Investigating the UTLS: ECHAM5/MESSy and comparisons with airborne observations

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1. Introduction:

Modelling of trace gas distributions in the UTLS-region provides a challenging task since the underlying transport processes span the range from subgrid to large scale dynamics. Here we present the results of simulations with the new chemistry circulation model ECHAM5/MESSy1.1 with 90 vertical levels from the surface up to 80 km providing a vertical resolution of about 600m in the UTLS-region.

A detailed comparison with in-situ data obtained during SPURT shows a good agreement between the model results and the observations. Although transport from the upper tropical tropopause into the extratropical lowermost stratosphere seems to be overestimated in the model, the distribution of CO is captured well. In particular the model is able to reproduce the structure of the vertical CO-profiles relative to the tropopause as well as slope changes in the correlation between ozone and CO. Both findings indicate that the underlying transport processes across the extratropical tropopause qualitatively are captured right by the model, which is crucial for a better quantification of stratosphere-troposphere-exchange.

2. The Modular Earth Submodel System (MESSy)

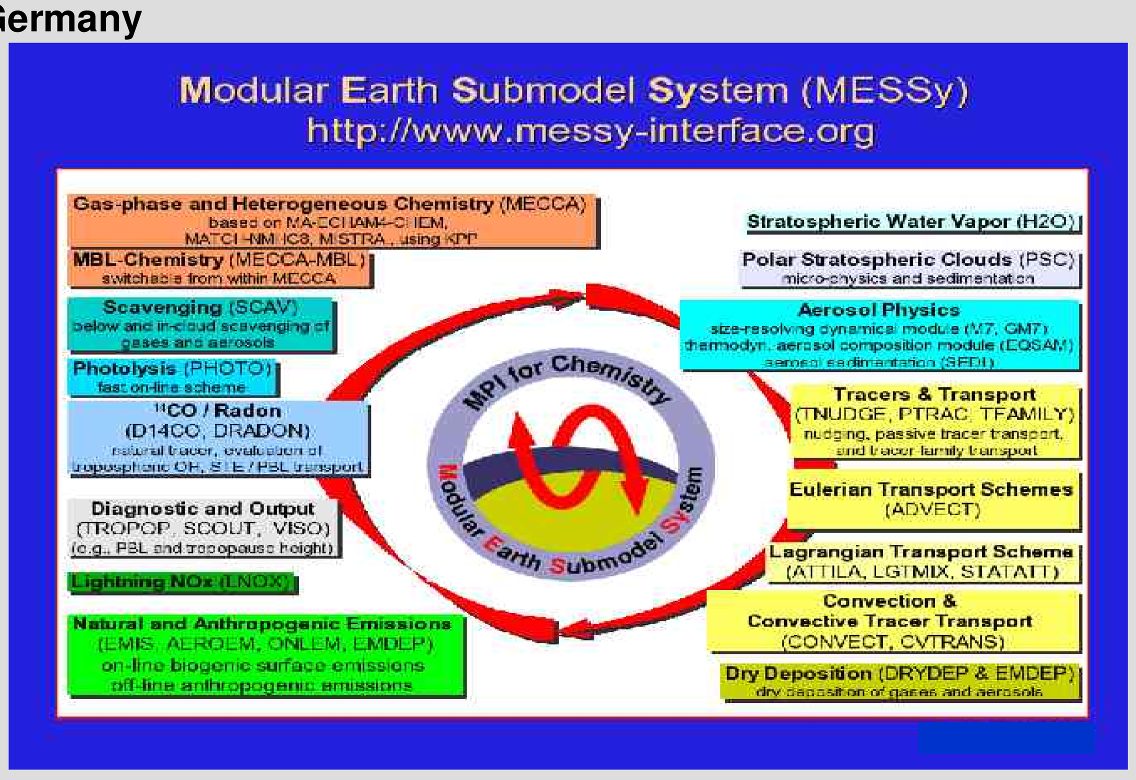
developed at

Max Planck Institute for Chemistry, Mainz, Germany

in collaboration with

Max Planck Institute for Meteorology, Hamburg, Germany

DLR Institute for Physics of the Atmosphere, Oberpfaffenhofen, Germany



