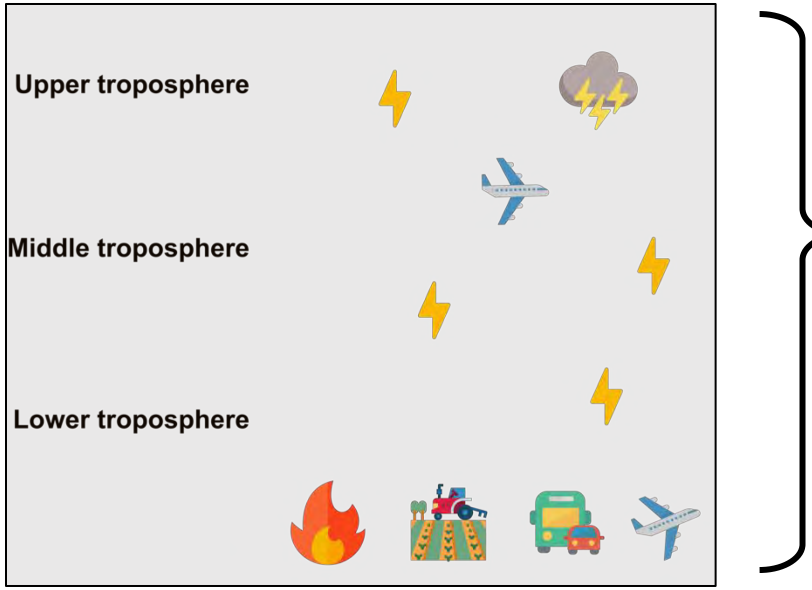
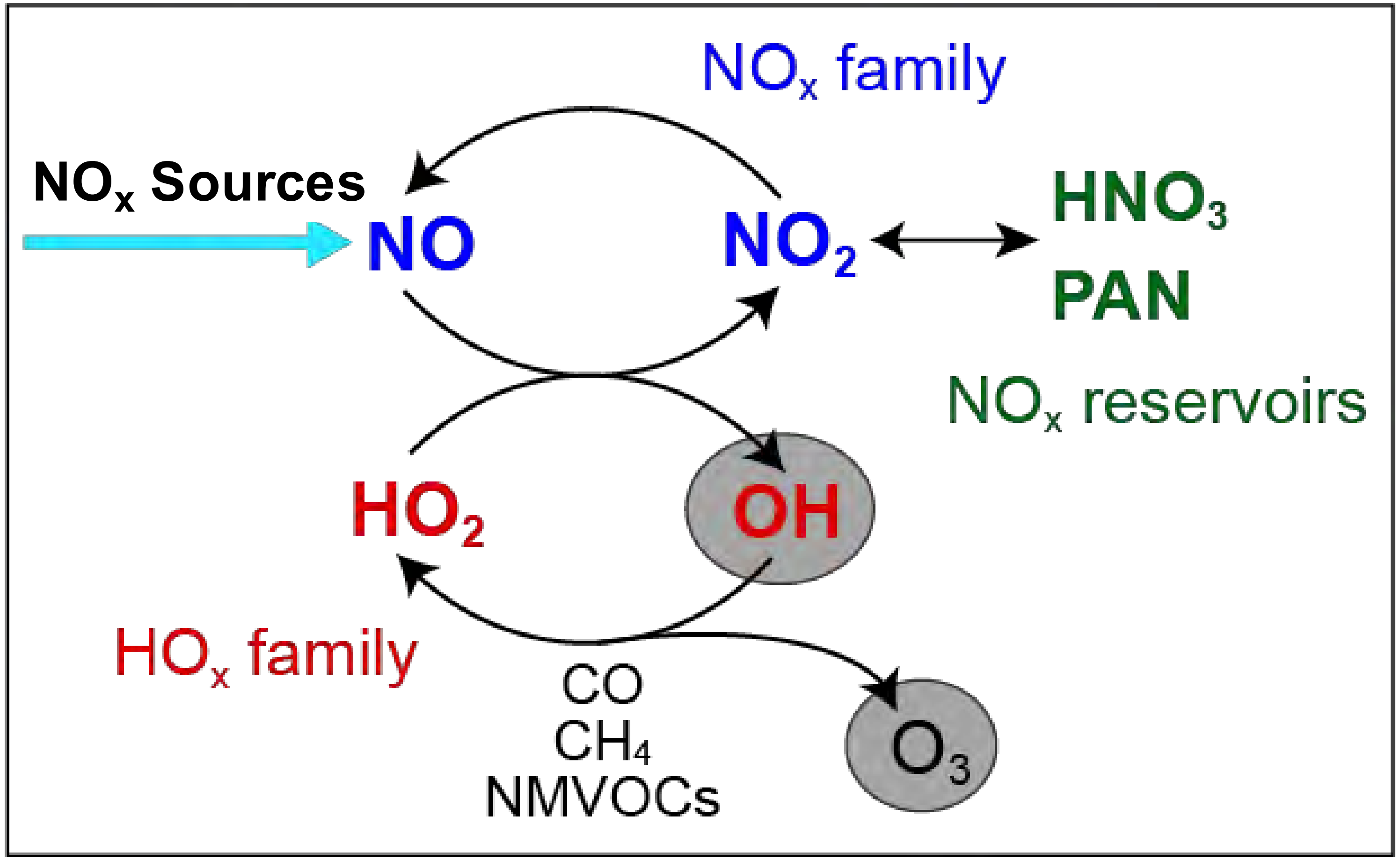
Cloud-slicing TROPOMI retrieval of vertically-resolved tropospheric NO_2 and O_3

Featuring work by PhD student Rebekah Horner

Eloise Marais, e.marais@ucl.ac.uk, AERSS Meeting, 2 Dec 2024

Tropospheric nitrogen oxides (NO_x) and ozone (O_3)





Influences climate, air quality, food security, tropospheric oxidation

Limitations of current observing systems

TROPOMI tropospheric NO_2 [μmol m^{-2}]

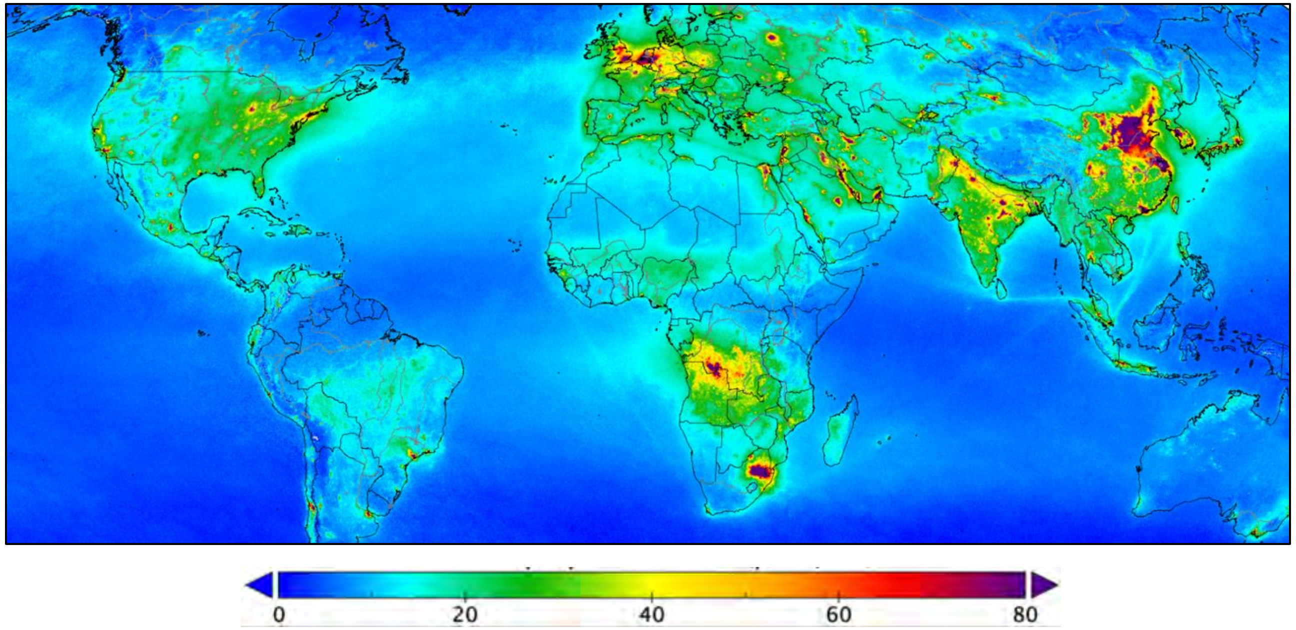
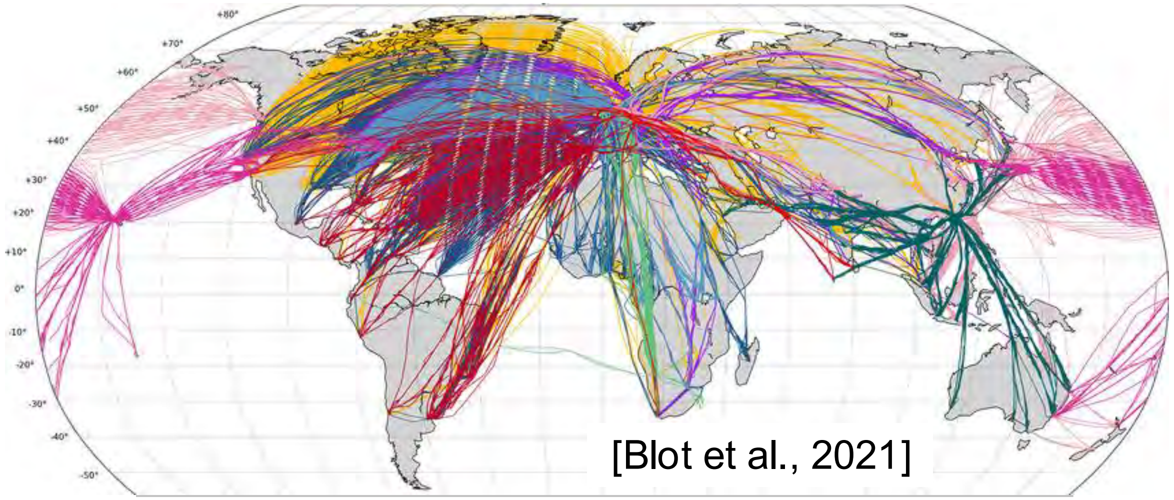


