Tropical Tropopause Temperature Control in a Hierarchy of Models

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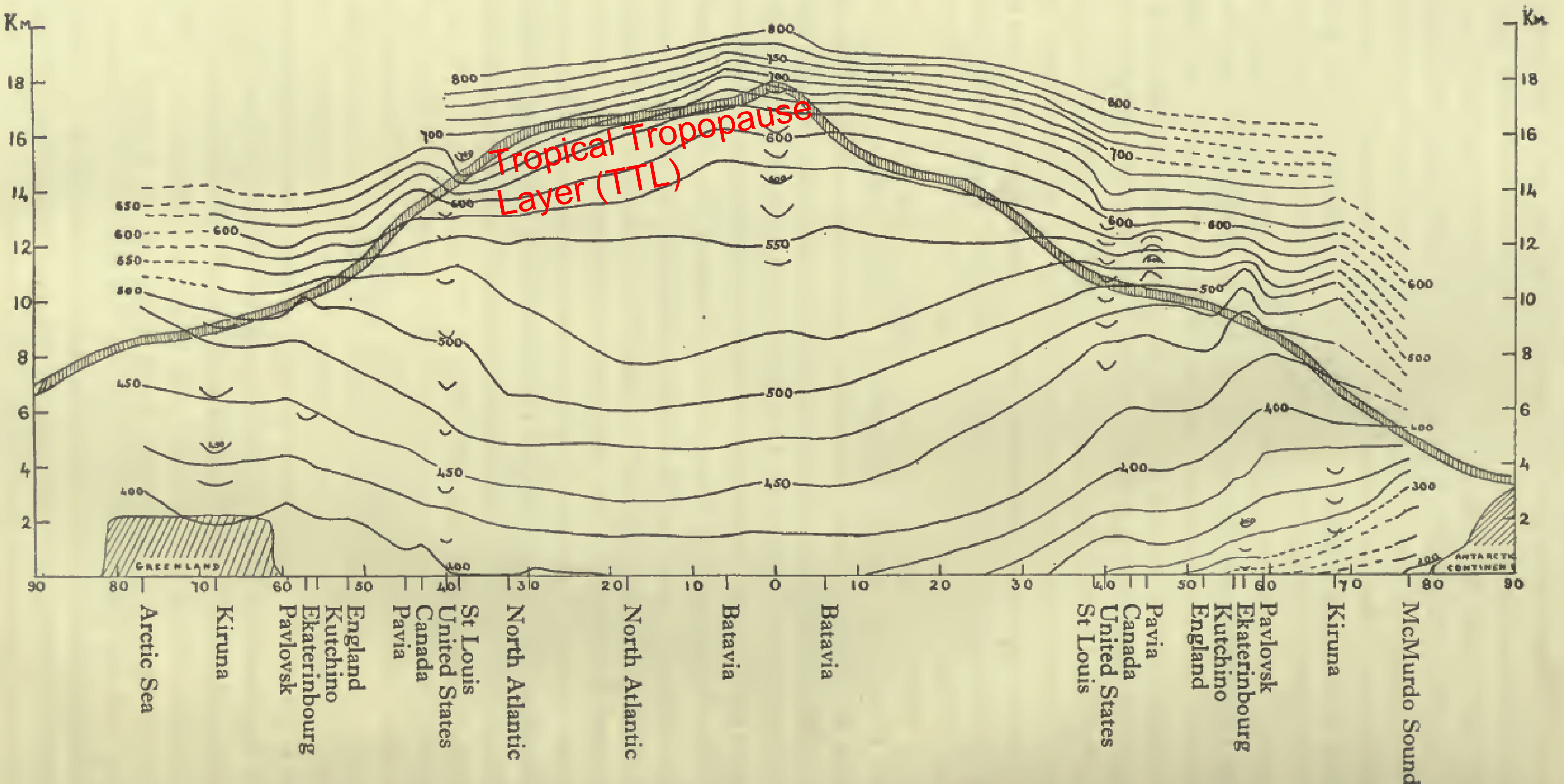
Isentropes and Tropopause according to Shaw (1930's):

FIG. 63. VARIATION OF REALISED ENTROPY IN A SECTION OF THE UPPER AIR FROM NORTH TO SOUTH.
REALISED ENTROPY = $C_p \log_e$ (POTENTIAL TEMPERATURE) + CONSTANT.



The shaded band with vertical hatching indicates the probable position of the tropopause.
The shaded areas with oblique hatching indicate the great land masses near the poles, namely Greenland and the Antarctic Continent.
⌣ indicates observations which give exceptionally high realised entropy. ⌢ indicates observations which give exceptionally low realised entropy.

From Sir Napier Shaw's Manual of Meteorology, Vol. II (1936)

Folkins et al. (1999)

Tropical Tropopause Layer (TTL)

