The tropospheric jet response to prescribed zonal forcing in an idealized atmospheric model

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1. Introduction

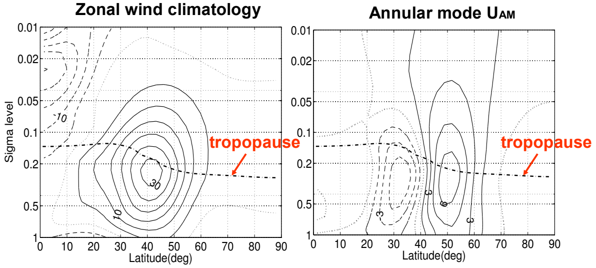
We study the response of tropospheric jets in an idealized atmospheric model to a prescribed zonal torque in a systematic manner. We first examine the process that gives rise to the tropospheric jet shift, when a zonal torque is applied in the troposphere, as in Ring and Plumb (2007), and then explore the stratospheric influence on the tropospheric jet with a zonal torque in the stratosphere, as in Song and Robinson (2004). The insights obtained from these idealized experiments can help to understand the shifts of tropospheric jets and surface westerlies during climate change.

2. The idealized dry model

- GFDL spectral atmospheric dynamical core
- Held-Suarez Physics (1994)
- Zonally symmetric radiative forcing and surface friction
- No topography, therefore no stationary waves
- T42, enhanced stratospheric resolution with a sponge layer at the top

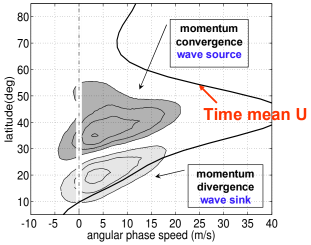
3. The control simulation

Zonal wind climatology / Annular mode U_{AM}



- The tropospheric winds are characterized by a midlatitude jet, and the wind anomalies vacillate about the mean jet latitude.
- The extratropical stratospheric winds are weak in the climatological mean and display relatively little variability.
- This configuration minimizes stratospheric intrinsic variability and its influence on the troposphere in the control simulation. While the results are mostly analogous to the dynamics in the Southern Hemisphere summertime, the forced response in this model is often similar to that in models with a stratospheric polar jet.

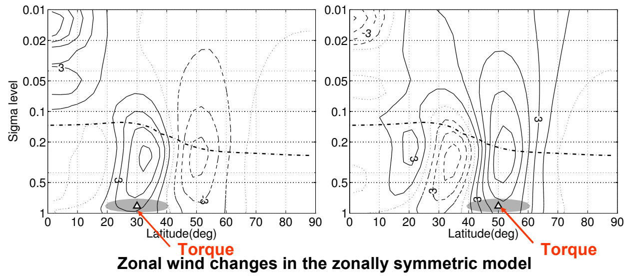
Eddy momentum flux convergence spectra in upper troposphere



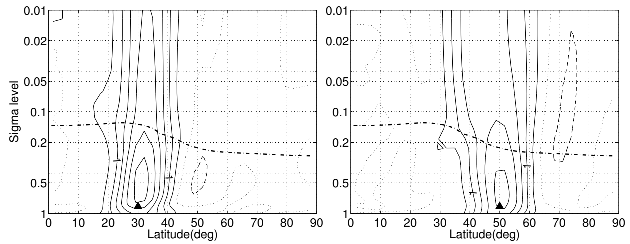
A key feature is that the absorption of upper tropospheric eddies in the subtropics is confined in a critical layer of 10-20 degrees in latitude poleward of their linear critical latitudes, and therefore the movement of the critical latitudes may be useful to understand the latitudinal movement of eddy momentum fluxes (e.g. Chen et al. 2007).

