Polar Vortex Regimes in a Simple GCM

Roland Walz, Hella Garny, Thomas Birner

Motivation

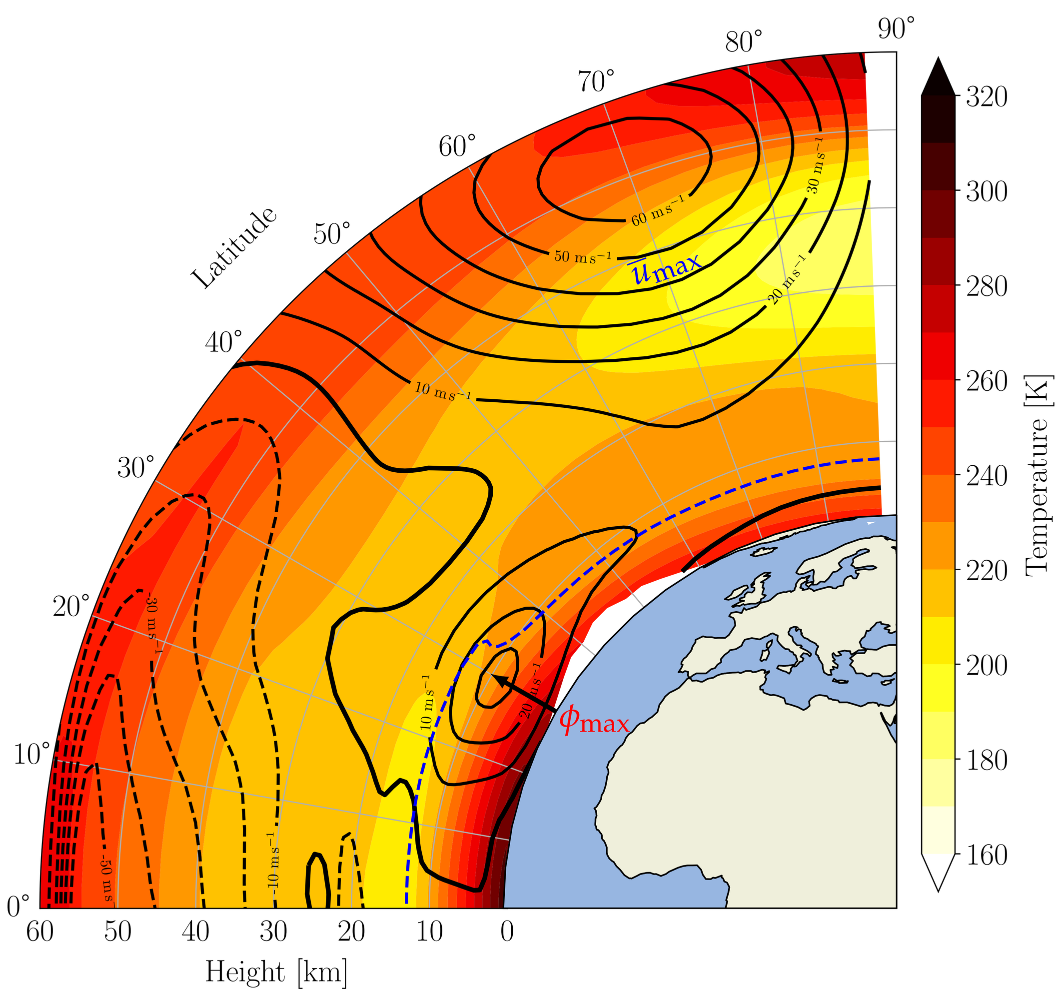
- Large uncertainty of polar vortex response to global warming in comprehensive climate models (Manzini et al., 2014)
- Nonlinear response of northern hemispheric stratospheric zonal-mean zonal wind $\overline{u}$ to CO_2 induced global warming (Manzini et al., 2018):
  - first 2 K temperature increase: deceleration of $\overline{u}$
  - second 2 K temperature increase: acceleration of $\overline{u}$

Method

- Use a dry dynamical-core general circulation model (GCM) to investigate circulation changes that are solely due to temperature variations
- Represent greenhouse gas-induced global warming by additional tropical upper-tropospheric heating of amplitude q_0

Research questions

- How does the atmospheric circulation respond to tropical upper-tropospheric warming in a simple general circulation model (GCM)?
- Specifically, how do the latitude of the maximum tropospheric zonal-mean zonal wind ϕ_{max} and the maximum zonal-mean zonal wind at 10 hPa $\overline{u}_{max}$ change?