Overview over MESSy with its various submodels. The dynamical core is the ECHAM5, which was used in free running mode for the current run. Highlighted are the submodels, which were used for the data on display. The resolution was T42 with 90 levels spanning from 0-80km with a vertical spacing of ~ 600m in the UTLS region. The model was nudged in the troposphere up to 200hPa using 6-hourly ECMWF operational data.

Further information on MESSy:

Jöckel, P. et al.: Technical Note: The Modular Earth Submodel System (MESSy) - a new approach towards Earth System Modeling, Atmos. Chem., Phys.,5, 433-444, 2005.

Jöckel P. et al.: The atmospheric chemistry general circulation model ECHAM5/MESSy1.1: consistent simulation of ozone from the surface to the mesosphere, Atmos. Chem. Phys. Disc., 6, 6957-7050, 2006.

Further information on ECHAM5:

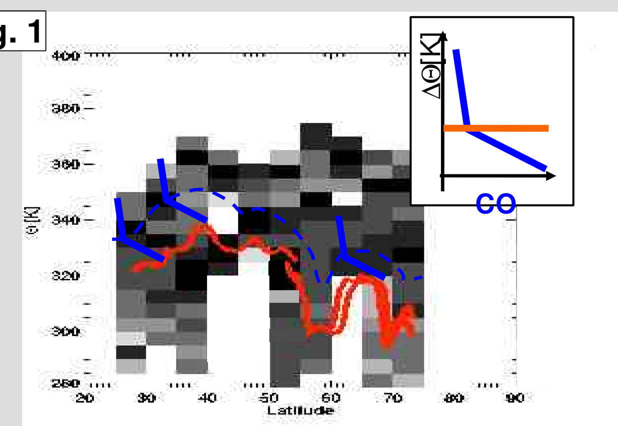
http://www.mpimet.mpg.de/en/extra/models/echam/echam5.php

Giorgetta, M. et al., Climatology and forcing of the quasi-biennal oscillation in the ECHAM5 model, J. Climate, 2005

3. Comparing model and observations: Vertical profiles

During the SPURT project a set of eight airborne in-situ measurement campaigns were performed between Nov 2001 and July 2003 in the tropopause region over Europe. Each campaign covered the region from approximately 30° N to 80°N and the local tropopause up to maximum potential temperatures of Θ≈375 K.

Fig. 1



We found that vertical profiles of CO exhibit compact vertical gradients within the lowermost stratosphere when using potential temperature relative to the local tropopause as vertical coordinate (Fig.2a). This implies a mixing layer which mainly follows the extratropical tropopause rather than isentropes (See **Fig.1**, dashed blue line)

Fig. 2a SPURT: Measurements
Fig. 2b ECHAM5/MESSy:

