Convective transport and mixing processes in the tropical tropopause region during TROCCINOX

JOHANN WOLFGANG GOETHE UNIVERSITÄT FRANKFURT AM MAIN

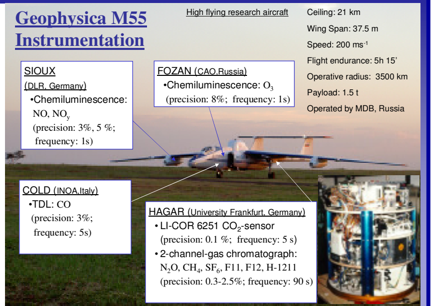
J. Baehr (1), C.M. Volk (1), A.C. Kuhn (1), S. Viciani (2), A. Ulanovski (3), F. Ravegnani (4), H. Schlager (5), P. Konopka (6), A. Stohl (7)

[1] Institut für Atmosphäre und Umwelt, J.W. Goethe-Universität Frankfurt, Germany. [2] Instituto Nazionale di Ottica Applicata (INOA), Florence, Italy [3] Central Aerological Observatory, Dolgoprudny, Russia [4] Institute of Atmospheric Science and Climate (CNR-ISAC), Bologna, Italy [5] Institut für Physik der Atmosphäre, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Oberpfaffenhofen, Germany, [6] Forschungszentrum Jülich, Germany, [7] Norwegian Institute for Air Research (NILU), Dept. Regional and Global Pollution Issues, Kjeller, Norway.

email: J.Baehr@meteor.uni-frankfurt.de homepage: www.meteor.uni-frankfurt.de and http://www.pa.op.dlr.de/troccinox/

Introduction

Mixing is essential in transporting air from its main convective outflow region at the bottom of the tropical tropopause layer (TTL) to higher TTL levels where slow ascent begins and lifts the air to the stratosphere. The analysis of constituent transport in the TTL was one of the main objectives of the second TROCCINOX aircraft campaign in February/ March 2005. Deep convection and mixing processes can be diagnosed by observations of CO, CO_2, O_3 and nitrogen oxides. These tracers were measured on board of the high flying aircraft M55 Geophysica operating from Aracatuba, Brazil (21 °S, 50 °W) (instrumentation see **Fig.1** →).



Mixing of Convectively Transported air in the TTL

Vertical mixing is essential in lifting convectively detraining air to altitudes above its original neutral buoyancy level, which is rarely above 350 K (~ 13 km). This lifting can be achieved if convectively overshooting air mixes irreversibly with its surroundings, thus increasing its potential temperature.

CO and CO_2 serve as tracers for uplifted boundary layer air whereas O_3 can be used as stratospheric tracer (high values). The boundary layer over Aracatuba exhibits relatively clean air. CO mixing ratios as measured from the Falcon (not shown) average to about 110 nmol/mol CO, while CO_2 as measured by the Geophysica is depleted in the local boundary layer due to photosynthetic uptake by vegetation. Low CO_2 and high CO signatures in the TTL (lower boundary ~13 km corresponding to Θ =~350 K) demonstrate the influence of convection above 13 km.

In tracer correlations plots mixing manifests itself as linear mixing lines (or bands e.g. red symbols of flight February 4 in Figure 2a). The O_3-CO and O_3-CO_2 correlations clearly show such mixing bands connecting tropospheric air (low O_3, high CO, low CO_2) with upper TTL background air (370-390K, see Figure 2b).

Figure 1 a) highlights mixing bands observed for the thunderstorm chase day on February 4 as well as for the eastbound survey flight on February 12. These events will be examined in more detail in the following case studies.