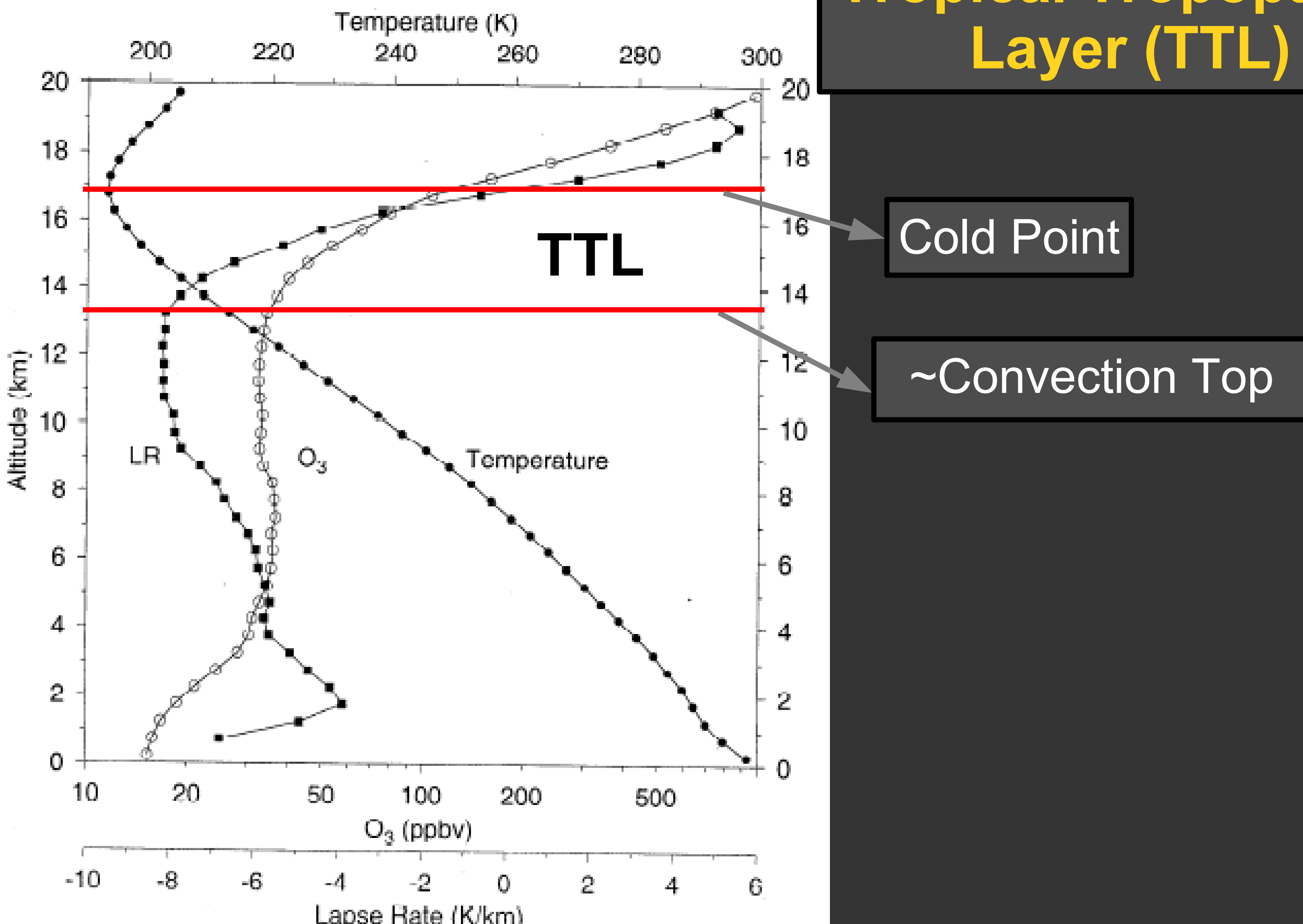
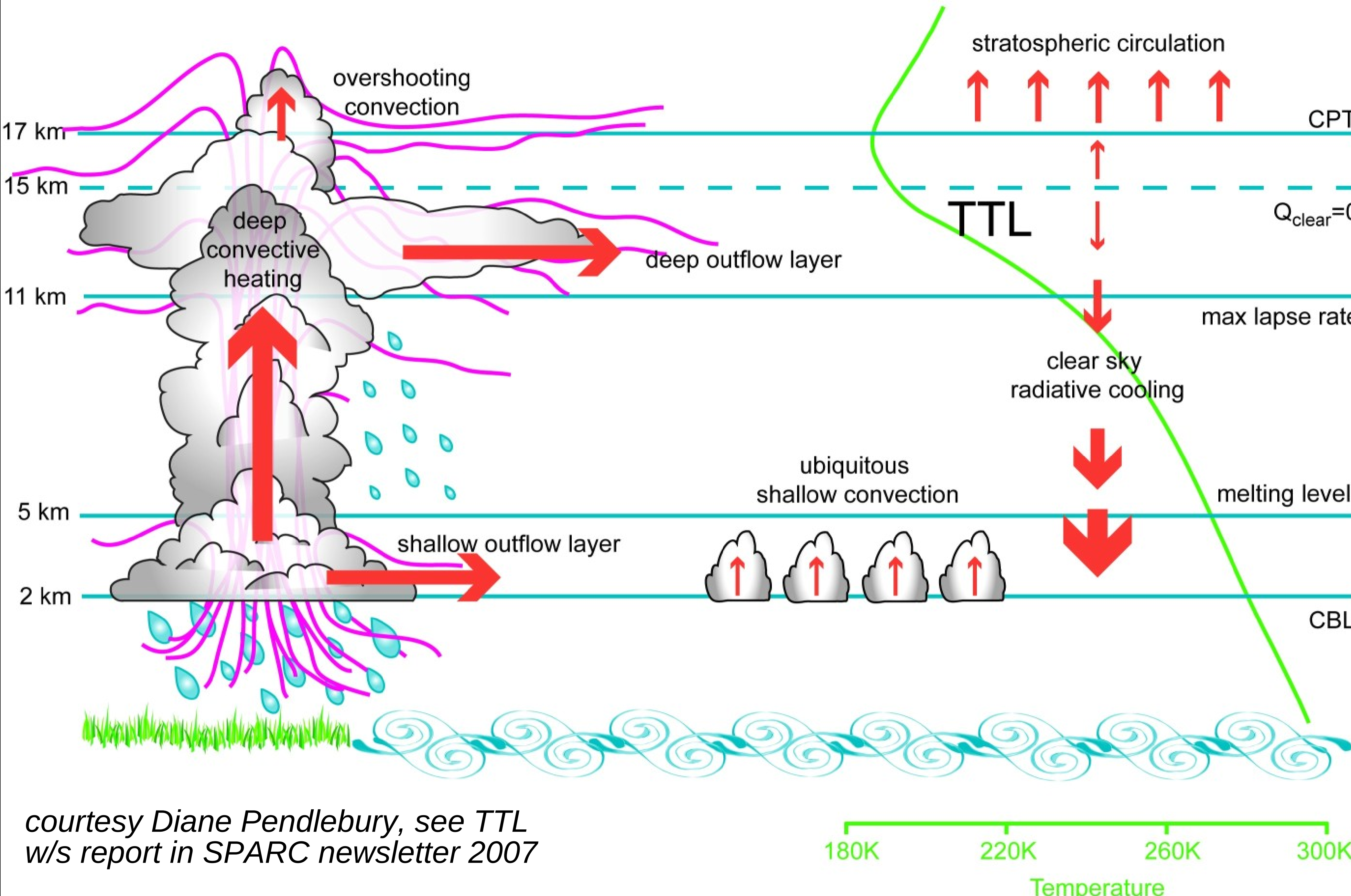


Figure 2. Average profiles of temperature, O_3, and lapse rate(LR) from all 108 Samoan ozonesondes.

Tropical Upper Troposphere / Lower Stratosphere ~ Tropical Tropopause Layer (TTL)

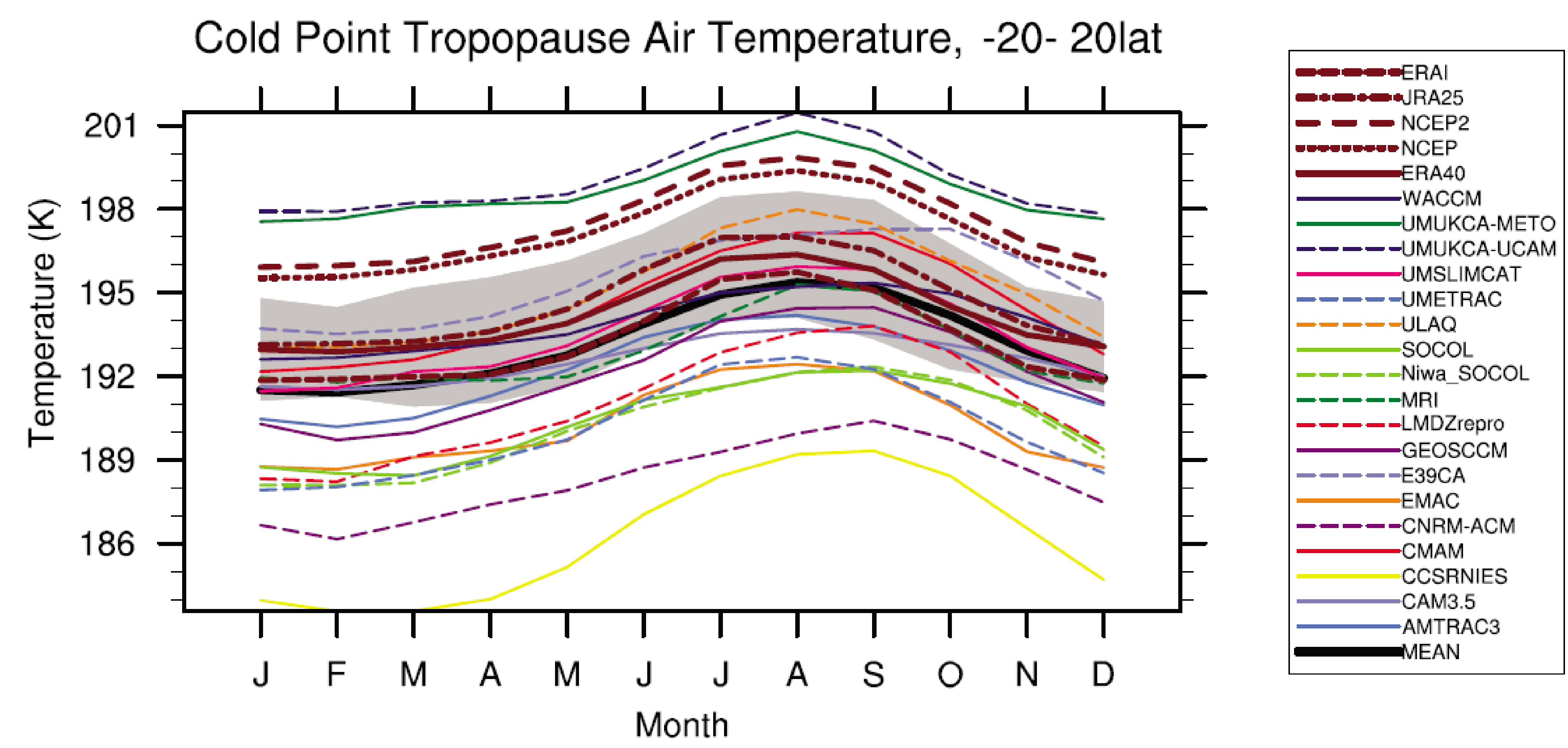
- Sets boundary conditions for constituents entering the stratosphere, most importantly water vapor
- Water vapor is crucial for stratospheric radiative budget (and for surface climate)
- Temperature variability is governed by unusually large number of processes, e.g. Dynamics on vast range of spatial and temporal scales (convective plumes, small & large scale waves, planetary-scale circulations)

