A long-term climatology of air mass transport through the TTL during NH winter

submitted to ACPD

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Motivation

The role of VSLS for stratospheric halogen and ozone trends

Residence time in the upper part of the TTL:

Füglistaler et al 2004: **20 days for the 360-380K layer**

Folkins and Martin 2005: **80 days for the 360-380K layer**

→ Large uncertainty, see the discussion in chapter 2 of WMO (2007).

1. **How fast is the large-scale ascend in the upper part of the TTL?**

3. **The role of interannual variability in the TTL?**

Alternative approach

- **Diabatic heating rates are used as vertical velocity in a quasi-isentropic trajectory model instead of the noisy and strong vertical winds (e.g. Manney et al 2005, Upalla et al., 2005)**

- **Calculate heating rates from an off-line radiation code (ECMWF radiation: Morcrette et al., 1998)**

- **Transport: Lagrangian approach (*real history of the air parcel pathway is taken*)**

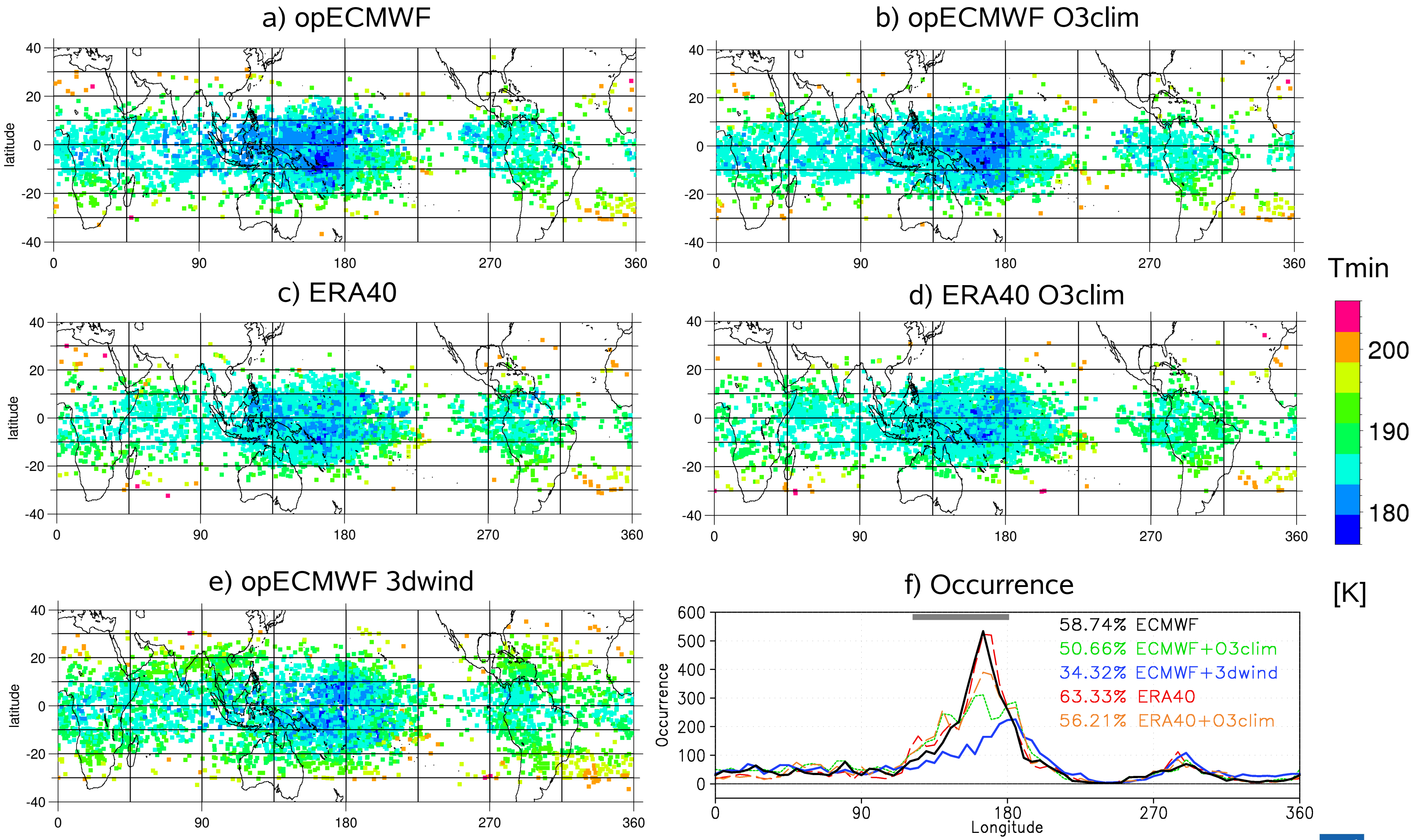
Recent papers addressing the residence time in the TTL used the noisy and too high vertical winds from data assimilations in the stratosphere (Füglistaler et al, 2004, Levine et al. 2007, Berthet et al., 2007).

