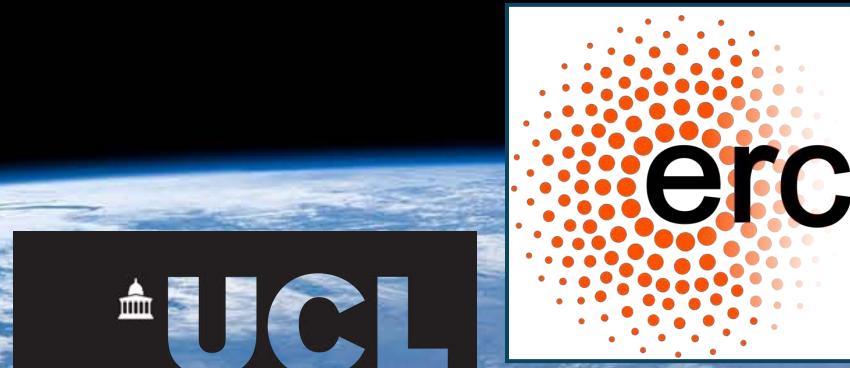


Cloud-slicing to obtain vertical profiles of tropospheric NO₂ and ozone: Challenges and opportunities with geostationary instruments



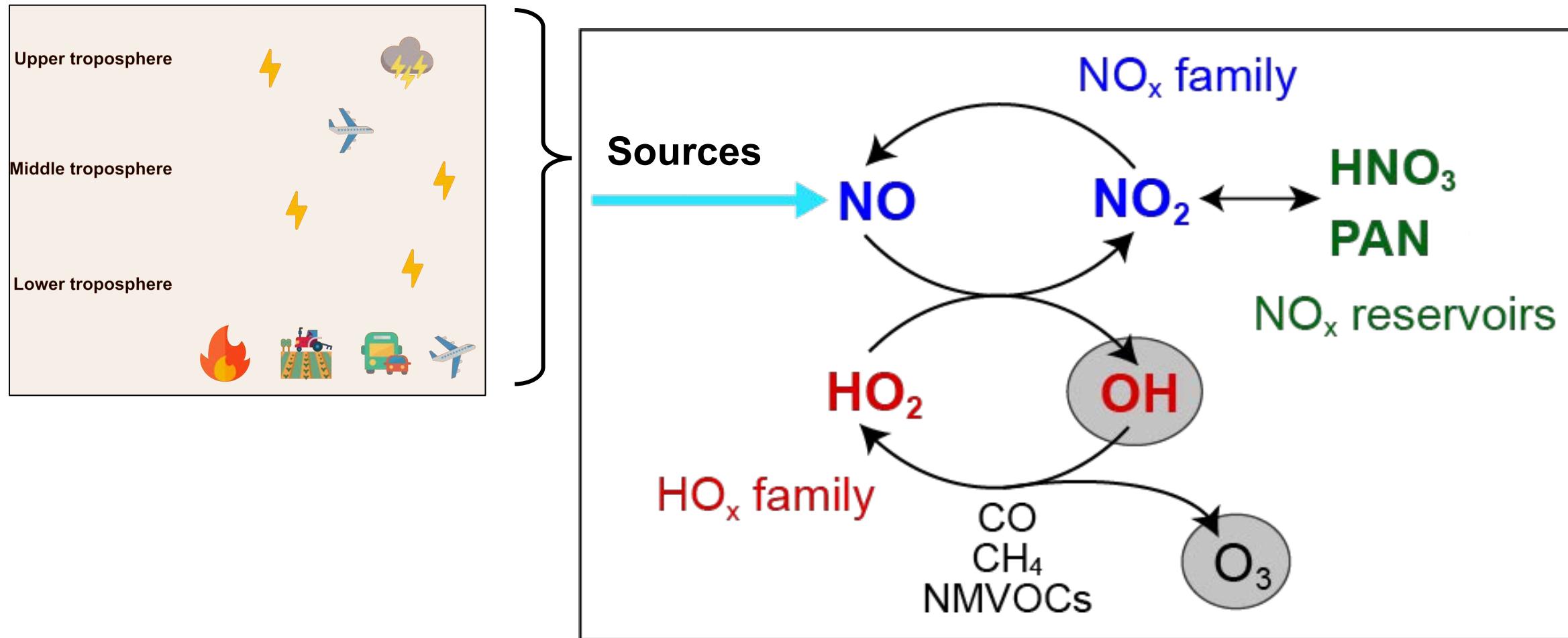
UCL Atmospheric Composition and Air Quality Group

<https://maraisresearchgroup.co.uk/>



Left to Right: Nana Wei (PhD), Eloise Marais (lead), Connor Barker (postdoc), Karn Vohra (postdoc), Eleanor Gershenson-Smith (PhD), **Bex Horner (PhD)**

Tropospheric nitrogen oxides ($\text{NO}_x \equiv \text{NO} + \text{NO}_2$)



Influences climate, air quality, food security, oxidative capacity of the troposphere

Limitations of current observing systems

TROPOMI tropospheric NO₂ [$\mu\text{mol m}^{-2}$]

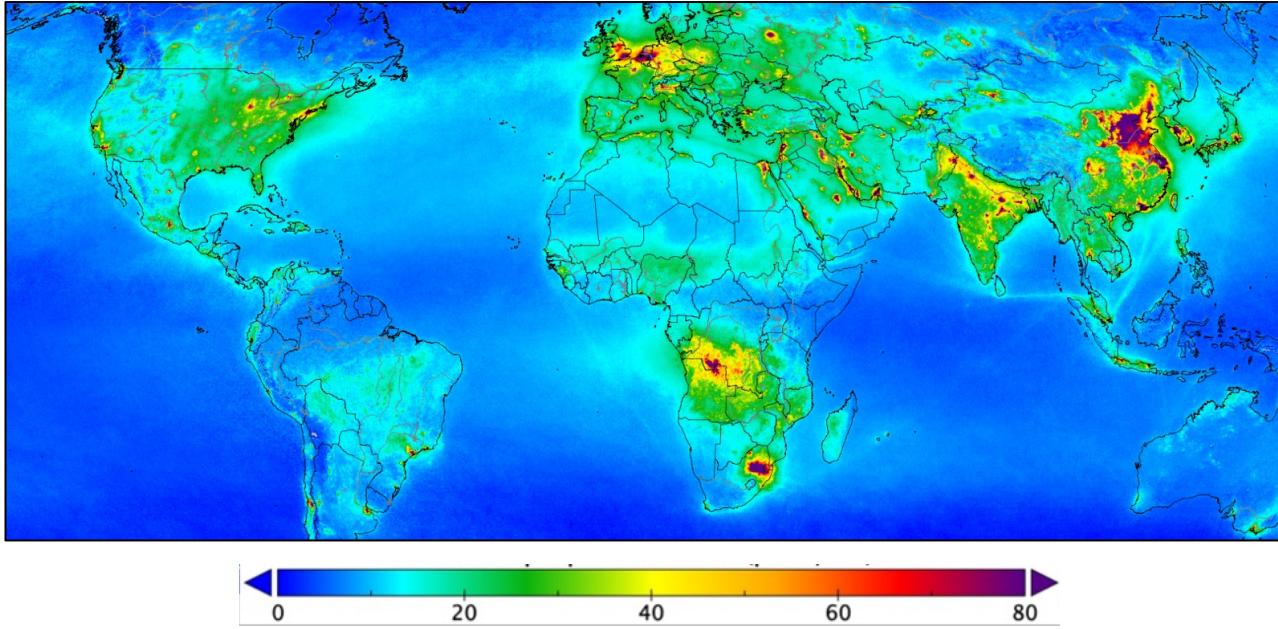
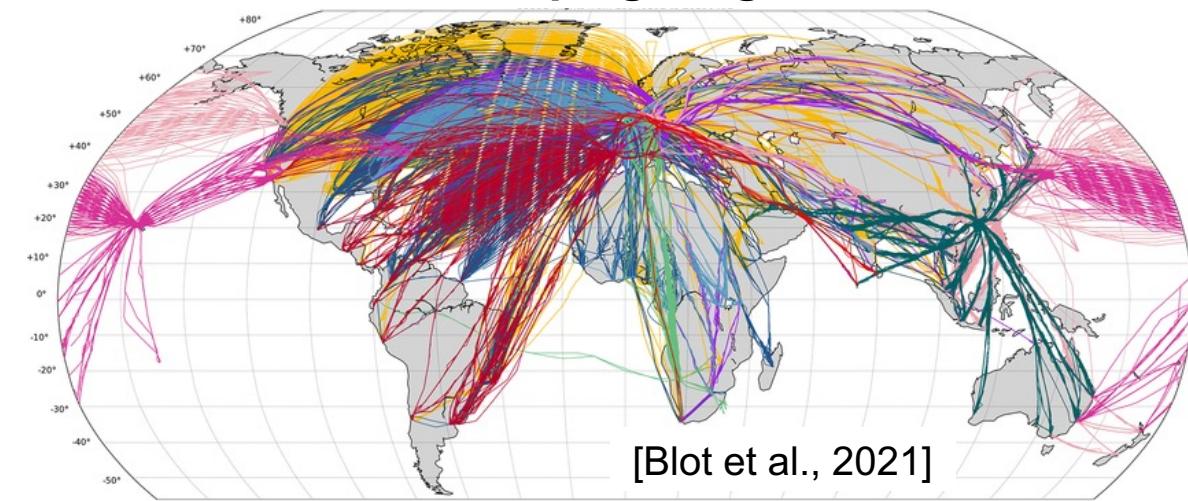


