Vertical profiles of global tropospheric nitrogen dioxide (NO_2) obtained via cloud-slicing TROPOMI partial columns

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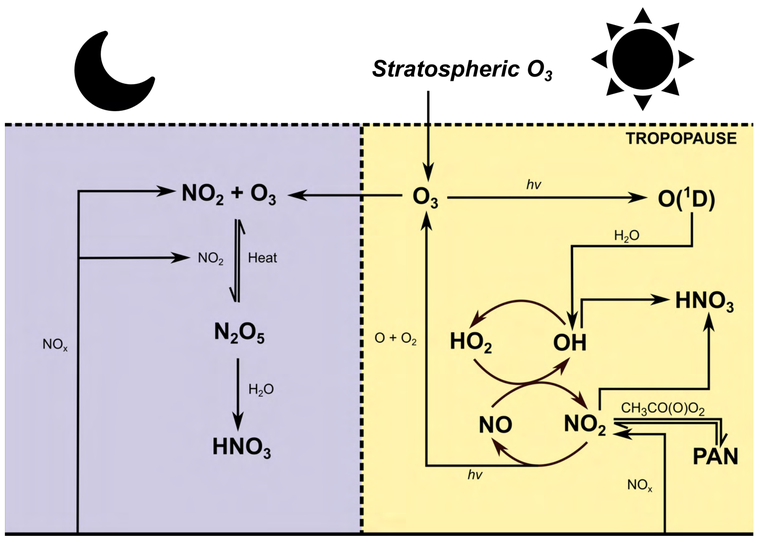
Major Finding: Cloud-slicing of TROPOMI NO_2 performs well globally between 320-800 hPa when compared to NASA DC-8 aircraft observations and GEOS-Chem underestimates by ~60% in this region of the troposphere.

1. Motivation

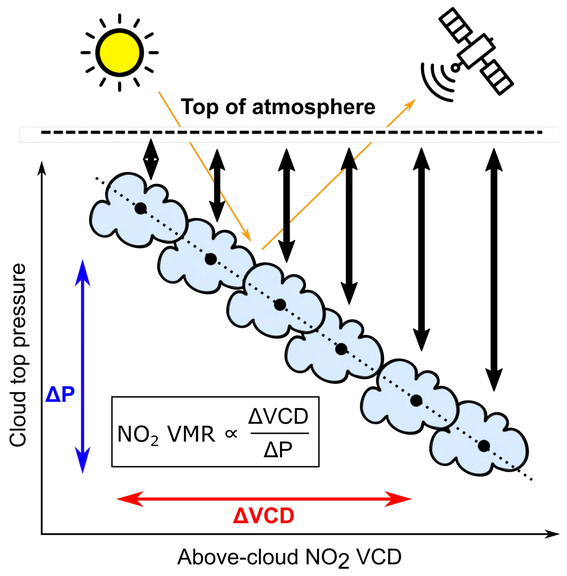
Cycle of NO_x in the troposphere during the day and at night



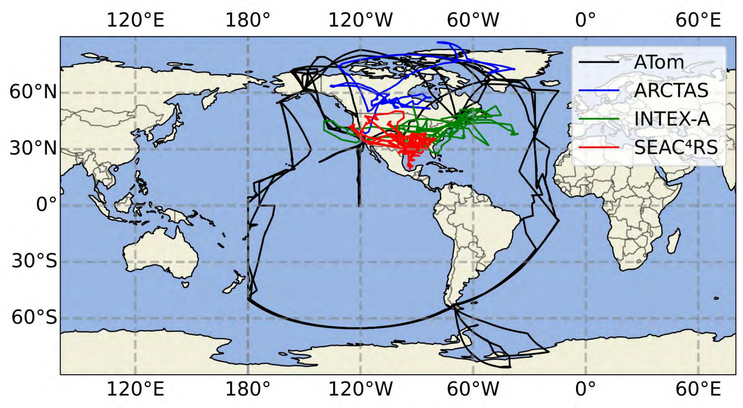
- Nitrogen oxides ($NO_x \equiv NO + NO_2$) are strongly linked to the formation of ozone (O_3) in the NO_x-limited regions of the troposphere.
- O_3 is a key contributor to the oxidation state of the atmosphere and maintaining the oxidation capacity of the troposphere.
- Well-mixed greenhouse gases have been responsible for a radiative forcing of 2.45 W/m² and O_3 is responsible for 26% of this.