Data and Method

- Met. Input: ERA40/ op ECMWF data on 60 model levels
  - 2°x2° grid from T106, 6 hourly, (~0.8 km vertical resolution in TTL)
  - trajectories: u, v, T, gH, p
  - heating rates: T, p, clouds, surface log p, O_3, H_2O from ECMWF data sets

  (GHG increasing with time, aerosol climatology)
- Trajectories are started backward for 3 months (DJF)
  - on 400K (~18km altitude)
  - from 28. February until 1. December
  - ERA40: for 40 years from 1962-63 until 2001-02
  - opECMWF: for 6 years from 2000-01 until 2005-06
- Modular tool: can use heating rates or vertical winds on model levels
- Validation of the new transport scheme by Tegtmeier (2007) for polar latitudes and tropics, Krüger et al. (2007 submitted) and Immler et al. (2007) for the TTL.
- Longer-term means, composites and anomalies fields are averaged on 5°x5° grid boxes
- Output stored for the Lagrangian Cold Point (**LCP**):
  - **T**emperature [K]
  - Diabatic heating: **Q** [K/day] between 400K and LCP
  - **Residence time** [K/day] between 400K and LCP
  - Density**:** relative number of trajectories

1. Case study NH winter 2001/02


a) opECMWF

b) opECMWF O3clim

c) ERA40

d) ERA40 O3clim

e) opECMWF 3dwind

f) Occurrence

Fig. 1

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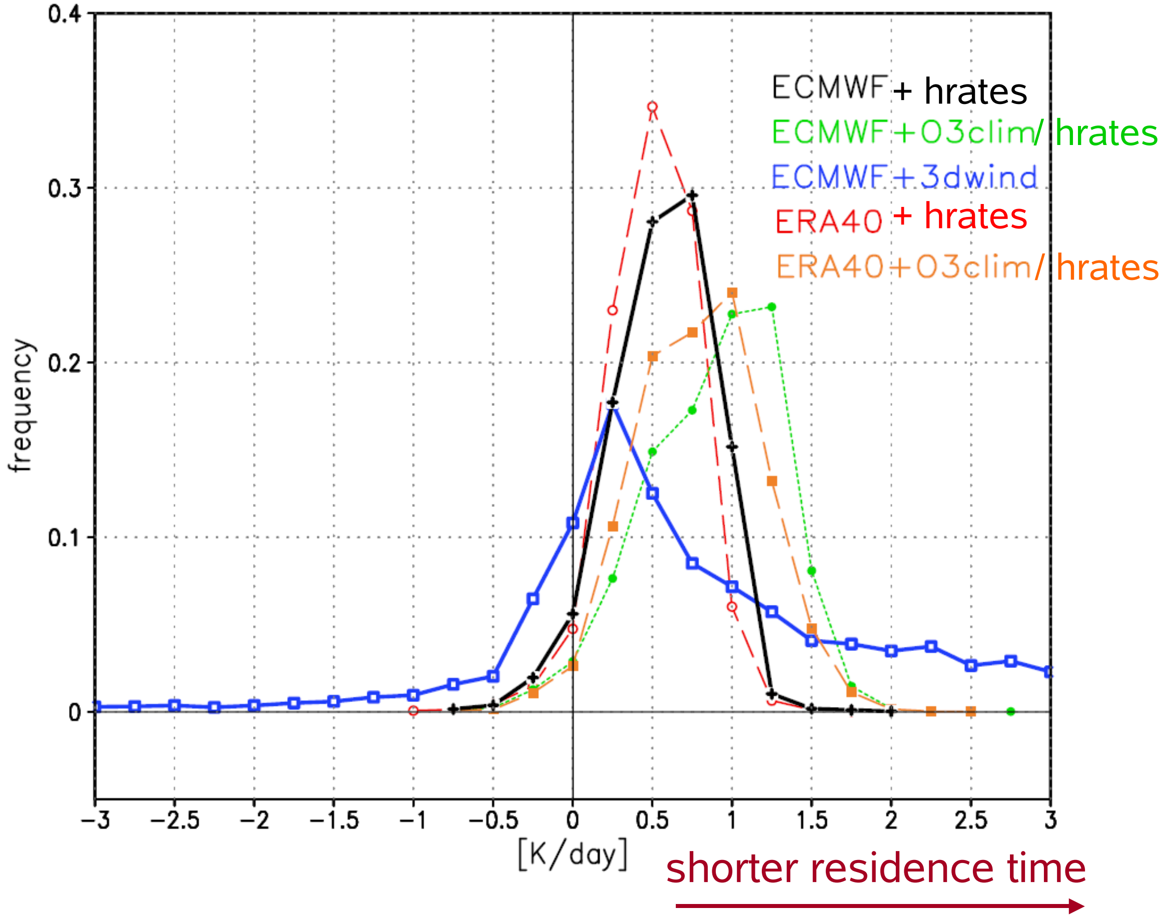
$Q_{400K-LCPT}$: Vertical velocity in the TTL_{upper}



