The Thermal Structure of the TTL in Observations and Models

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Background & Methodology

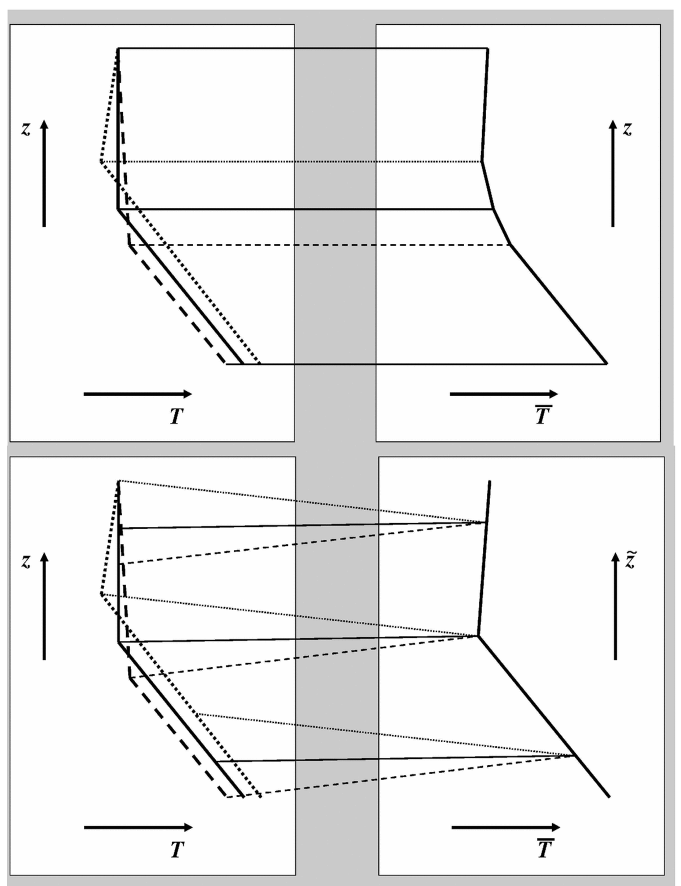
- water vapor enters stratosphere mainly through Tropical Tropopause Layer (**TTL**) where it experiences lowest temperatures and is dehydrated by condensation and precipitation
- therefore, temperatures in the TTL strongly influence the water vapor content of stratospheric air which in turn has important implications for climate
- here, we examine the climatological characteristics of the vertical temperature structure of the TTL in high–resolution radiosoundings as well as in NCEP/NCAR Reanalysis data, and in the Canadian Middle Atmosphere Model (CMAM)
- we employ a Tropopause–Based (TB) method for averaging vertical profiles (motivated by Birner, 2006):

Tropopause (Cold Point)–Based (TB) Average:

- conventional averages blur sharp features coupled to the tropopause
- TB–average utilizes tropopause (here: Cold Point, CP) as common reference level for all vertical profiles within the mean, i.e. profiles are averaged with respect to the local, time-dependent tropopause (cold point) altitude ($z_{TP} = z_{CP}$)
- characteristic features coupled to the tropopause (cold point) are preserved in a TB climatology

