C02 AirCore observations to constrain changes in stratospheric circulation

TPCHANGE

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Motivation

- Changes in Age of Air (AoA) reflect changes in overall transport in the stratosphere with impact on the UTLS region.
- CO_2 is a unique tracer as it carries short-term (seasonal cycle) and long-term (temporal increase) information, allowing to determine mean AoA.
- The Fractional Release factor (frf) describes which fraction of a trace gas entering the stratosphere has already been chemically broken down, i.e. has been released into other forms (in the case of methane this would be water vapour).
- Changing AoA and changes in fractional release of methane can influence trace gases, incl. water vapour in the UTLS with feedbacks on radiative transfer.

AirCore launch preparations

AirCore observations

- AirCore can be launched on small and inexpensive balloons.
- Good vertically resolved information on CH_4, CO_2 and CO from the ground to about 27 km altitude.
- Regular launches are possible from Frankfurt and an operational retrieval has been established.

Collaborations within TPChange

C07 We have used EMAC simulation results (including an artificial tracer especially implemented for the C02 project) during phase I. This collaboration, now using ICON, will be deepened in phase II with again special tracers related to methane and water vapour.

C03 The AoA and age spectra information and methane data along the AirCore trajectories provided by CLaMS will enable us to put the observations in a wider framework and to detrend the observations.

C09 We will collaborate with C09(N) on comparing mean age of air and fractional release from both AirCore and satellite data with the UA-ICON model to better constrain the model and to get a wider view of the composition of air downwelling into the ULTS.

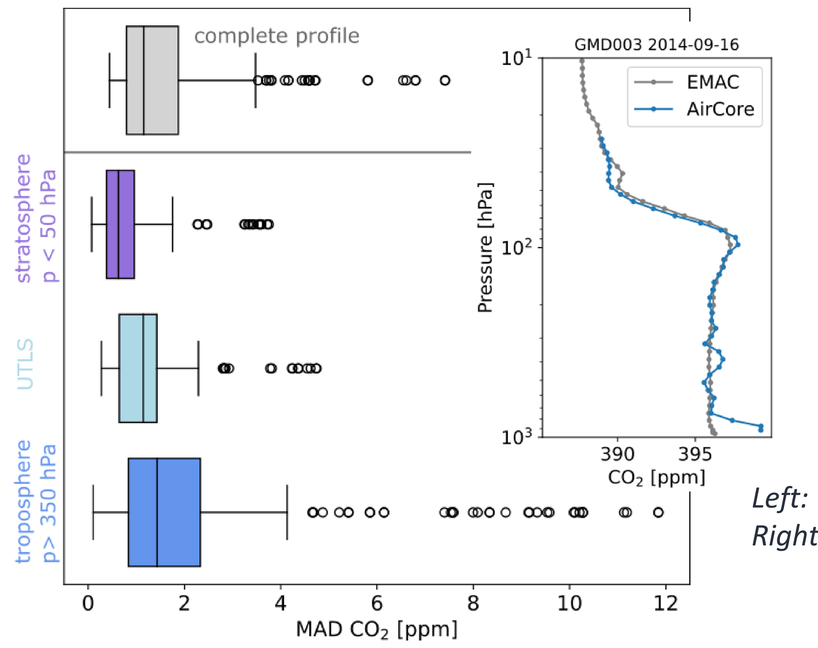
Contribution to TPChange synthesis

Z01 **Z03** Project C02 provides AirCore observations to Z01 and benefits from data harmonization efforts, including meteorological data interpolated to flight tracks (ERA5 reanalysis). The special tracers incorporated into the model will allow for a better model evaluation.

