The Tropical Tropopause Layer in Global Models

Andrew Gettelman, National Center for Atmospheric Research

NCAR

Summary

A coupled chemistry-climate model (WACCM3) with 1km vertical resolution reproduces major features of the TTL. Tropopause variations, radiative structure & the ozone minimum are well represented. Clouds are found at the tropopause with similar frequency to observations, but these are stratiform (cirrus) and not convective cloud. Simulated water vapor in the TTL is tightly coupled with coldest temperatures, which is different than observations (and due to cirrus microphysics). A high vertical resolution model has lower cloud top heights in the TTL, but similar structure.

The model reproduces TTL structures because the dominant forcings are large scale, including remote responses to convective heating

Definition of the TTL

Vertical Extent

The Tropical Tropopause Layer can be defined as *the region between the level of maximum convective outflow (10-12km) & the cold point tropopause* (16km).

These levels can be found from a temperature profile. The level of maximum convective outflow is where the potential temperature lapse rate is a minimum in the upper troposphere (See Gettelman & Forster, 2002)

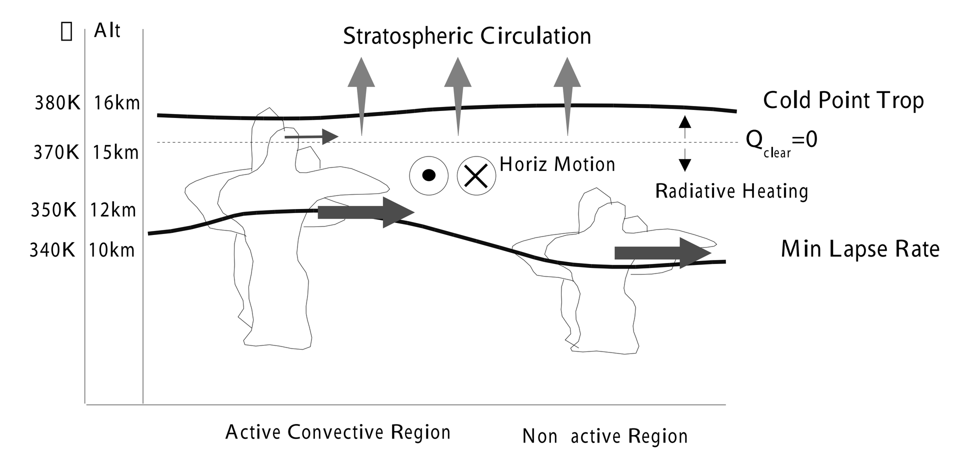

Figure 2: Schematic picture of the TTL

Radiative Heating

Radiative heating changes sign in the TTL from cooling (troposphere) to warming (stratosphere). Also shown below are the Tropopause and the Lapse Rate Minimum. Radiation calculations are based on radiosonde trace gas & temperature profiles.

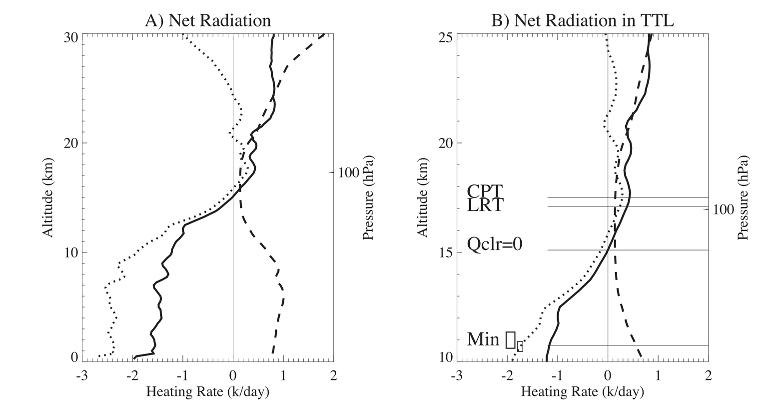

Figure 3: Heating rates (in K/day) from the NCAR CRM (CCM3.6). Shortwave (SW) dashed, Longwave (LW) dotted and Net solid

Model Description

Global Model: WACCM3

This study uses the NCAR Whole Atmosphere Community Climate Model version 3 (WACCM3), at 4x5 degree horizontal resolution. Two vertical resolutions have been tested: 66 Levels (1km vertical resolution in the TTL) & 91 Levels (300m vertical resolution in theTTL). The model domain goes to 140km, with full coupled chmistry (56 species). Simulations run for 4-5 years for 1995 conditions and fixed SSTs. WACCM3 physics is based on the Community Atmosphere Model version 3 (Collins et al 2006).

The Radiation code from CAM is used for estimating heating rates in the TTL (Figure 3).