Tropical Tropopause Layer and Deep Convection



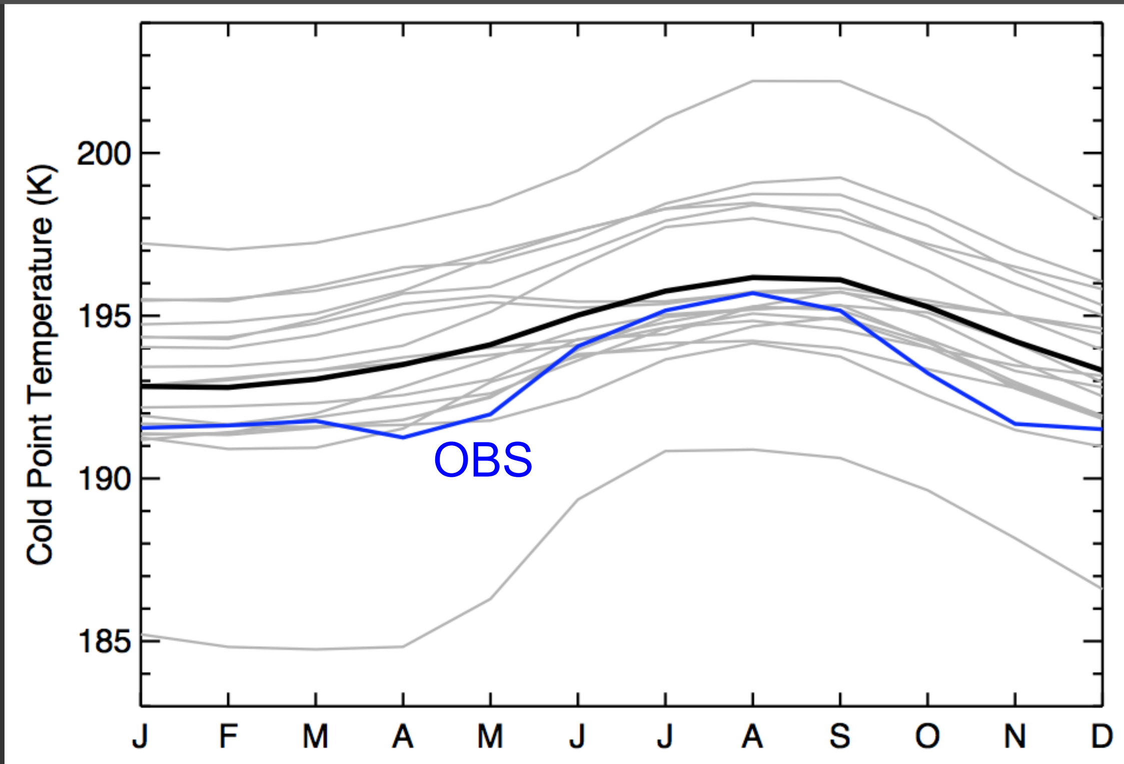
courtesy Diane Pendlebury, see TTL w/s report in SPARC newsletter 2007

Annual Cycle in Tropical Tropopause Temperature
CCMVal2 Models

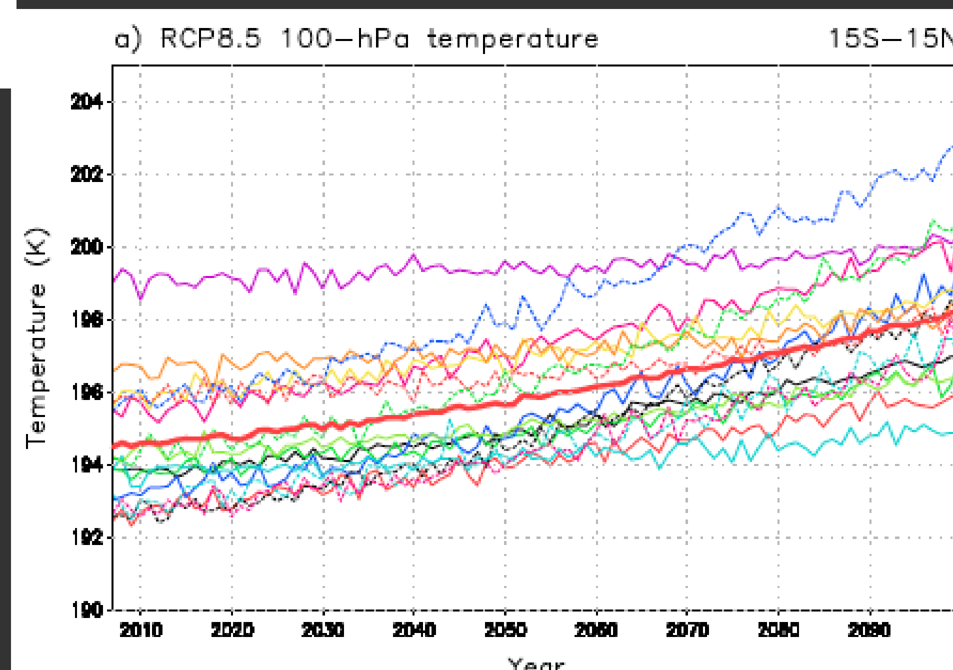


Gettelman et al., 2010

Tropical Tropopause Temperature
CMIP5 Models



Kim et al. (2013)