Image source: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Nitrogen_dioxide_pollution_mapped

Operational satellite data products offer one piece of vertical information

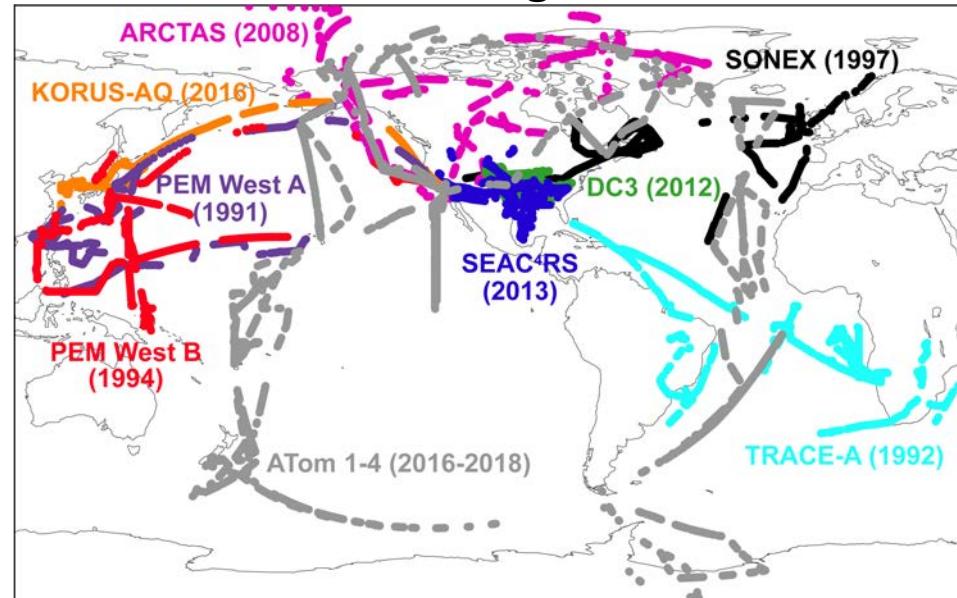
Aircraft observations intermittent and in situ instruments prone to interference from reservoir compounds

IGAGOS campaign flight tracks

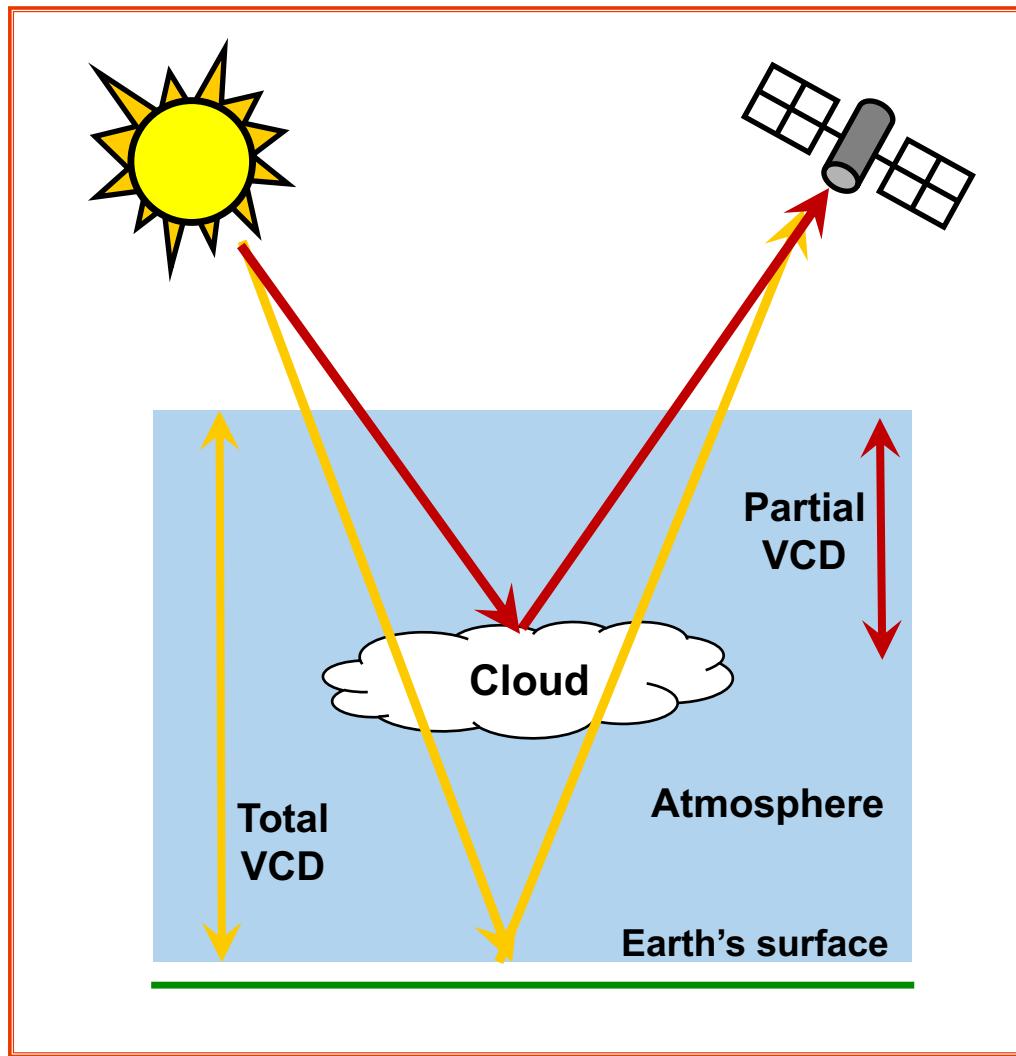


[Blot et al., 2021]