2. The cloud-slicing technique

- The cloud-slicing technique was first used to derive upper tropospheric ozone measurements from the TOMS satellite instrument[1].
- This takes advantage of the optically thick clouds present in the troposphere.
- The NO_2 volume mixing ratio (VMR) is calculated using the relationship between the cloud top pressure and the vertical column density (VCD).
- This technique allows us to eliminate the contribution of the stratosphere.



3. NASA DC-8 aircraft campaigns



INTEX-A - Summer 2004

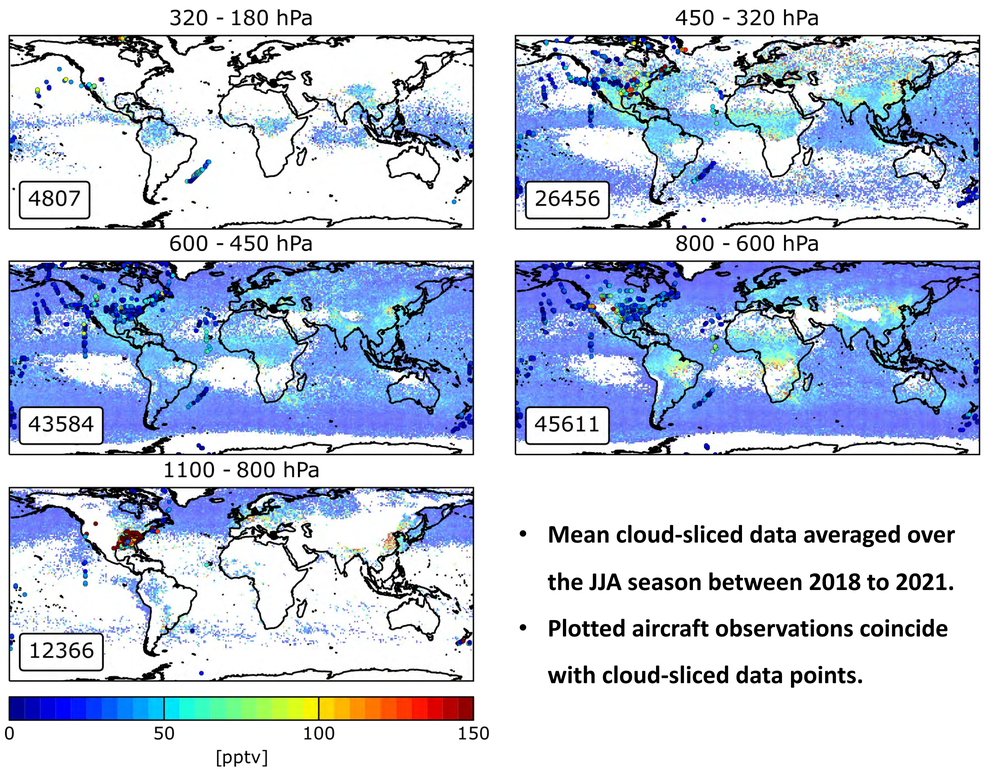
SEAC⁴RS - Summer 2013

ARCTAS – Spring & Summer 2008

- ATom-1 (Jul-Aug 2016)
- ATom-2 (Jan-Feb 2017)
- ATom-3 (Sep-Oct 2017)
- ATom-4 (Apr-May 2018)