Results from phase I

We used a compilation of vertical trace gas profiles derived from balloon-based AirCore measurements with EMAC model data to investigate the distribution and variability of CO_2 in the UTLS (Degen et al., EGUsphere, 2025)

① based on profile comparisons we evaluated the EMAC model performance

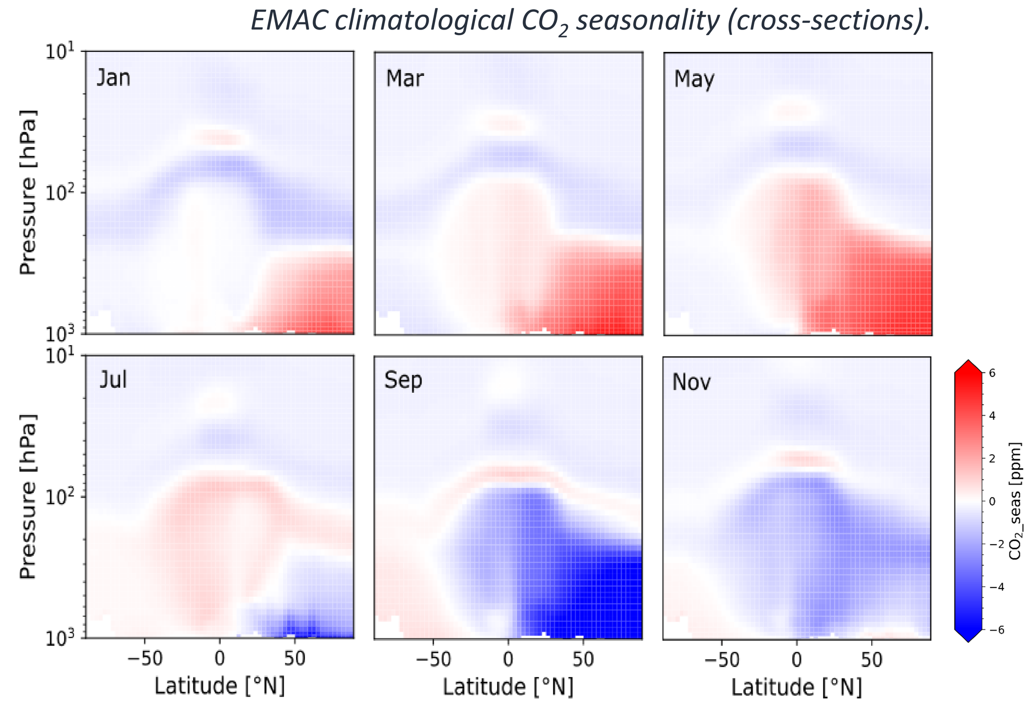


In most cases good agreement (75% of the profiles showed a MAD <1.8 ppm). Bigger structures are usually similar, but sometimes slightly shifted. Small-scale variations are not well-captured due to the different resolutions.

Left: Boxplot of MAD values from each profile (EMAC vs. AirCore) Right: Example comparison (flight 2014-09-16).

② the separation of the CO_2 seasonal cycle from transport contribution and long-term trend with artificial EMAC tracers allowed us to investigate how the CO_2 seasonal signal is propagated from the troposphere into the LMS. From those insights we formulated implications on large-scale transport processes and time scales.