NASA DC8 flight tracks



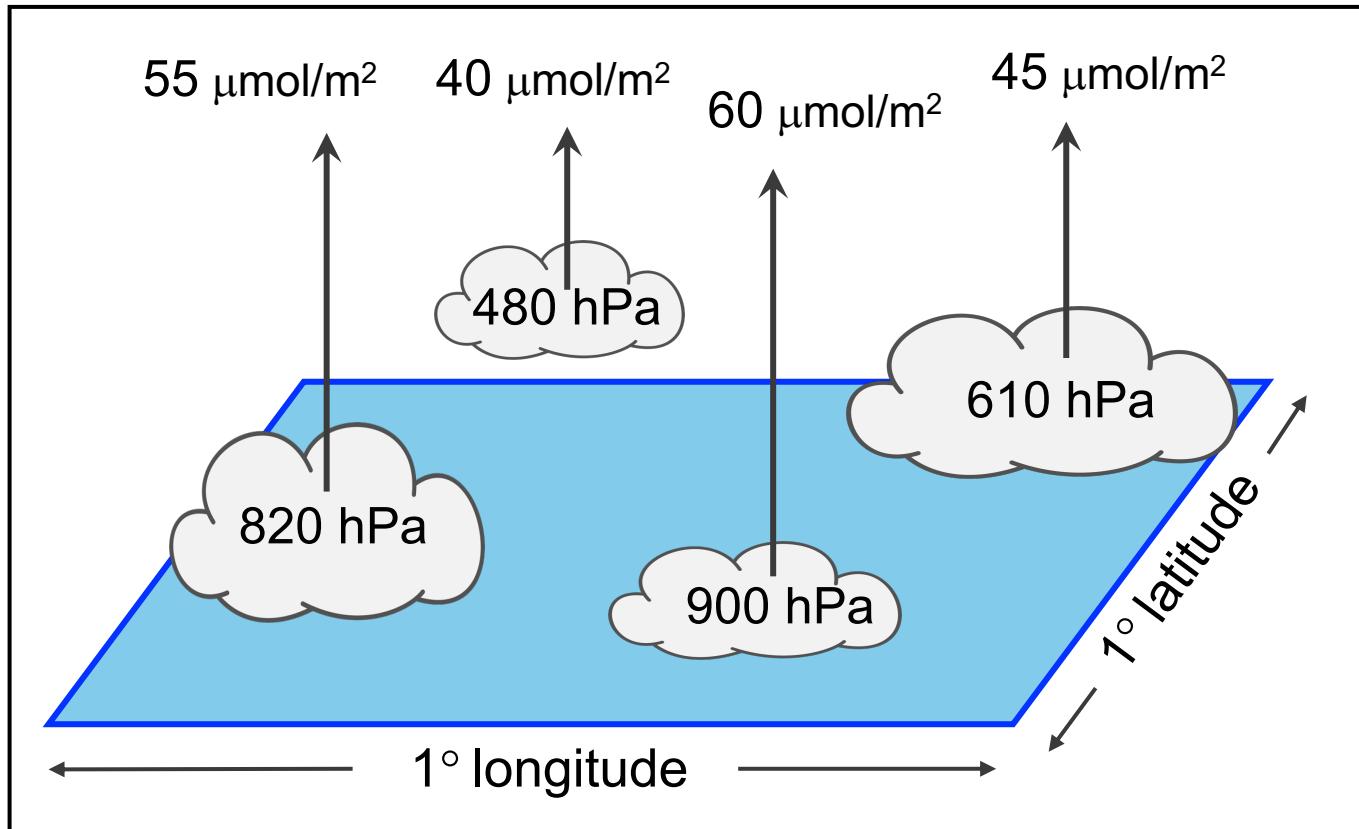
Optically thick clouds split up the troposphere



Retrieve partial columns above optically thick clouds (data typically discarded)

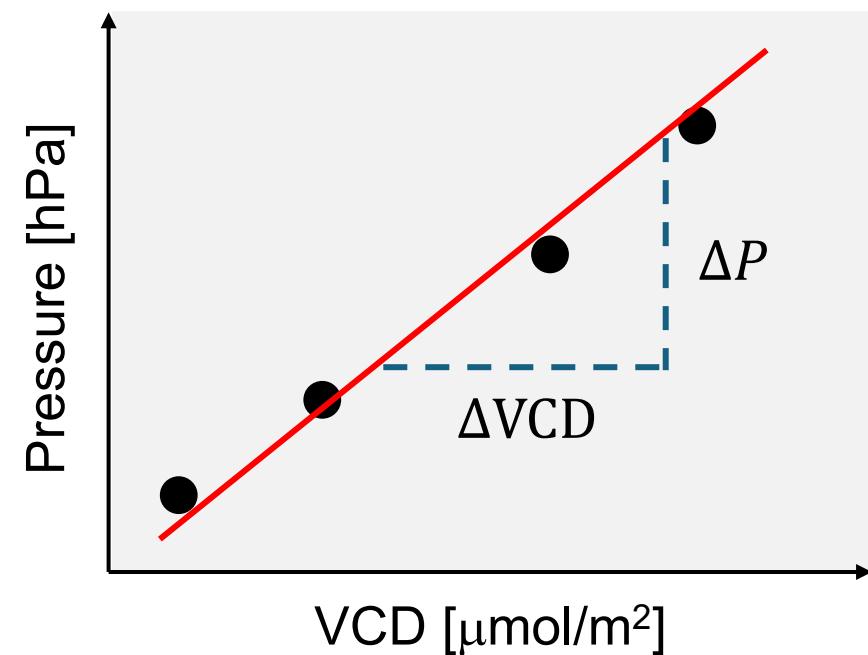
Convert partial columns to NO₂ mixing ratios: Cloud-slicing

Clusters of partial columns above optically thick clouds:



Calculate average mixing ratio between target pressure ranges:

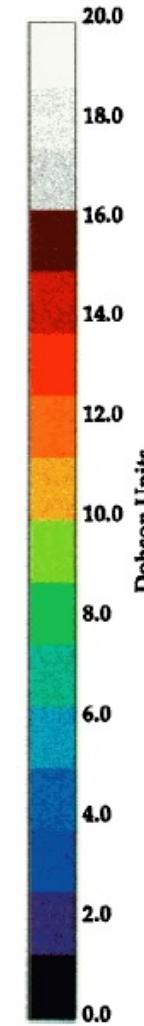
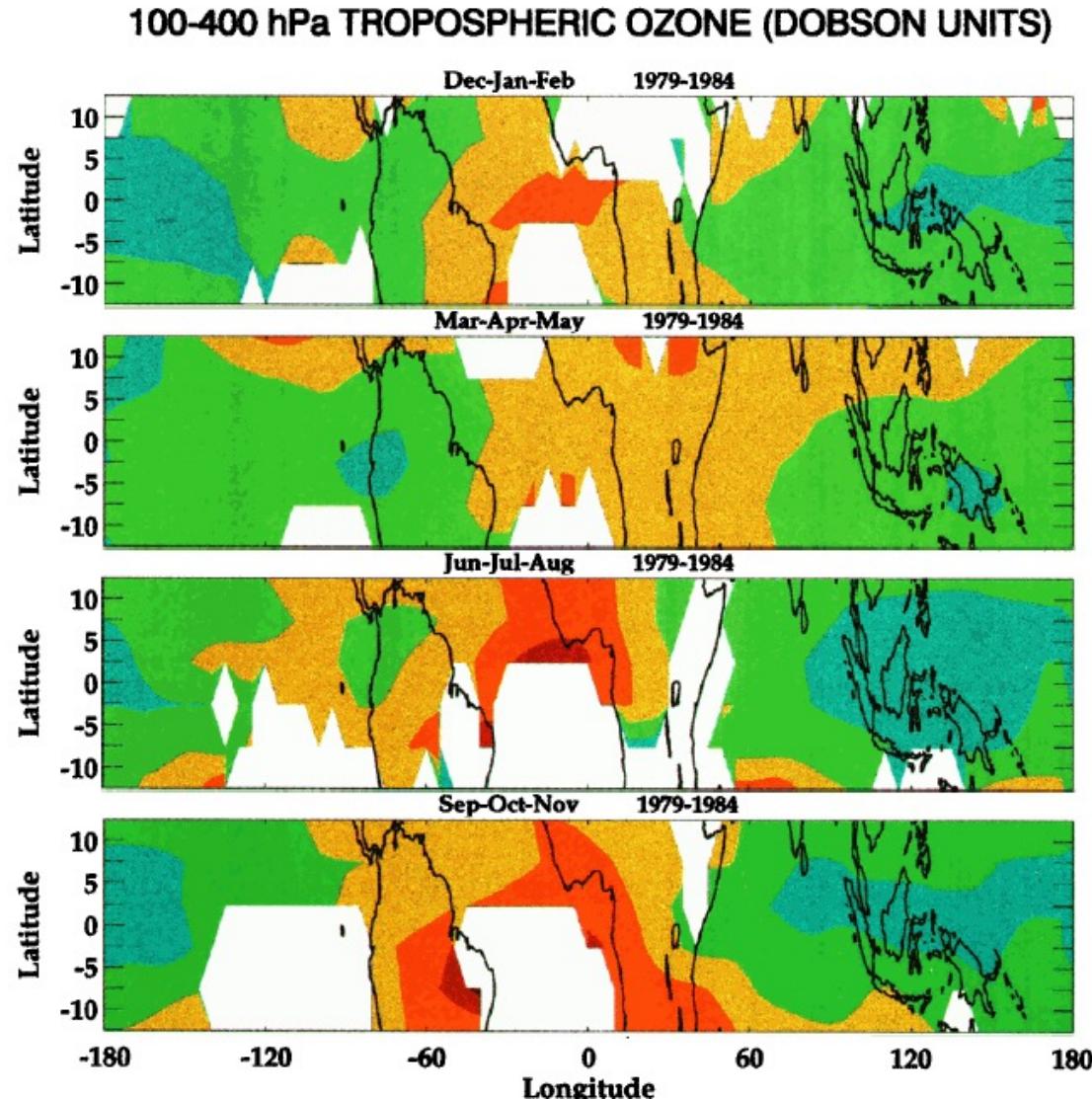
Regress cloud top pressures against partial vertical column densities (VCDs):



$$\text{NO}_2 \text{ VMR} = \frac{\Delta \text{VCD}}{\Delta P} \times \text{const}$$