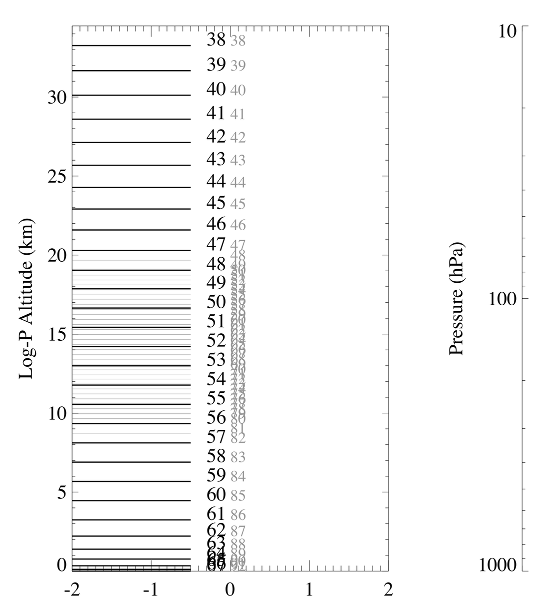

Figure 1: Vertical structure of model layer edges in the UT/LS for 66 Level (black) & 91 Level (gray) versions.

Observations

Observations of the TTL come from several sources:

Radiosondes, Ozonesondes and research water vapor sensors (Figures 3 & 6), are described by Gettelman & Forster, (2002)

Global Brightness temperatures from the GCI archive were compiled by Salby (Figure 7) and described by Gettelman et al 2002. ECMWF analysis temperatures are described by Gettelman et al (2002)

HALOE Water vapor and NCEP/NCAR temperatures and winds in Figure 10 are described by Randel et al (2001)

References

Collins, W. D., P. J. Rasch, B. A. Boville, J. J. Hack, J. R. McCaa, D. L. Williamson, B. P. Briegleb, C. M. Bitz, S.-J. Lin, , and M. Zhang, The formulation & atmospheric simulation of the Community Atmosphere Model: CAM3. in press, J. Climate, 2006

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Randel, W. J., A. Gettelman, F. Wu, J. M. Russell III, J. Zawodny and S. Oltmans, The seasonal variation of water vapour in the lower stratosphere observed in Halogen Occultation Experiment data, J. Geophys. Res., 106:D13, 14,313-25, 2001

Model Represenation of the TTL

Tropopause & Variability

The model does a good job of simulating tropopause structure. Temperatures, variability and zonal structure match GPS observations.

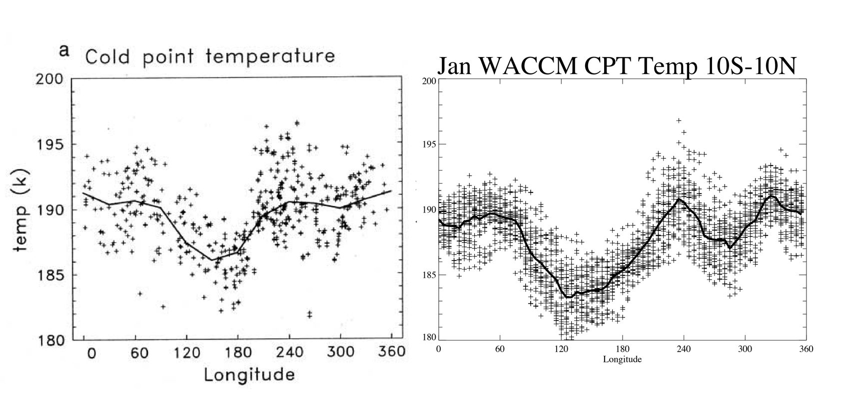


Fig 4: Scatter plot of CPT temperature 10N-10S. Solid line shows the average. Left: DJF from Observations (GPS-Randel et al 2003). Right: WACCM3

Structure of TTL

WACCM does a good job of reproducing TTL structure. There are slight differences with resolution.

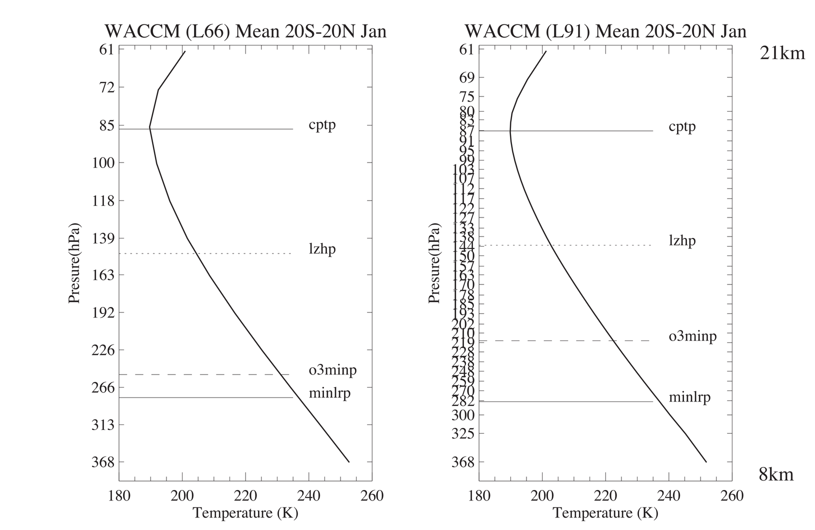


Figure 5: WACCM Tropical average January TTL structure: 66 levels (left) & 91 levels (right). Tropopause & min Lapse rate solid. Level of zero heating (lzhp) dotted, O3 minimum dashed.