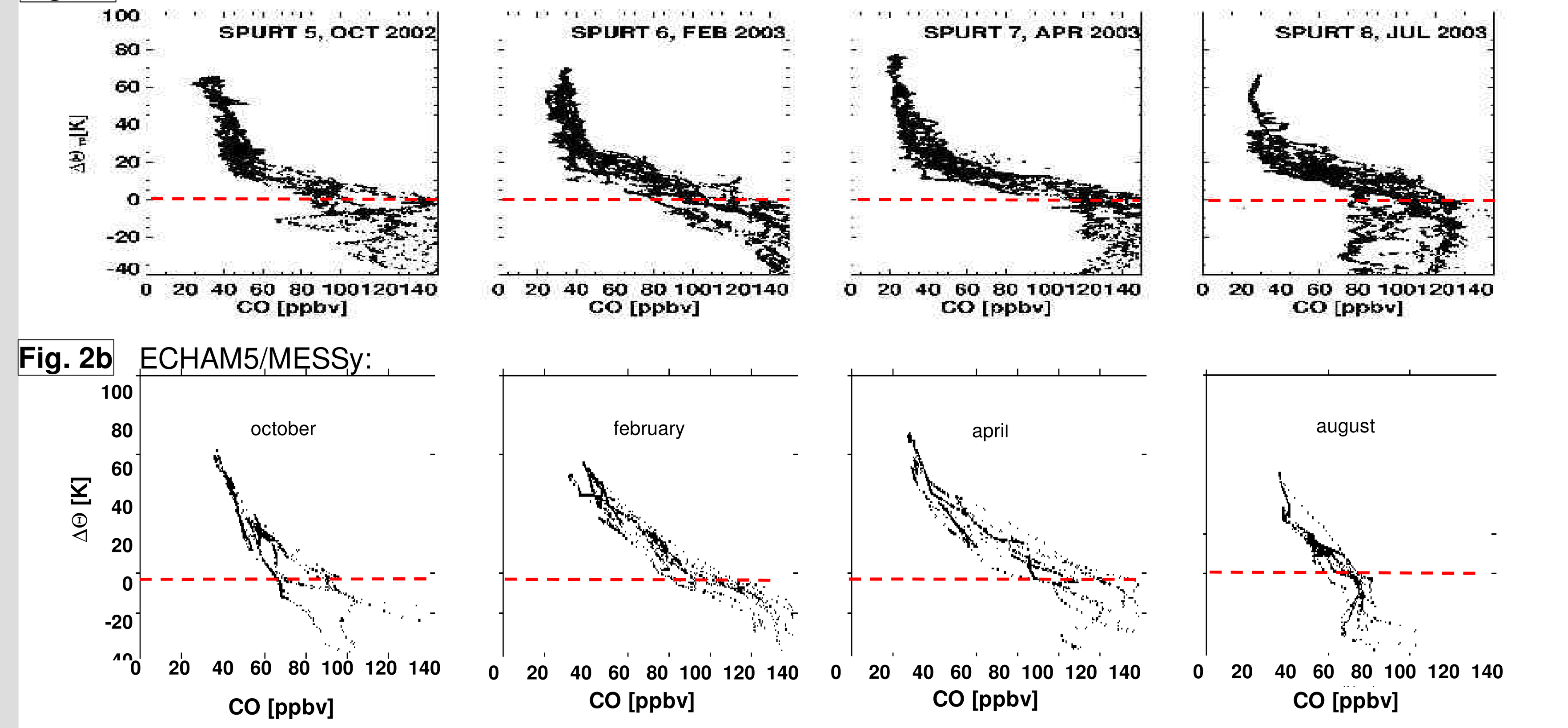


Fig.2: Measured (upper figures) and modelled CO distributions of CO as a function of ΔΘ [K] (ΔΘ [K] =potential temperature relative to the dynamical tropopause (2 PVU)).
The modeled CO profiles exhibit a similar overall structure like the measurements with decreasing CO-values above the local tropopopause accompanied with large variations at a given ΔΘ[K]-level. At higher altitudes the small variations and the lower absolute CO-values indicate less tropospheric influence within the lifetime of CO (~2 - 3 months). In the model the transition between both regimes is less pronounced and appears at higher altitudes than the sharp transition in the observed profiles.