Past Application of Cloud-slicing to TOMS ozone

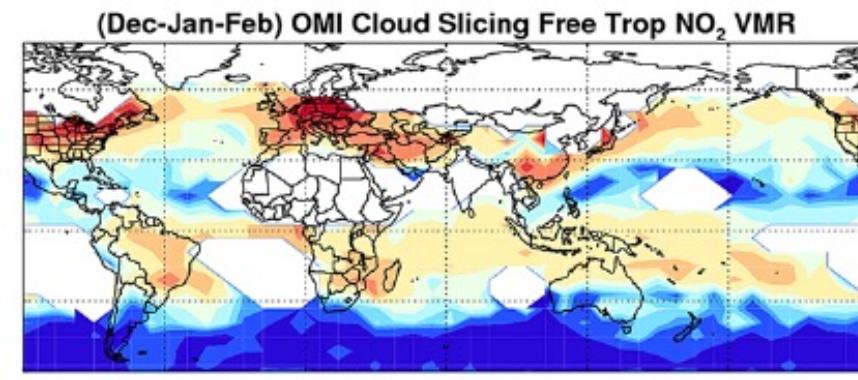
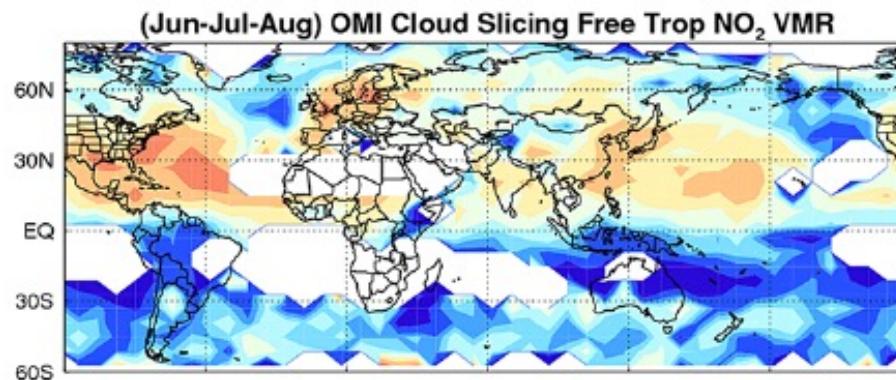
Cloud-slicing applied to Total Ozone Mapping Spectrometer (TOMS) to derive upper tropospheric ozone



[Ziemke et al., 2001]

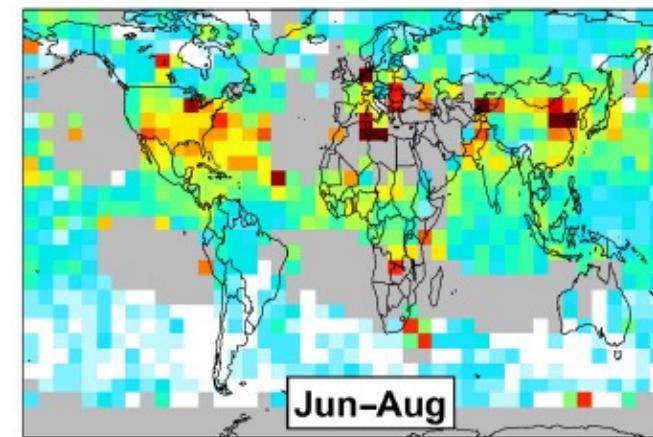
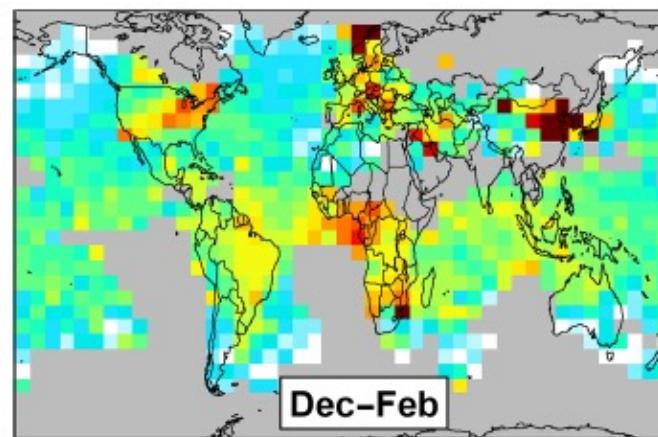
Past Application of Cloud-slicing to OMI NO₂

Cloud-slicing applied to OMI to yield NO₂ in the middle troposphere (Choi et al., 2014), multiple layers in the troposphere (Belmonte Rivas et al., 2015) and upper troposphere (Marais et al., 2018)



Resolution:
5° lat x 8° lon

[Choi et al., 2014]



Resolution:
5° lat x 8° lon

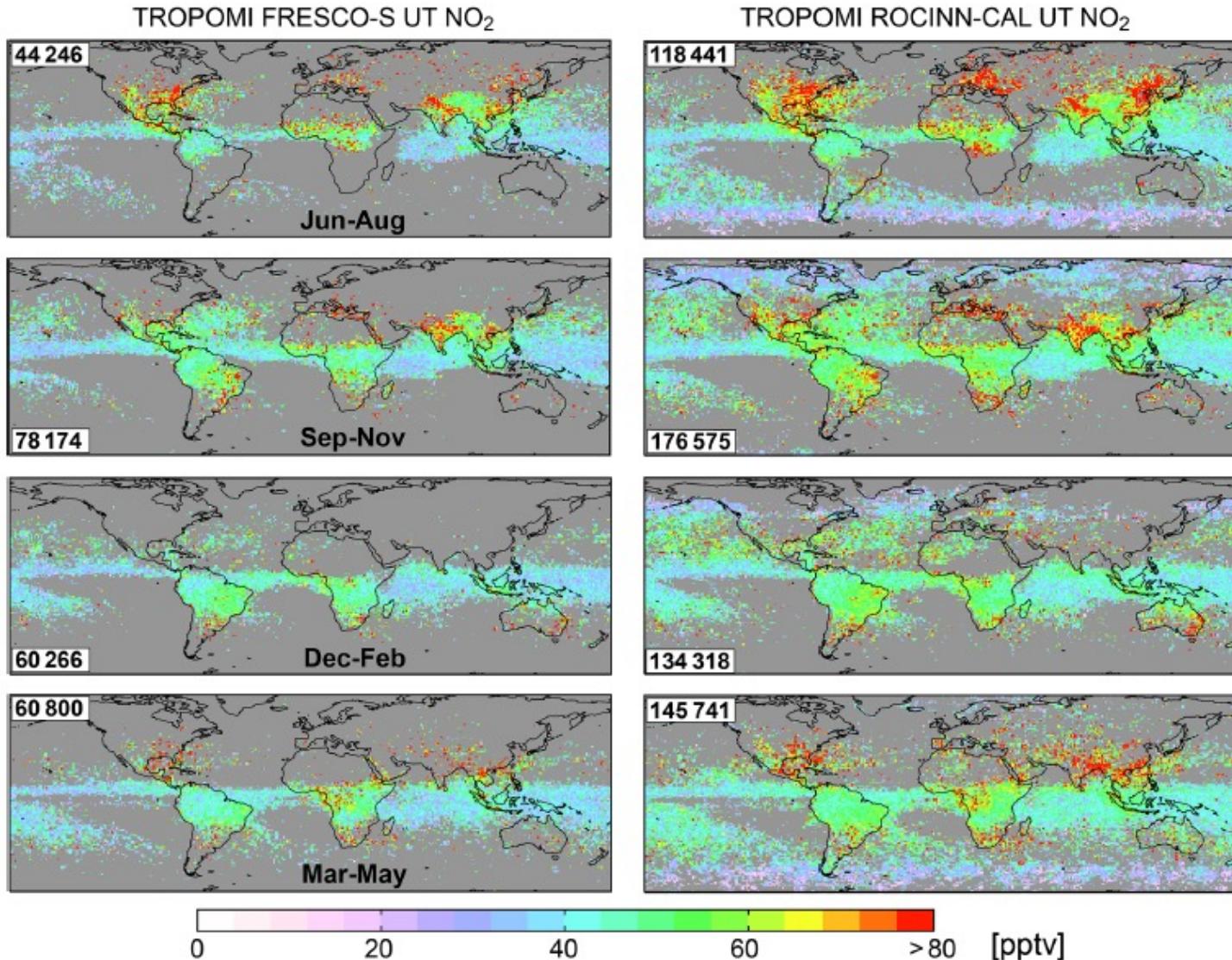
[Marais et al., 2018]