4. Implementing the cloud-slicing technique between 180-1100 hPa

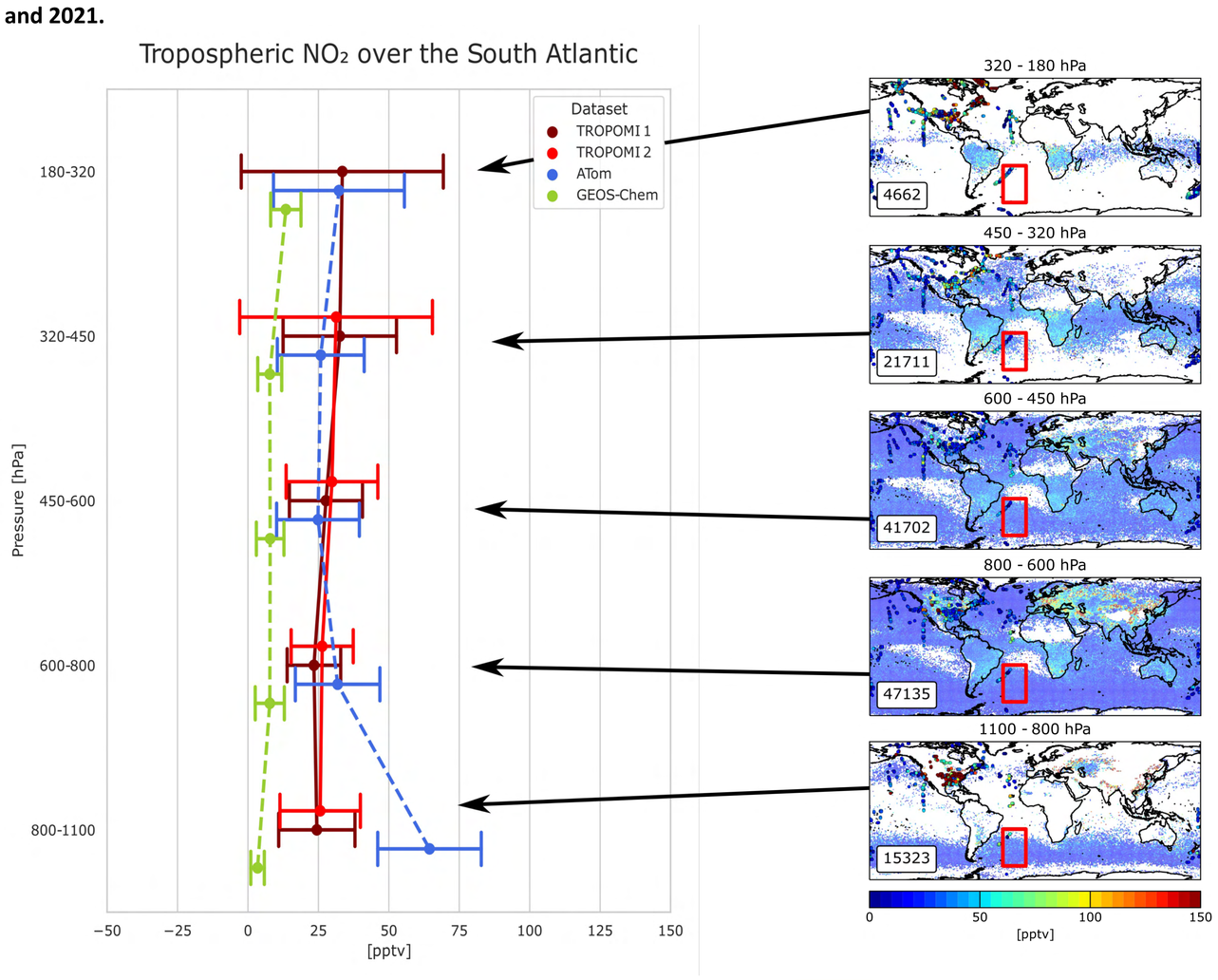
- Previous studies have used cloud-sliced OMI total columns of NO_2 to obtain NO_2 mixing ratios between 650-900 hPa[2] and between 280-450 hPa[3] as well as on TROPOMI measurements between 180-450 hPa[4].
- This has been expanded here using TROPOMI data at five pressure intervals between 180-1100 hPa and compared to measurements from the NASA DC-8 aircraft campaigns.



- Mean cloud-sliced data averaged over the JJA season between 2018 to 2021.
- Plotted aircraft observations coincide with cloud-sliced data points.

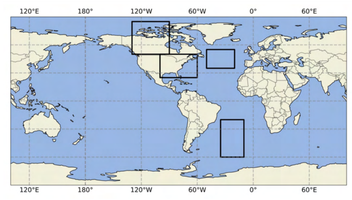
5. Creating vertical profiles of cloud-sliced NO_2 TROPOMI data

The mean of all the cloud-sliced data points within a given area is calculated and plotted to create a profile and the error bars represent the standard deviation. GEOS-Chem v13.3.4 is used at a resolution of 4° x 5°. GEOS-Chem simulations are shown here for the period DJF 2015/2016 and cloud-slicing observations averaged over the DJF season between 2018 and 2021.