Time-mean zonal-mean temperature (color shading) and zonal wind (black contour lines) without tropical upper-tropospheric heating (q_0 = 0 K day^{-1}).

Summary

Variation of tropospheric heating amplitude q_0 reveals two atmospheric circulation regimes:

1) Weak polar vortex regime for $q_0 < 0.3$ K day^{-1} with frequent formation of sudden stratospheric warming events (SSWs)

$$\phi_{max} \lesssim 35°N, \ \overline{u}_{max} \lesssim 50\,m\,s^{-1}$$

2) Strong polar vortex regime for $q_0 > 0.35$ K day^{-1} with very rare formation of SSWs

$$\phi_{max} \gtrsim 40°N, \ \overline{u}_{max} \gtrsim 70\,m\,s^{-1}$$

Both regimes present at transition (q_0 = 0.35 K day^{-1})

Possible mechanism

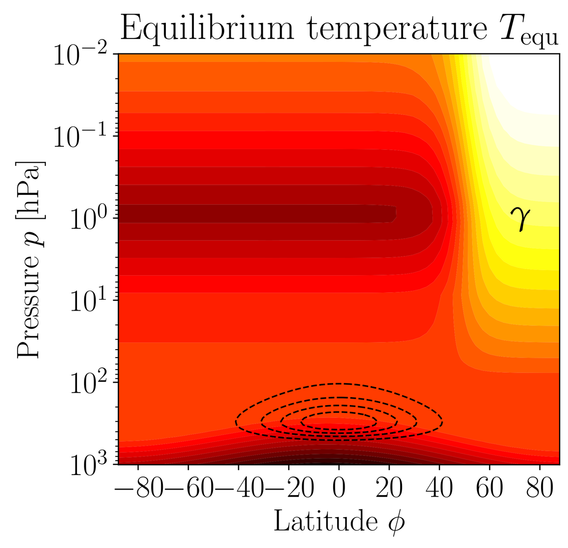
Increased tropical upper-tropospheric heating leads to a northward shift of the tropospheric jet and hence to an equatorward refraction of Eliassen-Palm (EP) flux. Thus, less EP flux enters the stratosphere making the polar vortex less disturbed and therefore stronger (Wang et al., 2012).

Conclusions

- Existence of critical value of ϕ_{max} above which stratosphere gives feedback on troposphere.
- Diversity of polar vortex response to increased CO_2 concentrations in comprehensive models possible due to different basic states