opECMWF + heating rates 0.56 K/day

opECMWF + vertical winds 0.81 K/day

Residence time

in the upper part of the TTL

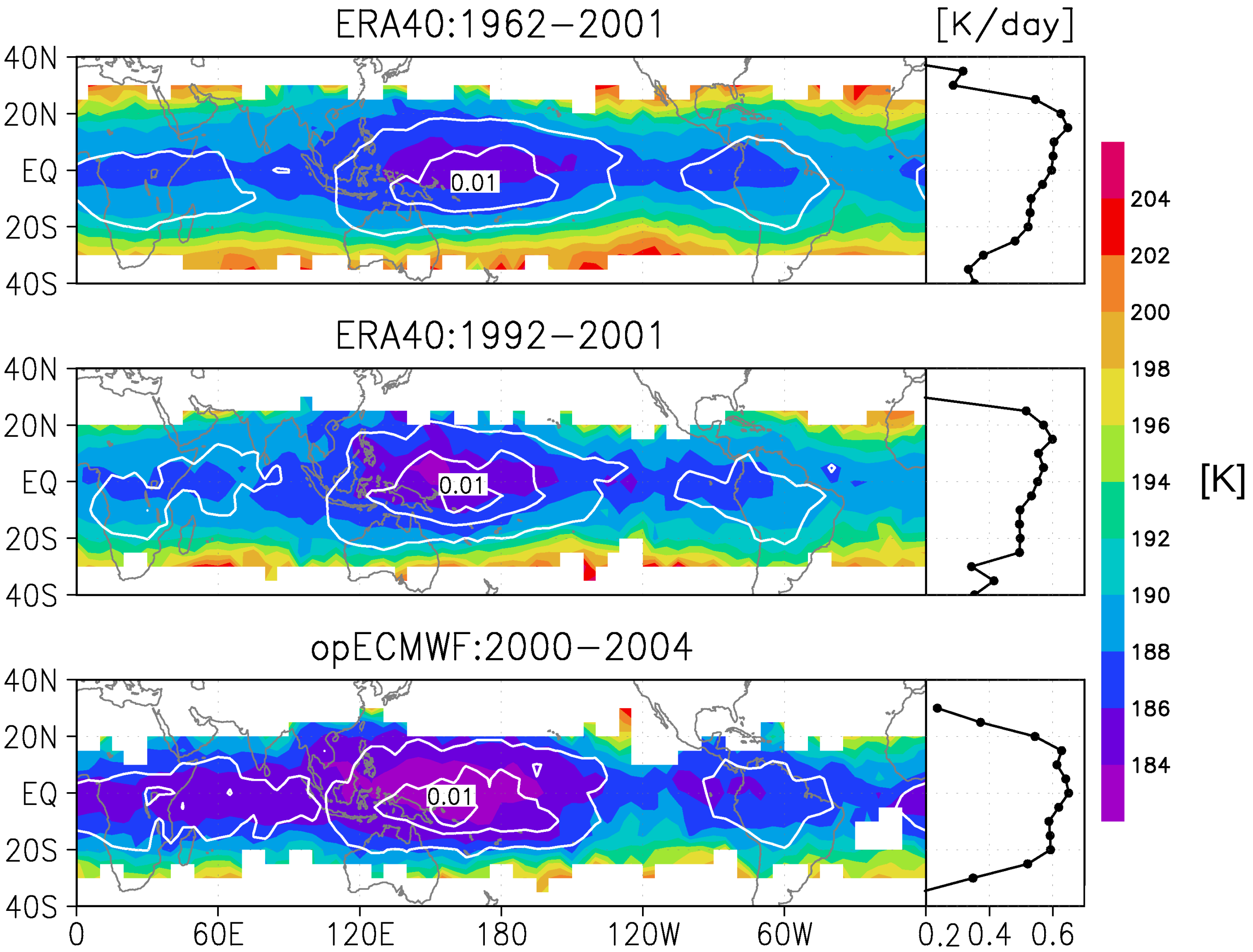
Füglistaler et al. (2004):	**20 days for 360-380K layer (2000/01 DJF)**
Folkins and Martin (2005):	**80 days for 360-380K layer (1999-2001)**

Krüger et al. (submitted to ACPD) using diabatic heating rates

ERA40 data: Q_{LCPT}	**38 days for 360-380K layer (2000/01 DJF)**
opECMWF: Q_{LCPT}	**48 days for 360-380K layer (2000/01 DJF)**

Kremser et al: two CCMs	**< 20 days for 360-380K layer (1 DJF year)**

LCP-climatology (DJF): T, freq,



The residence time of trace gases in the TTL is getting shorter during periods of enhanced ascend → during 2000s (enhanced wave driving in the extra tropics e.g. Randel et al, 2006).

Interannual variability in the TTL

- ENSO (El Nino and La Nina)

- Major volcanic eruptions (Mt. Agung, El Chichon, Mt. Pinatubo)

- The Quasi Biennial Oscillation (**E**asterly/ **W**esterly phase)

(e.g. Randel et al 2000, Zhou et al 2001, Gettelmann et al 2001, Bonazzola and Haynes 2004, Zhou et al. 2004, Fueglistaler and Haynes 2005)

- The 11-year solar cycle (Solar Max and Min)

