Upper-tropospheric inversion and jet in the tropics

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This region also exists in a radiative-convective model, as a radiative-equilibrium region above the convectively adjusted region (Thuburn and Craig, 2002)

They wrote, “in the tropics, the main convection top is not sharp …, so that attention has traditionally focused on … the cold point, overlooking the rather different physical processes … (there)”

Of course, infrequent overshooting clouds and cloud radiation effects may also contribute to the determination of the temperature structure there

Important lesson on the recent TTL discussion is …
Tropical Tropopause/Transition Layer or Substratosphere

- We may still overlook some important features even in the tropical temperature profiles.
- We need a closer look at original radiosonde observation data with high vertical resolutions.
- We need to understand dynamical, physical, and photochemical (?) processes controlling the TTL temperature structure itself (before discussing dehydration processes there … ?)
A new finding on the tropical upper tropospheric temperature and wind distributions

1. “Upper-tropospheric inversion and easterly jet in the tropics” by Fujiwara, Xie, Shiotani, Hashizume, Hasebe, Voemel, Oltmans, and Watanabe JGR, 2003 (a case in the tropical eastern Pacific)

2. Some other cases of the UTI in other tropical regions
1. “Upper-tropospheric inversion and easterly jet in the tropics”

- September-October 1999
- Tropical eastern Pacific (Hawaii – 2N – “Costa Rica dome” – Mexico)
- Radiosonde and ozonesonde soundings
- Fishery research vessel “Shoyo-maru” (for tuna fish, and other fishes)

- Purposes:
  - PBL response to a well-developed SST waves (air-sea interaction)
  - Survey of ozone profiles across the tropical eastern Pacific (as SOWER)

- A persistent, thin temperature inversion layer of 200-m thickness, at 12-13 km, for more than 5 days, along 2N (non-convective region)
- Easterly jet stream at the same region

- Mechanisms for the formation and maintenance of UTI & jet
- Hypotheses: Layering structures in trace gases; lower boundary of TTL
Shoyo-maru cruise in Sep-Oct 99

- Average OLR
- 18 September - 7 October 1999

- 20°N
- EQ
- Christmas
- San Cristobal

- Sep.23
- Sep.27

x : radiosonde sounding points; o : ozonesonde points
Shoyo-maru in Mexico

Ozonesonde and crews

Operation
Typical sky image in ITCZ

Typical sky image over “2N” (non-convective region) Only patches of low-level clouds
Successive vertical profiles of $T$ & $PT$ along the ship track (every 6 hours; displaced by 2.5 K)

at 2N track (non-convective)
Z ~ 12-13 km
dZ ~ 200 m
T > 5 days
dT ~ 0.5 K

Other invs. below 9km
e.g. trade invs.
0C invs.
Relation with RH & U
(Inversions: $dT/dz > 2K/km$)

**UTI & RH:**

3-4-km wet layer below
Dry layer above
→ Bottom of the TTL (?)

Inversions are located at sharp humidity drops

**UTI & U:**

Strong easterly jet at UTI & at 9-14 km for $>\#40$ (2-10N)

Center of the jet at 4N
Composite profiles relative to the UTI (#20 to #41)

RH and ozone → UTI is a clear airmass boundary
U → UTI corresponds to the center of the easterly jet
V → UTI separates northerly below & southerly above

Measured with RS80A
No correction here
Trajectory analysis for the wet layer at 10-12 km (below UTI)

3-day isentropic backward trajectories at 11 km, at ozonesonde sounding points at 2N

→ Convective outflow

Analyses using ECMWF data

Horizontal extent of the easterly jet in the ECMWF U at 200 hPa

→ 130W to 80W in zonal eq. to 10N in meridional

→ Shoyo-maru track
Role of Radiation for Formation of the UTI

Discussion on the mechanism (1)

CCSR radiative transfer model

Input data:
- Ozonesonde data (PTU, O3)
- AFGL atmosphere model
- RS80A data → “Miloshevich correction” to -70C for its T-dep./calib. dry bias error
  → the wet layer is nearly saturated over ice