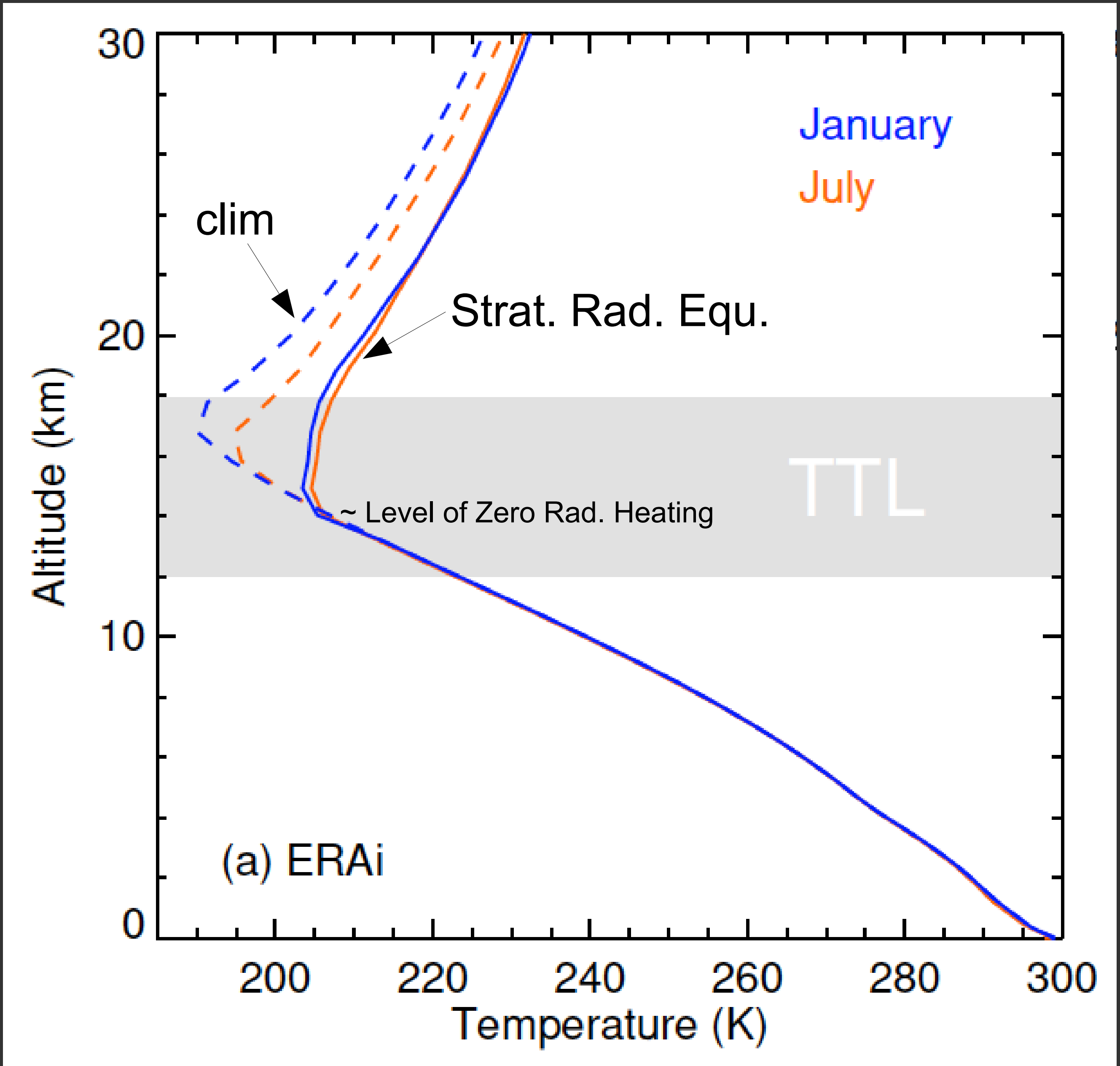


Stratospheric Radiative Equilibrium (SRE) Solutions:

- constrain tropospheric climate (e.g. equal to observed climate, incl. tracers)
- perform off-line radiative transfer calculations (clear-sky) to obtain stratospheric temperatures in radiative equilibrium for given tracer distribution
- Radiative heating rates calculated using RRTM (Rapid Radiative Transfer Model), Mlawer et al. 1997)

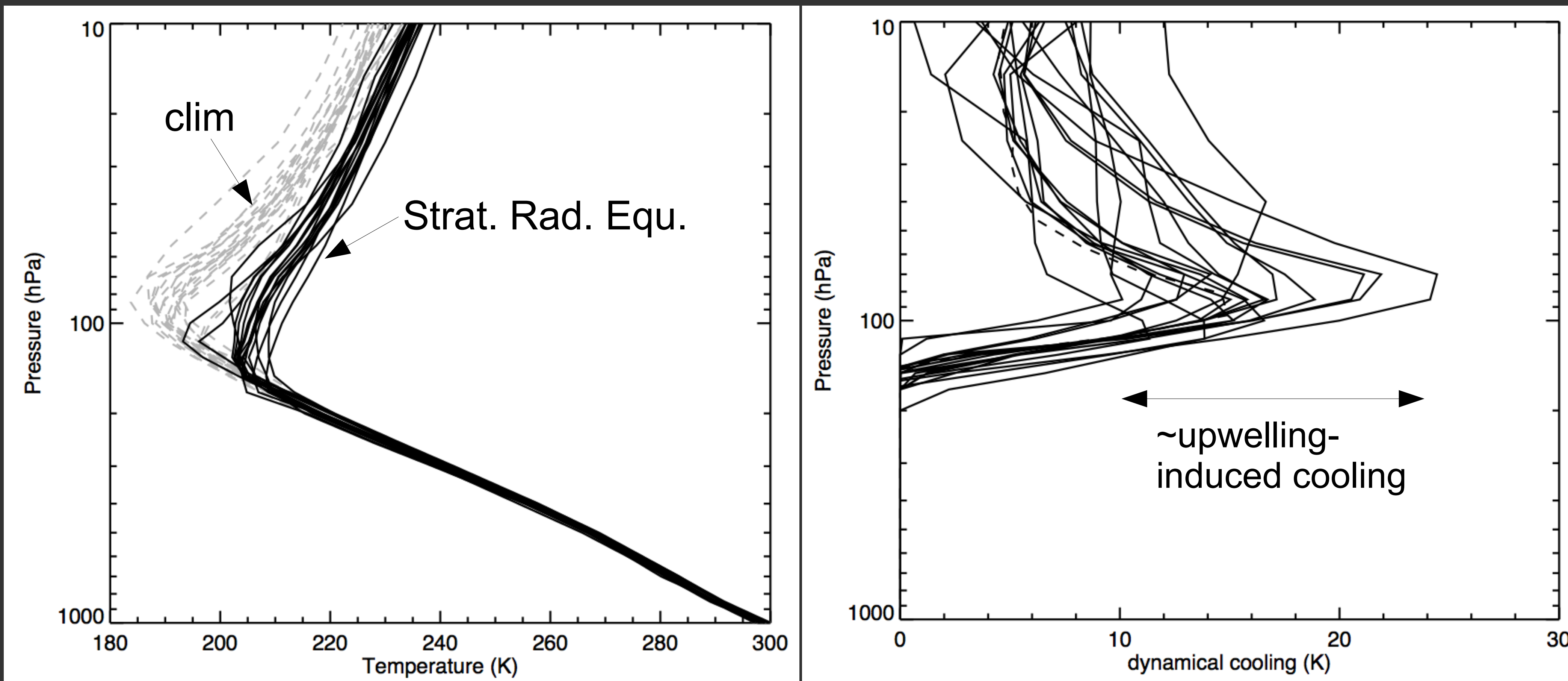
What is the resulting TTL structure?

as in Birner (2010)