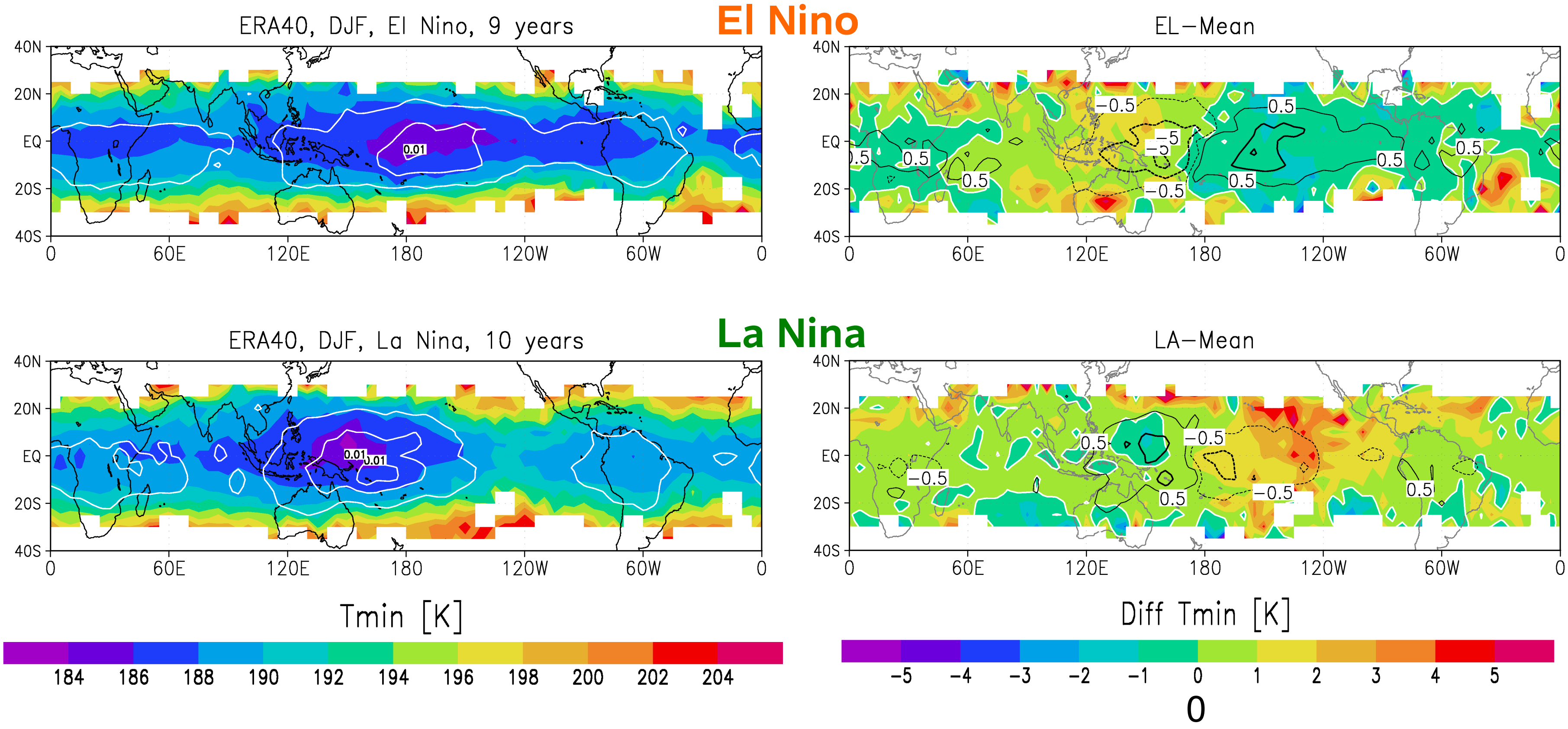
→ Using a different approach and a longer time series to investigate the interannual variability in the TTL

3. Interannual variability

ENSO

composite mean

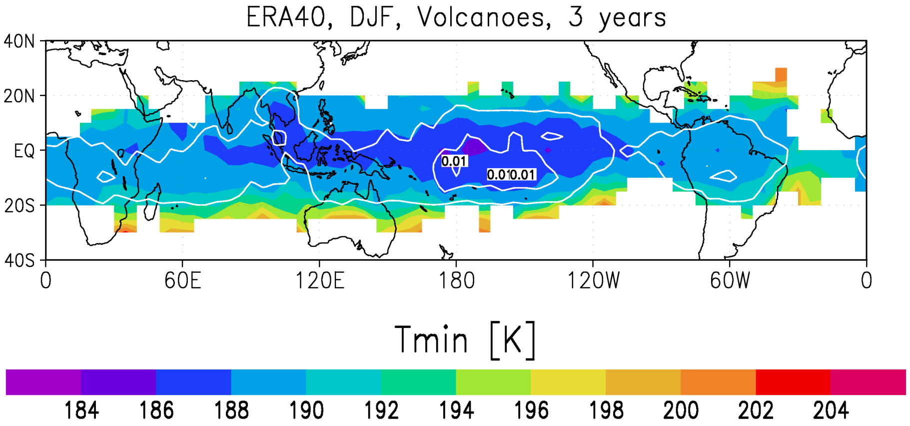
anomalies



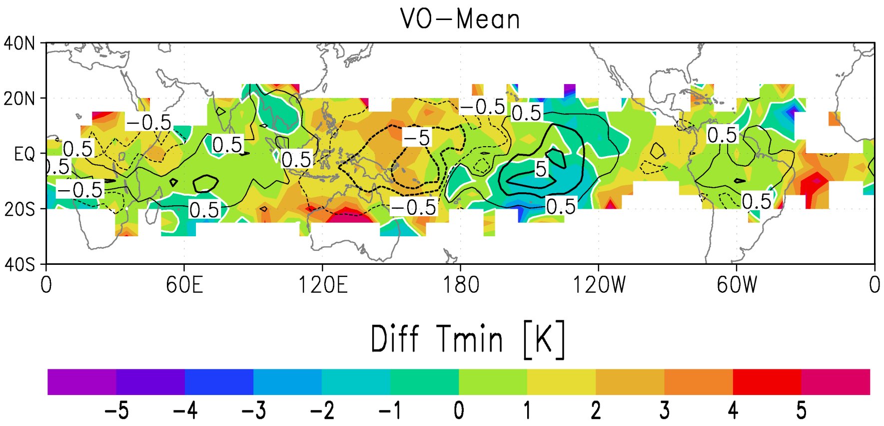
Left panel: White contours indicate the density of trajectories (0.01: ~1%) per 5°x 5° grid.
Right panel: Black contours indicate the anomalies of trajectory density (x100).

