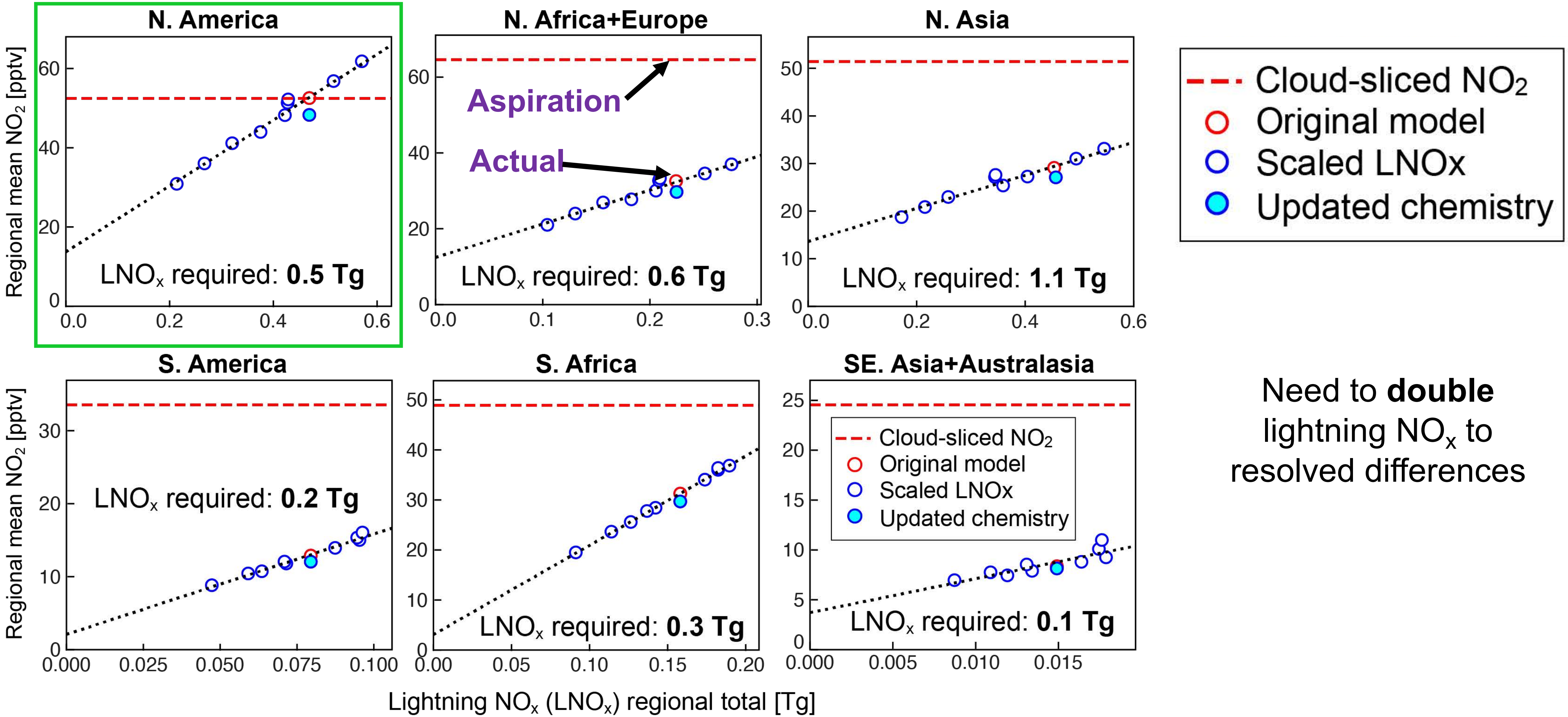
DC8 are photochemical steady-state derived values

>35 data points in each layer, except those indicated

Encouraging agreement in middle troposphere and marine boundary layer

Sensitivity to Lightning NO_x over Land

Observed versus modelled June-August upper tropospheric regional mean NO_2 **over land**

