The Tropical Tropopause Layer: What is the role of deep convection?

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Outline

• **Overview of the structure of the TTL**
  *(Temperature, humidity and clouds in the TTL)*


• **Using Radiative-Convective equilibrium simulations with a CRM to study some statistical features of deep moist convection in the TTL**

References:
“Big Picture” View

Holton et al., 1995
More “close-up” view (Fueglistaler et al, 2008)

(a) Deep convection with main outflow near 200 hPa decaying with height
(b) Radiative cooling and subsidence in the region surrounding convection
(c) Sub-tropical jets
(d) Radiative heating and ascent (→ Brewer-Dobson circulation)
(e) Meridional transport/mixing
(f) Edge of the stratospheric “surf-zone”
(h) Convective overshooting above the LNB
(i) Ubiquitous (optically) thin cirrus clouds
Figure 2. Average profiles of temperature, O$_3$, and lapse rate (LR) from all 108 Samoan ozonesondes.
Water vapour

Clear sky radiative heating
Statistical features of deep convection in the TTL from CRM simulations

(a) Cloud Resolving Model (Küpper et al., 2004):
- Doubly periodic domain (96km X 96km), 30 km deep
- Horizontal /vertical grid length: 2km / variable ≤ 300m
- Variable time-step (typically 2 min)
- Imposed Brewer-Dobson circulation
- Fully interactive radiative transfer with a diurnal cycle
- Wet (sea) surface with a specified temperature (300K)

(b) Simulation: run to radiative-convective equilibrium (100+ days of simulated time) and then extended by 120 days of simulated time. Archived domain mean at every time step
Domain averaged updraft mass flux and heating rate fluctuations near 3 km
Troposphere

\[ \langle M \rangle (\times 10^{10} \text{ kg/s}) \]

\[ z (\text{Km}) \]

\[ M (\text{Kg s}^{-1} \text{m}^{-2}) \]
$Q_T \times 5 \times 10^{-3}$ K/day

$z_{QT=0} = 14.4$ Km

$z_{LNB} = 10.5$ Km

$z_{T_{min}} = 16.2$ Km

$T$ (K)
Mass flux PDFs in the troposphere (Davoudi et al), compared to Craig&Cohen theory
Mass Flux PDFs above
The LNB (log-linear)
Total water PDF in the TTL
Küpper et al. (2004): Cloud–Resolving Model in Equilibrium

Question: Does moist convection moisten (hydrate) or dry (dehydrate) the TTL? CRMs produce contradictory results:

- Kuang & Bretherton: overshooting convection may induce drying in the TTL.
- Jensen et al, 2007: Convection moistens (hydrates) if the TTL is subsaturated.
- Küpper et al. and present study: penetration of overshooting convection to the vicinity of and above the cold point is very rare. However, the upward total moisture flux due to convection in the TTL dominates over the large-scale (B-D) ascent below the cold point i.e. convection may bring water close (within ~ 1km) to the cold point but does not play a significant role in moving water across the cold point.
- Modelling uncertainties, e.g. What is the sensitivity to microphysics in CRMs?
- Role of gravity-waves?

Observations of overshooting convection in the TTL and lower stratosphere are sparse. Recent observations from the TROCINOX and SCOUT-O3 campaigns suggest that convective overshoots in the stratosphere have a hydrating effect (Corti et al, 2008).
Long-Term changes Water Vapour in the UTLS

Preparation of an update of the SPARC (2000) Water Vapour Assessment is now under way. Key questions being addressed are:

1. **Data quality:** How reliable are *in situ* and remote sensing field data.

2. **Clear air and in-cloud supersaturation:** Can the observations be explained within the framework of our current knowledge or do we need new theoretical concepts and new laboratory investigations, *e.g.* of ice growth at extreme temperatures?

3. **Recent observations of UTS water vapour changes:** Are these observations mutually consistent, do we understand them, and what are our abilities for future predictions?

4. **Impact on atmospheric chemistry and climate:** What are the implications of changing UTS water vapour for radiation, dynamics, chemistry, clouds and climate?

*See Schiller et al, in SPARC Newsletter No. 30 at :*

http://www.atmosp.physics.utoronto.ca/SPARC/Newsletters.htm
EXTRA SLIDES
Java climatological mean temperature, potential temperature, lapse rate

(Fueglistaler et al)
Water vapour in the stratosphere

Water vapour in the stratosphere is important for the radiation budget, stratospheric chemistry, activation of PSC ...

- Air enters the stratosphere in the TTL and is transported across the tropopause into the stratosphere and toward higher latitudes in the Brewer-Dobson circulation.

- Moist boundary layer air is transported into the upper troposphere by deep convection.

- Details of how the air reaches the stratosphere is still the subject of ongoing debate. The mechanisms by which stratospheric air is dehydrated are closely linked to (uncertain) troposphere to stratosphere transport mechanisms (e.g. large-scale horizontal transports and slow ascent vs. convective overshooting)