4. Comparing model and observations: The CO-O_3 relation and mixing in the lowermost stratosphere

Fig. 3

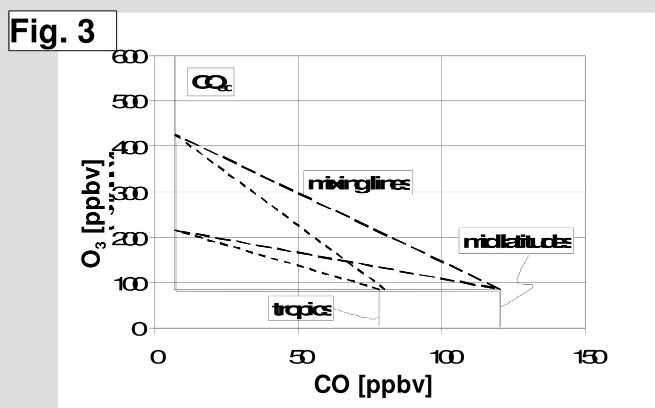


Fig.3: Idealized `L- shaped' CO-O_3 relation in the LMS in the absence of cross tropopause mixing in the extratropics. Transport and mixing of tropospheric air into the stratosphere leads to the formation of mixing lines.

Fig. 4

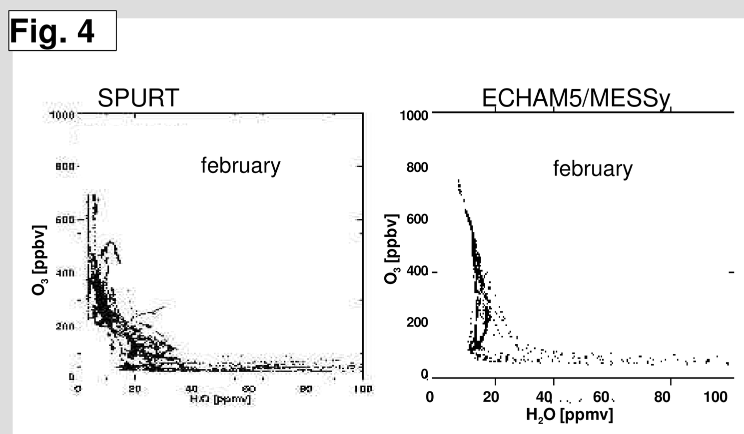


Fig.4: H_2O-O_3 correlation. Note the elevated H_2O at high ozone levels in the observations as well as in the model results mixing across the extratropical tropopause.

Fig. 5a SPURT measurements: 10°W-10°E, 35-80°N, Θ< 380 K, 2 days
Fig. 5b E5M1 along SPURT flight tracks

