Composition of air and its seasonality within the TTL: Impact of the Asian monsoon.

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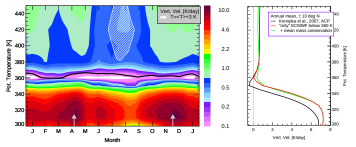
Abstract

Multi-annual simulations with the Chemical Model of the Stratosphere (CLaMS) are used to study transport of air and the seasonality of its composition within the tropical tropopause layer (TTL). In agreement with satellite and in-situ observations, CLaMS simulations show a pronounced seasonal cycle in CO and O_3 and, in addition, in the mean age. Below the zero clear sky heating rate level (Q=0) around 360 K potential temperature, the semi-annual cycle of convection, with strongest upwelling around April and November, determines the composition of the TTL. Although above this level, the contribution of photochemistry modulated by the annual cycle of the Brewer-Dobson circulation increases with altitude, the seasonality of O_3 and CO is overlaid by a clear annual and a weak semi-annual cycle of horizontal in-mixing from the stratosphere into the TTL. The strongest in-mixing occurs from the northern hemisphere during the boreal summer. Both, CLaMS simulations and pure trajectory calculations show that this equatorward transport is mainly driven by the Asian monsoon anticyclone.

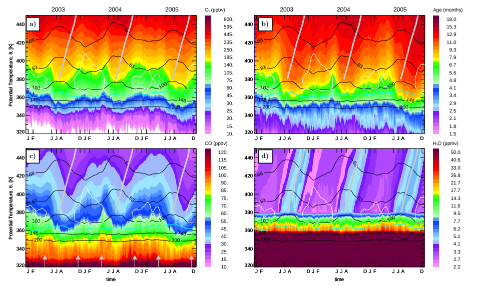
CLaMS Simulations

Multi-annual, global CLaMS simulations of the whole troposphere and stratosphere (from the ground up to $\theta = 2500$ K) follow the model set-up described by Konopka et al., 2007, and cover the time period from October 2001 to December 2005 with 100 km horizontal resolution and the highest vertical resolution of 400 m around $\theta = 380$ K. The horizontal winds are driven by the European Centre for Medium-Range Weather Forecast (ECMWF) analysis.



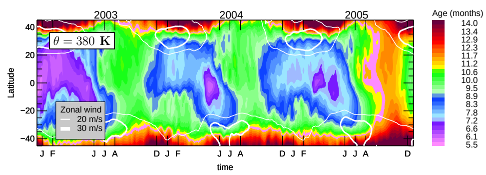
Seasonality of the upwelling in CLaMS described in term of the hybrid vertical velocity ζ averaged zonally and within the $\pm 10°$N range during the 2002-05 period. Below and above $\theta = 360$ K, ζ is derived from the ECMWF vertical velocity and from the clear sky radiation, respectively. In the white dashed regions, stratosphere is warmer by at least 3K compared to the annual average. Right: The corresponding annual mean (red) compared with the version described in Konopka et al., 2007, (black). The green line was derived from winds corrected in order to fulfill the annually averaged mass conservation.

Tape-Recorder in CLaMS Simulations



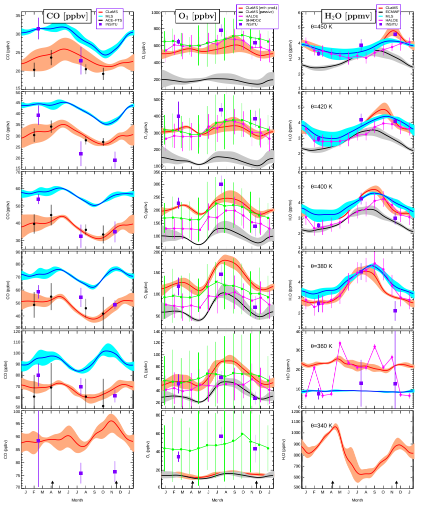
From a) to d): Time series of CLaMS O_3, mean age, CO and H_2O averaged zonally and within the $\pm 10°$N latitude range as function of θ. Black lines are the isobars. Above and below the blue lines ($Q = 0$), the upward transport is driven by radiation and convection, respectively. The thick gray lines denote the moist phase of the tape-recorder signal as derived from the HALOE climatology (annual cycle). The gray arrows in the CO plot approximate the semi-annual cycle of convection.