OMI coarse resolution and not fit for use after row anomaly (low data density)

Recent Application of Cloud-slicing to TROPOMI NO₂

Limited to upper troposphere for a single year. Achieve much finer resolution (1°) than OMI

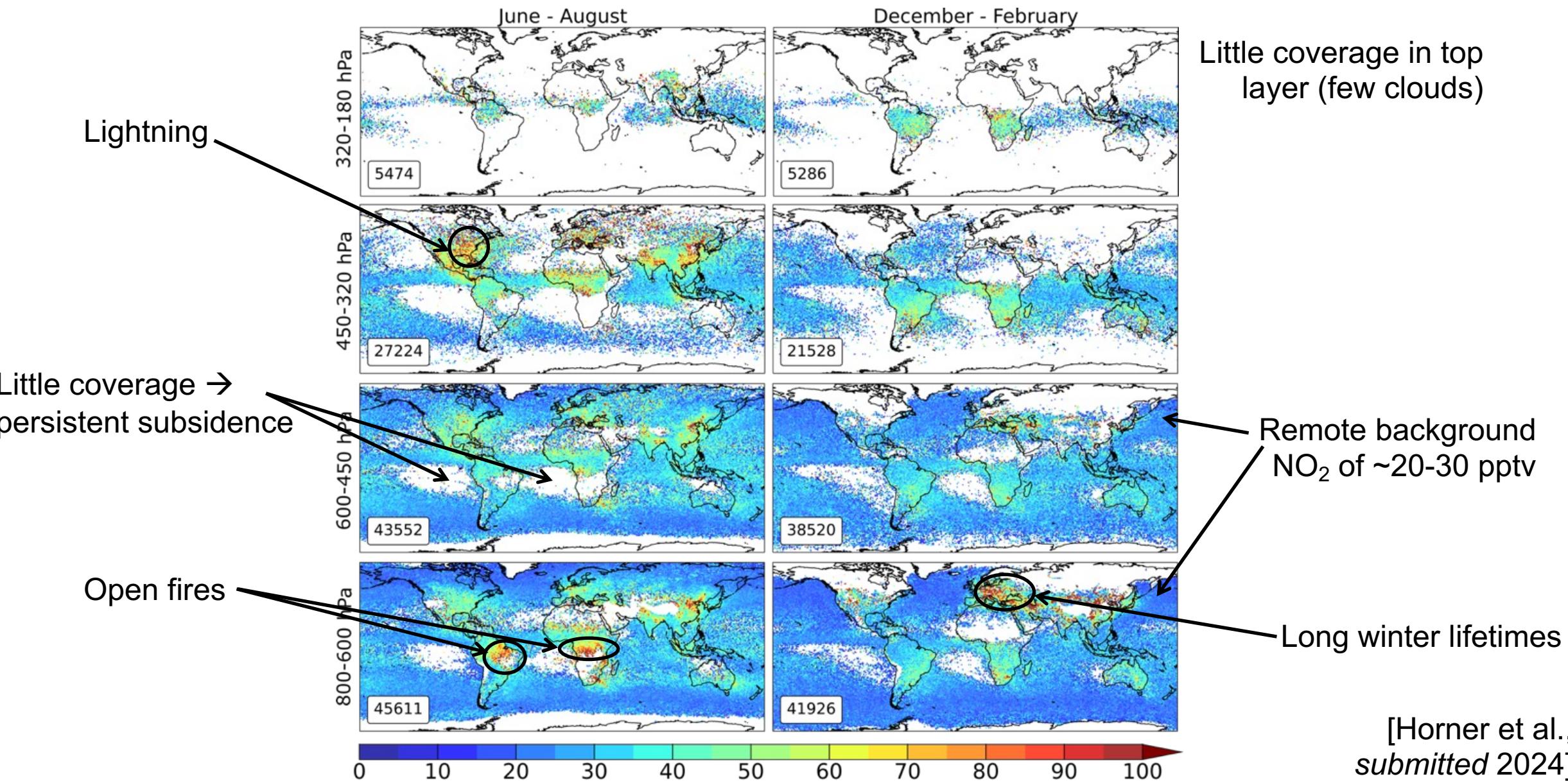


Seasonal means
obtained with different
cloud products

[Marais et al., 2021]

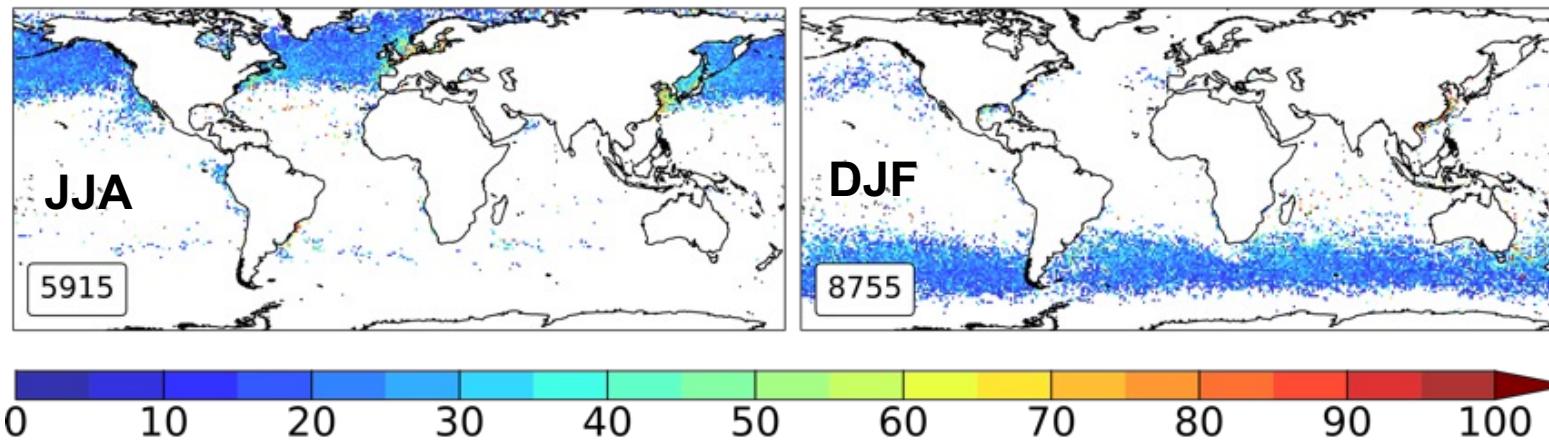
Current Application to TROPOMI: free troposphere

Cloud-sliced multiyear mean free tropospheric NO₂ [pptv]