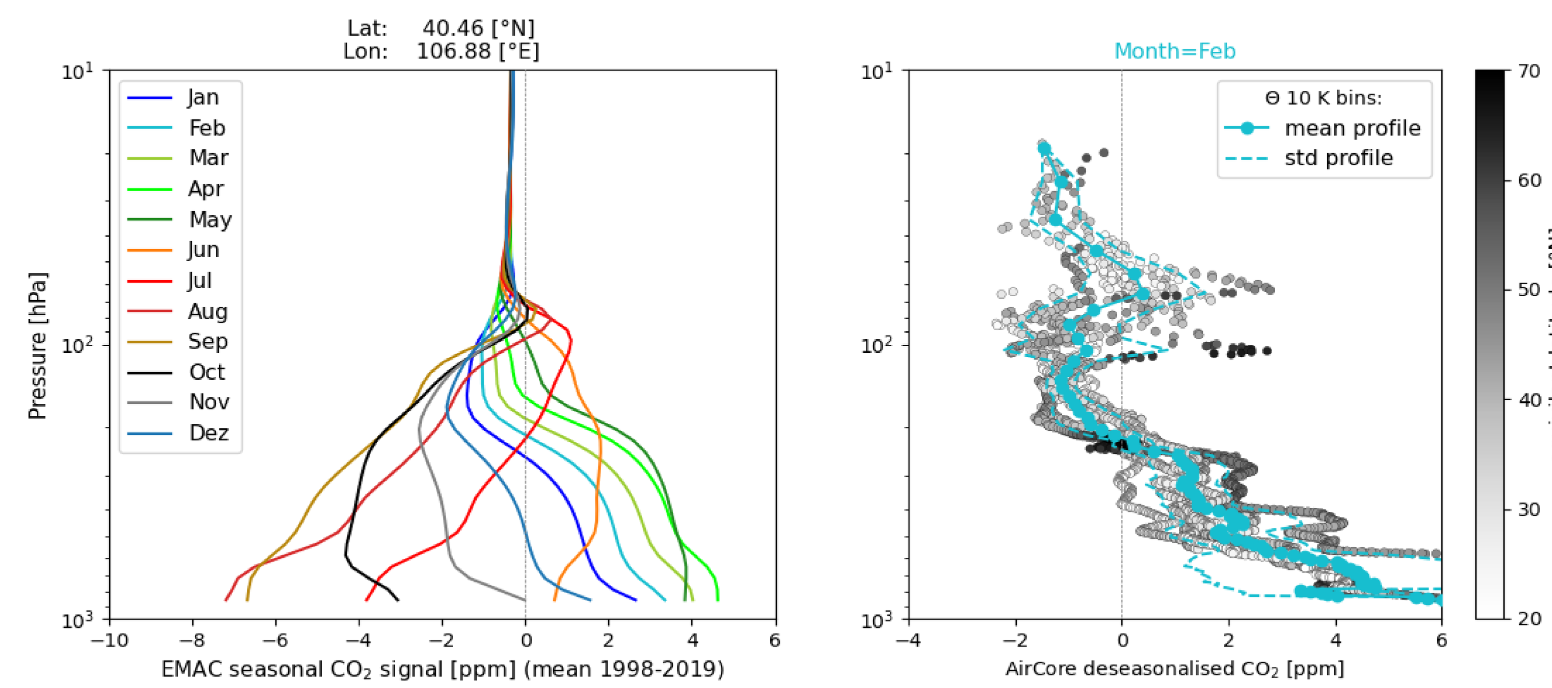
EMAC climatological CO_2 seasonality (cross-sections).



Strong modulation of CO_2_seas occurs in the extra-tropics in the UTLS, characterized by a shift, dampening and tilt. (STJ)

In the stratosphere, we identified both, a vertical and a horizontal 'tape recorder' of the CO_2 seasonal cycle. (BDC)

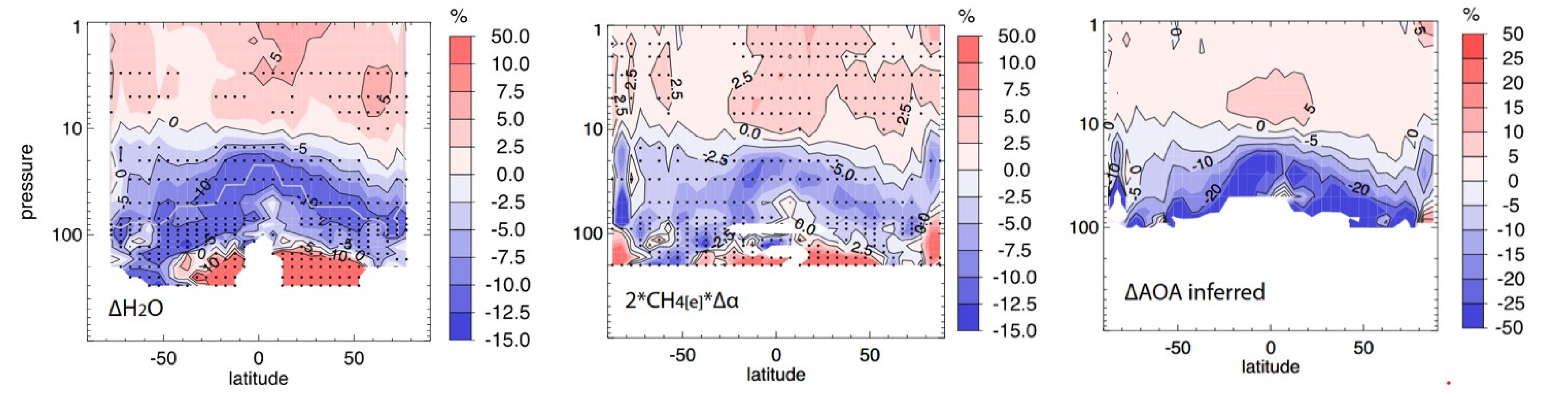
③ using a statistical approach, we checked if existing AirCore data are sufficient to resolve and to constrain CO_2 seasonality.