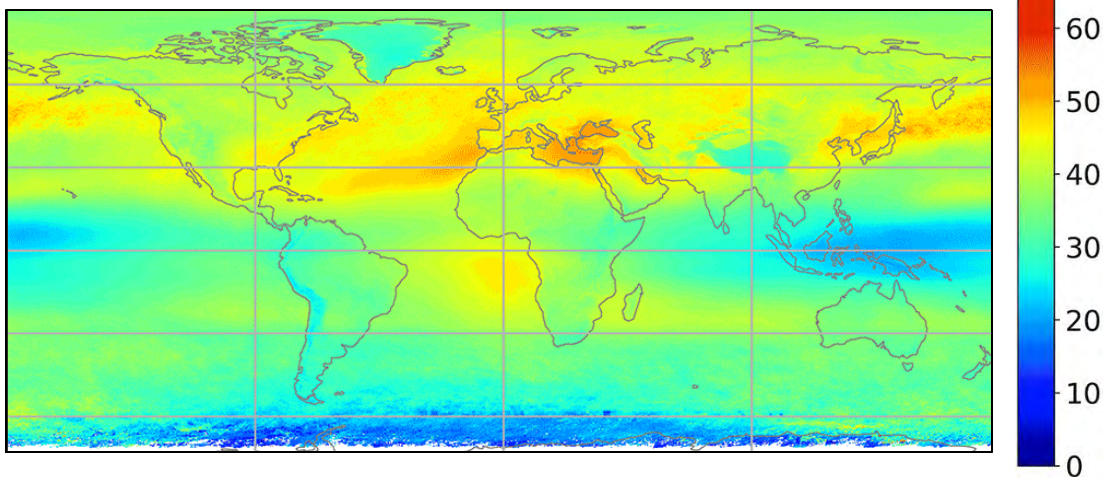
Image source: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Nitrogen_dioxide_pollution_mapped

IAGOS campaign flight tracks



[Blot et al., 2021]

TROPOMI tropospheric O_3 [DU]



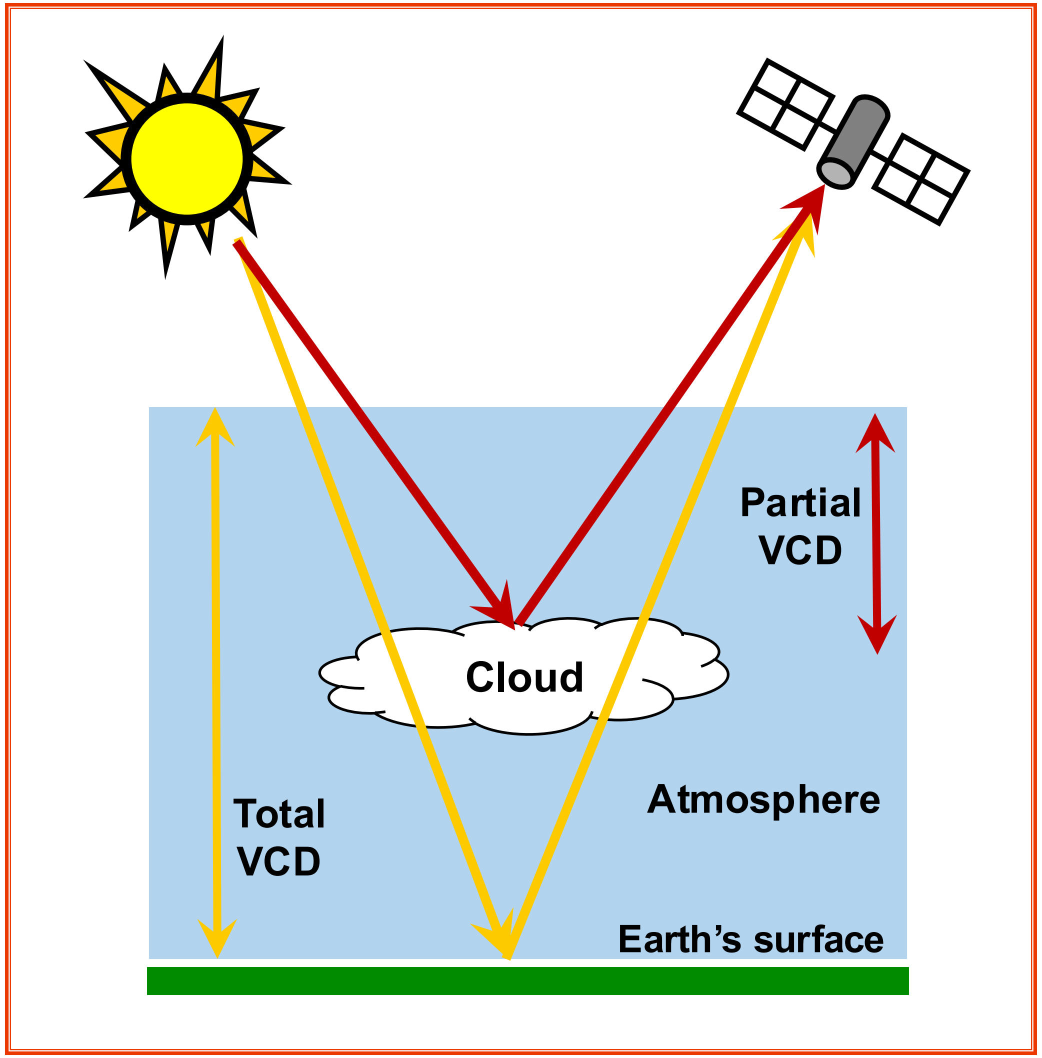
[Heue et al., 2022]

Operational and research grade satellite data products offer one piece of vertical information