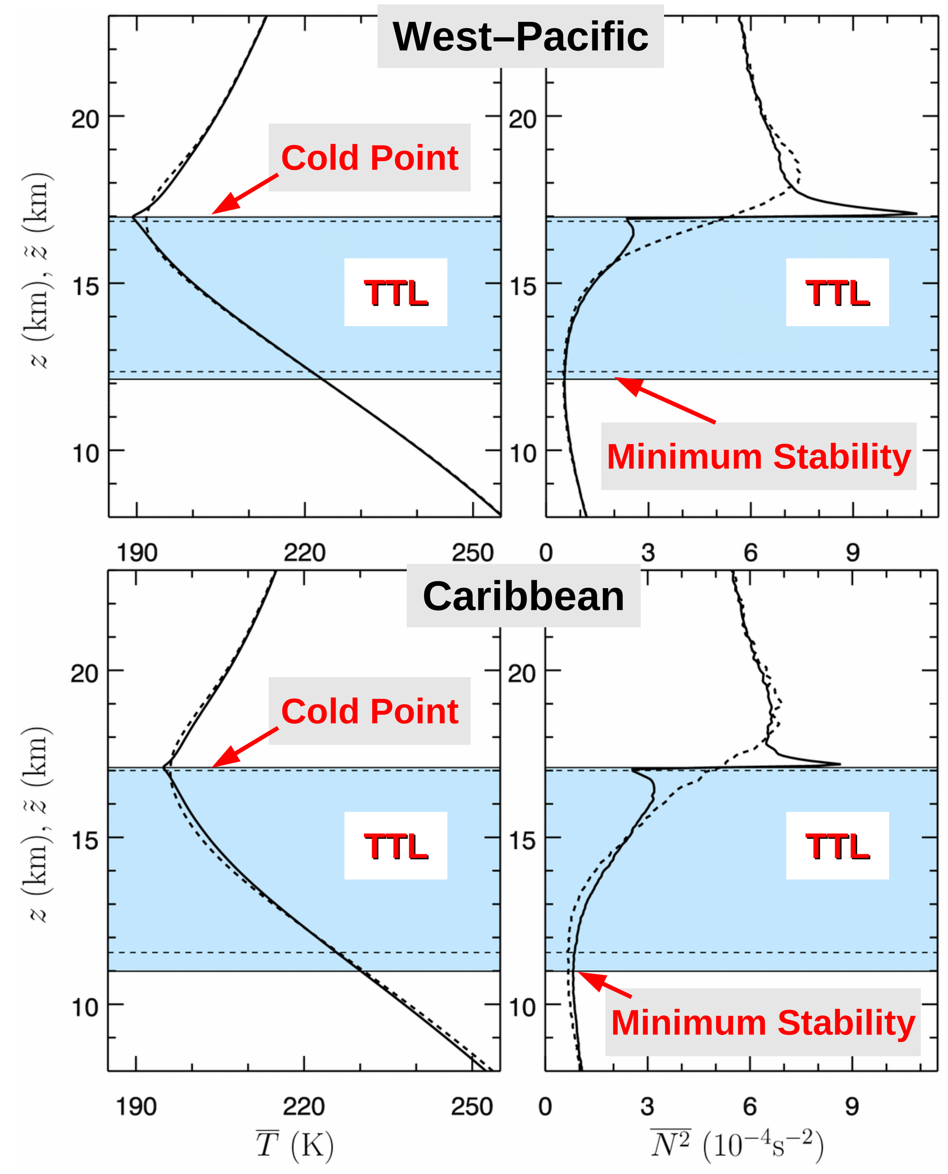
Where is the Base of the TTL?

- often taken to be level of zero radiative heating, which is hard to evaluate from temperature information alone
- Gettelman and Forster (2002) propose Minimum Stability Level
- here we propose Level of Maximum Variance in Static Stability



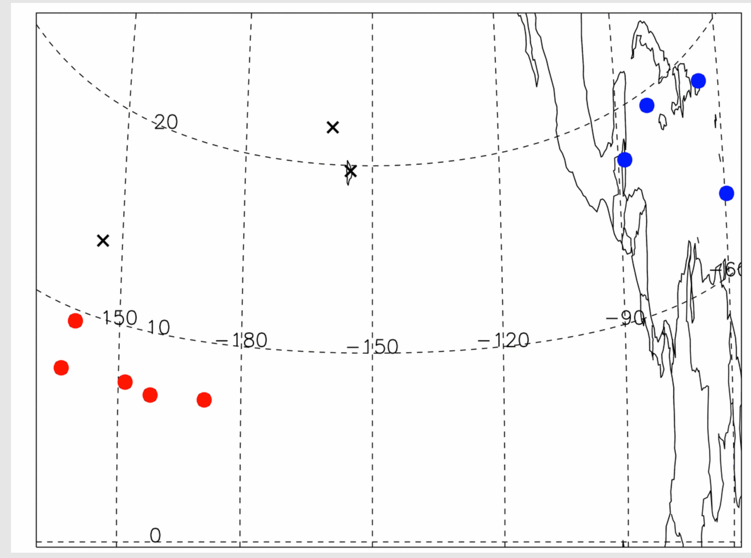
Schematic illustration of conventional (top) vs TB-average (bottom). Shown is the temperature profile (right) that results from averaging three hypothetical, individual temperature profiles (left). Each of the individual profiles exhibits a sharp tropopause, though at different altitudes. Only the TB-average preserves the sharp tropopause in the average. $\tilde{z} = z - z_{TP} + \overline{z_{TP}}$

