# High-latitude stratospheric temperatures - Global circulation and climate lectures, 7 & 14 January, 2020

## Outline

1. Introduction:
    a. The current situation in the middle atmosphere
    b. The typical high-latitude lower stratosphere cold bias in GCMs and why we care
2. Radiatively active gases in the stratosphere: $O_3$, $CO_2$, $H_2O$
3. Middle atmospheric zonal mean circulation
    a. Thermal wind
    b. Circulation under the assumption of radiative equilibrium
    c. Necessity for zonal momentum dissipation
4. Middle atmosphere waves and their influence on its circulation and temperature
    a. Gravity waves
    b. Planetary waves: non-acceleration theorem; Residual circulation; Transformed Eulerian Mean diagnostics; EP flux
5. Modeling studies of the observed bias

## Concepts

- Diabatic and adiabatic contributions to the temperature structure of the stratosphere
- Radiative equilibrium temperatures
- Thermal wind
- Eddy heat and momentum fluxes
- Wave-mean flow interactions
- Residual/Lagrangian circulation vs. Eulerian circulation - Transformed Eulerian Mean diagnostics

## Reading

A nice basic tutorial on middle atmosphere circulation is given by Geller (1983). It is demonstrated that summer easterlies and winter westerlies are basically caused by differential solar heating, but that the deviations of zonal mean temperatures from radiative equilibrium and the observed closure of the stratospheric jets with altitude requires some zonal momentum force. It is also shown how this force creates the mean meridional circulation of the middle atmosphere often called Brewer-Dobson-Circulation and argued that the momentum force should come from different types of waves.
Newman et al. (2001) argue that the polar lower stratospheric temperature is
Primarily controlled by planetary-scale waves.
Stenke et al. (2008) argue that in their general circulation model the typical cold bias in the lower high-latitude stratosphere is at least partly related to a positive water vapour bias (caused by too diffusive Eulerian transport). Maycock et al. (2011) provide a more specific discussion of the radiative heating effects of stratospheric water vapour.
Many textbooks are of course a great source of knowledge on basic issues related to this lecture. Although the book by Brasseur and Solomon (2005) has a focus on chemistry it

provides very useful chapters on middle atmosphere radiation and dynamics. Deeper insights into stratospheric dynamics are provided by the book of Andrews et al. (1990) where in particular information on wave-mean flow interactions, the Eliassen-Palm flux, and the Transformed Eulerian Mean diagnostics can be found.

## Exercises

- Explain, where in the middle atmosphere the radiative equilibrium temperature deviates strongly from observed temperatures, which zonal mean circulation would correspond to radiative equilibrium temperatures, and how that deviates from observations.
- Explain the term “residual circulation”.

## References


Andrews, D. G., J. R. Holton, and C. B. Leovy, Middle Atmosphere Dynamics, Academic Press, Orlando, 1990.

Brasseur, G. P., and Solomon, S., Aeronomy of the Middle Atmosphere, 3rd revised ed., Springer, Dordrecht, 2005.

Geller, M., Dynamics of the middle atmosphere, *Space Science Reviews*, 34, 359-375, 1983.

Maycock, A. C., Shine, K. P., & Joshi, M. M.. The temperature response to stratospheric water vapour changes. *Quarterly Journal of the Royal Meteorological Society*, 137(657), 1070-1082, 2011.

Newman, P. A., Nash, E. R., & Rosenfield, J. E., What controls the temperature of the Arctic stratosphere during the spring? *Journal of Geophysical Research: Atmospheres*, 106(D17), 19999-20010, 2001.

Stenke, A., V. Grewe, and M. Ponater, Lagrangian transport of water vapor and cloud water in the ECHAM4 GCM and its impact on the cold bias, *Climate Dynamics*, 31.5, 491-506, 2008.