Tropical upper tropospheric temperature - Global circulation and climate lectures, 5 & 12 November, 2019

Outline

1. Introduction: Models in general simulate a stronger increase of tropical upper tropospheric temperature with surface warming than suggested by observations.
2. Climatology: Tropical temperature profiles
3. Physics: Theoretical framework and understanding of processes that influence tropical upper tropospheric temperatures (see concepts)
4. Potential consequences for global circulation

Concepts

- Radiative convective equilibrium
- Static stability
- Moist adiabats
- Weak temperature gradient
- Convective Top and cold point tropopause

Reading

A short overview on some of the issues discussed in this lecture is provided by a blog entry from Isaac Held from December, 7, 2011.
A recent update on discrepancies between observations and simulations of tropical tropospheric temperatures is provided by Santer et al. (2017). This paper is fairly technical in the sense that it discusses extensively the statistical significance of the difference between some datasets. But it cites also many earlier studies on the subject which would provide further reading.
Bretherton and Smolarkiewicz (1989) perform idealized experiments of convecting clouds and provide an explanation for how gravity waves can be thought to sustain the tropical weak temperature gradients.
Consequences of upper tropical tropospheric warming in an idealized general circulation model are discussed by Butler et al. (2010). Sohn et al. (2016) argue that an overestimation of the upper tropical tropospheric warming by climate models may explain why they in general simulate a weakening of the Walker circulation which is not supported by observations.
Dacie et al. (2019) show an application of an, in principle, old tool, a 1D radiative convective equilibrium (RCE) model to study still open questions, in this case the role of different factors for the tropopause region and its influence on surface climate.

Exercises

1) Explain the meaning of potential temperature, liquid water potential temperature, equivalent potential temperature and saturated equivalent potential temperature.
2) Assuming that the temperature lapse rate in the free tropical troposphere is provided by a moist adiabat. How much warming would we expect at 10 km altitude for a surface warming of 1K.

3) More correctly than a weak temperature gradient (WTG) approximation would be a weak buoyancy gradient approximation. If we assume that the dry (downdraft) regions of the tropics are completely dry, and the wet (updraft) regions are saturated, what would the temperature difference between wet and dry regions be?
4) Think of the tropics as a mean updraft and mean downdraft following the moist adiabat. If specific humidity increases by 6% for a warming of 1K and precipitation only by 2%, how can this be reconciled.

References

Bretherton, C. S., & Smolarkiewicz, P. K. (1989). Gravity waves, compensating subsidence and detrainment around cumulus clouds. *Journal of the Atmospheric Sciences*, *46*(6), 740-759.

Butler, A. H., Thompson, D. W., & Heikes, R. (2010). The steady-state atmospheric circulation response to climate change–like thermal forcings in a simple general circulation model. *Journal of Climate*, *23*(13), 3474-3496.

Dacie, S., Kluft, L., Schmidt, H., Stevens, B., Buehler, S. A., Nowack, P. J., ... & Birner, T. (2019). A 1D RCE study of factors affecting the tropical tropopause layer and surface climate. *Journal of Climate*, *32*(20), 6769-6782.

Held, I (2011).The moist adiabat and tropical warming**,** https://www.gfdl.noaa.gov/blog_held/20-the-moist-adiabat-and-tropical-warming/

Santer, B. D., Fyfe, J. C., Pallotta, G., Flato, G. M., Meehl, G. A., England, M. H., ... & Cvijanovic, I. (2017). Causes of differences in model and satellite tropospheric warming rates. *Nature Geoscience*, *10*(7), 478.

Sohn, B. J., Lee, S., Chung, E. S., & Song, H. J. (2016). The role of the dry static stability for the recent change in the Pacific Walker circulation. *Journal of Climate*, *29*(8), 2765-2779.