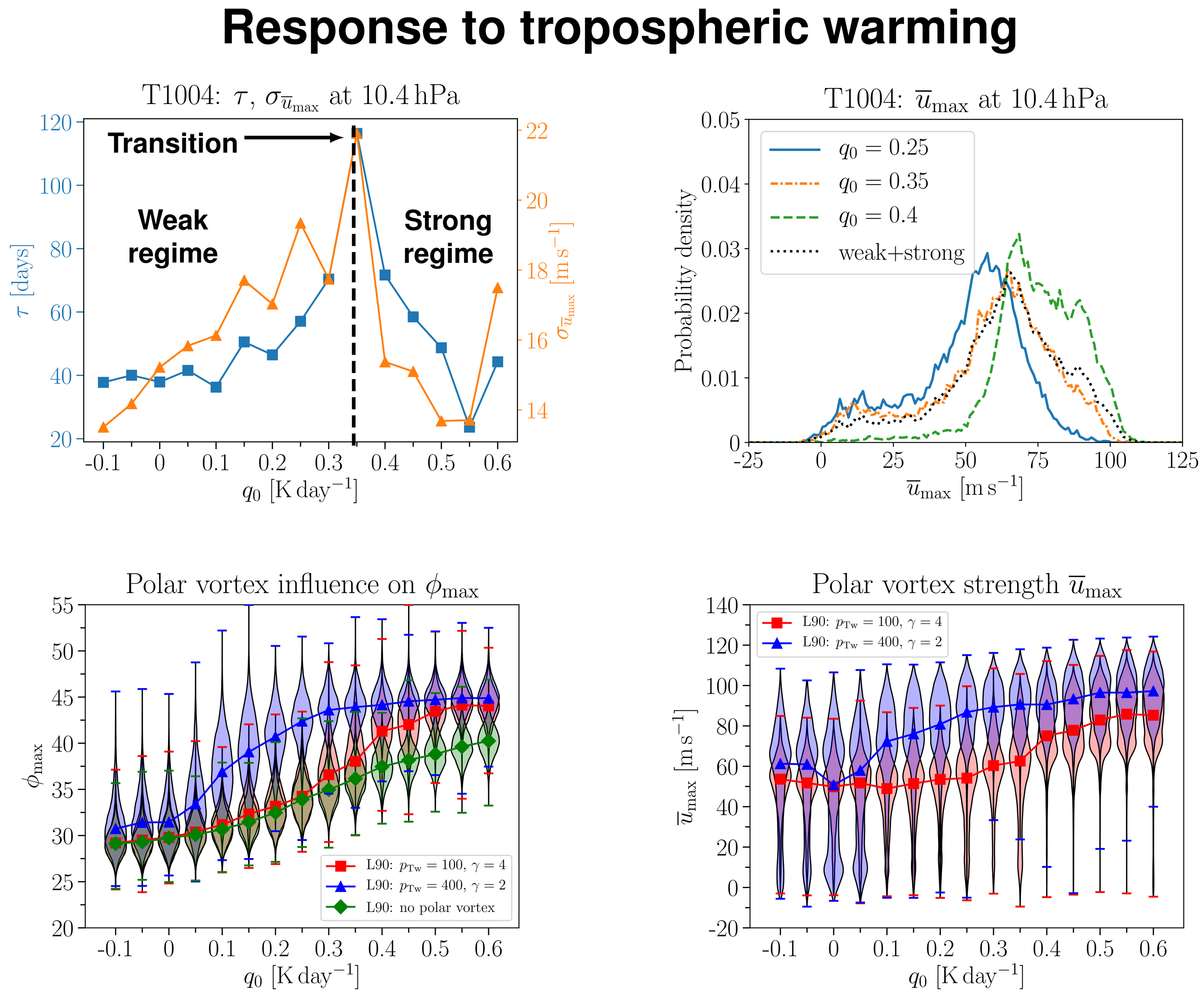
Simulation setup

- Setup based on Wang et al. (2012)
- Resolution: T42L90MA
- All simulations integrated for 30 years
- Perpetual January condition
- WN2 topography with 3 km amplitude
- Tropical upper-tropospheric heating $Q(\phi, p)$ (black dashed contour lines in 0.1 K day^{-1}, exemplary for q_0 = 0.5 K day^{-1} in figure)



