Untangling the tropical tropopause layer with an idealized moist model: Tropical vs. extratropical control

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EVIDENCE FOR A WORLD CIRCULATION PROVIDED BY THE MEASUREMENTS OF HELIUM AND WATER VAPOUR DISTRIBUTION IN THE STRATOSPHERE

By A. W. BREWER, M.Sc., A.Inst.P.

(Manuscript received 23 February 1949)

Fig. 5. A supply of dry air is maintained by a slow mean circulation from the equatorial tropopause.
The tropical tropopause layer’s notable **annual cycle**

[Figure 4. (a) Climatological tropical ($10^\circ S$–$10^\circ N$) mean annual cycle of temperatures (black lines, as labeled) and temperature anomalies from annual mean profile in K (contour lines, negative values grey shaded and dashed contour lines). The thick black line shows the pressure level of the cold point tropopause as represented in ERA-40. (b) Latitudinal structure of peak to peak difference of annual cycle of zonal mean temperatures (contour lines, values exceeding 5 and 7 K light and dark grey shaded, respectively). All data from ERA-40 [Uppala et al., 2005].]
The tropical tropopause layer’s notable annual cycle

\( \overline{T} \) deviation from annual mean

Microwave Limb Sounder water vapor measurements

[Fueglistaler et al. 2009] [Mote et al. 1996]
What drives the annual cycle in the TTL temperature?

- **Dynamics**: more upwelling in boreal winter than summer
  - extratropical planetary waves forcing stronger in NH winter than SH winter [*e.g. Yulaeva et al. 1994, Chen and Sun 2011]*
  - tropical planetary waves excited by convection (warm pool) respond to annual variations wind structure [*e.g. Ortland and Alexander 2014]*
  - synoptic wave forcing has a greater annual cycle in the is NH than SH [*e.g. Jucker et al. 2013]*
  - All three are important [*Randel et al. 2008, Grise and Thompson 2013]*

- **Radiation**: annual cycle of ozone (which is itself driven by cycle in upwelling); *Fueglistaler et al. 2011* show it explains ~ 2 K
Model Hierarchy

QG

clouds, aerosols, chemistry (full GCM)

complexity

Inspired by Held 2005
Model Hierarchy

QG

dry primitive equation dynamics (Held-Suarez)

gray radiation + latent heating (GRaM)

clouds, aerosols, chemistry (full GCM)

Inspired by Held 2005
Model Hierarchy

QG
- dry primitive equation dynamics (Held-Suarez)

Gray
- gray radiation + latent heating (GRaM)

Full
- full radiation, moisture; no clouds (MiMA)

Inspired by Held 2005

- clouds, aerosols, chemistry (full GCM)
A reasonable climatology
Representing the key forcings in an idealized model

1. extratropical planetary waves: midlatitude topography
Representing the key forcings in an idealized model

1. extratropical planetary waves: midlatitude topography
2. tropical planetary waves: oceanic heat flux in tropics
Representing the key forcings in an idealized model

1. extratropical planetary waves: midlatitude topography
2. tropical planetary waves: oceanic heat flux in tropics
3. synoptic wave activity: reduced heat capacity in NH
Tropical planetary waves control annual mean cold point structure

Tropical annual mean temperature profiles

Tropical mean zonal SST anomalies
Tropical planetary waves control annual mean cold point structure.
Tropical planetary waves control annual mean cold point structure
Tropical planetary waves control annual mean cold point structure
Tropical planetary waves control annual mean cold point structure

“warmpool”
tropical waves

“land-sea contrast”
synoptic waves

topography
planetary waves

Tropics:
Strong effect on height, temperature, and sharpness

Extratropics:
Neither land-sea contrast nor orographic facing have a strong effect on annual mean cold point structure
Annual Cycle of TTL Temperature

Tropical mean July - Jan temperature profiles

Extratropical mean NH/SH July-Jan T gradient
Annual Cycle of TTL Temperature

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Annual Cycle of TTL Temperature

Tropical mean July - Jan temperature profiles  
Extratropical mean NH/SH July-Jan T gradient
Annual Cycle of TTL Temperature

- **Tropics**: No annual cycle anywhere.
- **Land-sea contrast**: Strong dependence, peak in TTL.
- **Midlat topography**: Weak dependence, throughout strat.
Nonlinear impact on TTL temperature annual cycle with combined forcings
planetary waves keenly sensitive to annual cycle in zonal wind
planetary waves keenly sensitive to annual cycle in zonal wind

![Graph showing the relationship between zero crossing amplitude in hPa and TTL amplitude in K. The R-squared value is 0.77.](image)
Conclusions

• propose a new step in the hierarchy of idealized atmospheric models

• tropical planetary waves critically control mean TTL structure

• asymmetry in synoptic variability of NH and SH alone can drive a large fraction of TTL annual cycle

• planetary waves (from tropics or midlatitudes) substantially amplify impact of synoptic variability

The Dynamics and Variability Model Intercomparison Project (DynVarMIP) for CMIP6: assessing the stratosphere–troposphere system

(better vertical resolution though UTLS and stratosphere diagnostics for momentum + heat transport)
Extra slides …
Nonlinear impact on TTL temperature annual cycle with combined forcings

![Graph showing TTL amplitude in K with different forcings: W30, L10, O4. ECMWF and CMAM30 forcings are indicated.](image)
Nonlinear impact on TTL temperature annual cycle with combined forcings
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Tropical temperature profiles

• MiMA has different lapse rates throughout the column, so matching to reanalysis is difficult.
• Our choice was to match in mid-troposphere, and subsequently have the same tropical temperature at 700hPa for all simulations (adjusting albedo)
SSW frequency

- 2 Gaussian mountains (4km)

- 2 Gaussian mountains (4km); 10m land
Ozone influence on annual cycle in TTL

- Fueglistaler, Haynes, and Forster (2011), Fig 5(b):

Only ~2K (of 8K) can be attributed to O3.
Annual Mean Cold Point Structure

Tropics:
Strong effect on height, temperature, and sharpness

Extratropics:
Neither land-sea contrast nor orographic facing have a strong effect on cold point structure
Seasonal Cycle of TTL Temperature

Tropics:
No seasonal cycle anywhere.

Land-sea contrast:
Strong dependence, peak in TTL.

Midlat topography:
Weak dependence, throughout strat.
Nonlinearity of Results
TTL seasonal cycle
Nonlinearity of Results

![Graph showing temperature cold point for different forcing cases: ECMWF and CMAM30. The y-axis represents the temperature cold point in Kelvin, ranging from 186 to 196.]