Aircraft observations intermittent

In situ NO_2 instruments prone to interference from reservoir compounds

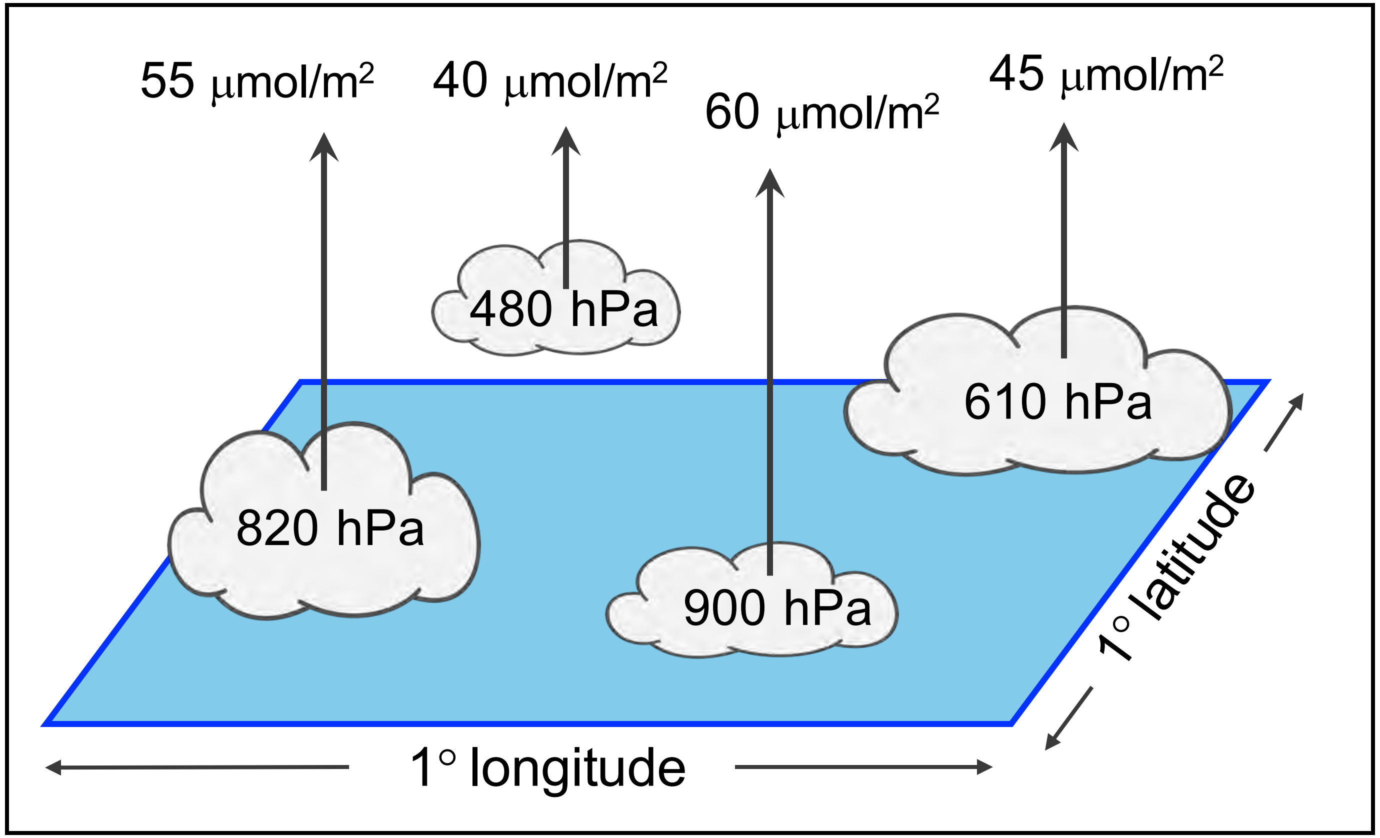
Optically thick clouds split up the troposphere



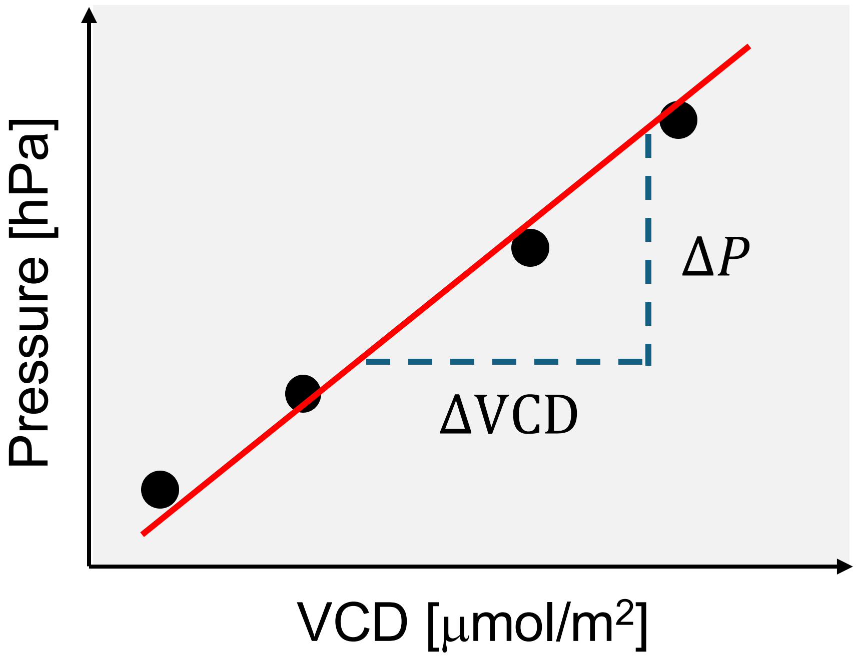
Retrieve partial columns above optically thick clouds (data typically discarded)

Convert partial columns to mixing ratios

Clusters of partial columns above optically thick clouds:



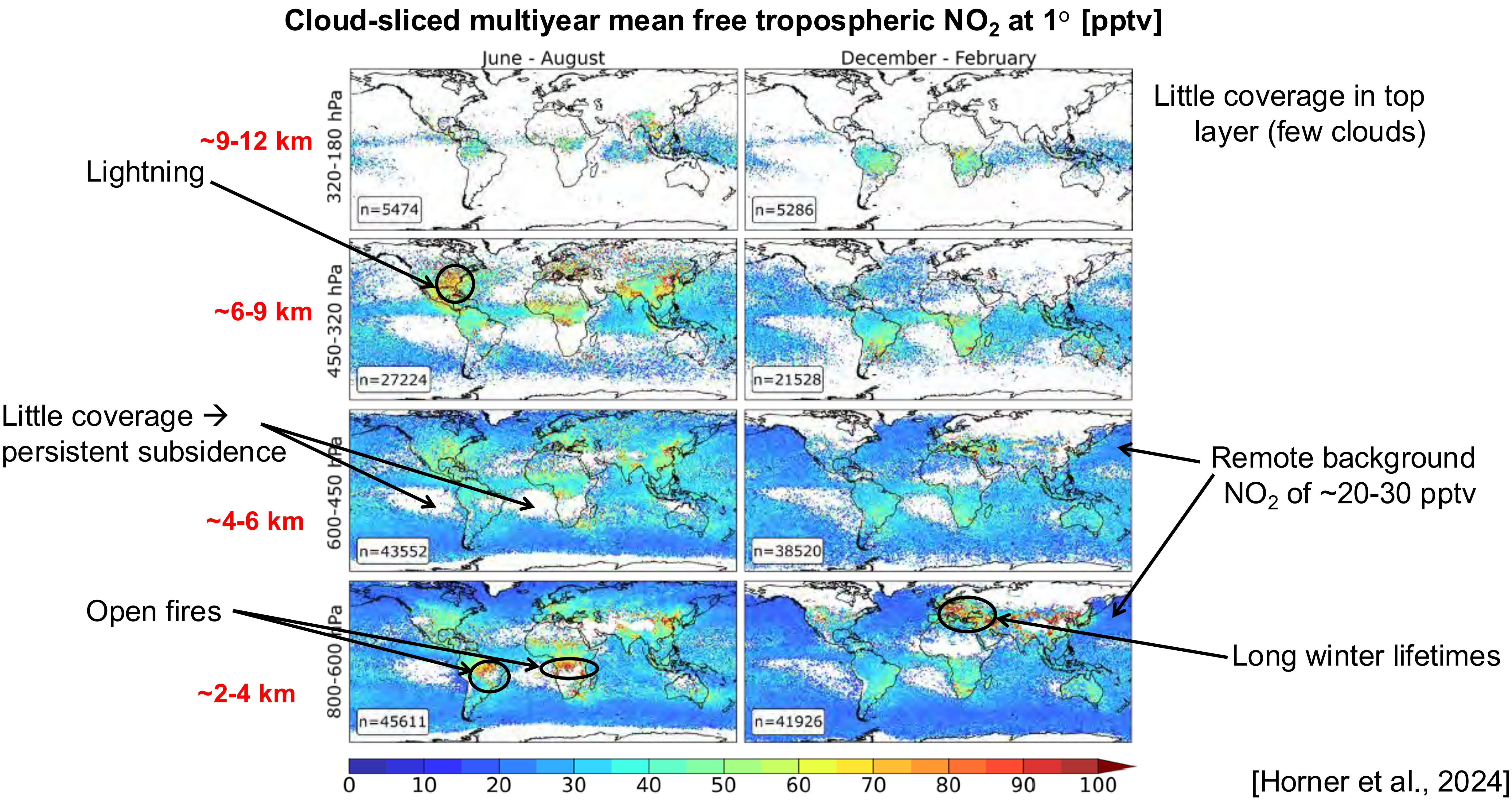
Regress cloud top pressures against partial vertical column densities (VCDs):



Calculate average mixing ratio between target pressure ranges:

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

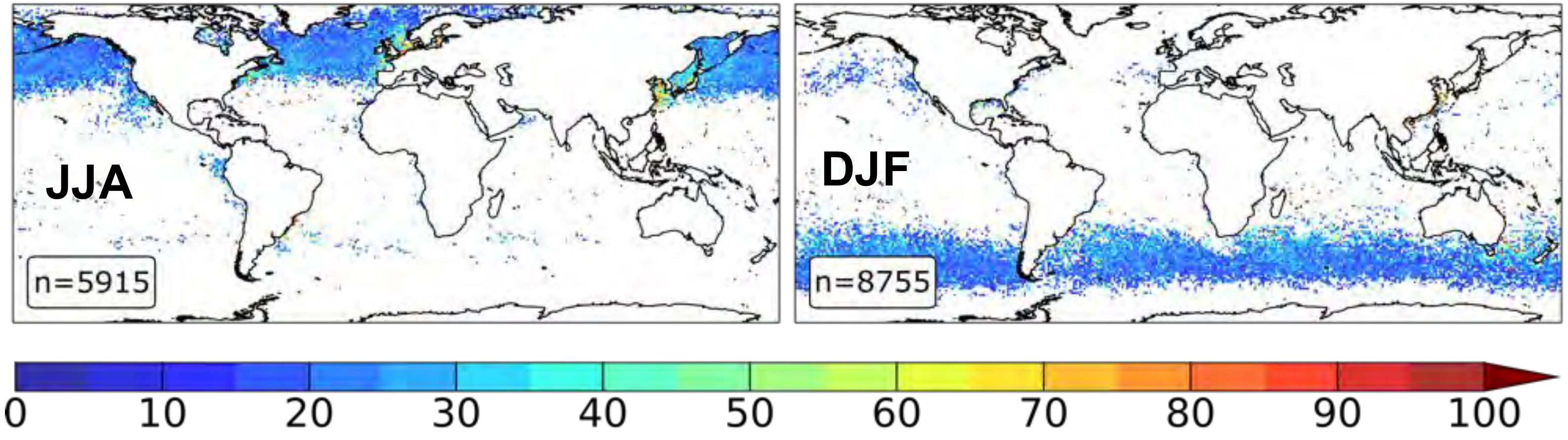
Current Application to TROPOMI: free tropospheric NO_2



[Horner et al., 2024]

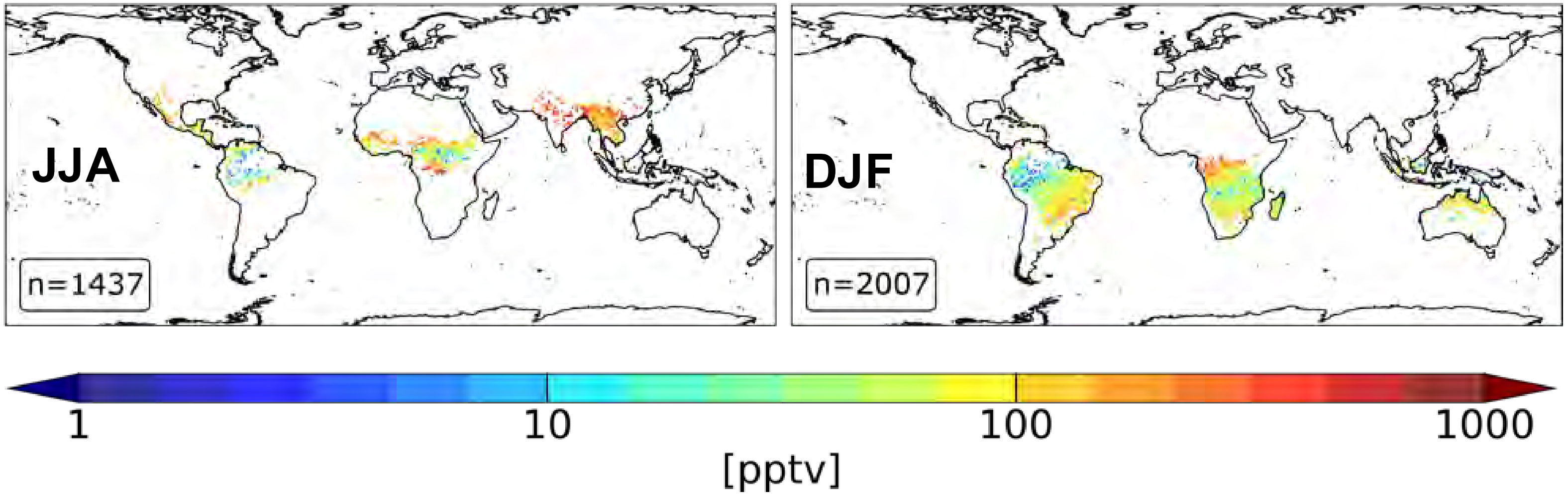
Current Application to TROPOMI: NO_2 boundary layer

Cloud-sliced multiyear mean boundary layer NO_2 [pptv]

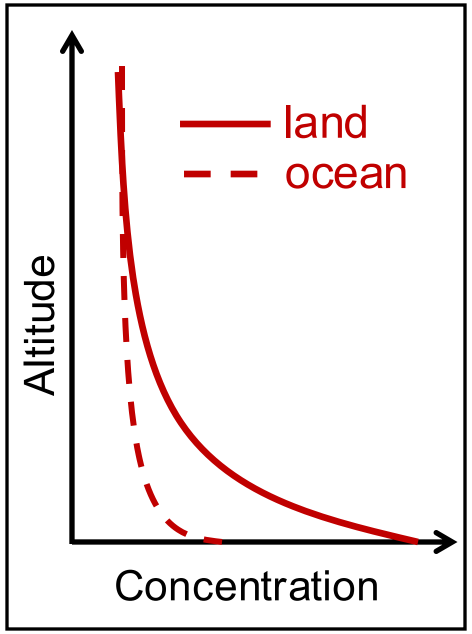


Cloud-slicing assumes NO_2 uniform within each layer. Assumption doesn't hold over surface source regions, so take difference of cloud-sliced and tropospheric columns:

Differenced multiyear mean boundary layer NO_2 [pptv]



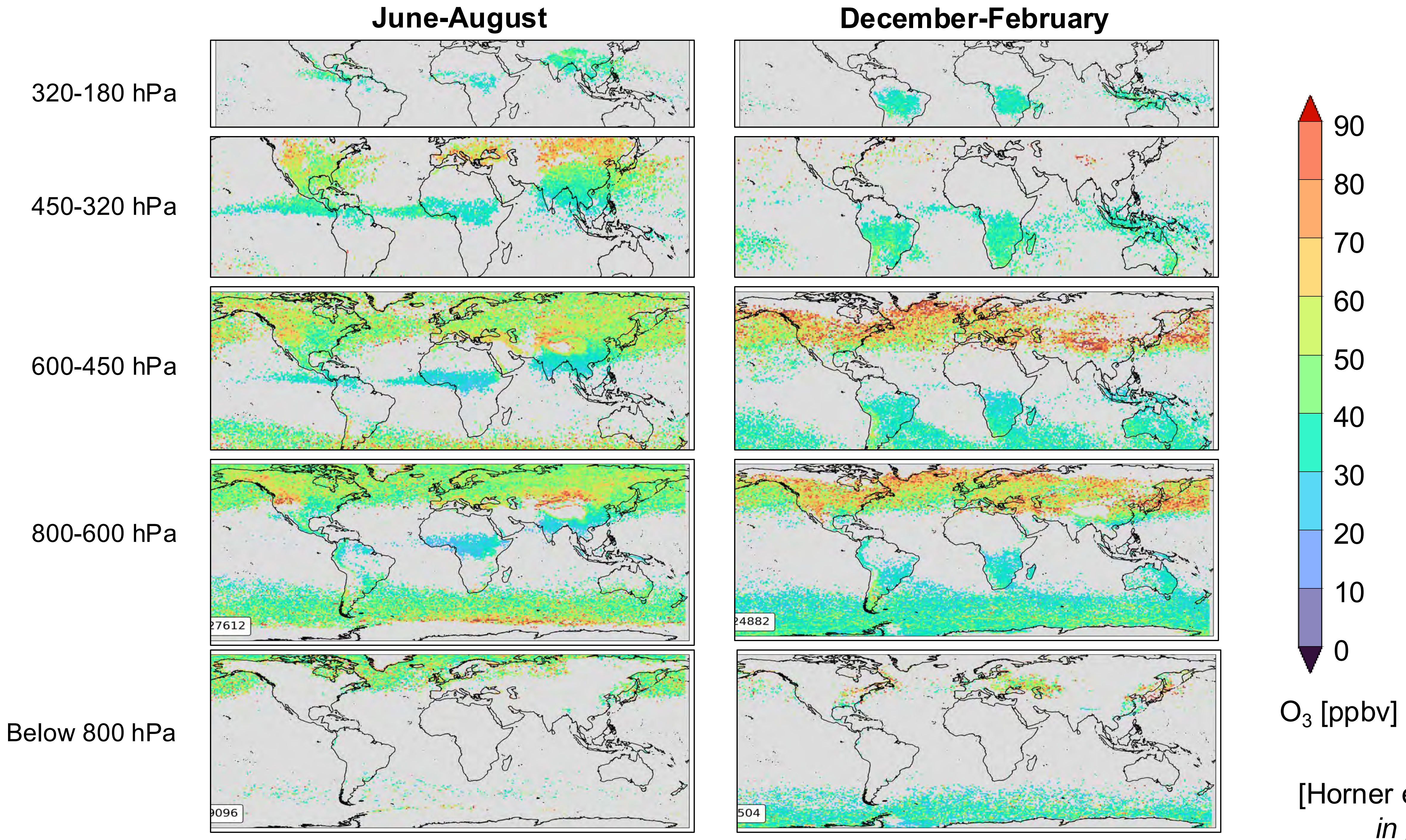
NO_2 vertical profile



[Horner et al., 2024]