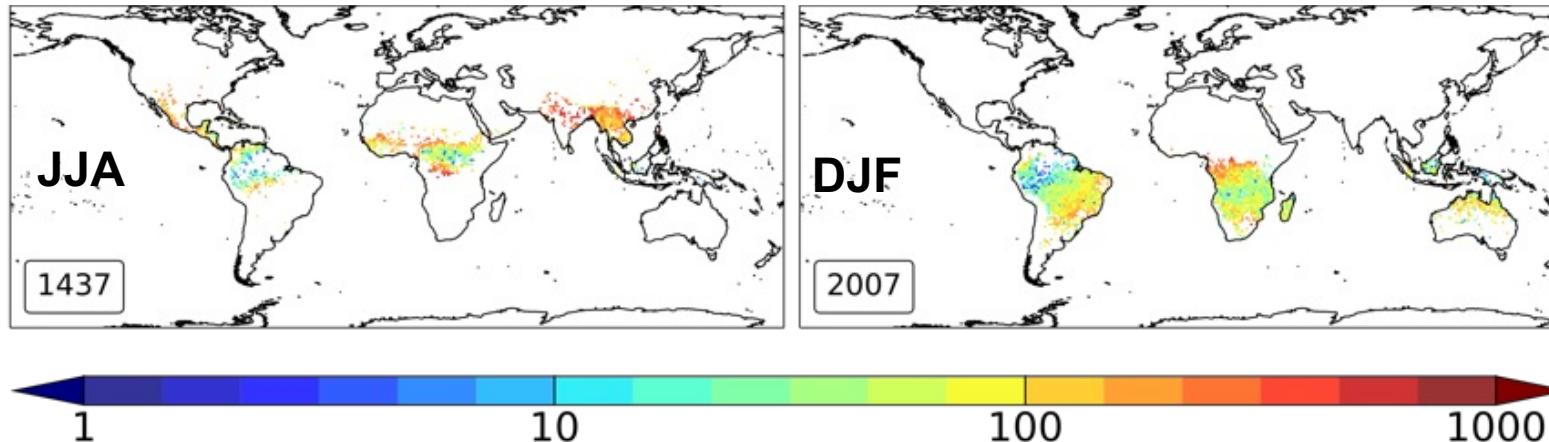
Current Application to TROPOMI: boundary layer

Cloud-sliced multiyear mean boundary layer NO₂ [pptv]

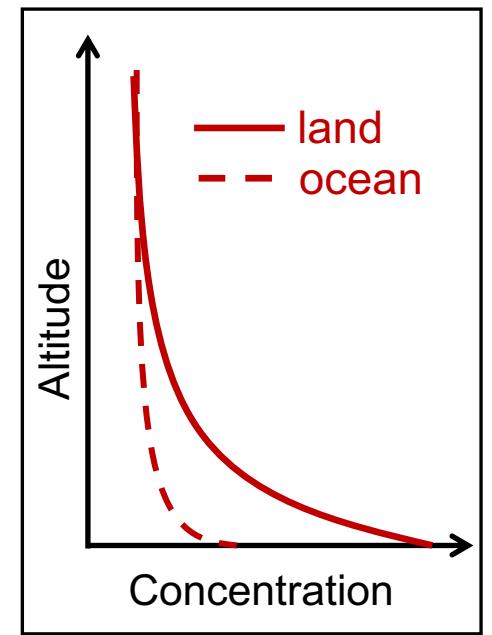


Cloud-slicing assumes NO₂ uniform within each layer. Assumption doesn't hold over surface source regions, so take difference of cloud-sliced and tropospheric columns:

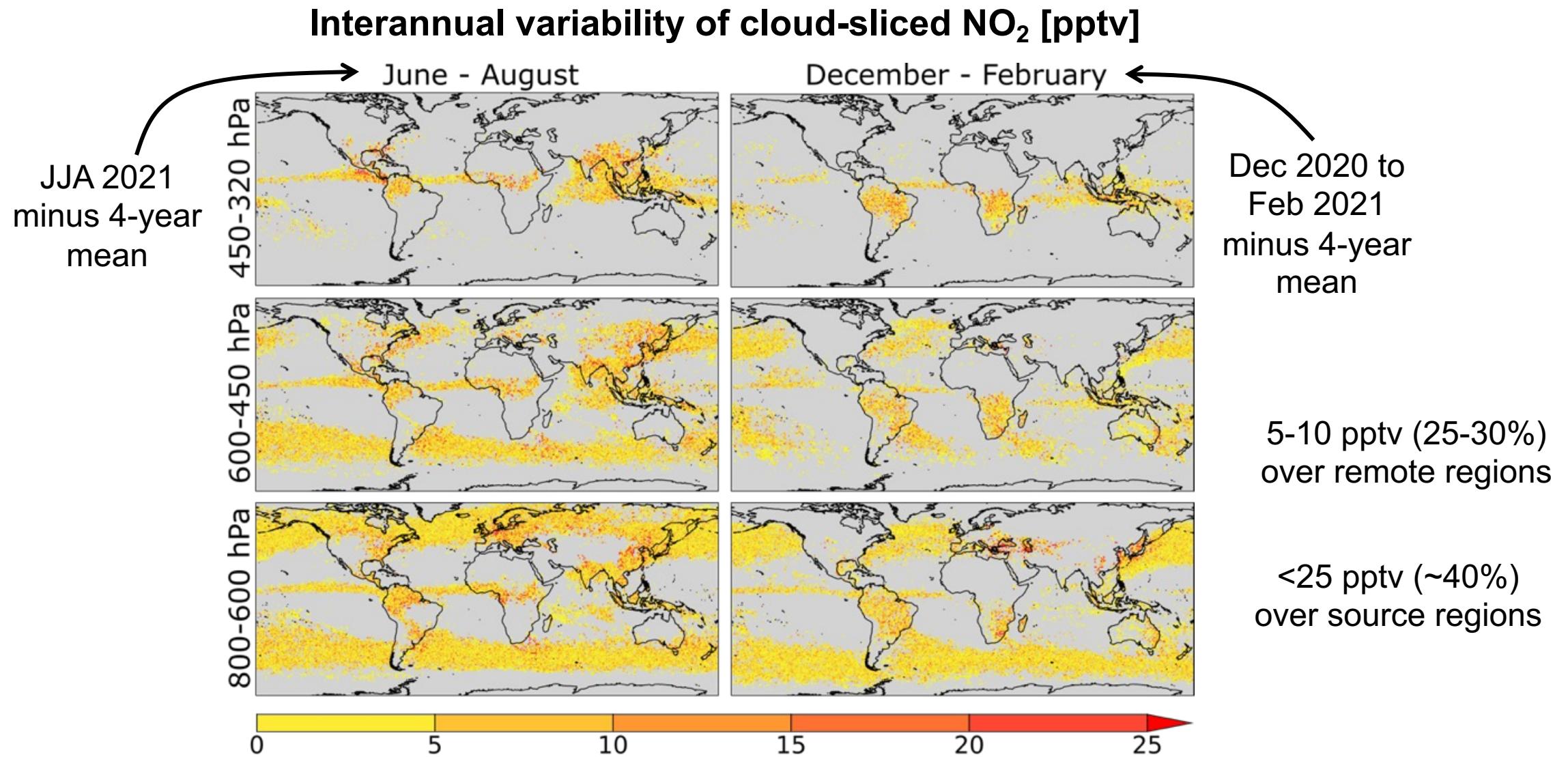
Differenced multiyear mean boundary layer NO₂ [pptv]