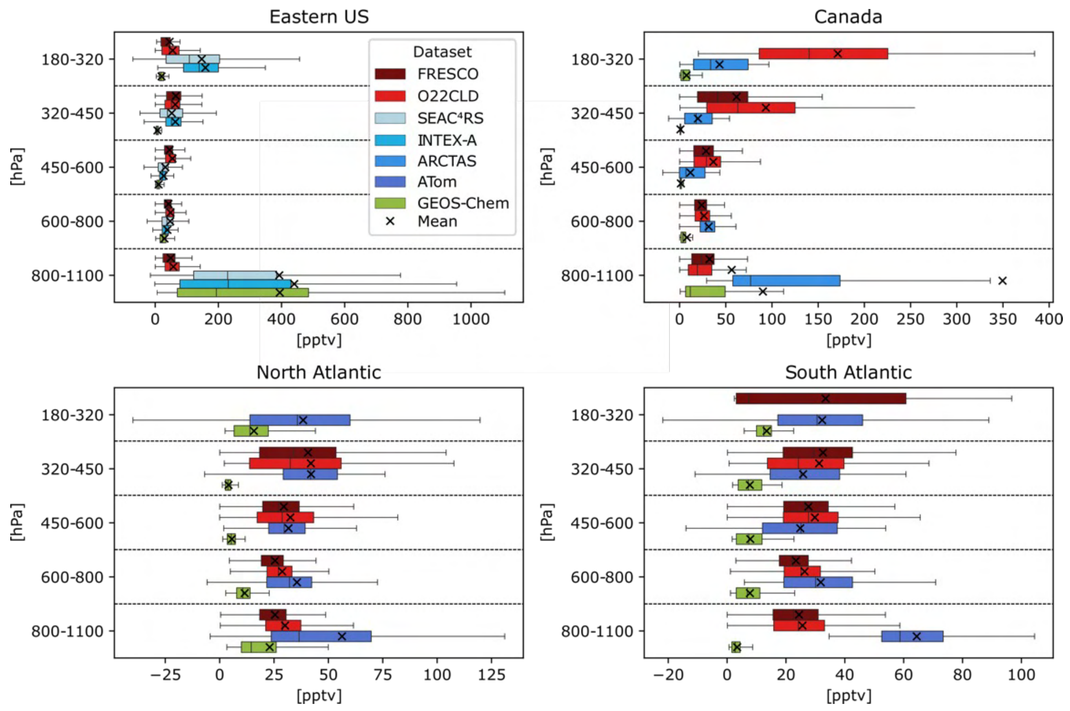


- TROPOMI 1: Uses cloud top height and cloud fraction information from the FRESCO product that minimises the difference between measured and simulated spectra in the O2 A-band between 752-766 nm.
- TROPOMI 2: Uses cloud top height and cloud fraction information from the O22CLD product that measures oxygen absorption in the O2-O2 band between 460-490 nm.

6. Comparing vertical profiles between different global regions



Mean and median cloud-sliced NO_2 data for summer 2018 to 2021 is shown here with the box plots representing the median value with the 5th, 25th, 75th and 95th percentiles.



- Concentrations of NO_2 deviate by less than 15% between cloud-slicing and aircraft observations in the mid-troposphere where data density is increased.
- Cloud-slicing results underestimate NO_2 concentrations compared to aircraft observations in the boundary layer where cloud-slicing is up to 300 pptv below aircraft observations.
- Differences of up to 150 pptv in the upper troposphere (320–180 hPa) may be due to the low sampling frequency here (see Box 3).

Next Steps

Explore the cause of inconsistencies in the boundary layer using AMF data and evaluating the correlation between ΔVCD and ΔP. Apply cloud-slicing to the OMPS instrument, as OMPS missions are sustained to 2040.

Acknowledgements

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References

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[2] Choi et al., ACP, https://doi.org/10.5194/acp-14-10565-2014, 2014

[3] Marais et al., ACP, https://doi.org/10.5194/acp-18-17017-2018, 2018

[4] Marais et al., AMT, https://doi.org/10.5194/amt-14-2389-2021, 2021