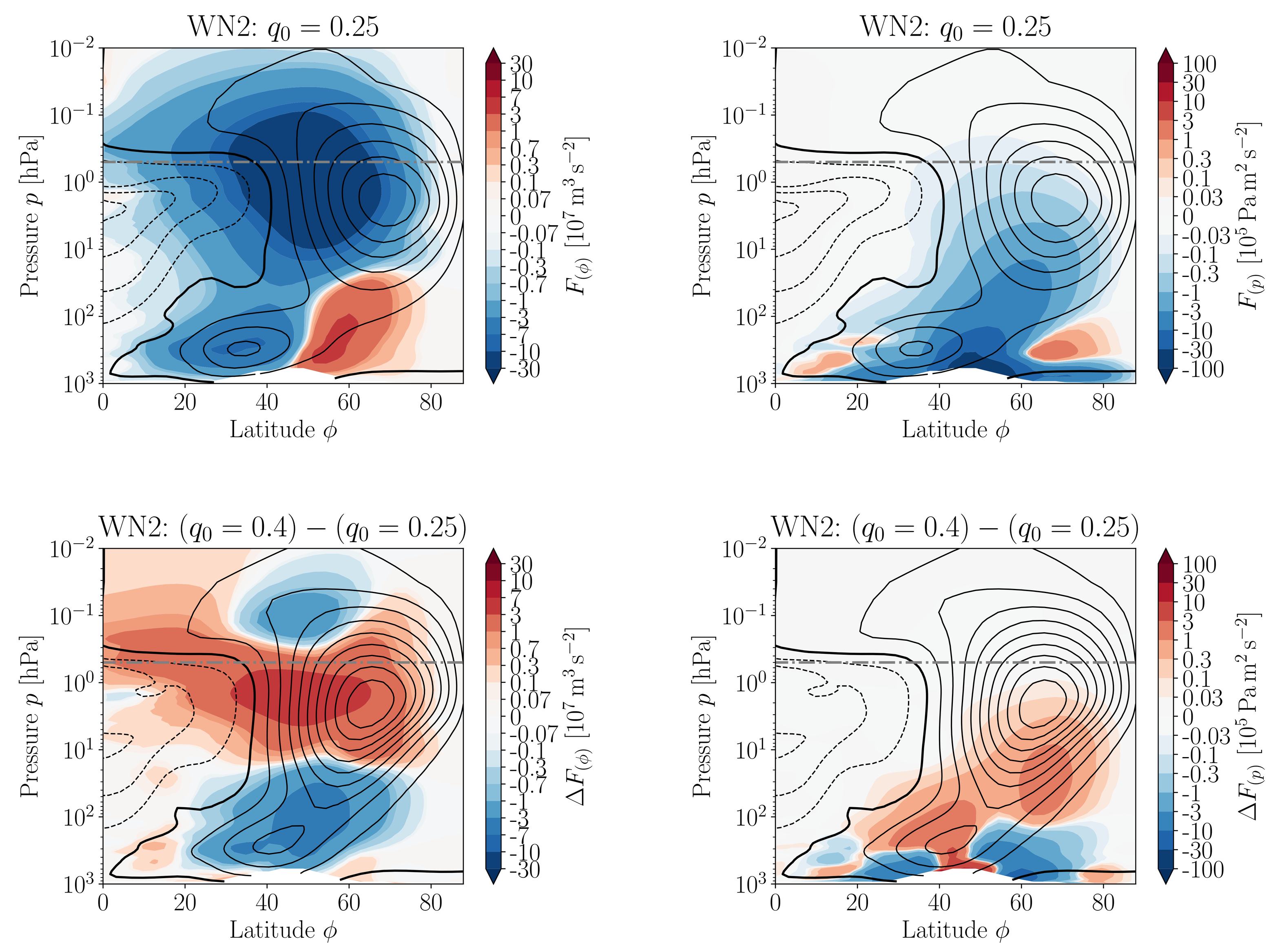
- **Experiment:** variation of q_0 from –0.1 to 0.6 K day^{-1} for three stratospheric states