NO₂ vertical profile



NO_2 Interannual Variability from Cloud-sliced Data

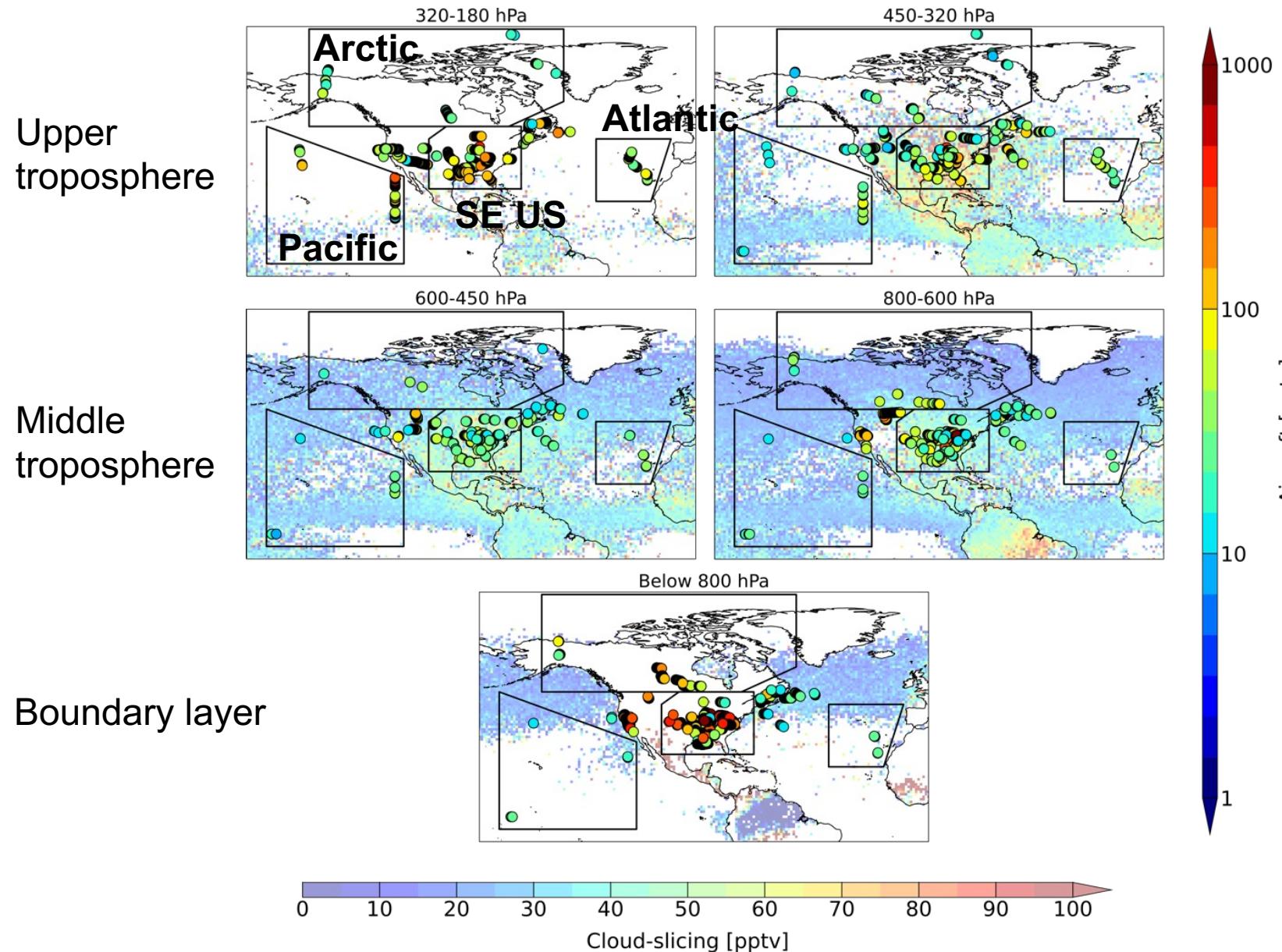


First ever observationally-derived interannual variability in the vertical distribution of tropospheric NO_x suggests NO_x relatively stable from year to year

[Horner et al.,
submitted 2024]

Assessment of Cloud-sliced NO₂

Use NASA DC8 aircraft observations for campaigns in 2008-2018



Application of Cloud-sliced NO₂

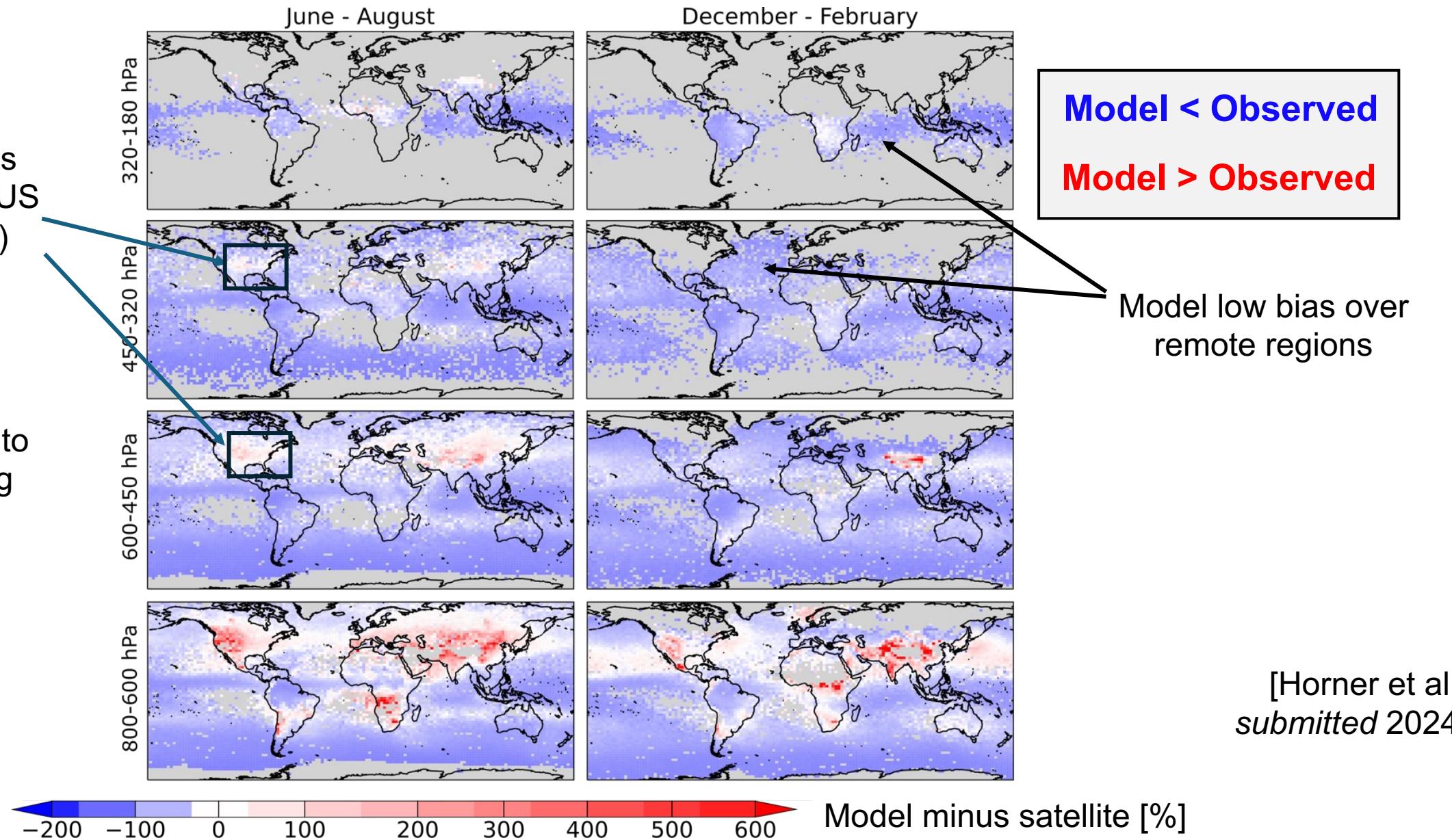
Assess best understanding of tropospheric NO₂ as simulated by the GEOS-Chem model

Model high bias
over Southeast US
(lightning NO_x)