High–Resolution Radiosonde Data



Climatological annual mean profiles of temperature (left) and buoyancy frequency squared (right). Dotted lines: conventional average; full lines: TB–average. Note modified vertical coordinate for the TB–average.

- 8 years (1998 – 2005) of about twice daily ascents from 9 tropical U.S. operated stations:



- we focus on two subsets of stations:

(1) close to the West–Pacific Warm Pool (five stations, red circles in Fig. above); no data available for January 1999!

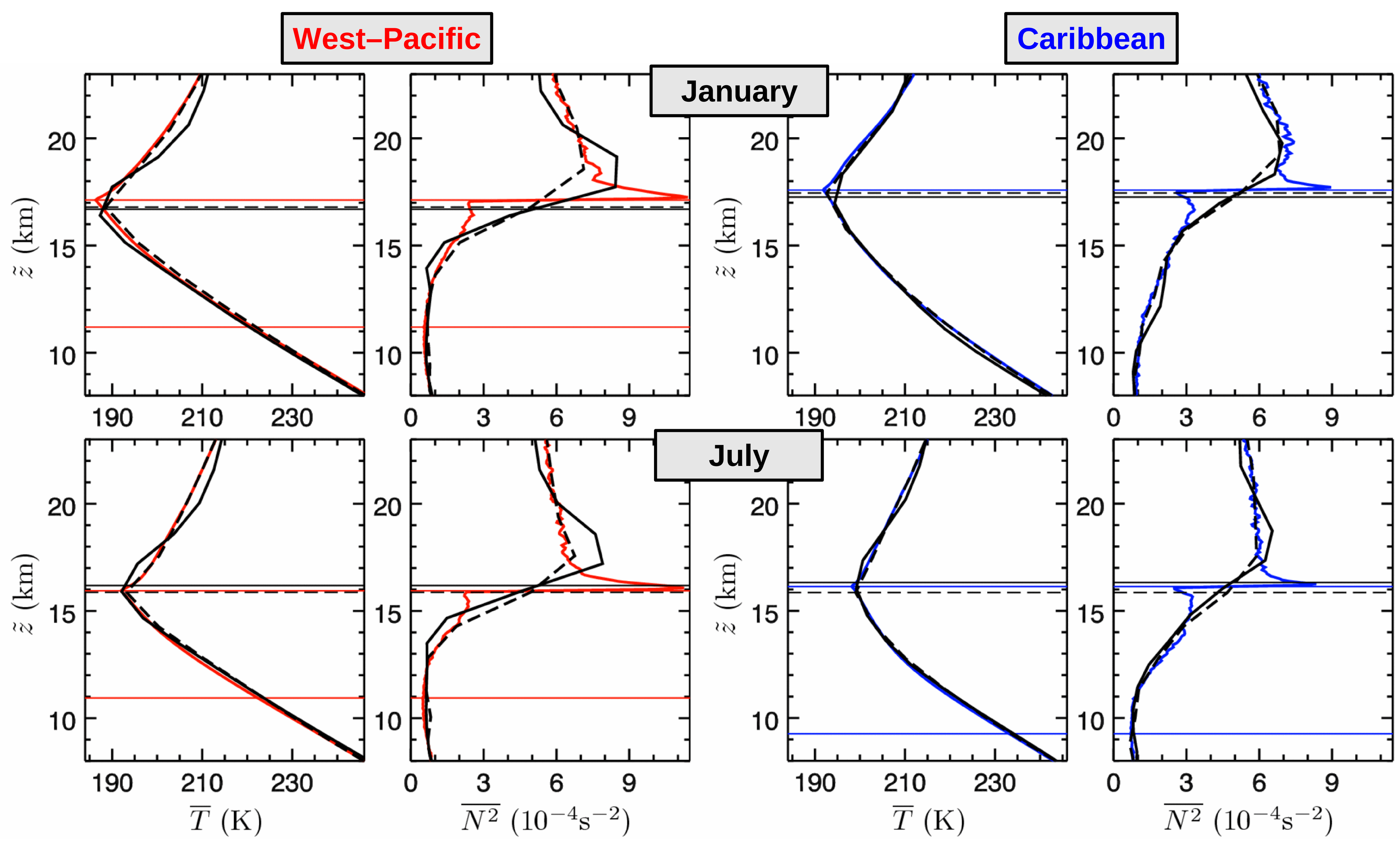
(2) in the Caribbean (four stations, blue circles in Fig. above); no data available for the Januaries of 1998 & 1999, only one station (San Juan, Puerto Rico) after 2003!