Next Slide:

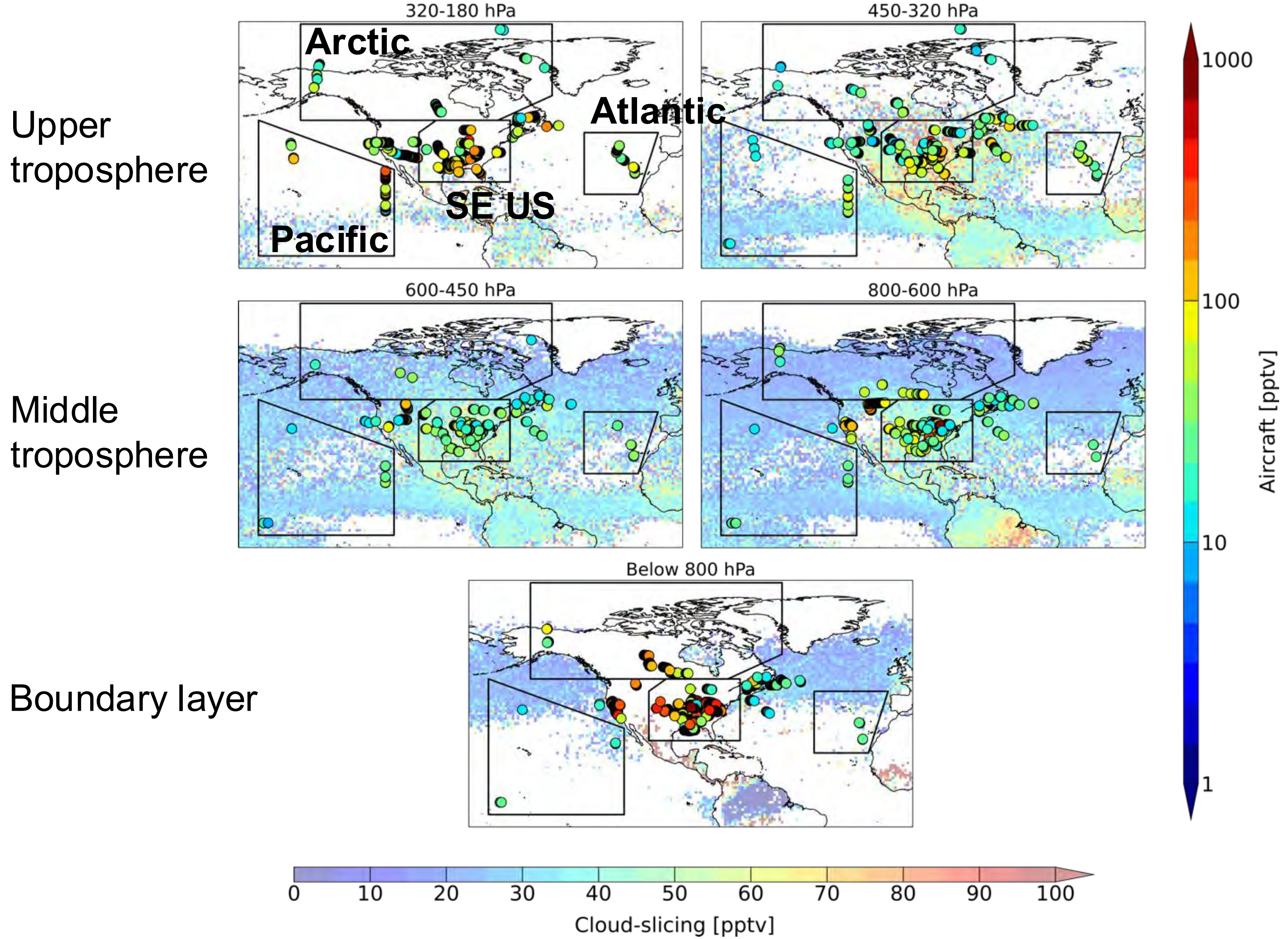
2 columns of multiyear means of cloud-sliced ozone for the TROPOMI record for 4 years from 1 May 2018 to 30 April 2022 at 1^{o} resolution



[Horner et al., *in prep*]

Assessment of Cloud-sliced NO_2

Use NASA DC8 aircraft observations for campaigns in 2008-2018



Symbols: aircraft NO_2

Background: cloud-sliced NO_2

In situ data for different years

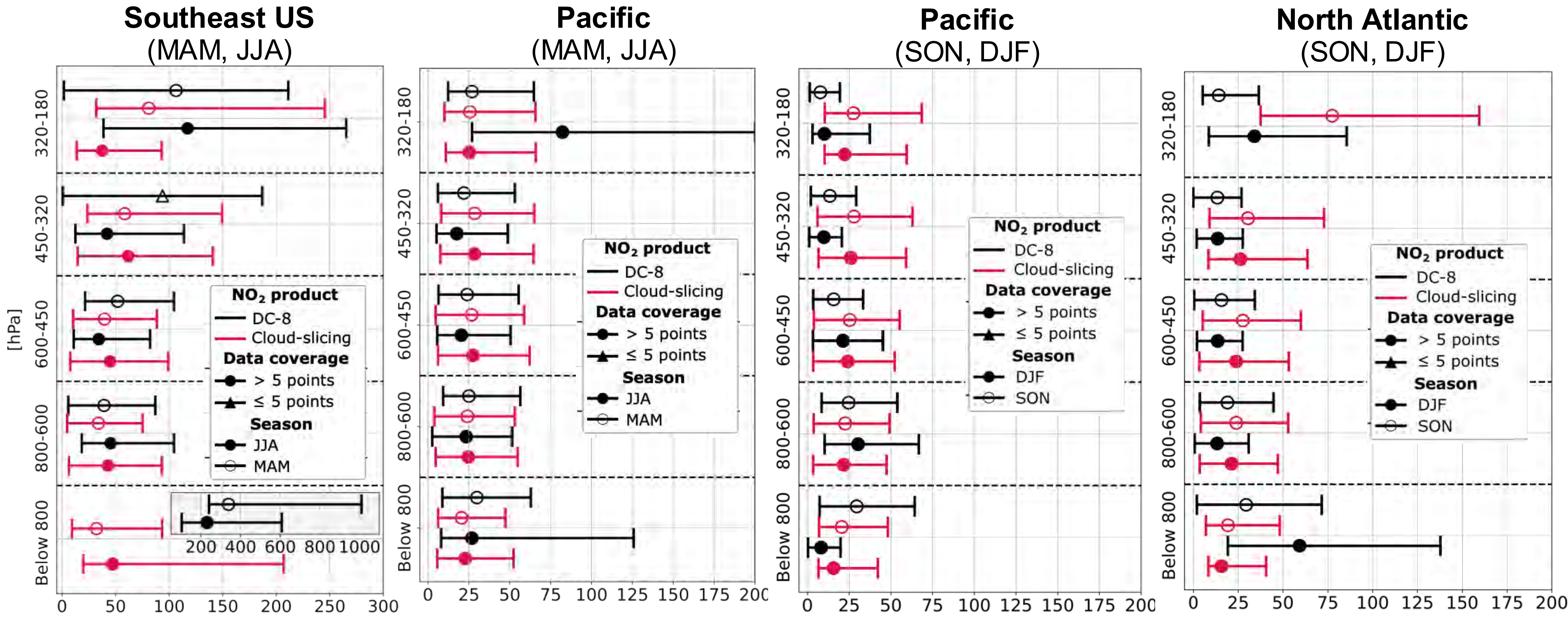
When spatial coverage similar, aircraft and cloud-sliced data difference < 10 pptv

But, few instances of coincidence

[Horner et al., 2024]