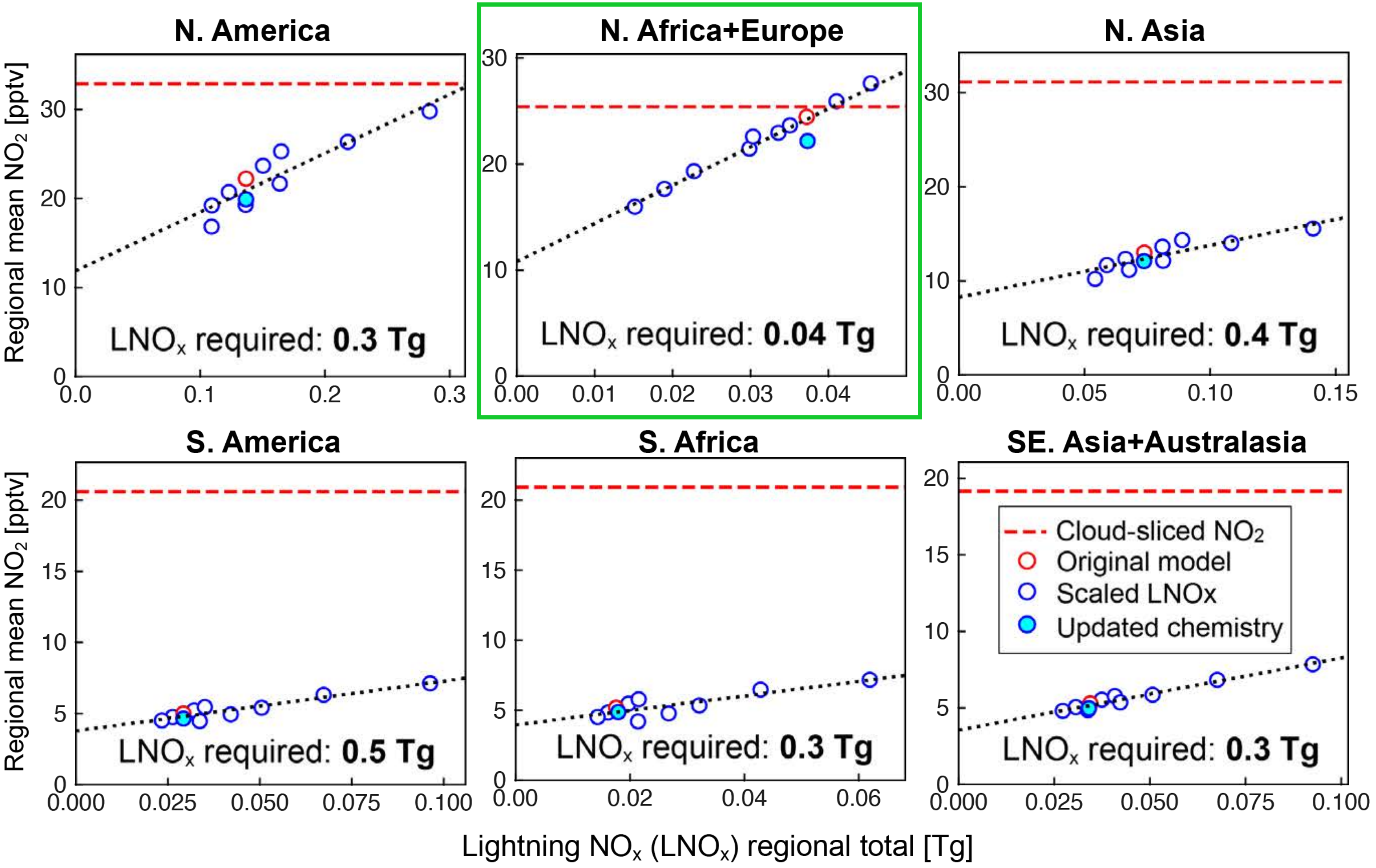


Need to **double** lightning NO_x to resolved differences

Original model emissions of **1.4 Tg NO**, whereas **2.7 Tg NO** required to match cloud-sliced NO_2

Sensitivity to lightning NO_x over the Ocean

Observed versus modelled June-August upper tropospheric regional mean NO_2 **over the ocean**



Need **6-fold** increase in lightning NO_x to resolved differences

Original model emissions of **0.3 Tg NO**, whereas **1.9 Tg NO** required to match cloud-sliced NO_2

Additional Gains Enabled by a GEO Instrument

***** Not an exhaustive list *****

Address an environmental injustice in air quality monitoring

Better match temporal variability of air pollution and exposure

Extend health risk assessment to short-term exposure to pollution episodes

Additional constraint of time component for enhanced source attribution

Greater data density for cloud slicing

Separating free troposphere from boundary layer using cloud-slicing may enhance diurnal variability information obtained from geostationary instruments

Greater data density and for oversampling to fine scales injustices in exposure

Temporal variability in the contribution of the mid troposphere to the tropospheric column