Volcanoes (+El Nino)

composite mean



anomalies



The three major volcanic eruptions (Mt. Agung 1963, El Chichon 1982, Mt. Pinatubo 1991) took place during El Nino events.

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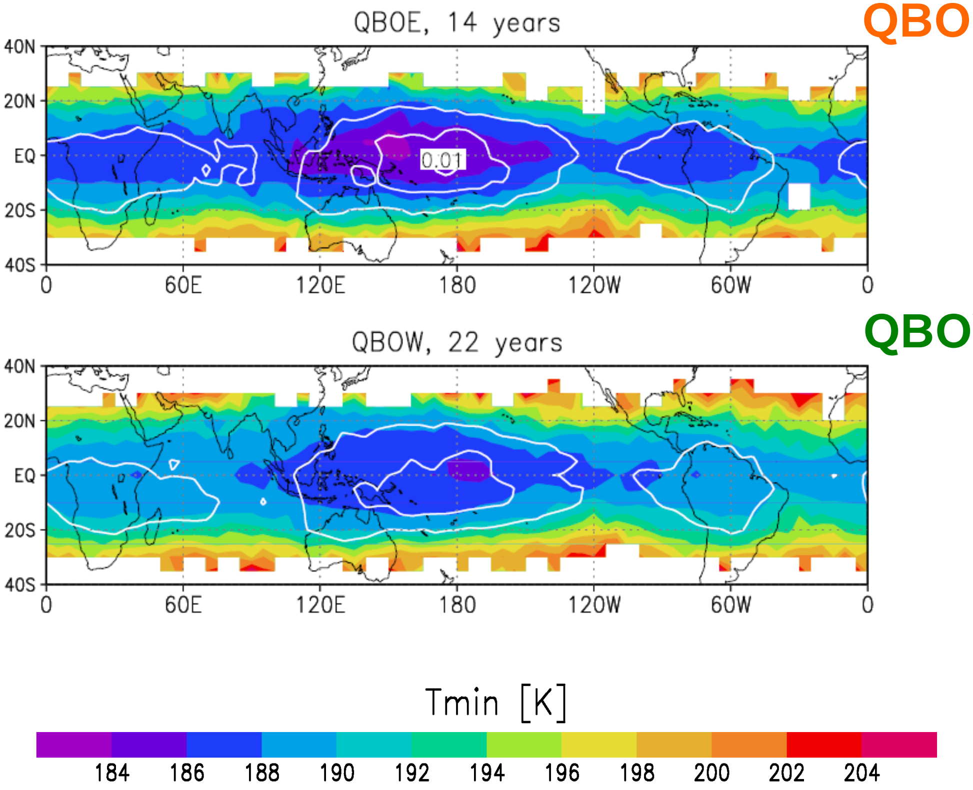
QBO phases

