Identification of transport pathways using CO-O3 correlations in Lagrangian model simulations

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Motivation

What can we learn from Lagrangian simulations about transport pathways and the preferred location of mixing in the Ex-UTLS?

1. Extratropical UT/LS Survey (including cirrus clouds) (RF 03, 09, 14, 17, 18)
2. Stratospheric Intrusion (Tropopause Fold) (RF 04, 06, 11, 12)
3. Tropospheric Intrusion (RF 01, 07, 08, 09, 14)
4. Convective Influence (RF 08, 13, 14, 18)
5. Gravity Wave (RF 02)
6. HIPPO (RF 05, 07, 08, 10, 13, 15, 16)
Chemical Lagrangian Model of the Stratosphere (CLaMS)

- NH 3D simulation from 1 April 2008 - 16 May 2008
- altitude range: surface until 500 K pot. Temp.
- horizontal / vertical resolution: 50 km / 35 levels
- horizontal winds: NCEP (every 6 hours)
- vertical winds [Konopka et al. 2007]:
  - < 100 hPa: $\omega =$ vertical velocity in pressure coordinates
  - > 100 hPa: radiation calculations
- using simplified chemistry (O$_3$ and CO)
- mixing is driven by strain and shear rates of the horizontal wind [Konopka et al. 2004]
Using tracers of air mass origin in CLaMS

Transport = Advection (reversible) + Mixing (irreversible)
Using tracers of air mass origin in CLaMS

Transport = Advection (reversible) + Mixing (irreversible)

Using artificial tracers that mark particular regions in the atmosphere yields [Günther et al., 2008]:
- identification of the origin of air masses
- the contribution of air mass origin in every air parcel
Definition of tracers of air mass origin at the beginning of the simulation at April 1, 2008

- PV = 2PVU
- lower stratosphere
- upper TTL
- lower TTL
- STJ
- PJ
- mid-latitude troposphere
- polar troposphere
- low latitude troposphere
- lowermost stratosphere

Pressure levels:
- 70hPa / 425K
- 150hPa / 355K
- 380K
Research Flight 1: Tropospheric intrusion

18.04.08 18:00:00 θ = 380 K

18.04.08 18:00:00 θ = 320 K

N² [10⁻⁴s⁻²]

-1.0 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0

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RF01: Deep tropospheric intrusion
vertical curtain along the flight path

NCEP 08041818 (3) lat=42.7–39.0°N

$N^2 \, [10^{-4} \text{s}^{-2}]$

Log. Pressure Altitude [km]

Longitude [deg]
RF01 CLaMS Results: Artificial Tracers

artificial tracers shown here are > 10%
CLaMS Results RF01: CO–O$_3$ Correlation

all CLaMS points within the vertical curtain along the flight path
CLaMS Results RF01: CO – O₃ Correlation

all CLaMS points within the vertical curtain along the flight path

artificial tracers shown here are > 10%, except of TTL (> 5%)
RF01: CO–O$_3$ Correlation
CLaMS vs. measurements

very good qualitative overall agreement

tropospheric branch in CLaMS is too low

CLaMS over-interprets the separation between mixing region 1 and 2
Location of mixing regions in physical space

Mixing 1 occurred within the tropopause fold
Mixing 2 occurred just below the tropopause
Mixing 3 occurred in air masses transported from the TTL into the stratosphere
Location of mixing regions in physical space

→ Most mixing regions in CLaMS and observations agree
Fraction of air masses originate in the TTL

In CLaMS the tropospheric intrusion has a life time of \( \approx 20 \) days
Research Flight 4: 2008-04-28
Stratospheric intrusion

28.04.08 18:00:00  θ = 380 K

28.04.08 18:00:00  θ = 320 K

N^2 [10^{-4} s^{-2}]
RF04: Stratospheric Intrusion
vertical curtain along the flight path

NCEP 08042818 lat=39.5°N

Log. Pressure Altitude [km]

Longitude [deg]

N² \left[10^{-4}\text{s}^{-2}\right]

6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0

Vogel et al. (b.vogel@fz-juelich.de)
Extra-tropical UTLS workshop
Boulder, Oct. 19 – 22, 2009 14 / 17
Location of mixing regions in physical space

Mixing 1 occurred within the tropopause fold
Mixing 2 occurred below the tropopause
Mixing 3 occurred in air masses transported from the TTL into the stratosphere
Most mixing regions in CLaMS and observations agree
- mixing region 1 and 2 in CLaMS are at slight lower altitudes compared to observations
Results: transport pathways

Idealized initial conditions

- Pressure levels:
  - 70hPa / 425K (upper TTL)
  - 150hPa / 355K (lower TTL)
  - 380K (lower stratosphere)

- Temperature levels:
  - 380K (polar troposphere)
  - 380K (upper TTL)

- Pathways:
  - Low latitude troposphere
  - Mid-latitude troposphere
  - Polar troposphere
  - Lowermost stratosphere

- PV = 2PVU

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Results: transport pathways

"Disturbed situation"

- 70hPa / 425K
- 150hPa / 355K
- 380K
- PV = 2PVU
- ExTL
- STJ
- PJ

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Extra-tropical UTLS workshop
Results: transport pathways

- Pressure levels: 70hPa / 425K, 150hPa / 355K, 380K
- PV = 2PVU
- Transport pathways:
  - Upper TTL
  - Lower TTL
  - Lower stratosphere
  - Mid-latitude troposphere
  - Polar troposphere
  - Lowermost stratosphere (ExTL)
  - Mixing 1

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Results: transport pathways

- Transport pathways are illustrated in the graph.
- The graph shows transport processes at different latitudes and pressures.
- Key areas include:
  - Lower stratosphere
  - Mid-latitude troposphere
  - Polar troposphere
  - Lower TTL
  - Upper TTL
  - ExTL
  - Lowermost stratosphere
  - Mixing 1 and 2

- PV = 2PVU indicates the potential vorticity at different points in the stratosphere.

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Results: transport pathways

- Transport pathways through different atmospheric layers:
  - 70hPa / 425K (upper TTL)
  - 150hPa / 355K (lower TTL)
  - 380K (ExTL, PV = 2PVU)

- Key regions:
  - Low latitude troposphere
  - Mid-lat troposphere
  - Mid-latitude
  - Polar troposphere

- Mixing processes:
  - Mixing 1
  - Mixing 2
  - Mixing 3

- Other regions:
  - Lower stratosphere
  - Polar stratosphere
  - Lowermost stratosphere

- Latitudes:
  - 0°
  - 30°
  - 60°
  - 90°
Conclusions

Using tracers of air mass origin CLaMS gives information about:

- fraction of air mass origin
- transport pathways
- time scales of mixing

mixing processes within stratospheric intrusions (mixing 1) are influenced by air masses from the polar lowermost stratosphere and occurred within the last days.

mixing occurred at the dynamical tropopause (mixing 2) between air masses from the low latitude troposphere and the mid-latitude lowermost stratosphere.

deep tropospheric intrusions (mixing 3) originate in the TTL and mixing processes occurred with stratospheric air masses within the last 10 – 20 days.