The role of synoptic eddies in the tropospheric response to stratospheric variability

Daniela I. V. Domeisen[1], Lantao Sun[2] and Gang Chen[3]

[1]Institute of Oceanography, Center for Earth System Research and Sustainability (CEN), University of Hamburg, Hamburg, Germany.
[2]Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, Colorado, USA.
[3]Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, New York, USA.

Abstract

The tropospheric response to sudden stratospheric warmings (SSWs) is analyzed in an idealized model setup regarding the respective roles of planetary-scale and synoptic-scale waves. The control model run includes a full interactive wave spectrum, while a second run includes interactive planetary-scale waves but only the time-mean synoptic-scale wave forcing from the control run. In both runs, the tropospheric response is characterized by the negative phase of the respective tropospheric annular mode. But given their different latitudinal structure, the control run shows the expected response, i.e., an equatorward shift of the tropospheric jet, whereas the response in the absence of interactive synoptic eddies is characterized by a poleward jet shift. This opposite jet shift is associated with a different planetary wave variability that couples with the zonal flow between the stratosphere and the surface. These results indicate that the synoptic eddy feedback is necessary for the observed tropospheric response to SSWs.

Model Setup

- GFDL dry dynamical spectral core
- T42, 40 sigma levels [Chen & Zurita-Gotor, 2008]
- Polvani and Kushner [2002] setup with
  - γ = 4 K/km (strong midwinter polar vortex)
  - ε = –10 K (tropospheric asymmetry between the winter and summer hemispheres)
- no seasonal cycle
- zonal wave- 2 topography of height 3000 m (Gerber and Polvani [2009])
- model run length of 20,000 days each, of which the last 19,600 days are used for the analysis

Two model runs are compared:

1) full model run: including all resolved waves
2) truncated model run: including only the zonal mean and the planetary zonal wave numbers 1, 2, and 3. All smaller-scale eddies are truncated by setting the short-wave spectral coefficient for all model variables to zero at every time step.

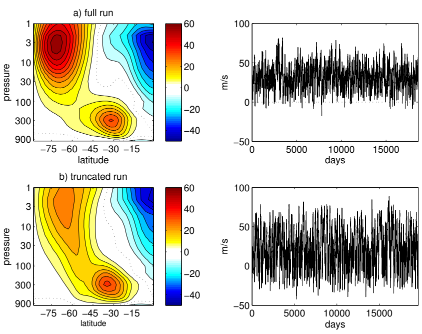

Figure 1: The zonal mean zonal wind [contour interval: 5 m/s] averaged over the entire run for (a) the full model run and (b) the truncated model run. The zero-wind line is dotted. The panels to the right show the corresponding time series at 10 hPa and 60°.

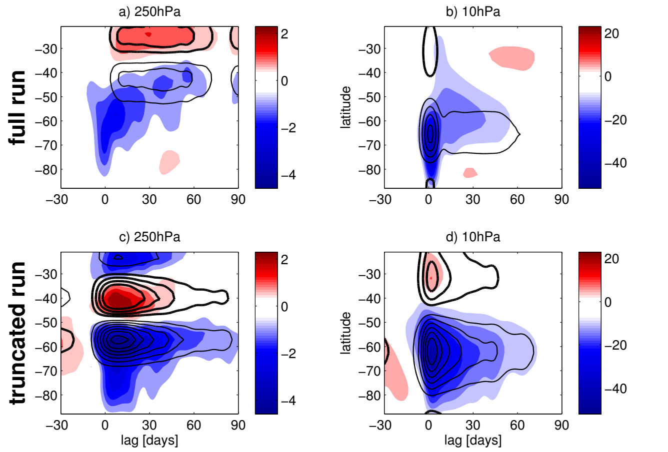

Figure 2: Composites of the 5 day running mean zonal mean zonal wind anomaly (shading) [contour interval: 0.5 m/s at 250 hPa, 5 m/s at 10 hPa] around the stratospheric sudden warming as a function of lag (with respect to the onset of the sudden warming) and latitude for (a) the full model run at 250 hPa, (b) the full model run at 10 hPa, (c) the truncated model run at 250 hPa, and (d) the truncated model run at 10 hPa. The plotted wind anomalies are significant at the 99% level (using a t test). The black contours (same contour interval as shading) denote the wind anomalies regressed onto the dominant empirical orthogonal function; positive patterns are printed in bold, the zero contour is omitted.