→ Strong net cooling in the wet layer at 10-12 km due to water vapor

→ UTI is maintained/produced by the wet layer, which is the ITCZ outflow

(similar to the PBL inversions)
Discussion on the mechanism (2)

Easterly Jet and the UTI

Thermal Wind Equation

\[
\frac{\partial u}{\partial z} \approx - \frac{g}{f T} \frac{\partial T}{\partial y}
\]

Average for 2.0N – 5.3N
Difference between 7-10N and 2N

\[\rightarrow\] The easterly jet is in the thermal wind balance, with meridional T-grad.

cf. Thermal wind equation on the equatorial beta plane

\[
\frac{\partial u}{\partial z} \approx - \frac{g}{\beta T} \frac{\partial}{\partial y} \left( \frac{\partial T}{\partial y} \right)
\]

Estimation of the TW equation from the radiosonde data
Summary: Observed system including the UTI & the easterly jet

1. Water vapor transport from ITCZ at 10-12 km (trj.)
2. WV radiative cooling produces the UTI (rad.)
3. Meridional T gradients: positive below 12-13 km, negative above 12-13 km → this T anomaly pattern formed the easterly jet
4. The jet transports water vapor further downstream; radiative cooling continues to operate → wide extent of the UTI
Hypotheses

- The proposed feedback mechanism (between the transport of radiatively active water vapor and the formation of a jet through the thermal wind relationship) may explain the omnipresence of inversion layers and layering structures in trace gases in the tropical troposphere.

- The UTI may be characterized as one of the “climatological” inversions (with frequent occurrence and well-defined formation mechanisms), such as the trade inversions and the 0C inversions, and may form the lower boundary of the TTL.
2. Some other cases of the UTI in other tropical regions

- Galapagos in Sep-Oct 1999
- Tropical western Pacific in 1993-2002 (JAMSTEC)
- Thailand in 1995-2000 (GAME-Tropics)
1. Galapagos in Sep-Oct 1999

- Covers the Shoyo-maru observation period
- Downward phase propagation → passage of Kelvin waves?
2. Tropical western Pacific in 1993-2002 (JAMSTEC) 1/2

Japan Agency for Marine-Earth Science and Technology

R/V Natsushima, R/V Kaiyo, R/V Mirai

DJF : 7 cruises
MAM : 3 cruises
JJA : 6 cruises
SON : 1 cruise

Fig. 1. Radiosonde observation sites. Dotted rectangle indicates the analyzed area.

Fig. & Table from Yoneyama, JMSJ, 2003
2. Tropical western Pacific in 1993-2002
(JAMSTEC) 2/2

~20 days in August 1997

~30 days in November-December 2002

^ 4-day gap  \rightarrow \text{Steady-state UTI & disturbance-related UTI ?}

GEWEX (Global Energy and Water Cycle Experiment)
Asian Monsoon Experiment (GAME)
– Tropics

Enhanced/operational rawinsonde observation data (AIR system)
archived by S.-Y. Ogino

JJA : 11 (rainy season)
MAM : 10 (monsoon onset)
DJF : 1
(One campaign for 10 – 30 days)
EGAT (Electricity Generating Authority of Thailand)  
Tower Site (17N, 99E), Feb. 15 – Mar. 3, 1999  
(dry season over Indochina Peninsula)

→ UTI corresponds to Southerly Jet  
  ( cf. Rossby-response circulation from the  
  equatorial western Pacific/Indonesia  
  → effective horizontal transport? )

( AIR humidity sensor may have more serious  
  dry bias in the upper troposphere )
Upper tropospheric inversion (UTI) is widely observed in the tropics, with high-resolution radiosonde measurements.

The UTI may be a “climatological” inversion, forming the lower boundary of the TTL.

In most cases the UTI has a corresponding jet stream.

Formation and maintenance of the UTI may be explained by a feedback mechanism between the transport of radiatively active water vapor and the formation of a jet through the thermal wind relationship.

This feedback mechanism may explain the omnipresence of inversion layers and layering structures in trace gases in the tropical troposphere (not only for upper troposphere).

Steady-state UTI & disturbance-related UTI.

Further analyses are needed for its climatology, spatial distribution, variability associated with large-scale disturbances, etc.