Quasi-Stationary Temperature Structure in the Upper Troposphere over the Tropical Indian Ocean Inferred from COSMIC RO

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Quasi-stationary statically stable layer

- Small vertical scale – Good target for COSMIC dry temperature data

\[ \text{dT/dz (K/km)} = 2.5 \text{S-2.5N Jul-Aug 2007 (COSMIC RO)} \]

Average has large dT/dz over the Indian Ocean. Inclination from the horizontal surface. It looks like stationary Kelvin mode, but…
Shallow stable layer – basically around the equator.

But, tilted structure is also extended widely.

Not symmetric about the equator..
COSMIC dry temperature data

- Compiled by the COSMIC Data Analysis and Archival Center (CDAAC)
- Obtained from refractivity data
  - Assumption – Electron density and water vapor pressure is zero
  - Refractivity difference between relative humidity 0% and 100% is correspondent to that of temperature of 0.1K at 14-15km, tropics.

- Higher part – by Geometric Optics (GO)
  - Vertical resolution ~ 1 km (Kuo et al. 2004, JMSJ)
- Lower part – by Radioholographic (RH:FSI) method
  - Vertical resolution ~ 10-100 m (Sokolovskiy et al. 2006, GRL)
- Around 14.5 –15km, larger than 60 % is by FSI.
Introduction

• Many studies on the fine structure of the temperature near the tropical tropopause
  – Statistics – e.g. Seidel et al. (2001) -- with radiosonde
  – Double tropopause -- e.g. Randel et al. (2003) – GPS-RO
  – Horse-shoe shape – e.g. Randel and Park (2007)

• Mechanism of the temperature structure and related items
  – Downward motion over the Maritime Continent – Sherwood (2001)
  – Tilt of the isentropic surface – e.g Hatsushika and Yamazaki (2003), Randel and Wu (2005)
  – Inversion due to outflow from ITCZ – Fujiwara et al. (2003)
  – Ray of the waves – e.g. Suzuki and Shiotani (2008), Alexander et al. (2008)
  – Relationship with ozone distribution – e.g. Takashima and Shiotani (2007)

• This study reports one interesting pattern of the temperature over the Indian Ocean during boreal summer…with Radio Occultation data by COSMIC
dT/dz around 150 hPa (=14.5-15km)

- Around 30-60E, dT/dz has **continuously large values** during almost two months

- The longitude of the maximum dT/dz has slightly different from level to level… *in next slide*
Frequency of Inversion layer: GPS-RO

- We counted the occurrence of the inversion
- Many inversions – particularly, during boreal summer, Longitude….

Fujiwara et al. (2003)

Inversion near the ITCZ

Maximum in solstice seasons; (though tropopause height has annual cycle rather than semi-annual)
Maybe related to the asymmetric circulation about the equator.

Calculating $dT/dz$ in 200 m height. If at least one inversion is detected in 500m, the day is flagged as the occurrence of inversion.
• Triangular shape of the stable region – down to 13.5-14 km
• Very stable part is at the eastern edge of the region
  – Also relatively unstable region is just west of the very stable part
Shallow stable layer – basically around 10 deg from the equator
But, tilted structure is also detected in three Jul-Aug

COSMIC-RO
Comparing 4 seasons in Temperature at 100hPa (Objective reanalysis: ERA-40)

- Strong **isolated warm anomaly** is only observed in boreal summer
  - In the boreal winter, slightly detected
  - In the equinox seasons, not remarkable
With ERA-40: Lower levels, relation with Z, U

- Around 60E
  - Warm 100hPa, Cole 250 hPa
  - Large dT/dz at 150hPa, correspond to COSMIC results
- Inclined structure is detected in

Inclined structure: coincident with COSMIC results

In the middle troposphere, low center shifts downward with increasing longitude (E)

Relation with U
Low center is at the west edge of the strong monsoon easterly
U and Z Structure at 150hPa

- Monsoon jet
  - Extend to 0E in the subtropics.
  - Limited to the east of 50E around the equator
- Equator: Low-height at 50-60E is at the western edge of strong Easterly

“Dent” shape of the strong easterly

Northerly component in the Hadley cell is also large at 150 hPa. It may some contribution.
Year-to-year variability

T (zonal mean removed) (K) 60E

ERA-interim

T (zonal mean removed) (K) 100hPa

GrADS: COLA/IGES

8-09:46

GrADS: COLA/IGES

ERA-interim
Discussion: 1. As part of monsoon structure

- ‘Gill Pattern’: linear response for the forcing shifted from the equator
  - Meridional minimum of the height can be explained
  - However, difficult to explain the zonal minimum near the forcing
  - → Response with finite amplitude can explain the zonal minimum

- Explaining zonally tilted structure is also difficult.
  - Tibetan high – equivalent barotropic, not tilted with height


Gill(1980,QJRMS)
2. Stationary equatorial Kelvin wave in the monsoon easterly

- Hypothesis: Stationary Kelvin wave with upward propagation in the monsoon basic easterly
- <Problems>
  - What is meridionally inclined structure?
  - Why only in boreal summer?
  - What is the wave source?

Gill pattern: Equivalent barotropic – great meridional extent

Basic easterly with meridionally wide extent

Randel and Wu (2005, JGR) shows zonally tilted wave-like structure in boreal winter and interpreted as a stationary Kelvin wave

Baroclinic and upward propagating Kelvin wave may have a stationary shape – meridionally compact (~1000km)
Vertical resolution

- For our study, vertical resolution is very important
- The standard product
  - Upper part: GO (~ 1 km) ; Lower part: FSI (=10-100 m)

- At 14.5-15 km used in this study, many profiles are calculated by FSI. However, around the tropopause (~17 km) most of them are by GO method.
- We have made a dry-temperature product with only FSI method even in the lower stratosphere
  - We confirmed that almost same structure appears around 14.5 -15 km height
  - It makes possible to examine fine vertical structure of dT/dz even near (and above) the tropopause
Summary

- **Quasi-stationary shallow stable layer** in the upper troposphere in equatorial western Indian Ocean was detected by COSMIC RO (2006-2008)
  - Only in boreal summer
  - Isolated warm region is zonally compact at the western edge of equatorial monsoon easterly jet
  - Zonally and meridionally inclined structure

- We have made a dry-temperature product only by FSI method in the tropopause region