Recent COSMIC Observations of Tropical Tropopause Layer Temperatures and Their Implications for Climate Variability and Change

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Outline

• What do we know (and not know) about tropical tropopause layer?
  - Review of dynamics and recent trends

• How can COSMIC data help?
  - Empirical evidence for tropical tropopause layer dynamics

• Where do we go from here?
  - Possibilities with longer COSMIC data record
Tropical Tropopause Layer (TTL)

*Introduction*

- Stretches from lapse rate minimum level (~12 km) to cold point tropopause (~17 km)
- Important for transport of chemical constituents into stratosphere

Gettelman and Forster (2002)
TTL Trends: Temperature

1979-1999 Temperature Trends (30°N-30°S)

- Radiosondes:
  - Cooling trend in tropical upper troposphere

- Models:
  - Warming trend in tropical upper troposphere

Cordero and Forster (2006)
TTL Trends: Temperature

1979-1999 Temperature Trends (30°N-30°S)

- Why the discrepancy between observations and models?
  - Measurement errors (Santer et al. 2008; Wang et al. 2012)
  - Exaggeration of upper tropospheric warming in models (Fu et al. 2011; Seidel et al. 2012)
  - Poor representation of ozone and stratospheric dynamics in models (Polvani and Solomon 2012)

Cordero and Forster (2006)
**TTL Trends: Ozone**

1979-2005 Observed Ozone Trends (%)

- Stratospheric ozone depletion observed in tropical lower stratosphere
  - Cannot be explained by ozone chemistry!
**TTL Trends: Ozone**

- **Stratospheric ozone depletion observed in tropical lower stratosphere**
  - Cannot be explained by ozone chemistry!
  - Linked to increased transport (upwelling) from troposphere

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20°N-20°S Vertical Velocity Trend

Lamarque and Solomon (2010)
Tropical Upwelling

What governs vertical velocity across tropical tropopause?

Tropical Upwelling

What governs vertical velocity across tropical tropopause?

December-February Temperature Climatology

New evidence: Local forcing in subtropical upper troposphere associated with both tropical and extratropical waves drives upwelling near tropical tropopause. (Randel et al. 2008; Garny et al. 2011; Birner and Bönisch 2011; Ueyama et al. 2013; Grise and Thompson 2013)
Where We Stand

• Warming trends are larger in models than in radiosondes in tropical upper troposphere.

• Observed temperature trends are linked in part to stratospheric constituent changes and vertical velocity changes near tropical tropopause.

• Dynamics driving vertical velocity in TTL remain poorly understood.
How can COSMIC data help?

• Diagnose the influence of various large-scale wave types on high vertical resolution temperature variability near tropical tropopause.
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• Diagnose the influence of various large-scale wave types on high vertical resolution temperature variability near tropical tropopause.

• To do this, we need:
  • COSMIC GPS Radio Occultation data (2007-2010)
    • 1500-2000 daily temperature profiles (~45% in tropics/subtropics)
    • Interpolated to 100-m vertical resolution
    • Pentad-mean, zonal-mean

Data Set: July 2006 - Present
Anthes et al. (2008)
How can COSMIC data help?

• Diagnose the influence of various large-scale wave types on high vertical resolution temperature variability near tropical tropopause.

• To do this, we need:
  • COSMIC GPS Radio Occultation data (2007-2010)
  • Wave indices derived from ERA-Interim reanalysis

1. Poleward eddy heat fluxes
   (25°-90° latitude; 100 hPa)

2. Poleward eddy momentum fluxes
   (25° latitude; 1000-100 hPa)

3. Pulsation in climatological-mean wave pattern in tropics
   (Grise and Thompson 2012)

Adapted from Garny et al. (2011)
Results

COSMIC Temperature Tendencies (K/day)
Grise and Thompson (JAS, 2013)

- Poleward Eddy Heat Fluxes (25°-90° latitude; 100 hPa)
- Poleward Eddy Momentum Fluxes (25° latitude; 1000-100 hPa)
- Equatorial Planetary Waves
- EPW Index (Grise and Thompson 2012)
Results: Reverse Engineering

Regressions on COSMIC Temperature Tendencies ($\partial T/\partial t$)

Eddy Heat Flux

Increasingly important role of heat fluxes from extratropical stratospheric waves at progressively higher altitudes

Grise and Thompson (2013)
Results: Reverse Engineering
Regressions on COSMIC Temperature Tendencies ($\partial T/\partial t$)
Eddy Momentum Flux

Momentum fluxes from tropical and subtropical tropospheric waves are key in narrow layer near tropical tropopause.
Large-scale wave forcings uniquely contribute to temperature variability in tropical lower stratosphere.

1) **Extratropical**: Influence increases above 16 km

2) **Subtropical**: Influence peaks 15.5 – 20 km

3) **Equatorial**: Influence peaks 16 – 18.5 km

Adapted from Garny et al. (2011)
Results: Limitations

- COSMIC data have yielded valuable insight into dynamical processes that govern temperature variability near tropical tropopause.

- These empirical methods are less relevant for understanding dynamics behind climatology and seasonal cycle.

- Ultimately, we need consistent long-term high vertical resolution temperature measurements to better understand:
  1) Climatology
  2) Stratosphere/troposphere transport
  3) Cloud-radiative effects
  4) Vertical profile of temperature trends: Where cooling? Where warming?
Conclusions

- Observed temperature trends are linked in part to stratospheric constituent changes and vertical velocity changes near tropical tropopause.

- COSMIC data have provided insight into large-scale wave forcings responsible for temperature variability near tropical tropopause.

- Longer, consistent observational records are necessary to better understand climatology and trends.
Questions??

TTL Trends: Ozone and Water Vapor

SAGEII ozone 16–18km 20S–20N

Randel et al. 2006

Hurst et al. 2011
Results: Limitations

What wave forcings matter for long-term mean and annual cycle in temperatures near tropical tropopause?

Grise and Thompson (2013)
Tropical Upwelling: Results

COSMIC Temperature Tendencies (K/day)
Grise and Thompson (JAS, 2013)

- Poleward Eddy Heat Fluxes (25°-90° latitude; 100 hPa)
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Equatorial Planetary Waves

Why do the equatorial planetary waves exist?
- Resemble the idealized model response to a localized mid-tropospheric heat source centered on the Equator (Gill 1980; Highwood and Hoskins 1998).
Equatorial Planetary Wave Index (EPWI):
- Projection of daily-mean 150-hPa $u^*$ anomalies onto the seasonally-varying climatological-mean 150-hPa $u^*$ field over the domain 20°N–20°S
- Describes pulsation in amplitude of climatological-mean pattern of equatorial planetary waves
- Positive when climatological wave structures are enhanced
EPW: Seasonality

150 hPa Geopotential Height

Regressions on EPW

EPW > 1

EPW < -1
COSMIC:
Equatorial Planetary Waves
COSMIC: Extratropical Wave Forcing

\( \frac{dT}{dt} : \text{NH & SH Eddies} \)

Waves Propagating Meridionally into Subtropical Stratosphere

\( \frac{dT}{dt} : \text{NH Eddies} \)

Waves Propagating Vertically into Extratropical Stratosphere

\( \frac{dT}{dt} : \text{SH Eddies} \)

Waves Propagating Meridionally into Subtropical Troposphere
Wave Forcing Temperature Signatures