Work underway to
improve lightning
NO_x emissions

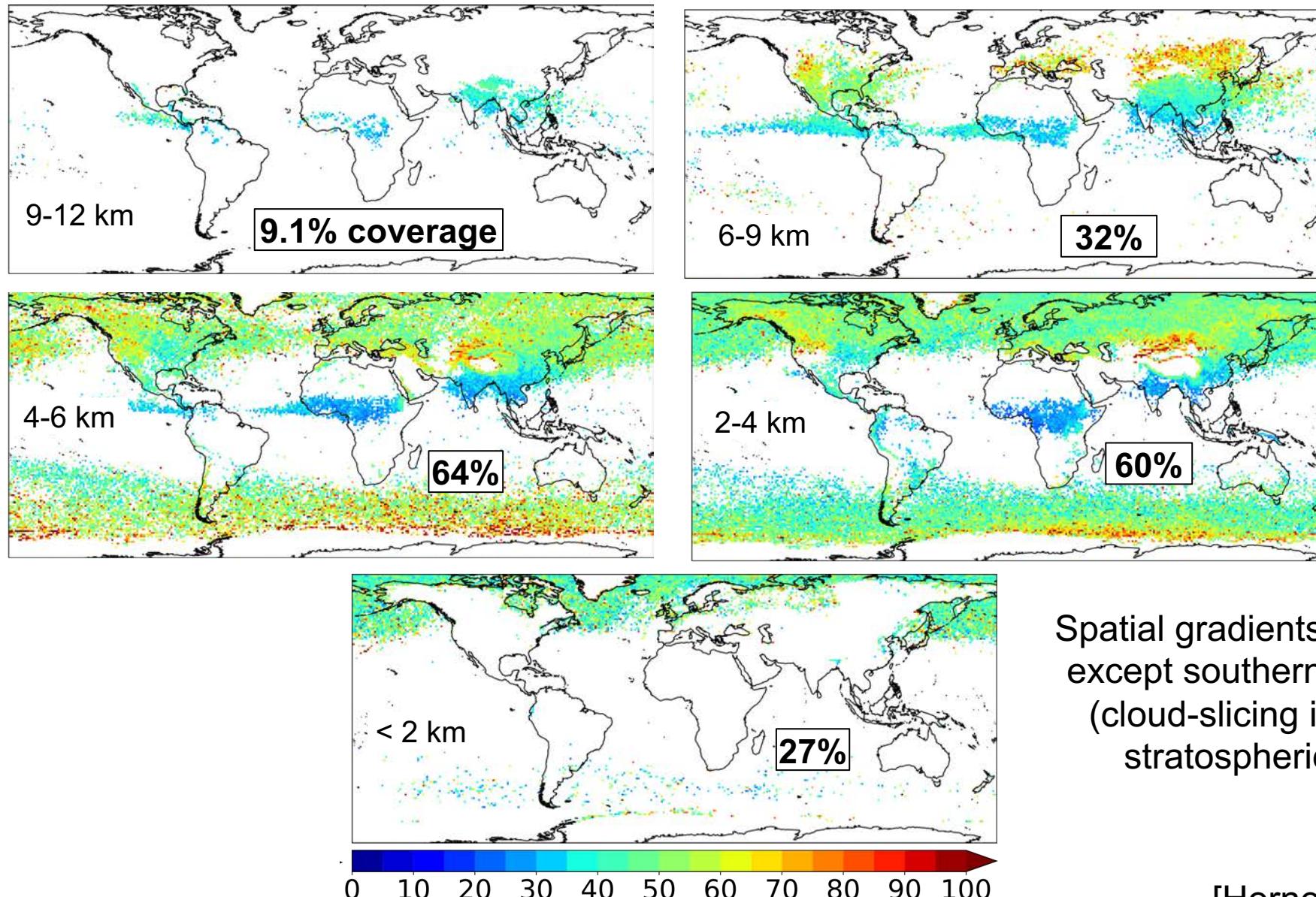
Model < Observed
Model > Observed

Model low bias over
remote regions



Extending Cloud-slicing to TROPOMI ozone

June-August multiyear mean ozone [ppbv]

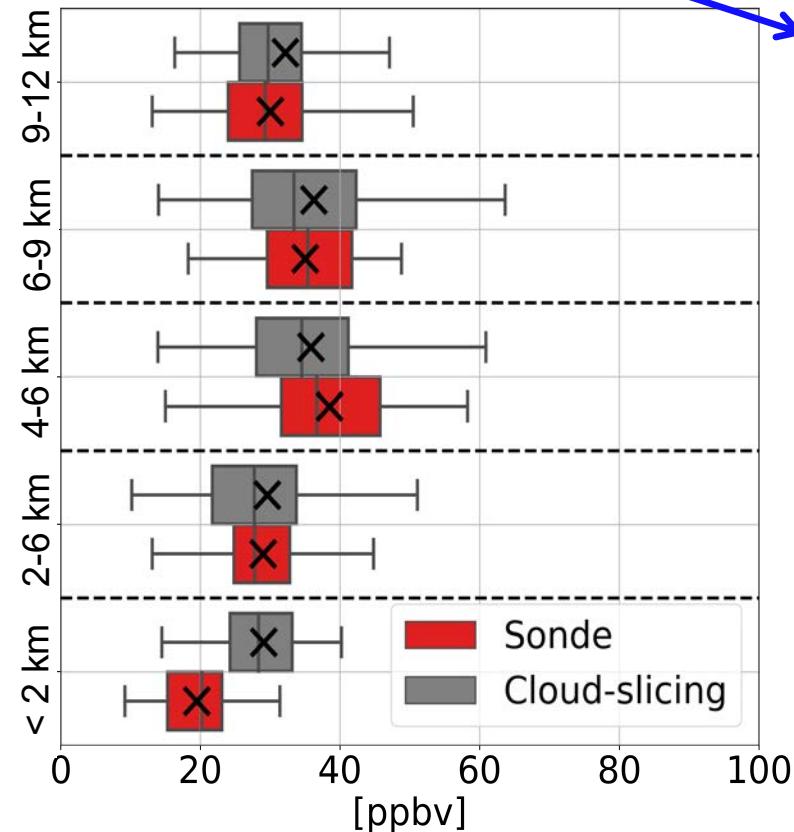


[Horner et al., *in progress*]

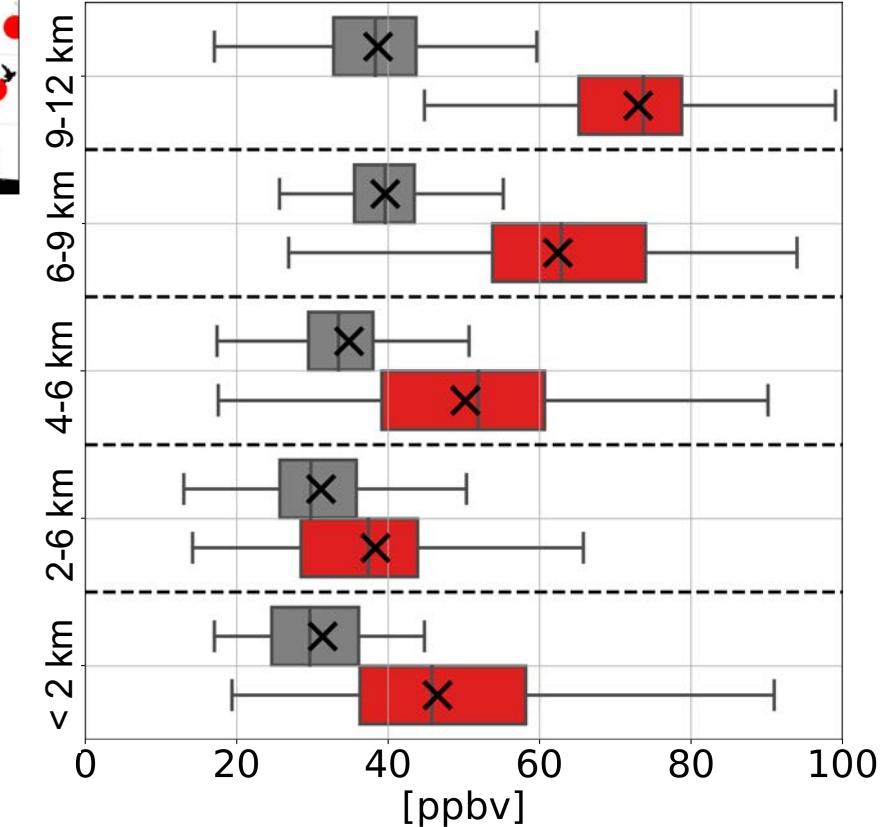
Assess Cloud-slicing Ozone with Ozonesondes

Ozonesonde network sites used

Samoa, JJA



Hanoi, JJA



Ozonesondes with measurements
during TROPOMI overpass

Most with good agreement like
Samoa (left)

Only 3 with poor agreement like
Hanoi (right)

Validation against ozonesondes encouraging

[Horner et al., *in progress*]

Opportunities & Challenges with GEO Instruments

- All cloud-sliced products are from LEO instruments, so only provide one snapshot (midday) of atmospheric composition
- <10% of original pixel data retained for cloud-slicing
- GEO offers greater number of observations and could be used to interrogate diurnal variability in NO₂ in distinct layers in the troposphere
- Need reliable, coincident, independent observations to validate cloud-sliced data

Resources:

Cloud-sliced vertical profiles of NO₂ data: <https://doi.org/10.5522/04/25782336>

Accompanying ACP preprint should appear on EGUsphere soon!

UCL-CSC Visiting research (PhD) student scheme:

<https://www.ucl.ac.uk/scholarships/ucl-csc-visiting-research-student-award>