Assessment of Cloud-sliced NO_2

Select locations comparing DC-8 (black) and cloud-sliced (red) NO_2

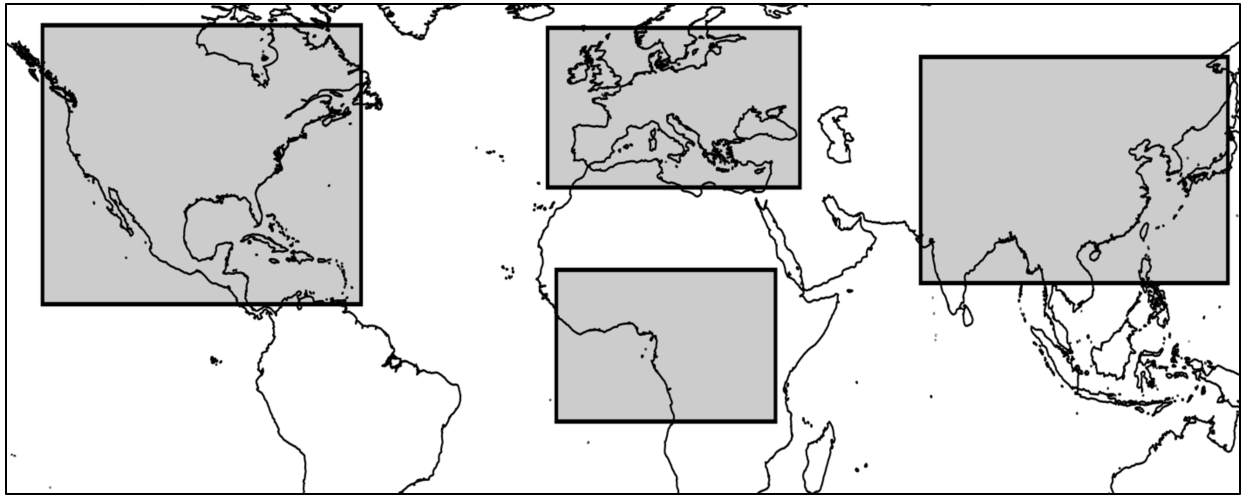


[Horner et al., 2024]

When sampling extent is consistent (within 10-15 pptv), but coincidence is rare

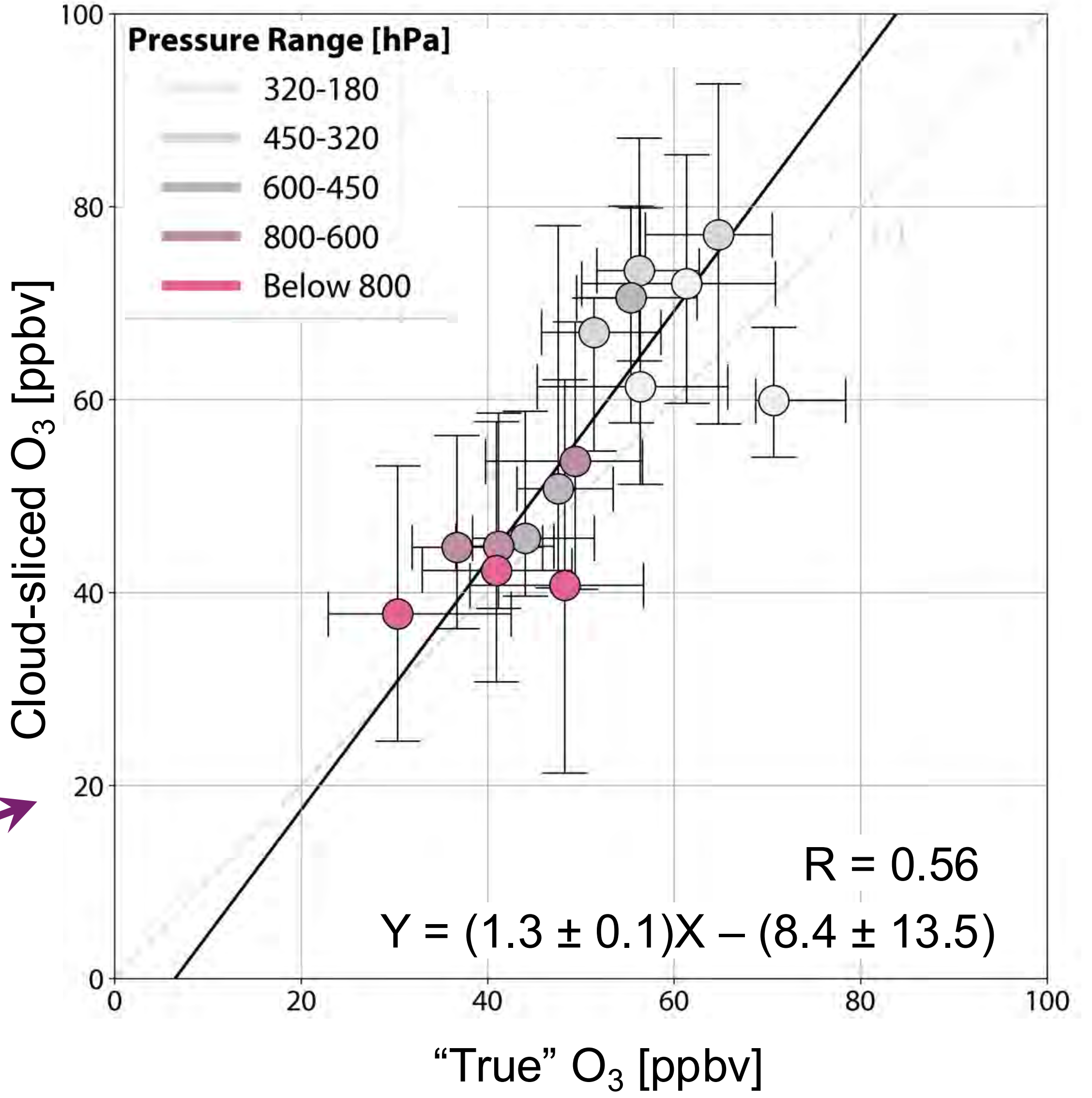
Assessment of Cloud-sliced O_3 using GEOS-Chem

Conduct GEOS-Chem simulations over target regions at the nested grid resolution (0.25° x 0.3125°):



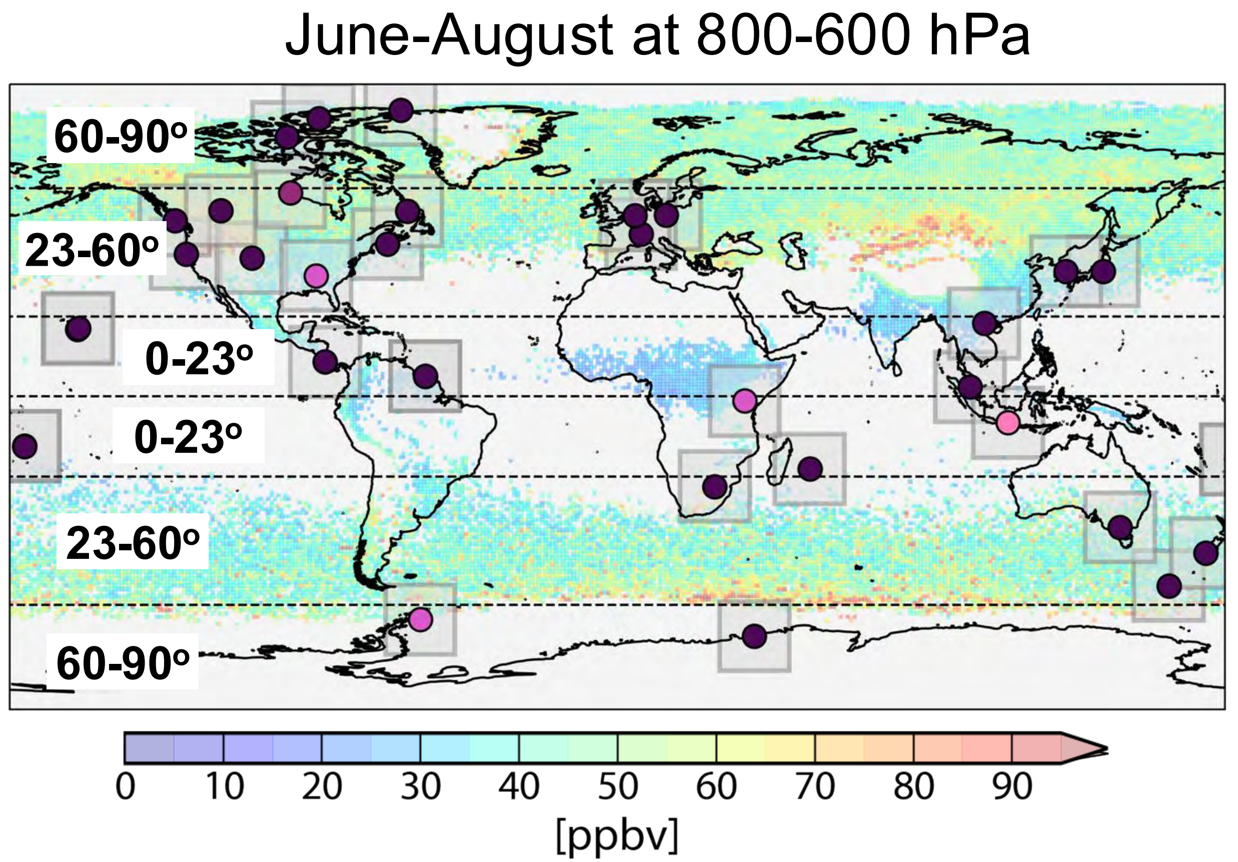
Apply cloud-slicing to synthetic total O_3 columns and compare to “true” O_3 mixing ratios within discrete layers of the troposphere