4. Responses to the zonal torque near the surface

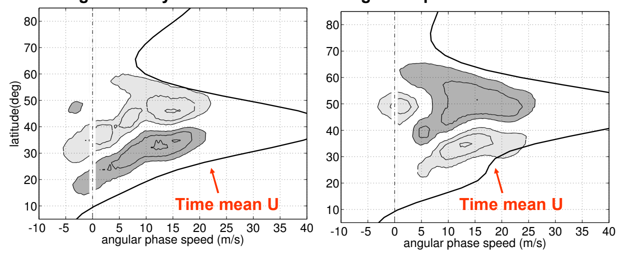
Zonal wind changes in the full model



Zonal wind changes in the zonally symmetric model



Changes in eddy momentum flux convergence spectra in the full model



Interpretations:

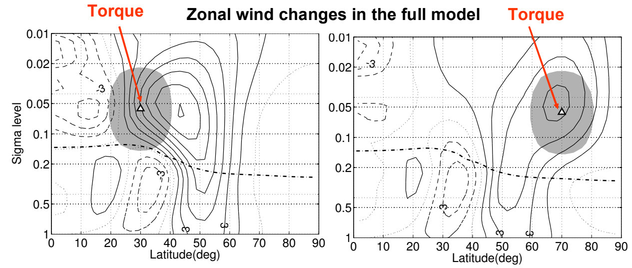
These jet movements can be explained by changes in the critical latitudes of tropospheric eddies (e.g. Chen et al. 2007). For a westerly torque near the surface, the response can be thought of a two-step adjustment:

1) A zonally symmetric balance between the torque and surface friction. The zonally symmetric response in the zonal wind is nearly barotropic above the forcing.

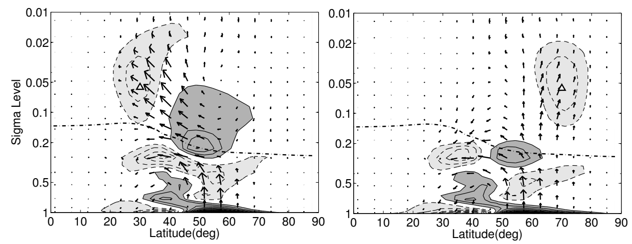
2) The subsequent modifications on the eddies and the eddy-driven circulations. While the increased zonal winds in the subtropics allow the midlatitude eddies to propagate further into the tropics and result in the equatorward shift in the critical latitudes, the increased winds in the midlatitudes accelerate the eastward eddy phase speeds and lead to the poleward shift in the critical latitudes.

5. Responses to the zonal torque in the lower stratosphere

Zonal wind changes in the full model



EP flux divergence changes in the full model



This downward penetration of zonal winds displays a poleward slope for the subtropical torque, an equatorward slope for the subpolar torque, and less tilting for the midlatitude torques.

The appearance of anomalous EP flux convergence in the stratosphere corresponds to the increased EP flux divergence near the tropopause between the latitudes 45° and 55°, and the direction of anomalous wave propagation coincides with the slope of the zonal wind change.

Despite the differences in the stratospheric changes, the tropospheric jet shifts poleward in both cases, and projects strongly onto the tropospheric internal mode.

6. Summary

The tropospheric jet shifts equatorward for the westerly zonal torque on the equatorward flank of the jet in the troposphere. In contrast, the tropospheric jet moves poleward for the torque on the poleward flank of the jet in the troposphere, and for the torque in the extratropical stratosphere.

These jet movements can be explained by changes in the critical latitudes of the tropospheric eddies, due to the eastward acceleration of the tropospheric torque or the downward influence of the stratospheric torque.

References

Chen, G., I.M. Held, and W.A. Robinson, 2007: Sensitivity of the Latitude of the Surface Westerlies to Surface Friction. *J. Atmos. Sci.*, 64, 2899–2915.

Ring, M.J., and R.A. Plumb, 2007: Forced Annular Mode Patterns in a Simple Atmospheric General Circulation Model. *J. Atmos. Sci.*, 64, 3611–3626.

Song, Y. and W. A. Robinson, 2004: Dynamical mechanisms for stratospheric inuences on the troposphere. *J. Atmos. Sci.*, 61, 1711-1725.