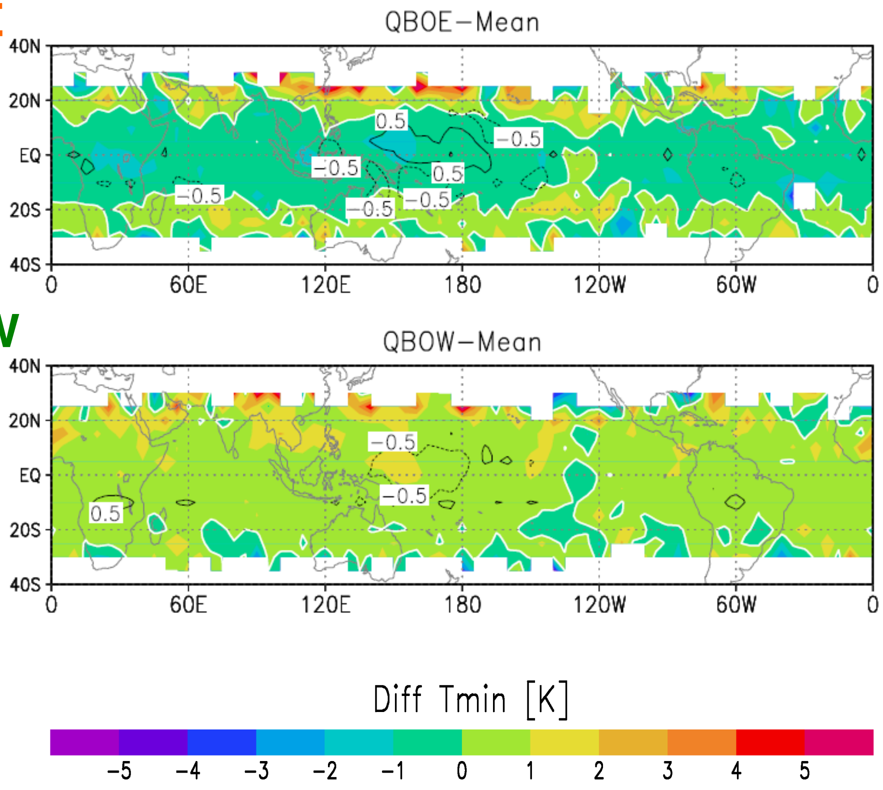
composite mean

anomalies

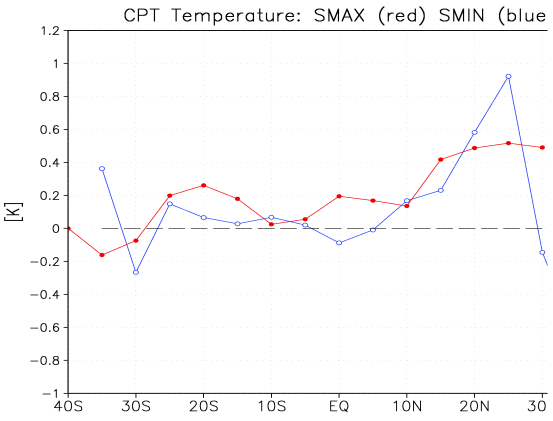
QBOE

QBOW

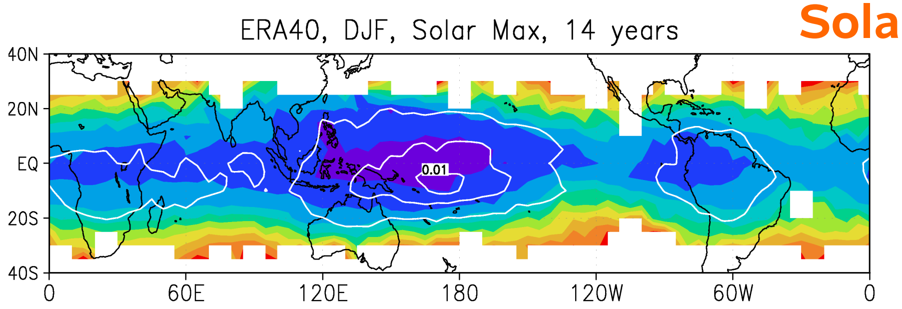




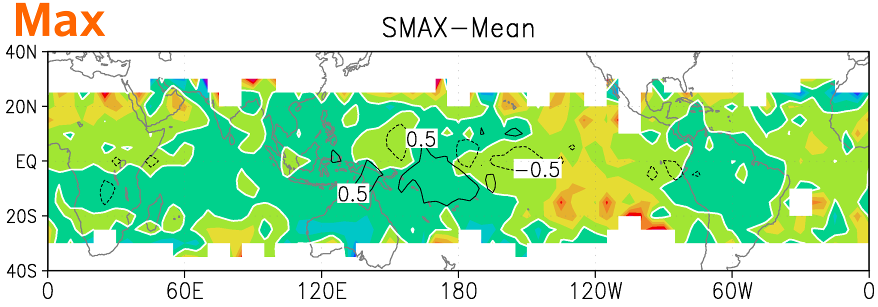
Solar cycle

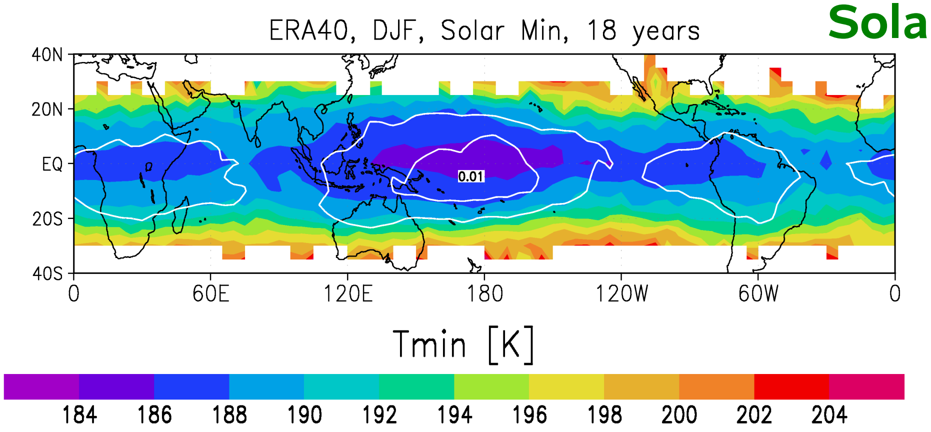


composite mean

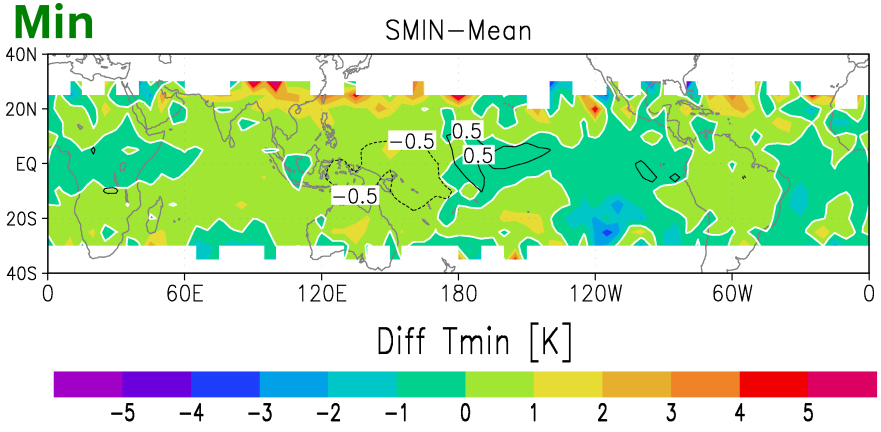


Solar Max





Solar Min



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Summary I

- The geographical distribution of the stratospheric entry points is very robust and does not seem to be much affected by using our method compared to the vertical wind method (*Bonazzola and Haynes*, 2004; *Fueglistaler et al 2004; Fueglistaler and Haynes*, 2005).