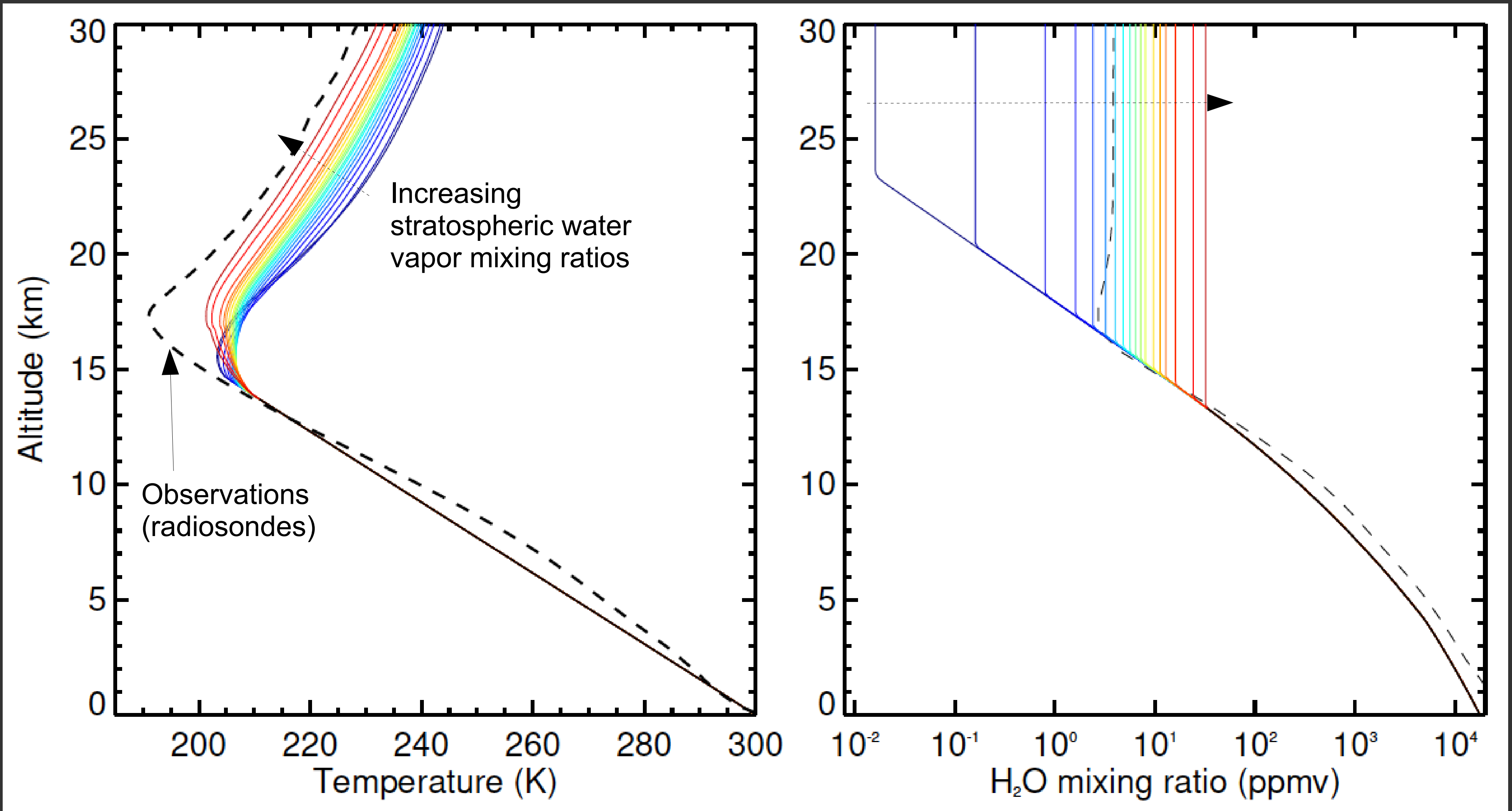
→ much reduced TTL thickness without stratospheric dynamics (in Strat. Rad. Equ.)

Stratospheric Radiative Equilibrium Solutions
CCMVal-2 Models (historical runs)



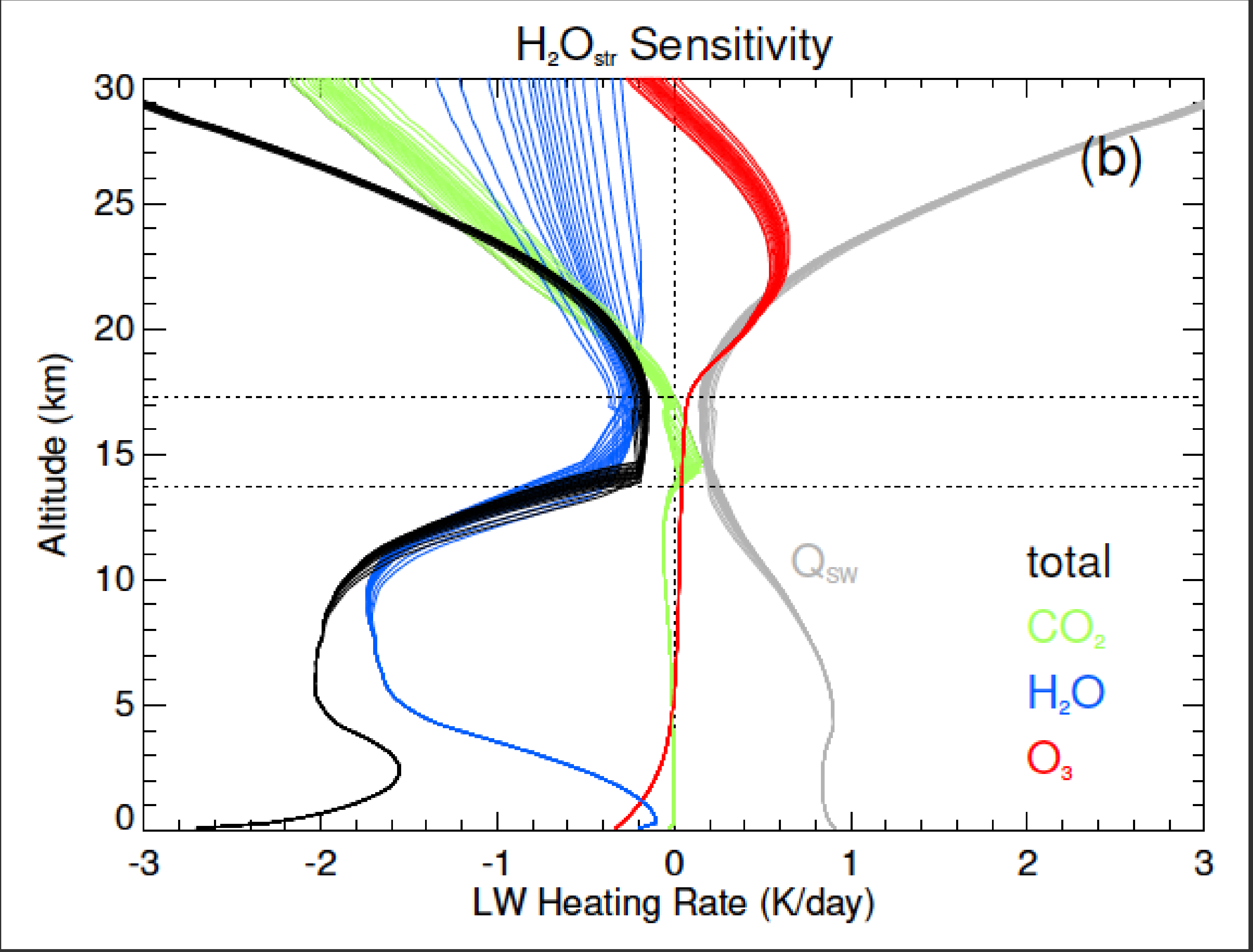
→ much reduced TTL thickness without stratospheric dynamics, qualitatively consistent across models