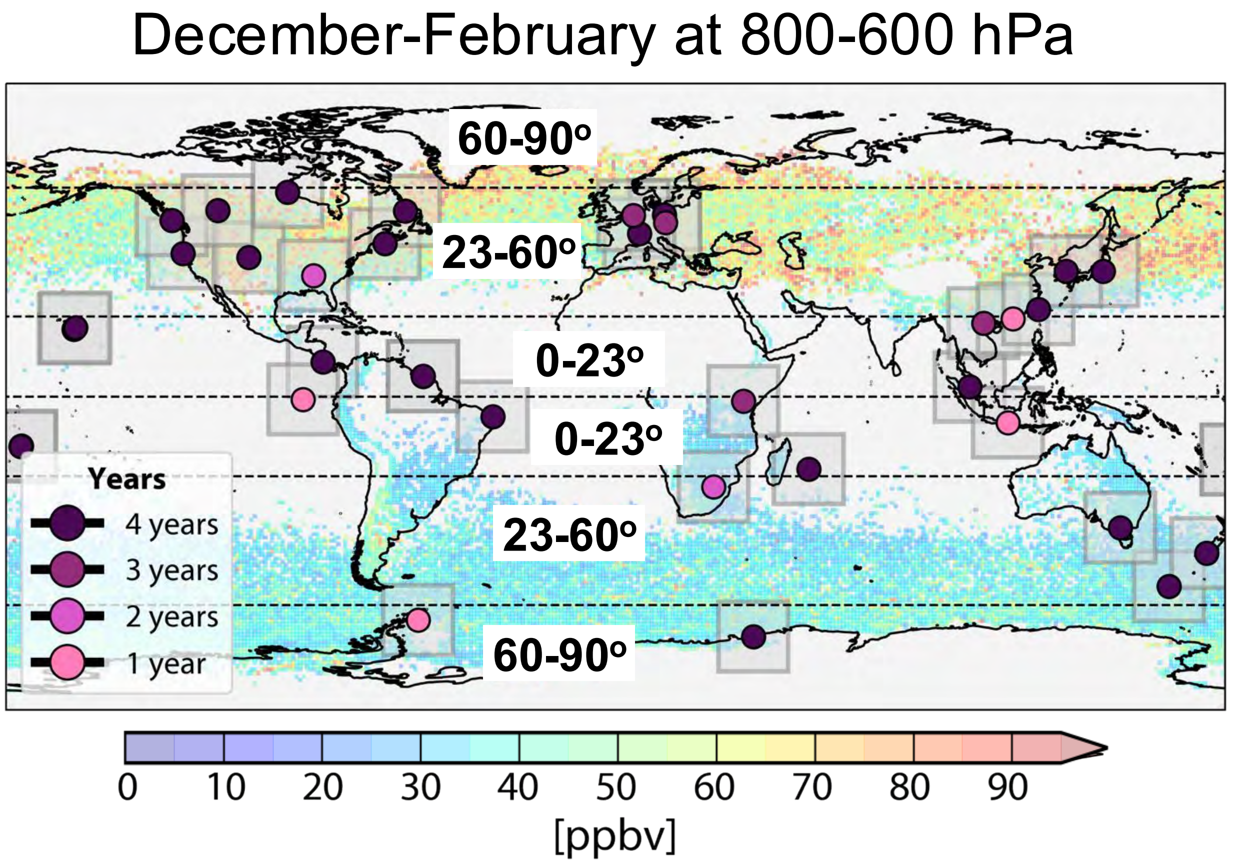
Comparison of regional means



Suggests ~10 ppbv positive bias in cloud-sliced values for upper layers

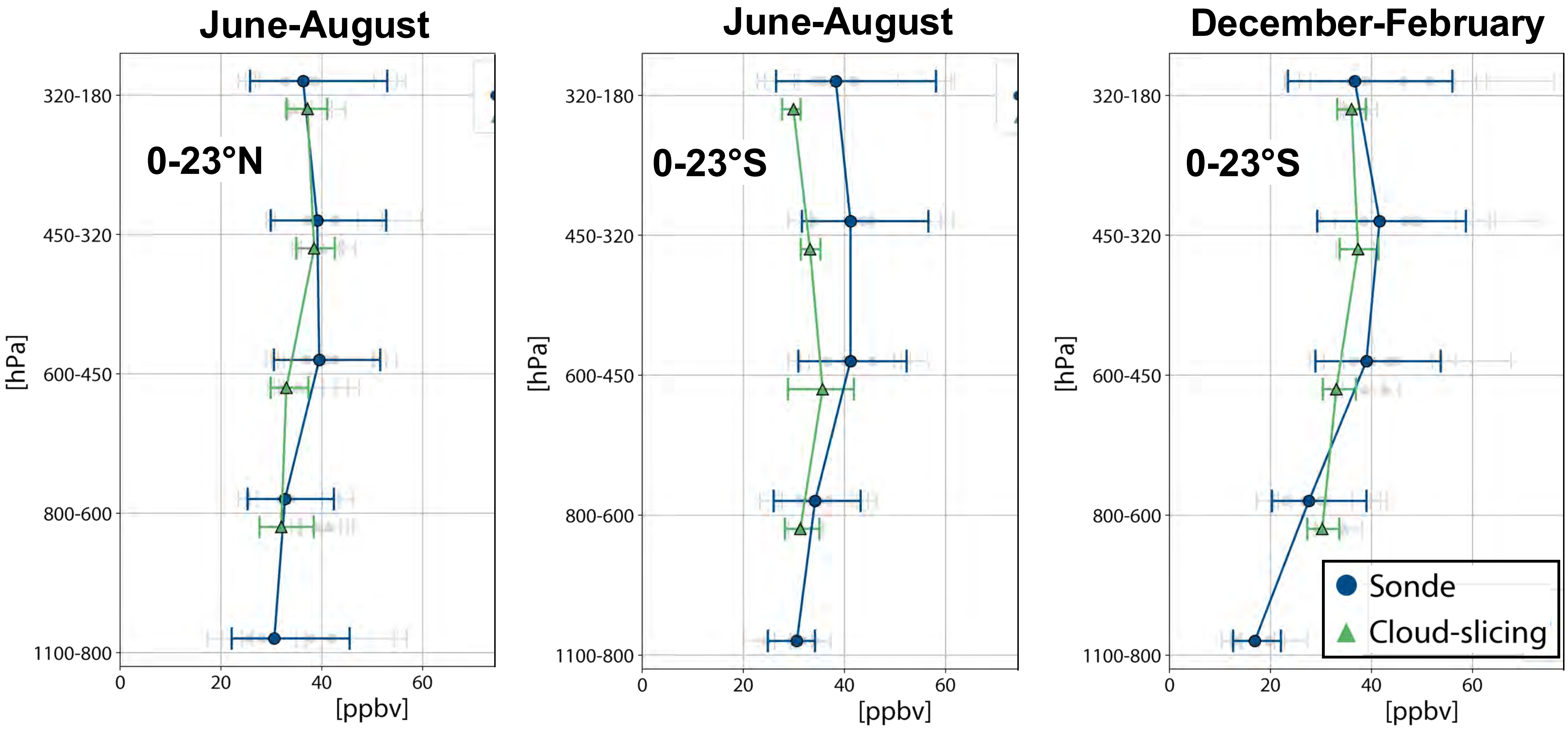
Comparison of Cloud-sliced O_3 to Ozonesondes