Results

While the evolution of the stratospheric wind deceleration is similar (Figures 2b and 2d), the tropospheric response differs considerably between the full and the truncated run (Figures 2a and 2c). In the full model run, the tropospheric jet shifts equatorward with respect to its climatological mean position (around 32°) after the onset of the SSW, consistent with observations [e.g., Baldwin and Dunkerton, 2001]. In the truncated run, however, the jet strengthens poleward and weakens equatorward of the climatological jet.
These different responses can partly be explained from a zonal mean perspective: For both runs, the tropospheric response can be described by the dominant tropospheric mode of the respective model run (black contours in Figures 2a and 2c). The tropospheric annular mode of each run, however, exhibits a different latitudinal structure. While the stratospheric dominant mode shows a maximum at the location of the polar vortex for both runs indicating a strengthening/weakening pattern of the vortex, the dominant tropospheric mode exhibits its node at the location of the climatological jet for the full run, while the truncated run has its node close to the latitude of the peak in the topography (45°). Deducing the tropospheric response from the stratospheric mode indicates that a weakening of the stratospheric polar vortex goes along with a negative phase of the respective tropospheric mode, corresponding to a strengthening of the tropospheric winds equatorward of the node of the tropospheric mode.

Conclusion

While for both runs, the tropospheric response can be described by the intrinsic tropospheric mode, this mode is represented by a different latitudinal structure. In the full model, the variability corresponds to a latitudinal shift about the location of the climatological jet, while in the truncated run, the signal is represented by a latitudinal shift about the topography. This yields an equatorward shift of the tropospheric jet for the full run, but a poleward shift for the truncated run as a response to the SSW, although in both cases, the tropospheric response to SSWs is characterized by the negative phase of the respective tropospheric mode.

These results indicate that while planetary waves in the absence of interactive synoptic eddies are able to induce a tropospheric response to a stratospheric forcing, the equatorward shift of the tropospheric jet following a SSW, which is observed in reanalysis and idealized models, cannot be interpreted as a simple Eliassen response to the stratospheric event, but that the dynamics controlling the observed jet shift are linked to the synoptic eddy momentum fluxes. Further research will have to focus on the role of planetary-scale waves in the vertical coupling of the atmosphere [e.g., Shaw et al., 2010].

References

Baldwin, M., and T. Dunkerton (2001), Stratospheric harbingers of anomalous weather regimes, Science, 294, 581–584.
Chen, G., and P. Zurita-Gotor (2008), The tropospheric jet response to pre- scribed zonal forcing in an idealized atmospheric model, J. Atmos. Sci., 65(7), 2254–2271, doi:10.1175/2007JAS2589.1.
Domeisen, D. I. V., L. Sun, and G. Chen (2013), The role of synoptic eddies in the tropospheric response to stratospheric variability, Geophys. Res. Lett., 40, doi:10.1002/grl.50943.
Gerber, E., and L. Polvani (2009), Stratosphere-troposphere coupling in a relatively simple AGCM: The importance of stratospheric variability, J. Clim., 22, 1920–1933.
Polvani, L., and P. Kushner (2002), Tropospheric response to stratospheric perturbations in a relatively simple general circulation model, Geophys. Res. Lett., 29(7), 18-1–18-4, doi: 10.1029/2001GL014284.
Shaw, T. A., J. Perlwitz, and N. Harnik (2010), Downward wave coupling between the stratosphere and troposphere: The importance of meridional wave guiding and comparison with zonal-mean coupling, J. Clim., 23, 6365–6381.