Radiative–Convective Equilibrium Solutions with varying stratospheric background H_2O concentrations



Parameters: T_{sfc} = 300 K, tropospheric lapse rate = 6.5 K/km, relative humidity = 50%, observed O_3 profile

Longwave Heating Rates in RCE as a function of stratospheric background H_2O concentrations

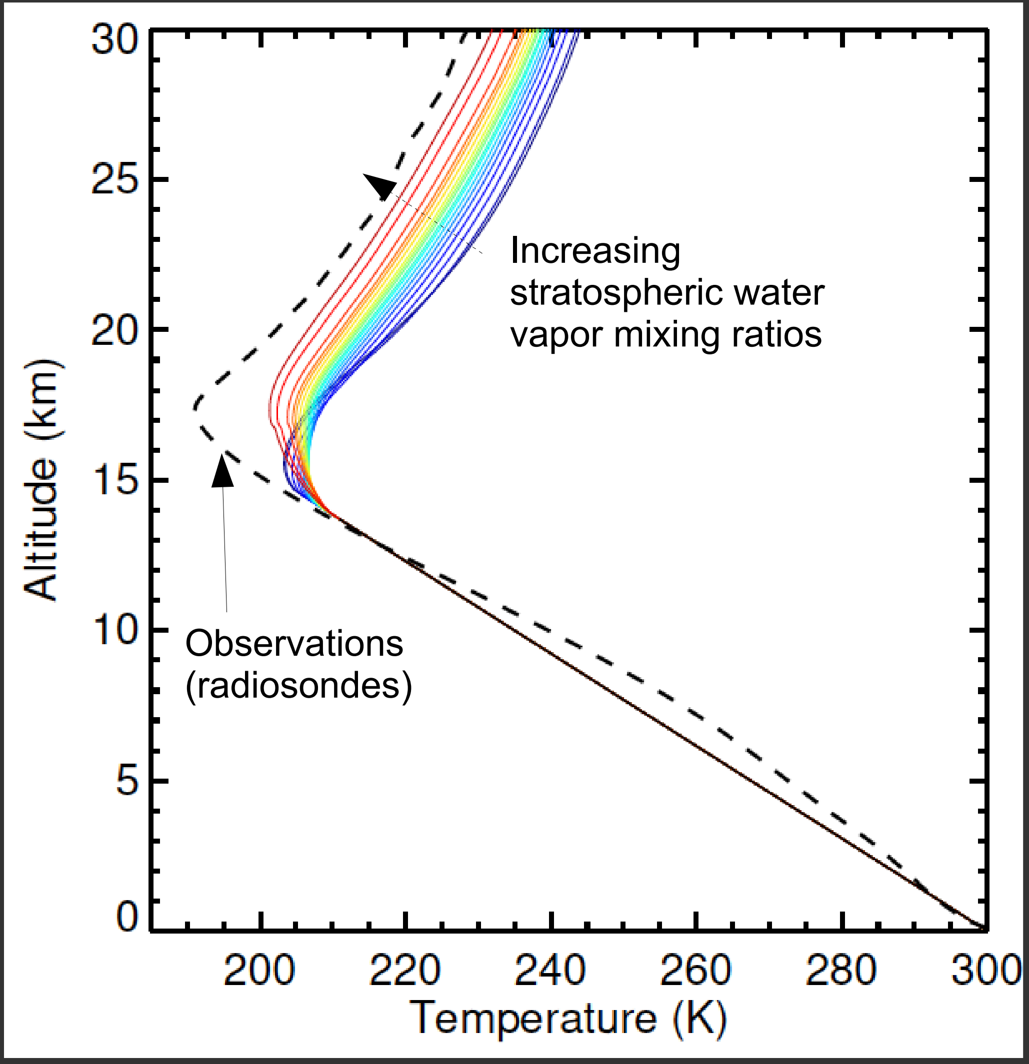


cold point

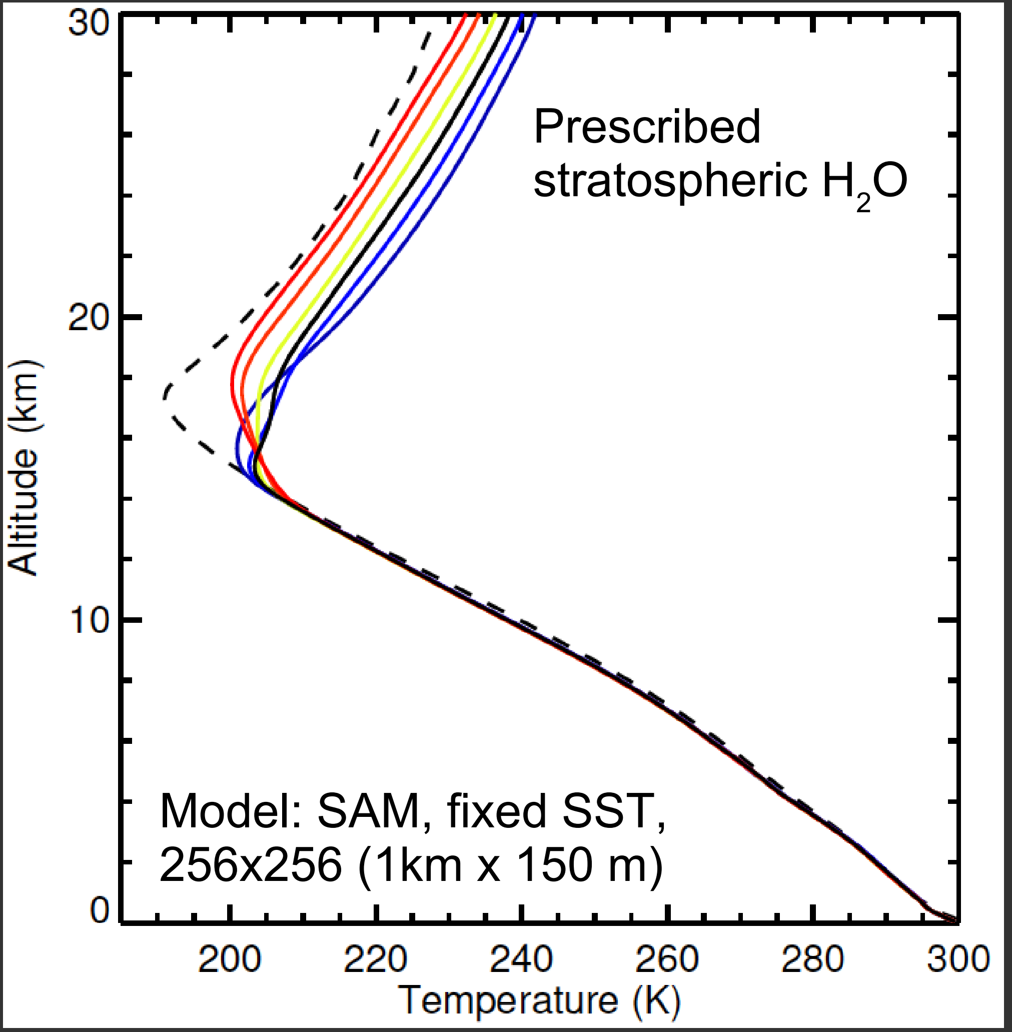
conv. top

Radiative–Convective Equilibrium Solutions with varying stratospheric background H_2O concentrations