However, differences in the density of trajectories, distribution of Q_{LCPT} and in residence time are large. These are important for troposphere-stratosphere transport processes and particularly for the chemistry of VSLS in the TTL!

- Tropical ascend derived from the „tape recorder“ shows a zonally averaged heating of ~0.4 K/day in the TTL during NH winter in the 1990s (*Mote et al.*, 1996), which is in good agreement with our tropical average derived Q_{LCPT} of 0.5 K/day for the period 1992-2001.
- The residence time for NH winter 2001/02 varies up to 70% between the method using the vertical wind and the heating rates.
- The case study for 2000/01 gives a residence time, which lies in between the previously published estimates (see WMO, 2007) → 40 to 50 days for the 360-380K layer.

Analyse the residence time in the TTL with CCMs → important for the Br_y VSLS related studies

Summary II

Long-term calculations of transport processes in the TTL during NH winter show the following new results:

3. A) The coldest and driest TTL exists north of the maritime continent during the 1990s and early 2000s.

   B) An increase of zonally averaged diabatic ascent is analysed during the early 2000s (locally exceeding 0.9 K/day). → This increase of upwelling (shorter residence time) is consistent with an enhanced stratospheric wave driving observed since the late 1990s [*Randel et al.*, 2006; *Dhomse et al.*, 2006].

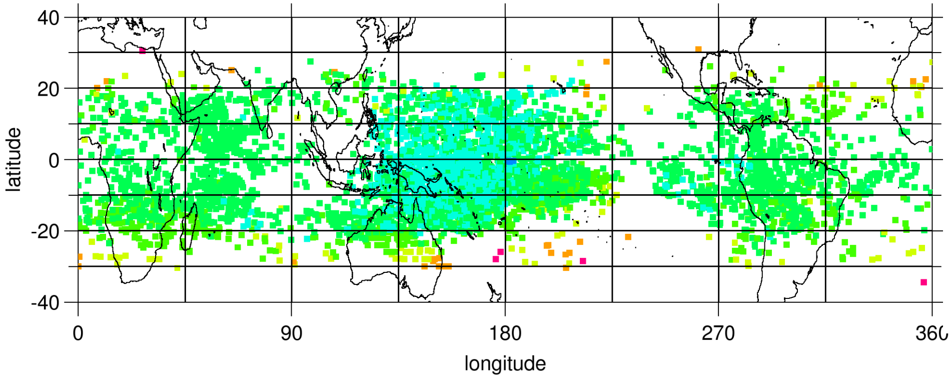
6. Natural processes such as Volcanic eruptions, ENSO events and QBO phases show an impact on the pattern and magnitude of cold point temperatures and the relative frequency of trajectories.

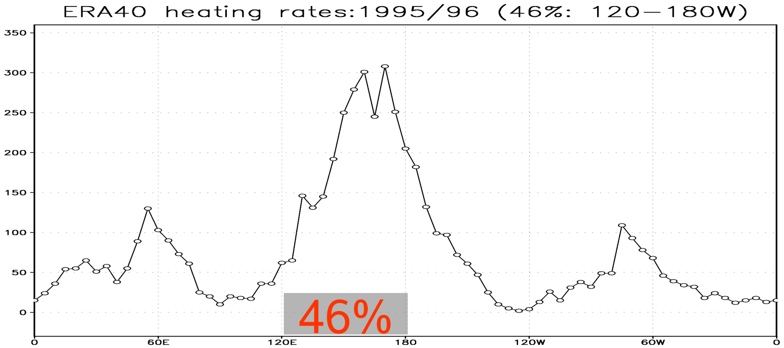
8. ENSO, volcanoes and solar cycle composites exhibit a *longitudinal asymmetry*, whereas the QBO presents a *zonally symmetric* structure in the TTL. In contrast to *Zhou et al. (*2001) larger differences in LCPT fields are found for ENSO and QBO phases.

10. The coldest and driest TTL is analysed during QBO-E and La Nina north of the maritime continent, whereas during volcanic eruptions, El Nino and QBO-W, a warmer and less dry TTL is detected over the maritime continent.

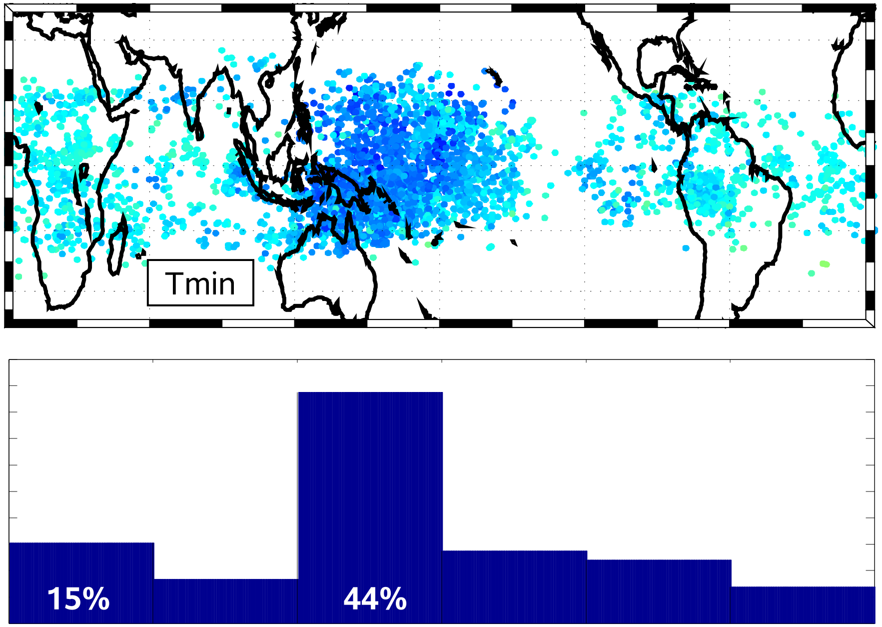
1. Case study NH winter 1995/96

ERA40 (AWI heating rates)