EMAC NH mid-latitudes CO_2 seasonal signal vertical profiles (left). Deseasonalised CO_2 from AirCore for February (right).

Research plan phase II

Main goal: Investigate if fractional release of methane shows spatial variations or a long-term trend and assess impact on stratospheric water vapour.

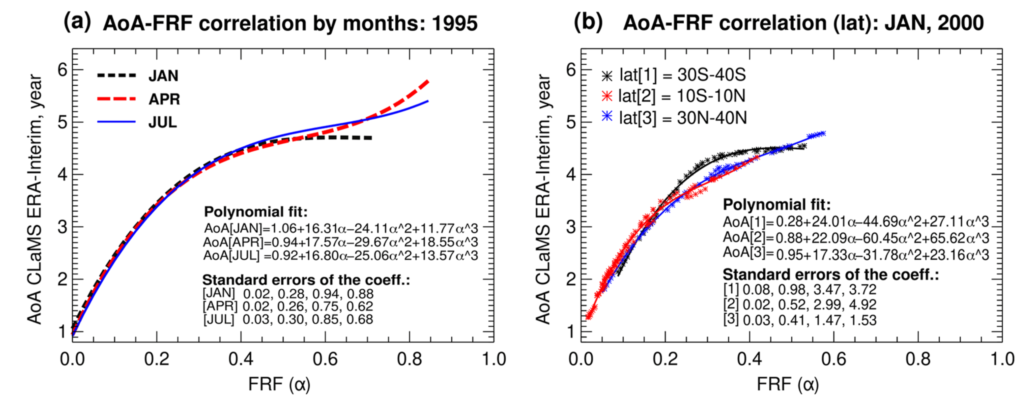


Left: Changes in water vapour derived from merged satellite data set; middle: inferred contribution due to change in tropospheric Methane; right: inferred changes in Age of Air. (from Hegglin et al., 2014).

Research question

- Does H_2O show a decreasing trend in the lower stratosphere and an increasing trend in the middle to upper stratosphere due to changes in circulation? Based on approach suggested by Hegglin et al., 2014.
- **BUT:** Hegglin et al., did not have simultaneous observations of methane and mean AoA. Needed to assume an unchanged relation between mean AoA and frf of methane. This is not necessarily the case (Poshyvailo-Strube, et al. 2022). Combined mean AoA and frf data are now available from AirCore (e.g. Engel et al. 2017) and from ACE-FTS (Saunders et al., ACP, 2025).

Right: The relation between mean AoA and frf from model calculations (CLaMS). This is not necessarily constant in either space or time. From Poshyvailo-Strube, et al. (2022).



Our approach

- Continue bi-monthly AirCore starts to take full advantage of the now established measurements and growing database.
- Combine with global satellite observations (ACE-FTS)
- Investigate trends and variability in relation between mean AoA and frf.
- Assess potential impact on water vapour trends in the lower stratosphere.