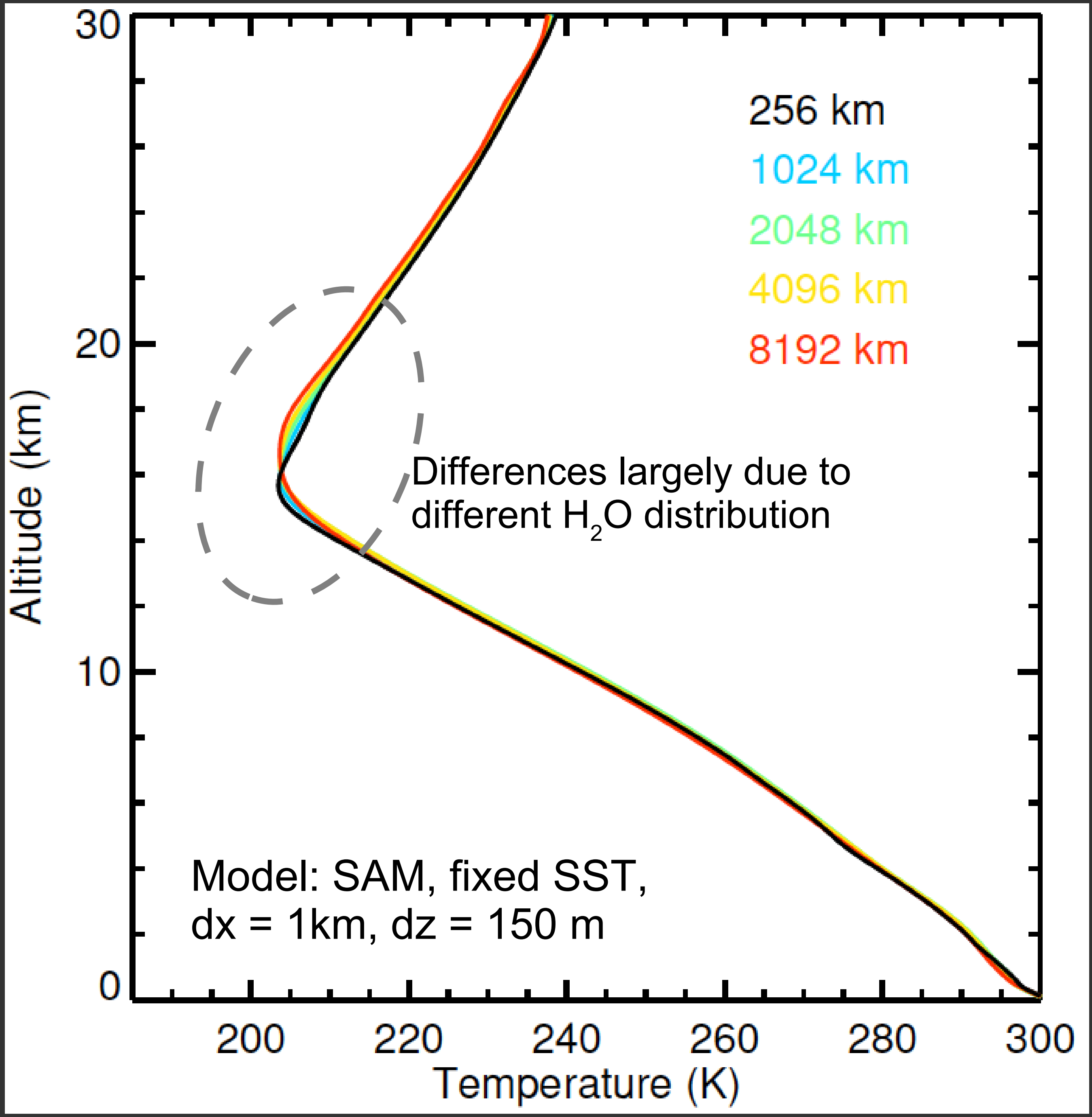
Single-column, convective adjustment



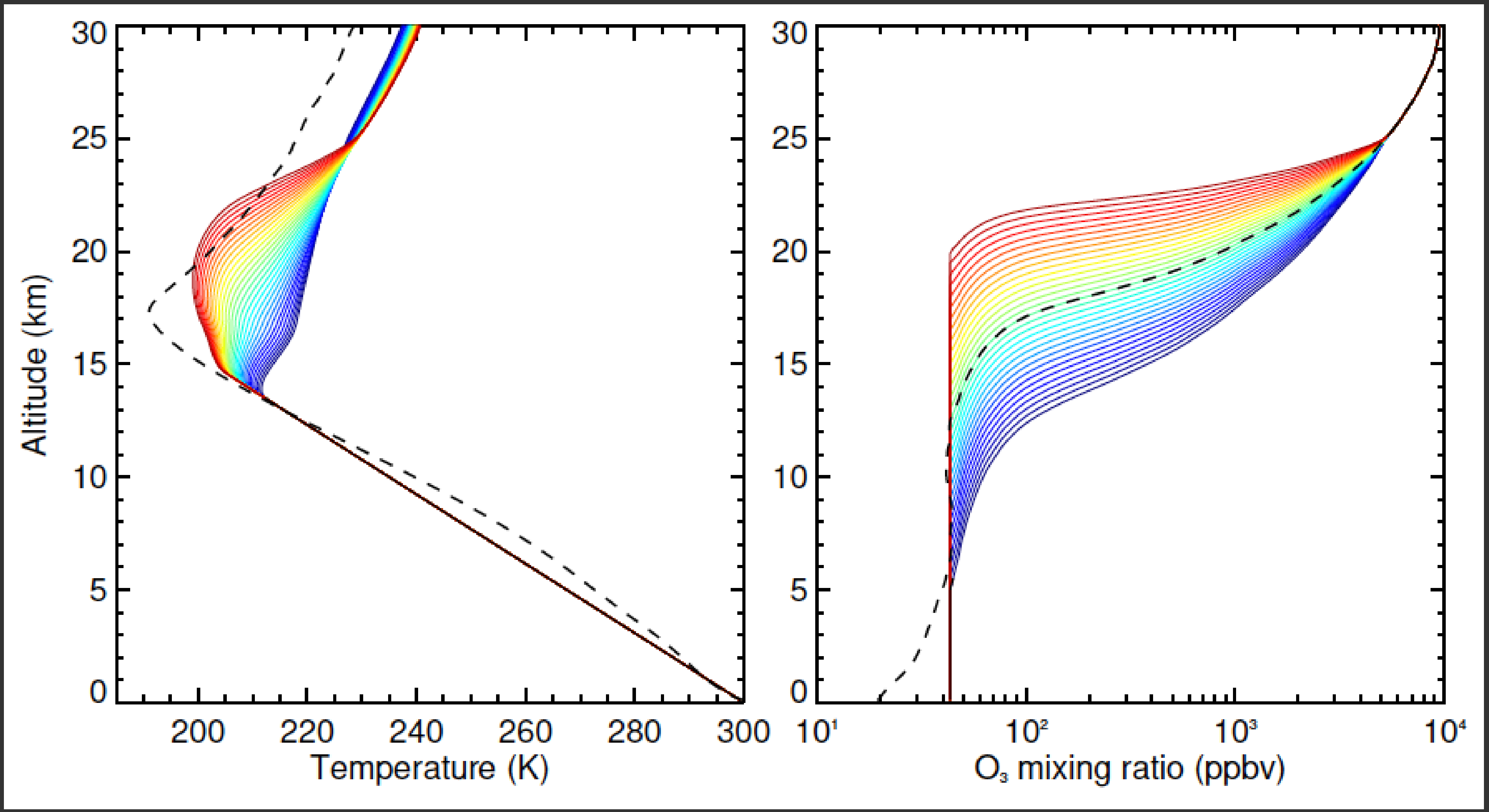
Highly truncated 2-d CRM



2-d CRM: domain size sensitivity



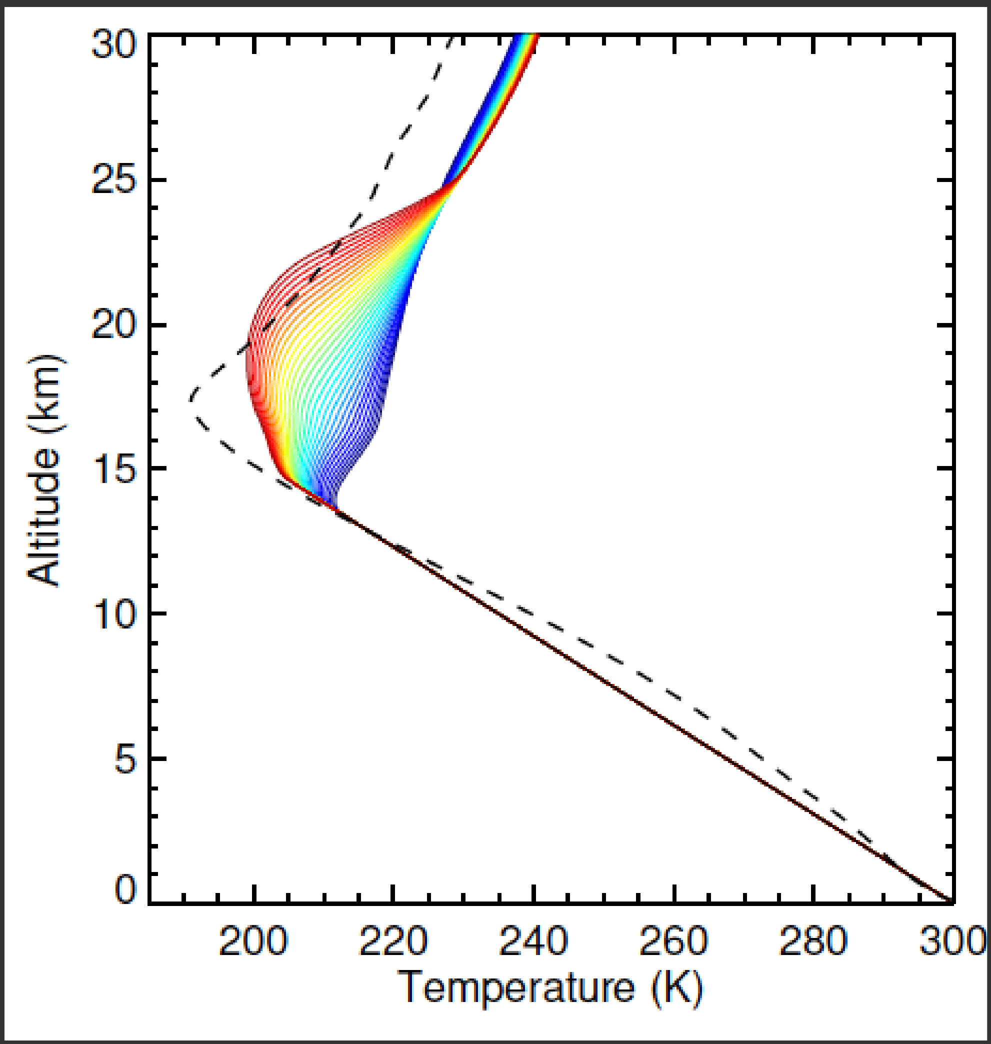
Radiative–Convective Equilibrium Solutions with varying Ozone transition levels



Parameters: T_{sfc} = 300 K, tropospheric lapse rate = 6.5 K/km, relative humidity = 50%, q_{str} = 4 ppmv

Radiative–Convective Equilibrium Solutions with varying Ozone transition levels

Single-column, convective adjustment