TTL Ozone Minimum

The minimum in Ozone is generally located near the bottom of the TTL, just above the maximum convective outflow level (Fig 6). WACCM also reproduces this feature.

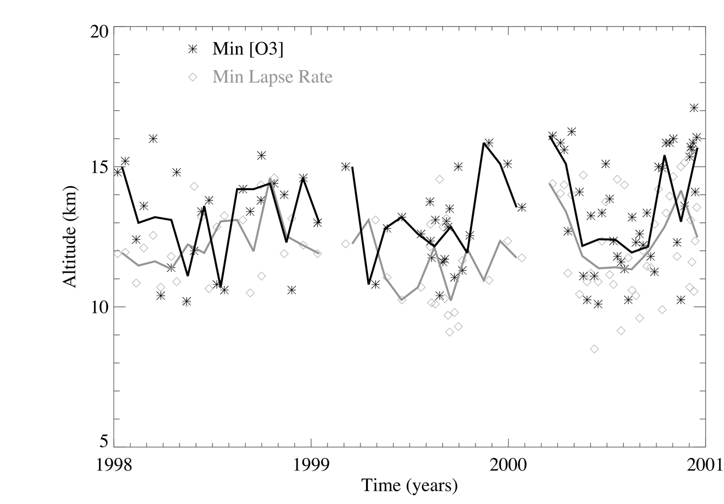


Fig. 6. Altitude of tropospheric ozone minima (black) and lapse rate minimum (LRM-gray) over Indonesia (7 S, 112 E). Symbols are individual soundings, solid lines monthly means.

Convection

Clouds Above the Tropopause

Clouds are observed above the tropopause in observations (Fig 7), 1-3% of the time. WACCM (model) cloud above the tropopause is cirrus, not convective (Fig 8), with1-5% frequency (Fig 9). A higher resolution model has *less* cloud at the tropopause.

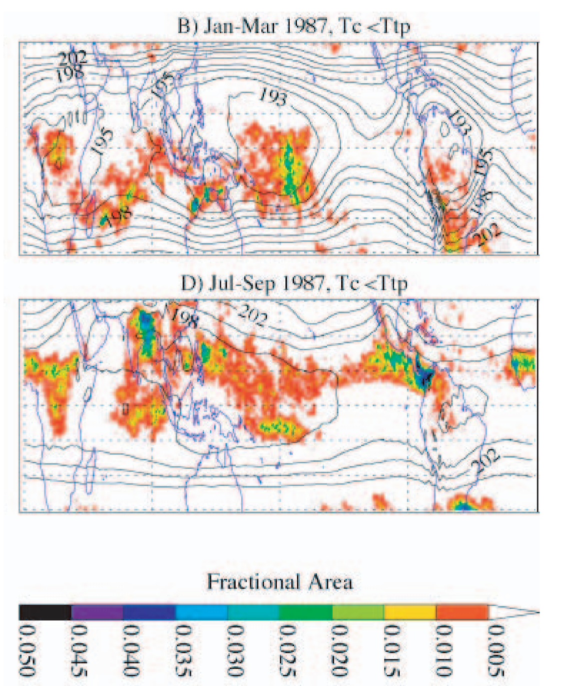


Fig 7: Fractional area with cloud top temperature colder than the tropopause for 2 seasons. Contours are seasonal mean tropopause temperature. From Gettelman et al. (2002).

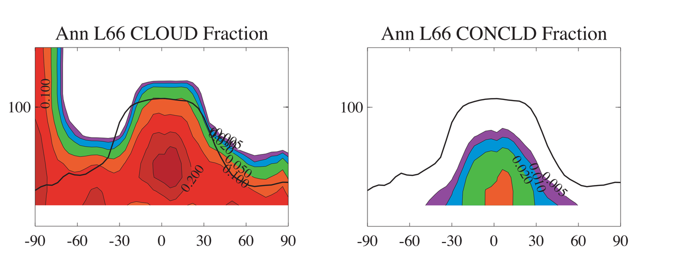


Figure 8: WACCM zonal mean cloud frequency Left: total cloud, Right, Convective Cloud only