Response to tropospheric warming



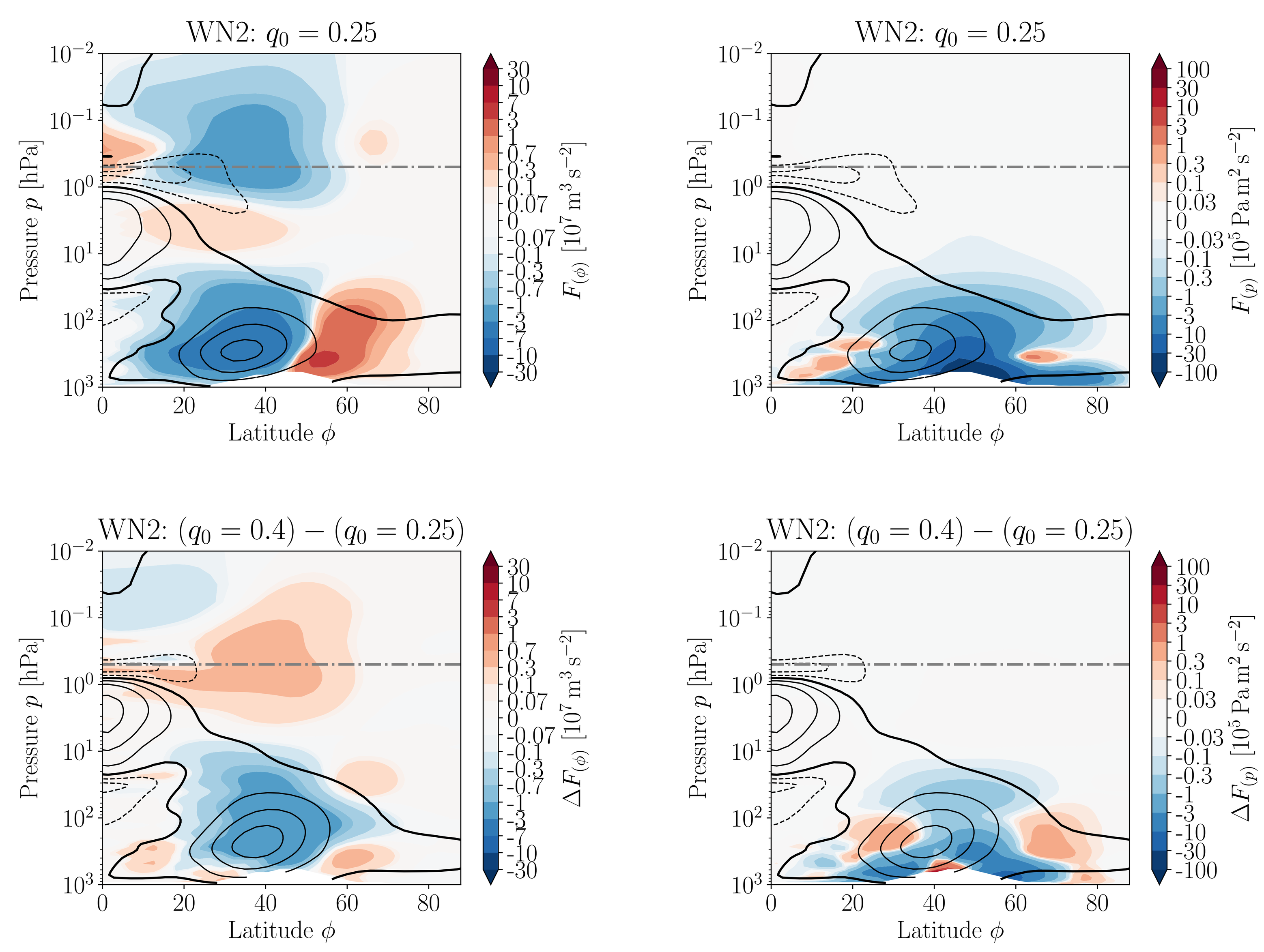
Active stratosphere

(p_{Tw} = 100 hPa, γ = 4 K km^{-1})



Passive stratosphere

(no polar vortex)



References

Manzini, E. et al. (2014). Northern winter climate change: Assessment of uncertainty in CMIP5 projections related to stratosphere-troposphere coupling. Journal of Geophysical Research: Atmospheres, 119(13):7979–7998.

Manzini, E., Karpechko, A. Y., and Kornblueh, L. (2018). Nonlinear Response of the Stratosphere and the North Atlantic-European Climate to Global Warming. Geophysical Research Letters, 45(9):4255–4263.

Wang, S., Gerber, E. P., and Polvani, L. M. (2012). Abrupt Circulation Responses to Tropical Upper-Tropospheric Warming in a Relatively Simple Stratosphere-Resolving AGCM. Journal of Climate, 25(12):4097–4115.