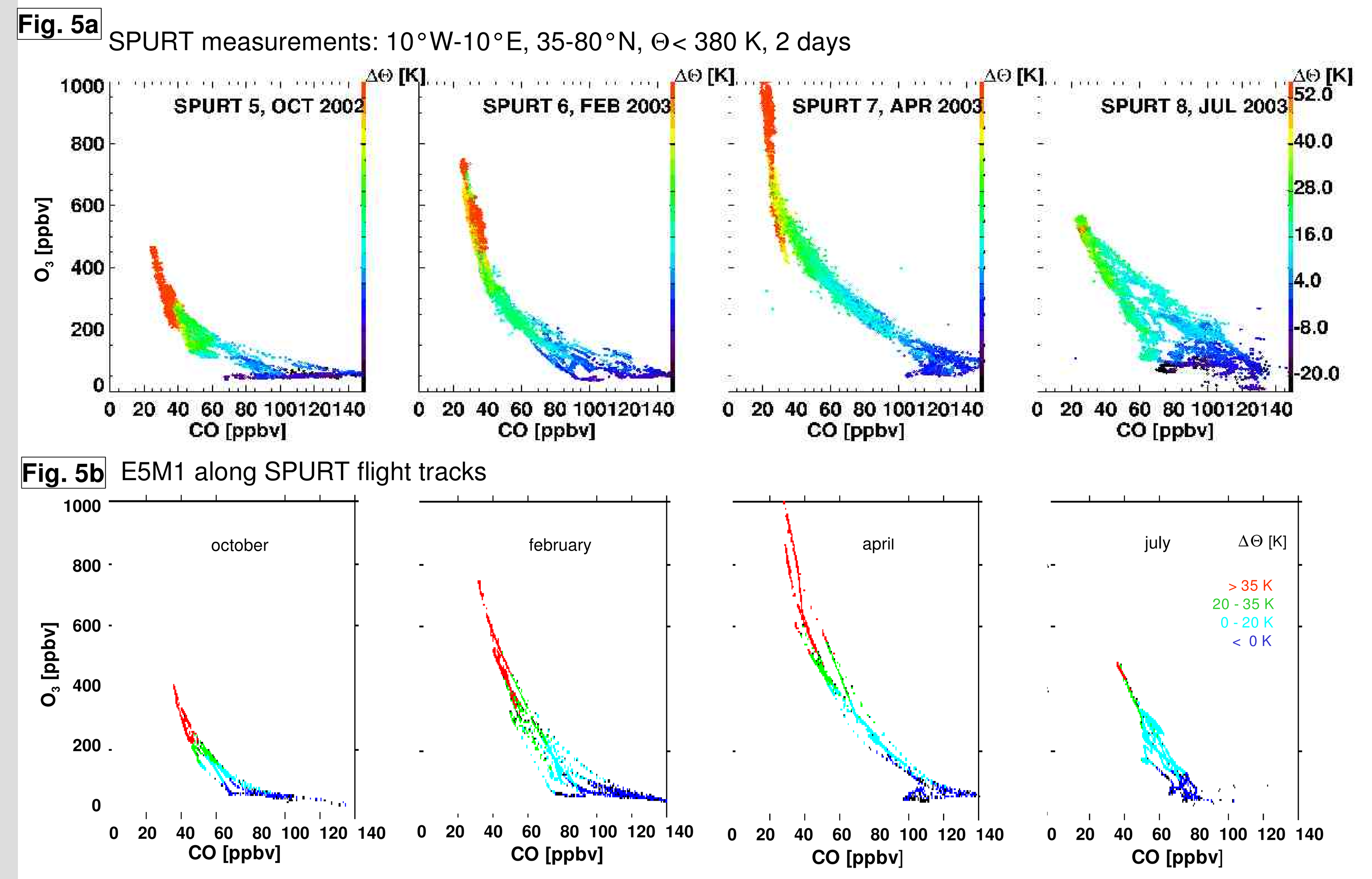


Fig.5: Observed (a) and modelled (b) CO-O_3 relation in the LMS, colors according to ΔΘ The model agrees well with the observations in particular for summer and autumn. The modelled mixing region extends to higher altitudes above the local tropopause (color code) in agreement with the larger transition zone of the CO profiles in Figure 2.