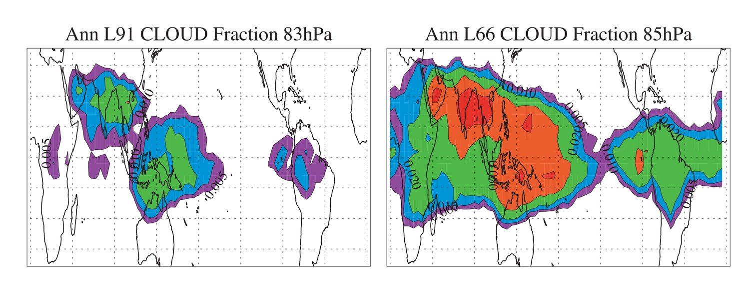


Figure 9: WACCM Cloud frequency at tropopause pressure level for 91 (left) and 66 (right) level model.

WACCM TTL Clouds

WACCM Convective cloud (CONCLD) almost never gets to the tropopause. Stratiform (cirrus) cloud does (fig 8).

The frequency of total cloud (CLOUD) at the tropopause is lower at higher vertical resolution (Fig 9).

Coupling

Observations show coherent coupling between clouds, winds, temperatures and water vapor. The H2O minimum in January is downwind of the coldest temps.

WACCM is similar, but the minimum H2O & temperatures are coincident. This may be due to cirrus cloud microphysics not in the model.

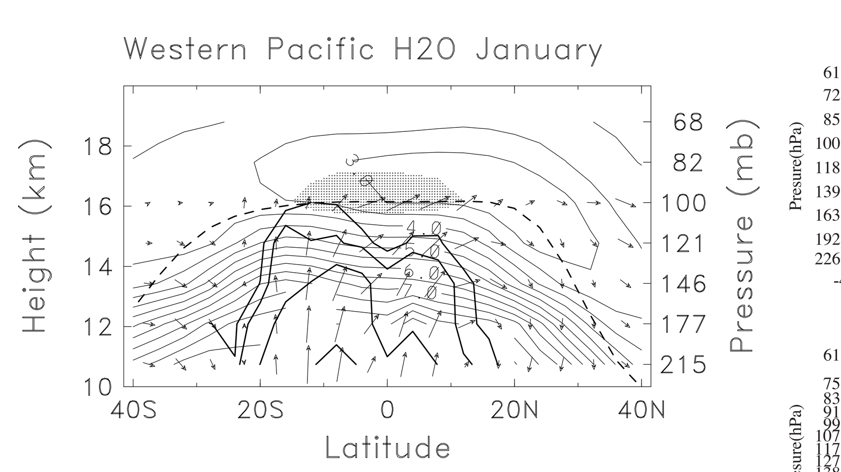
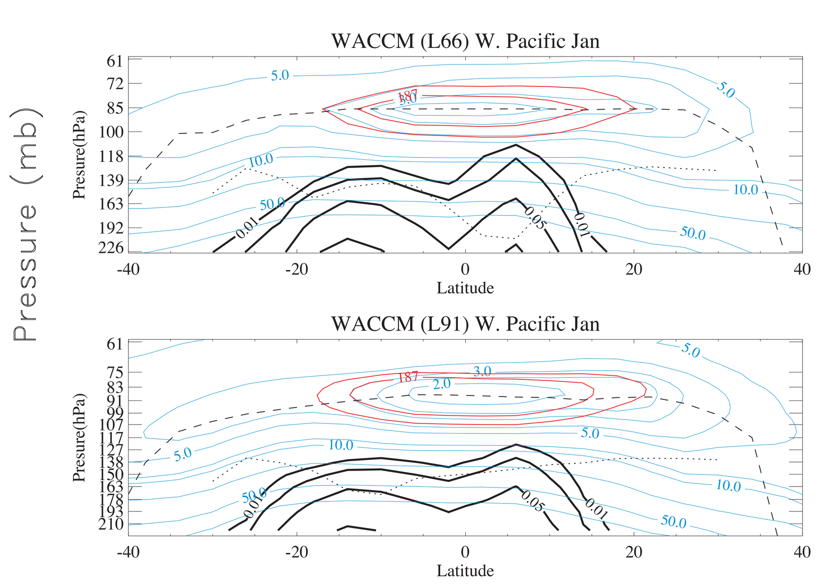


Fig 10: W. Pacific (120-180 lon): cloud fraction (thick contours at 10%, 5%, 2%, 1%), H_2O (ppmv) from HALOE (thin contours), and kinematic velocities (vectors). Shaded region indicates mean temperatures below 188∝K. (Randel et al., 2001).



WACCM results similar to observations, but H2O minimum co-located with cold temps. Convection in 91 level model is lower.

Figure 11: As for Fig 10 but for WACCM simulations. 66 level (top) & 91 level (bottom) Red lines are 188 & 187 temperature contours Dashed line is the tropopause, dotted line is the level of zero heating. Cloud frequency is convective only.