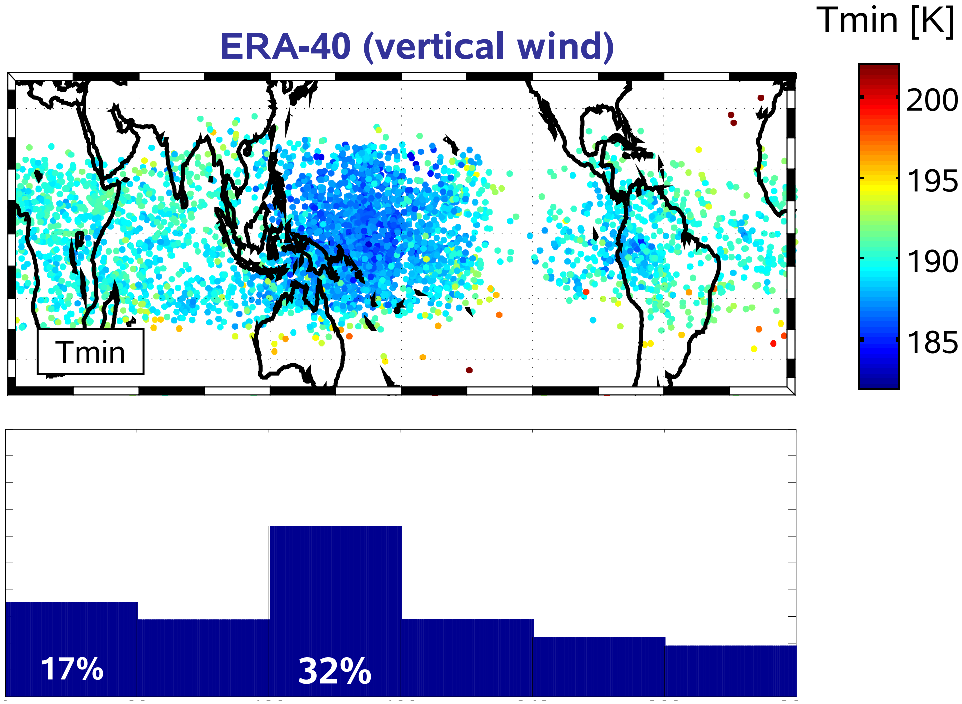




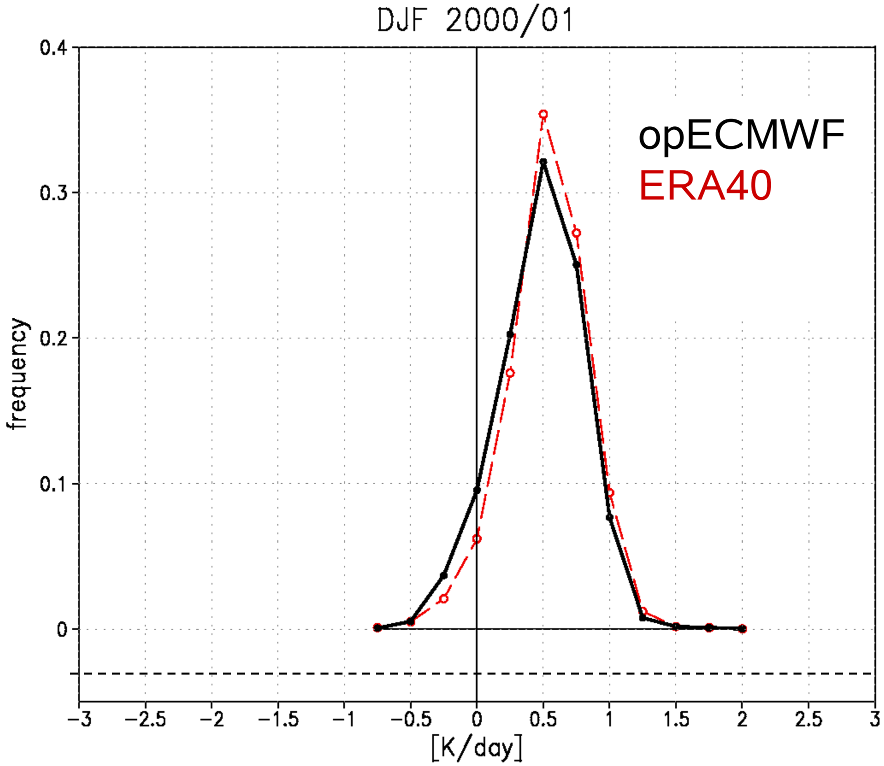
ERA-40 (ECMWF heating rates)



ERA-40 (vertical wind)



Mean Q_{LCPT}



ERA40 data: mean Q_{LCPT} 10K/19 days

opECMWF: mean Q_{LCPT} 10K/24 days