5. The winter case: Source regions

Fig. 6

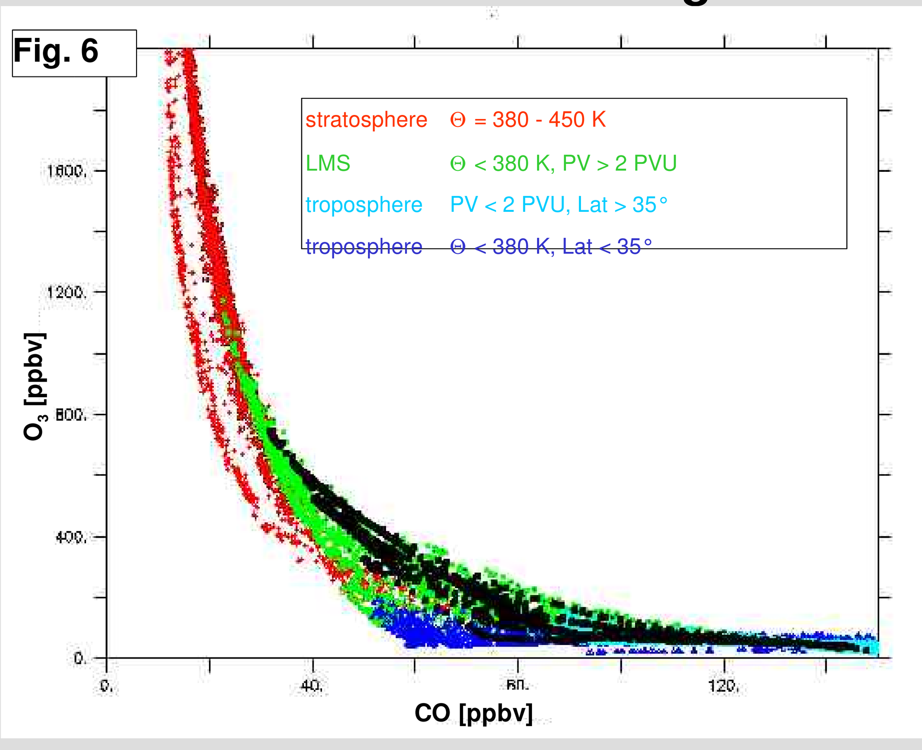


Fig 6.: Model data along 0w for two days during the SPURT6 (Feb. 2003) campaign vertically extended to Θ=450K.

The region between Θ= 380 - 450 K exhibits a compact relation between CO and O_3 from the equator to the pole (red). The large variations of CO are characteristic for the lowermost stratosphere (green) and connect the extratropical troposphere (light blue) and the tropical troposphere (dark blue) with the stratospheric correlation (red). **Black** are the measurements

Fig. 7

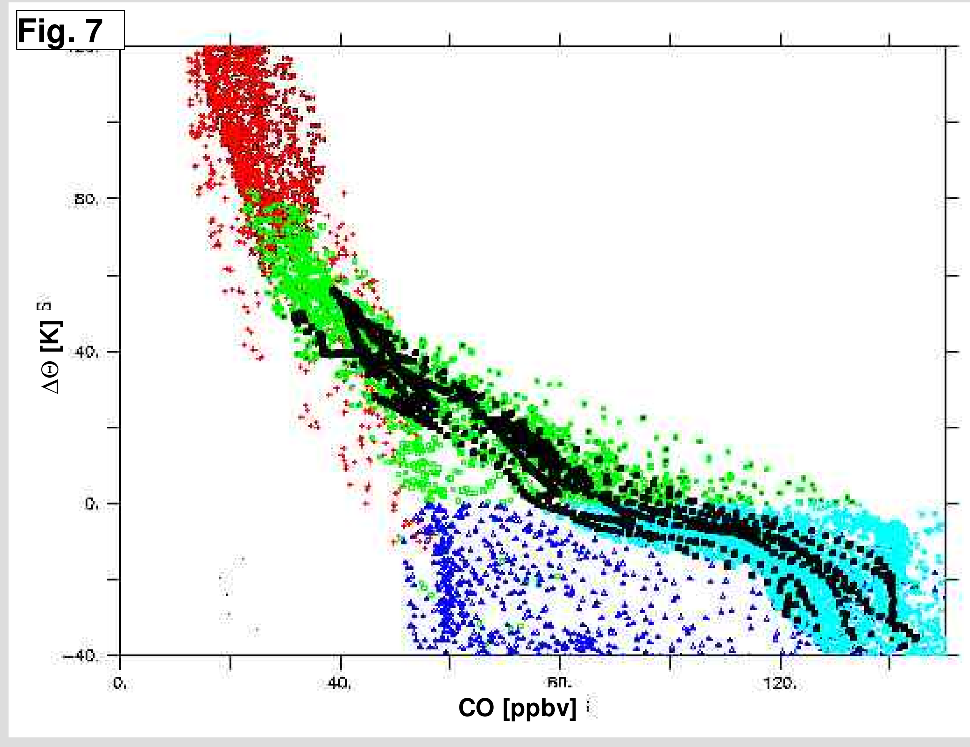


Fig. 7) Same data as in Fig.6 but as a function of ΔΘ Modelled CO values along the flight track connect the extratropical troposphere and the lowermost stratosphere indicating cross tropopause mixing mainly from the extratropics.
Note that the vertical CO gradient changes at ΔΘ~50K or Θ≈380K (green) indicating too strong mixing from the extratropics into the lowermost stratosphere. The measurements indicate the "kink" at ΔΘ~25 K (compare Fig. 2).