- vertical resolution: Δz ~ 25 m for temperature

Model Data

- **Canadian Middle Atmosphere Model (CMAM):** comprehensive GCM with interactive chemistry, T47L71, Δz ~ 1.2 km around tropical tropopause, data on model levels used, two arbitrary months: January & July
- **NCEP/NCAR Reanalysis (NCEP):** T63L28, Δz ~ 1.6 km around tropical tropopause, data on model levels used, 8–year climatology (1998–2005), January & July
- since models have strongly varying resolution in altitude, an Exner function like vertical coordinate (T/Θ) is used here (yielding about constant vertical resolution) and transformed to log–pressure altitudes for plotting

High–Resolution Observations vs Model Results



Climatological seasonal TB–mean profiles of temperature and buoyancy frequency squared. ***Colored lines:*** *radiosonde data;* ***Black full lines:*** *CMAM;* ***Dashed lines:*** *NCEP. Model data has been sampled at the radiosonde locations only. Note that vertical coordinate is log–pressure altitude. Horizontal lines mark respective cold points, and in the case of radiosonde data the minimum stability level (outside the range for January, Caribbean).*

An Alternative Definition of the Base of the TTL

- Level of minimum stability (proposed by Gettelman & Forster (2002) to serve as a proxy of the top of convection) does not seem to be very distinct in general
- top of convection varies strongly in time and space
- therefore, the hope is that the top of convection shows up as a maximum in the vertical profiles of the variance of static stability (buoyancy frequency squared)