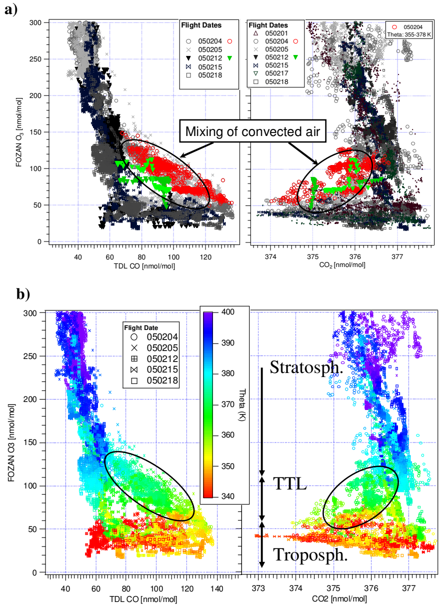


Fig. 2: **(a)** O_3-CO (left) and O_3-CO_2 (right) correlations of all flights. Coloured symbols indicate mixing regions for the local convection flight on February 4 (red circles) as well as for the eastbound survey flight on February 12 observed during the dive at 42°W (green triangles)

(b) as above colour coded by potential temperature (Θ).

Active (Local) Convection on February 4, 2005

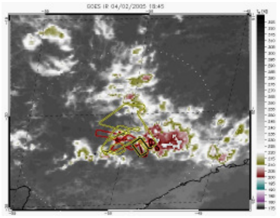
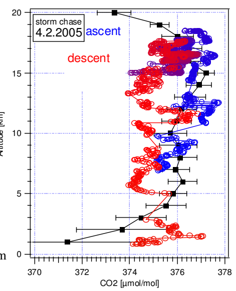


Fig. 3: GOES IR image of February 4, 2005 at 18:45 UTC showing the cloud top temperatures. Superimposed the flight tracks of the M55 in yellow and Falcon in red. Bold lines mark the position of the aircrafts from 18:30 to 19:00 UTC. (Patrick Minnis NASA, Dominik Brunner ETH)

→ **Fig. 4 :** Vertical CO_2 profiles on February 4 2005 compared to the median profile of all non-convective flights: 1.2, 8.2, 12.2, 17.2. and 18.2. in the region over Aracatuba: Lat.[-24; -18°N], Long.[-56°;-46°W])



The link between the observed vertical mixing signatures and local deep convection is well demonstrated by the „golden thunderstorm chase day" on February 4, 2005. The Geophysica flight was performed between 18:00 and 21:00 UTC when the diurnal convective activity was at its maximum. The afternoon satellite images (see IR-GOES Fig. 3) and LINET lightning stroke measurements (Fig. 5) confirm very high cloud tops with brightness temperatures below 195 K (>16km) and lightning activity. Figure 4 shows the convective vertical profile of CO_2 in comparison to non-convective flights. Low CO_2 signatures observed particularly in the middle part of the flight (purple circles in Fig. 4) and during the descent (red circles in Fig. 4) demonstrate the presence of boundary layer air throughout the TTL. This convective influence up to the cold point tropopause at 378 K (17.2 km) is presumably due to vertical mixing following overshooting plumes.

Mixing ratios of CO_2 and NO along the flight path between 355 K and 378 K are shown in Figure 5a). Particularly low CO_2 is observed together with high NO and high CO in the lee side of recent lightning events at an altitude between 15 and 15.7 km (see circles in Figure 5a & b). The second marked plume at 19:05 UTC exhibits mixing ratios of 0.57 nmol/mol NO and 0.82 nmol/mol NO_y yielding a high NO/NO_y ratio of > 0.7 typical for recent lightning.

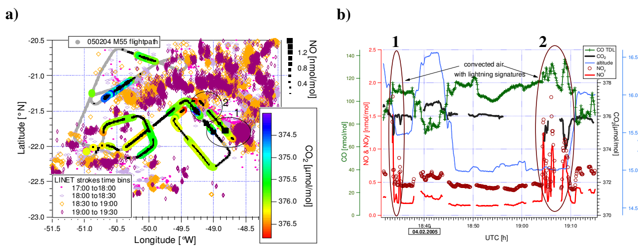


Fig 5: a) LINET stroke distribution during half hour periods shortly before and during the M55 flight on February 4 2005. The flight track (grey) is superimposed by CO_2 (colour coded) and NO (black rectangles) mixing ratios. All CO_2 and NO points correspond to the mixing band between 355K and 378 K highlighted in Figure 2a. Black circles indicate locations where the M55 sampled strong lightning signatures (see Fig. 5a). **b)** Time series of CO, NO, NO_y, CO_2 and altitude during the flight interval between the two plumes highlighted in Fig. 5a.