Comparison of Cloud-sliced O_3 to Ozonesondes

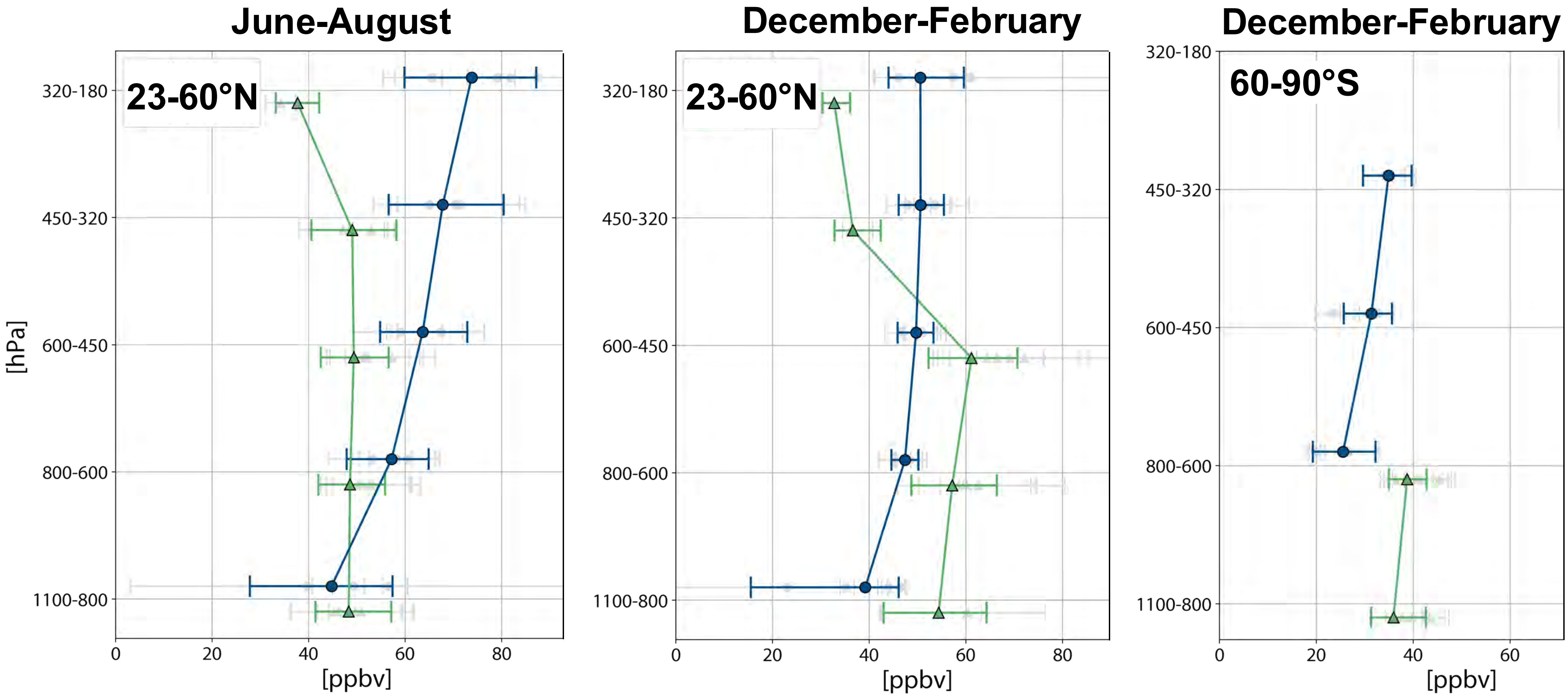
Examples of comparisons with good agreement (typically <5 ppbv difference)



Excellent agreement between cloud-sliced and ozonesonde O_3 in the tropics / subtropics

Comparison of Cloud-sliced O_3 to Ozonesondes

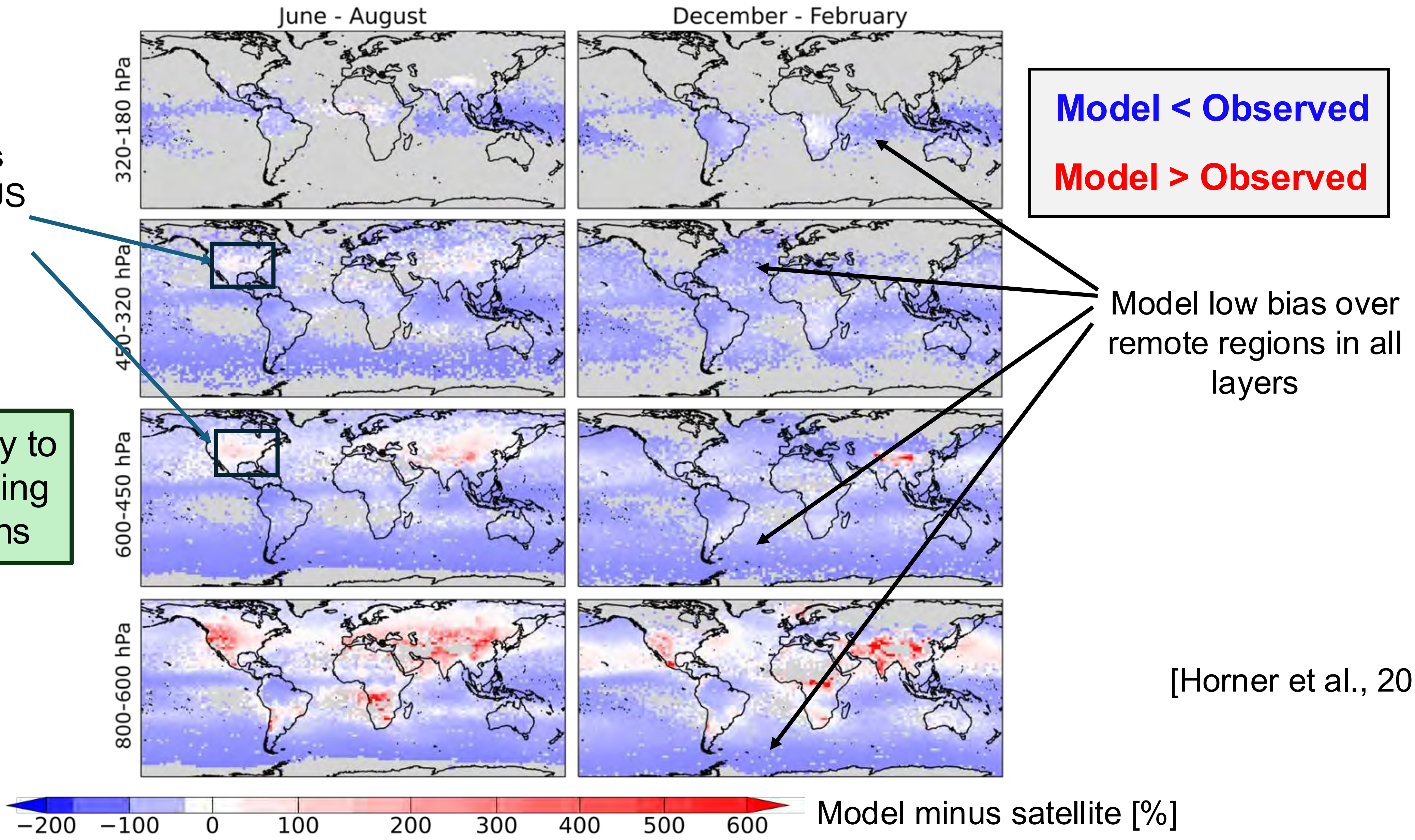
Examples of comparisons with large discrepancies (differences up to 30 ppbv)



Causes still under investigation, such as selection of latitudinal bands for comparison

Assess Contemporary Knowledge of Tropospheric NO_2

Assess best understanding of tropospheric NO_2 as simulated by the GEOS-Chem model



Work underway to improve lightning NO_x emissions

[Horner et al., 2024]

Take-home Messages

- Very promising method of addressing absence of routine vertically resolved tropospheric ozone and NO_2
- Encouraging consistency with independent observations (in situ for NO_2, sondes for ozone)
- Evaluation of GEOS-Chem model provides steer for future research
- All are LEO instruments. GEO would offer greater data density and ability to interrogate and understanding diurnal variability
- Need reliable, coincident, independent observations to validate cloud-sliced data

Links to Papers and Data:

Horner et al., ACP, 2024: https://acp.copernicus.org/articles/24/13047/2024/

Cloud-sliced vertical profiles of NO_2 data: https://doi.org/10.5522/04/25782336

Application beyond my group: Opacka et al., 2024:
https://egusphere.copernicus.org/preprints/2024/egusphere-2024-2912/

Past cloud-slicing papers:

Marais et al., ACP, 2018: https://acp.copernicus.org/articles/18/17017/2018/
Marais et al., AMT, 2021: https://amt.copernicus.org/articles/14/2389/2021/