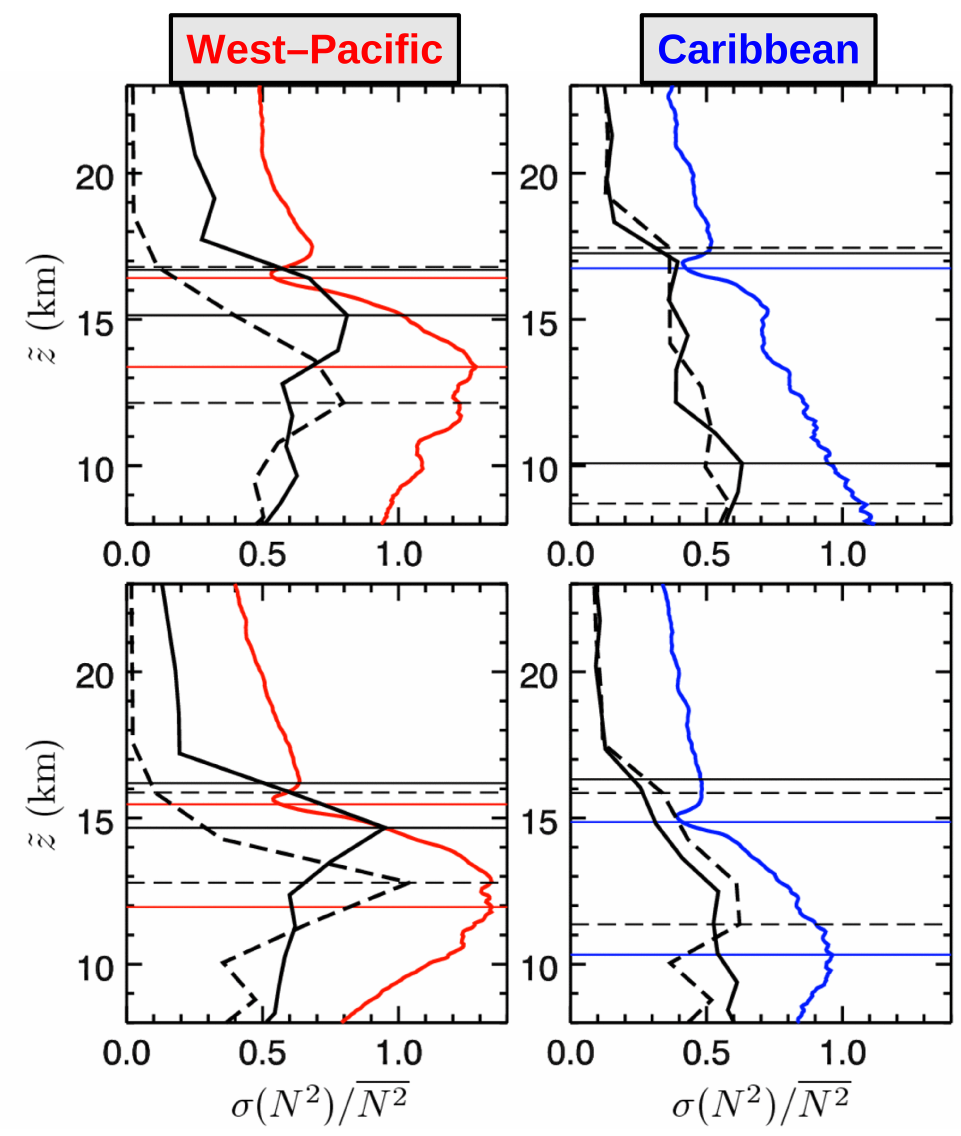
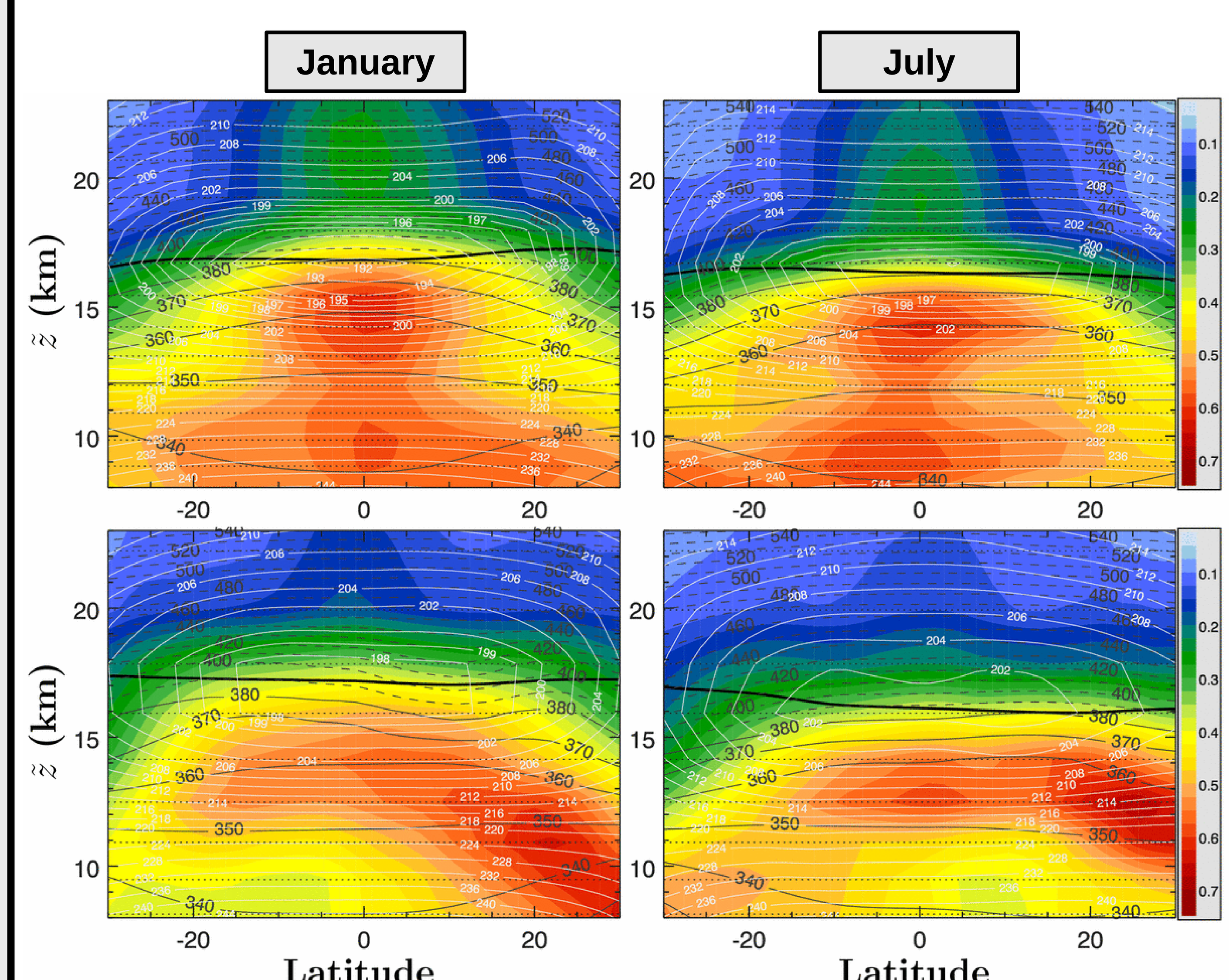