Aged (Remote) Convection on February 12, 2005

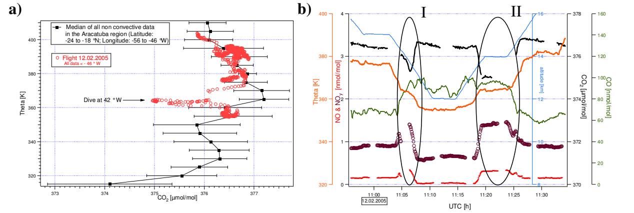


Fig. 6: a) CO_2 vertical profile on February 12 (red circles) compared to the median profile of all non-convective flights. **b)** Measurements of NO (red), NO_y (dark circles), CO (green), CO_2 (black), potential temperature Theta (orange) and altitude (blue) during the dive at 42°W Longitude on February 12.

The mixing signature observed during the eastbound survey flight on February 12 (as highlighted in Figure 2 a) was sampled during a dive at about 20°S and 42°W. At a potential temperature of ~365 K (14 km) significant CO, NO and NO_y enhancements are observed along with depleted CO_2 (Fig. 6 a&b)). A low NO/NO_y ratio of below 0.2 corroborates that the air mass has not seen recent convection with lightning.

The particle dispersion model FLEXPART (NILU) is used to analyse the history of the air mass sampled by the Geophysica at 11:18 UTC (circle II in Fig. 6b). The transport analysis of plume number 2 for the last three days indicates that the air mass originated from the west following the Bolivian High circulation (Fig. 7a). Figure 7b shows that the contributing source regions for CO in the layer 0 to 3 km altitude are located over Bolivia where the air was lifted to at least 12 km (not shown) 2-3 days earlier. The presence of deep convection of 2.5 days before sampling is confirmed by GOES satellite images (brightness temperature below 200K, see Figure 8). Thus the observed signatures in the TTL are associated with aged (at least ~ 2 days) remote continental convection.

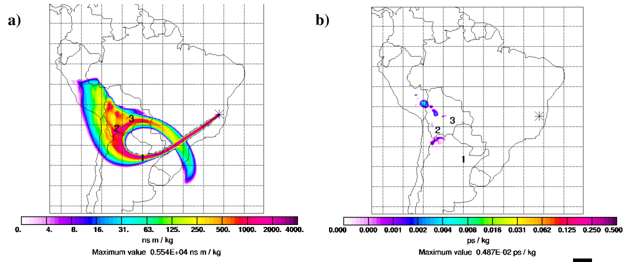
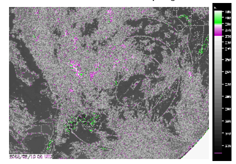


Fig. 7: a) FLEXPART (NILU) column integrated source receptor relationship indicating the origin, amount and transport age (numbers show days). Geophysica position is marked with a star. **b)** Emission sensitivity showing the footprint of CO from the planetary boundary layer up to 3 km (numbers show days).

Fig. 8→**:** GOES-IR satellite image of February 10, 0:00 UTC (2.5 days before M55 sampling) showing cloud brightness temperatures. (NASA)



Conclusions

- CO_2 and CO observations show that the TTL over south eastern Brazil is significantly influenced by transport from the boundary layer up to 17 km.
- Correlations of CO and CO_2 with ozone support the assumption that vertical transport to the upper TTL (way above the neutral buoyancy level of the detraining air) occurs by mixing of overshooting air with its surroundings.
- In the case of February 4, 2005 this mixing process was observed in the vicinity of active local convection, where low CO_2 correlated well with lightning produced NO_x.
- In the case of February 12, 2005 the observed mixing signature is associated with aged remote convection with air masses originating from the continental boundary layer more than 2 days ago.

Acknowledgements

This research was supported by the European community. We would also like to thank the pilots and the crew of the M55-Geophysica, Falcon and Bandeirante.