In-mixing



Mean age (relative to the boundary layer) at $\theta = 380$ K as calculated with CLaMS.Cross equatorial transport from the Asian monsoon anticyclone dominates latitudes lower then 15°N where easterly jet prevails at the southern edge of the monsoon anticyclone.

CLaMS versus Observations



Seasonal CLaMS time series of CO (left, red), O_3 and pO_3 (middle, red and black) and H_2O (right, red) at θ-levels 450, 420, 400, 380, 360 and 340 K (from top to bottom) versus HALOE (pink) MLS (blue) ACE-FTS (black circles) SHADOZ (green circles) and the in situ observation on board the high altitude Russian aircraft, Geophysica (violett squares). Below $\theta = 380$ K, CLaMS H_2O (red) is set to the assimilated ECMWF water vapor. The dashed regions describe the year-to-year variability, the vertical lines denote the standard deviations with exception of the SHADOZ data where total variability between the considered 7 stations is shown.

Conclusions

- Seasonal variability of O3/CO/mean age (in the TTL) can be understood as a superposition of the following cycles:
  1. below ≈ 360 K: semi-annual cycle, with strongest upwelling in April and November (mainly over Africa/Amazon and Western Pacific regions, Liu et al., GRL, 2007)
  2. $360 < \theta < 400$ K: annual cycle of the vertical velocity that responds to the well-known annual cycle of the temperature with enhanced upwelling during the boreal winter.
  3. $360 < \theta < 400$ K: annual cycle of horizontal in-mixing from the northern hemisphere stratosphere into the TTL
  4. $360 < \theta < 450$ K: weak semi-annual cycles of upwelling and in-mixing
  5. $\theta > 400K$ semi-annual cycle of the photo-chemistry
- during the boreal summer, ≈12-25% of the air in the TTL originates from the sub- and extra-tropics.

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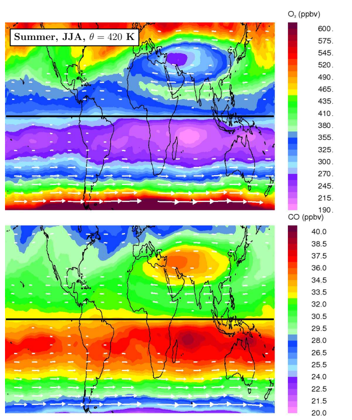
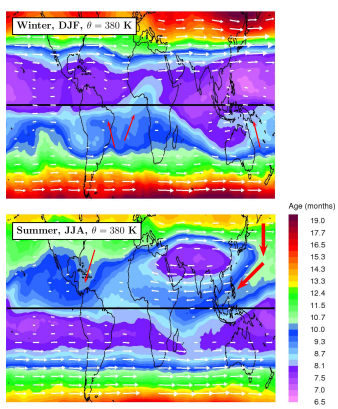
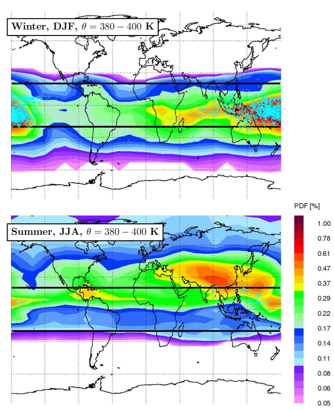
In-mixing and the Asian Monsoon Anticyclone



Mean distributions of O_3 (top) and CO (bottom) as calculated with CLaMS during the summer (JJA, 2004) at $\theta = 420$ K indicates that the Asian monsoon anticyclone strongly isolates the air masses with tropospheric character within the anticyclone from the air masses with stratospheric character outside.



Mean age as calculated with CLaMS during the winter (DJF, top) and summer (JJA, bottom) at $\theta = 380$ K. The red arrows indicate the region of isentropic in-mixing. The thick red arrows illustrate the main direction of in-mixing triggered by the Asian monsoon anticyclone.



PDFs of the 3 month backward trajectory positions starting from September 1, 2004 (top) and March 1, 2004 (bottom) within the TTL.

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