Figure: *Climatological seasonal TB–mean profiles of* ***relative standard deviation*** *of buoyancy frequency squared.* ***January (top); July (bottom). Colored lines:*** *radiosonde data;* ***Black full lines:*** *CMAM;* ***Dashed lines:*** *NCEP. Model data has been sampled at the radiosonde locations only. Vertical coordinate is log–pressure altitude here. Horizontal lines mark the location of the cold point and the* ***level of maximum variance, respectively****. As expected the variance in models is biased towards smaller values due to coarse resolution.*

Zonal Averages from Models



Climatological seasonal TB–zonal mean cross sections of the relative standard deviation of buoyancy frequency squared (colors), potential temperature (dark grey contours), and temperature (light grey contours). ***Top:*** *CMAM;* ***Bottom:*** *NCEP. Vertical coordinate is log–pressure altitude. Thick black lines denote climatological seasonal mean position of cold point. Both models have distinct regions of maximum variance, though of quite different latitudinal extent. CMAM exhibits a consistent signature of a second maximum further below.*

Short Summary and Thoughts

- High–resolution radiosoundings show strong stability maximum just above cold point: **Signature of Overshooting Convection?**
- **Level of Minimum Stability not very distinct** in general, especially in model data (presumably due to coarse resolution)
- **Level of Maximum Variance – A useful Alternative?**

References

- Birner, T. (2006), Fine–scale structure of the extratropical tropopause region. *J. Geophys. Res., 111,* D04104, doi:10.1029/2005JD006301.
- Gettelman, A. and P. F. de F. Forster (2002), A climatology of the tropical tropopause layer, *J. Met. Soc. J., 80*, 4B, 911–924.

Acknowledgements

The U.S. radiosonde data is freely available at the SPARC data center at Stony Brook University, NY, USA: http://www.sparc.sunysb.edu/. NCEP Reanalysis provided by the NOAA–CIRES Climate Diagnostic Center: http://www.cdc.noaa.gov/. Thanks to David Sankey for providing CMAM data.