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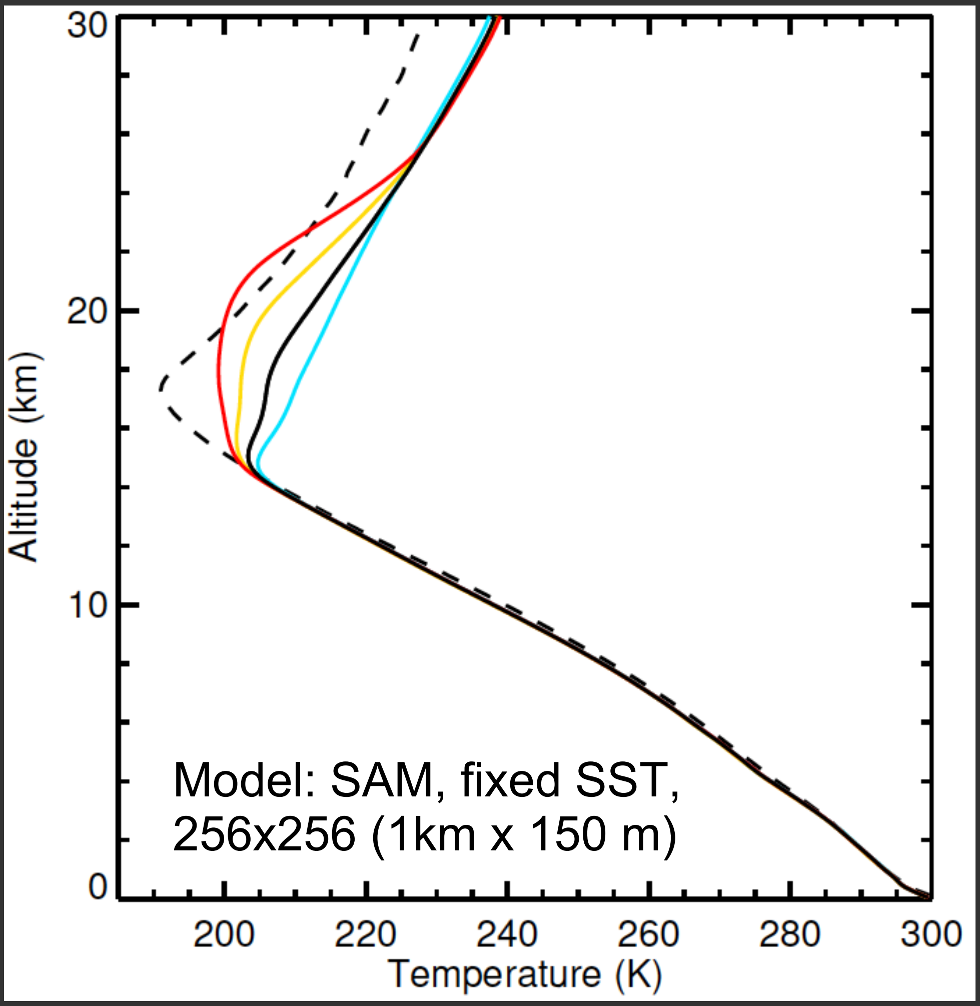

Conclusions

- TTL temperatures predominantly shaped by stratospheric upwelling (cooling), but also sensitive to radiative tracers
- TTL upwelling also shapes stratospheric H_2O and O_3 profiles, which in turn have strong impacts on TTL temperature structure
- Negative feedback between upwelling and H_2O in the stratosphere, but feedback reversed in TTL
- Positive feedback between upwelling and O_3 in TTL

RCE Sensitivity to Microphysics Parameterization in 3-d CRM (with imposed stratospheric upwelling)