Fig. 8

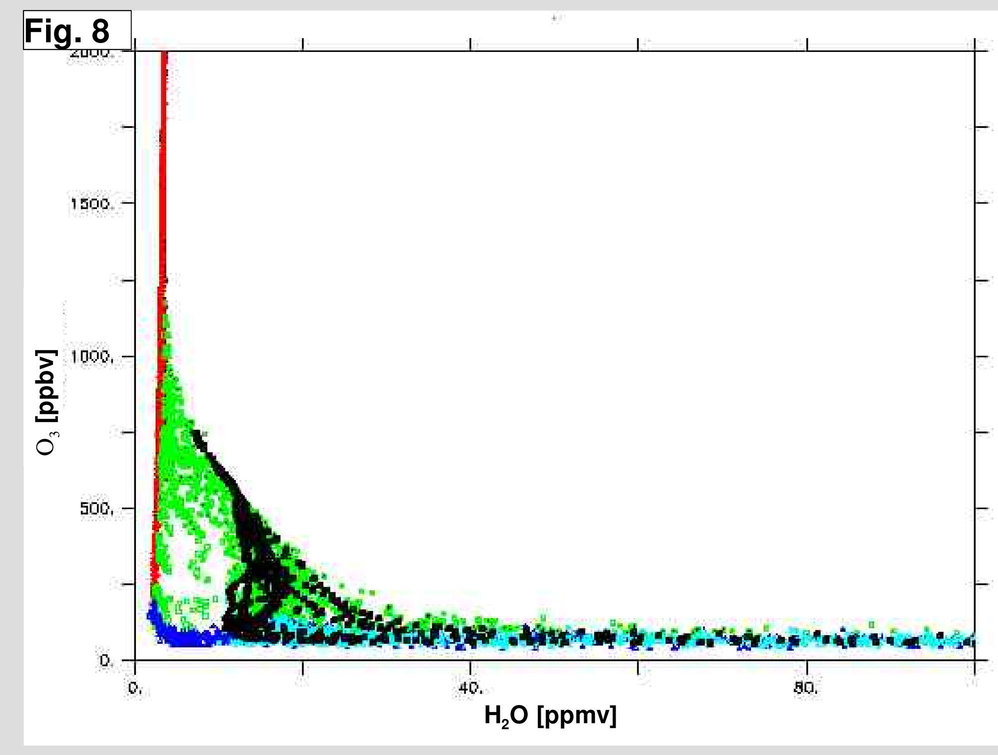


Fig. 8) Same domain and colour code as in Fig.6 but for H_2O and O_3.
The extratropical lowermost stratosphere is strongly influenced by mixing as indicated by enhanced water (green).
However, mixing is too strong since water vapor with mixing ratios < 10 ppmv are not found in the modelled LMS indicating too much moisture.
The measurements indicate that both, very dry air of tropical origin and enhanced water vapour from the extratropics contribute to the composition of the LMS (compare Fig. 4)

Conclusions and Outlook

The comparison between ECHAM5/MESSy and observations shows that the model is able to rproduce the overall structure of CO in the lowermost stratosphere. In particular the modelled vertical profiles of CO relative to the local tropopause are in reasonable agreement with the observations. The correlations between CO and O_3 as well as water vapor are reproduced very well indicating that the modell is able to reproduce the mixing layer in the lowermost stratosphere.

Using the the CO-O_3 correlation to investigate possible processes it turns out, that the model tends to overestimate the mixing from the extratropical troposphere into the lowermost stratosphere. Low H2O background values indicative for air from the tropical tropopause are rarely found in the model. Enhanced CO well above the stratospheric background as well as above the observations indivate that the fraction of aged stratospheric air is slightly underestimated in the model UTLS.