Role of Zonally Asymmetric Ozone in Modulating Downward Influence Exerted by Steady, Transient and Pulse Wave Forcing

John R. Albers and Terrence R. Nathan

Atmospheric Science Program, University of California, Davis, CA

Introduction

A growing body of research has been dedicated to understanding the dynamical connections between the stratosphere and tropospheric climate. Several pathways for communication have been suggested including: planetary wave reflection (Perlwitz and Harnik 2003); downward penetration of the meridional circulation (Haynes et al. 1991); and the downward migration of wind anomalies (Plumb and Semeniuk 2003). Hardiman and Haynes (2008) found that imposing a localized momentum pulse within the middle stratosphere produced downward signals that propagated into the lower stratosphere.

In this study, we extend the experiments of Hardiman and Haynes (2008) and Plumb and Semeniuk (2003) to include the effects of zonally asymmetric ozone and zonal-mean ozone. Our emphasis is on downward signal migrations that are modulated by the effects of zonal asymmetries in ozone on planetary wave drag and wave ozone flux convergences.

Are results indicate that zonal asymmetries in ozone alter the downward penetration and duration of downward propagating zonal-mean wind signals.

Pathways

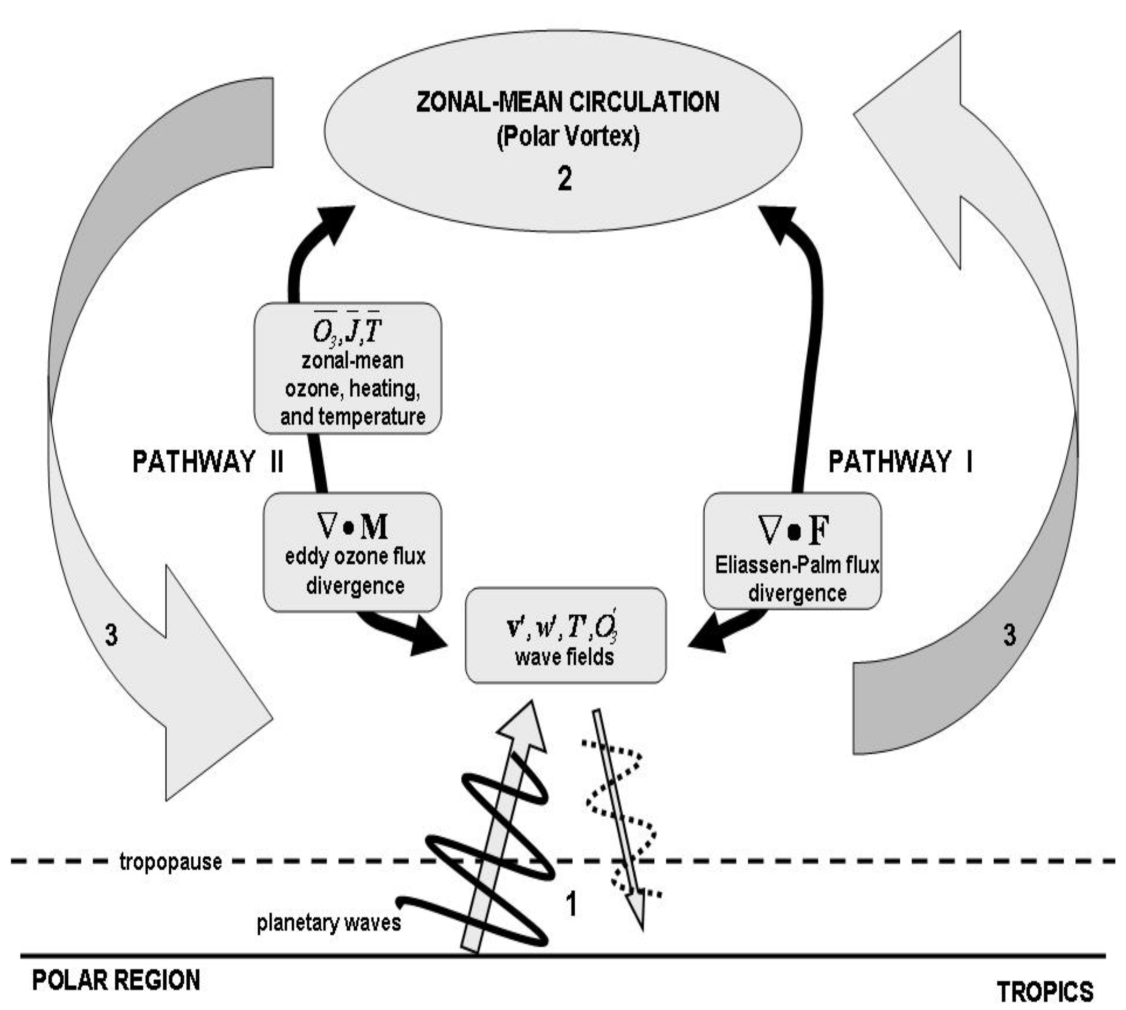

Figure 1. Schematic of ozone-modified pathways that affect wave-mean flow interaction. A planetary wave propagates vertically into the stratosphere where it is partially reflected (**1**). The phasing between the wind, temperature and ozone wave fields affects the planetary wave drag (**pathway P1**) and eddy ozone flux convergence (**pathway P2**). Along P2, the wave ozone flux convergence, wave-driven residual circulation (**3**), and zonal-mean ozone production/destruction combine to change the zonal-mean ozone heating rate and temperature. Changes in temperature produce, via thermal wind, changes in the zonal-mean wind. Pathways I and II combine to produce a net change in the zonal mean circulation, which manifests in the polar vortex (**2**) and the Brewer-Dobson circulation (**3**). Changes in the zonal-mean circulation, in turn, cause changes in the attenuation and propagation of the wave fields.

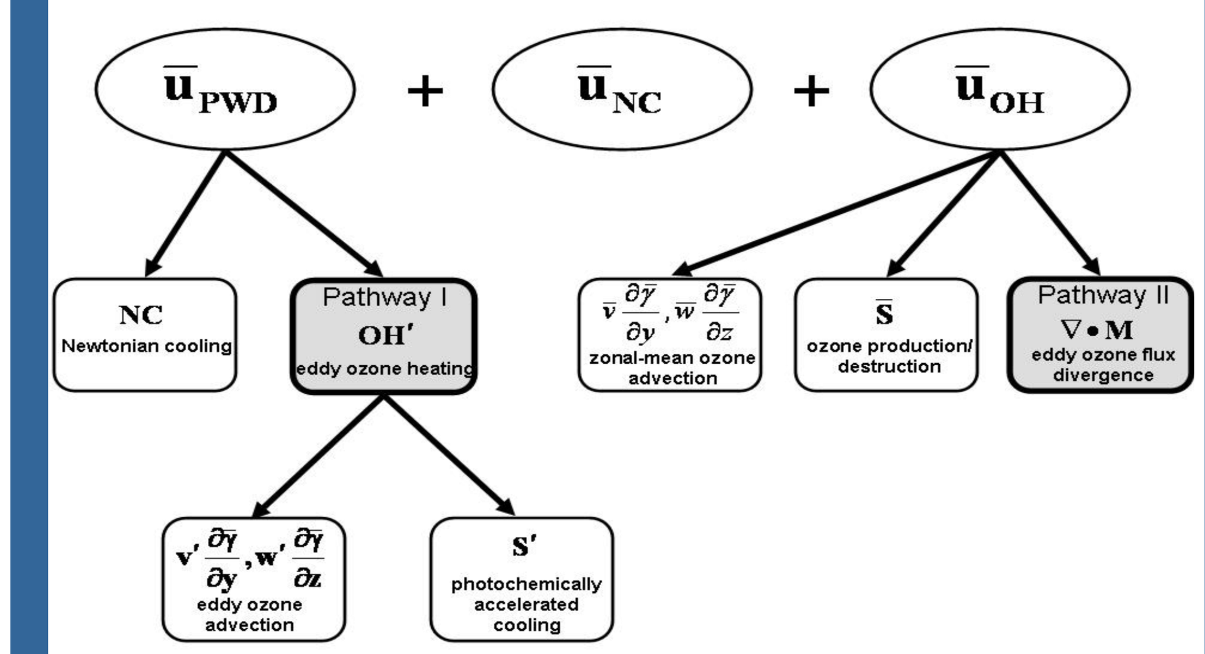

Figure 2. Schematic showing contributions to the steady state zonal-mean wind. The net driving of the zonal-mean wind is due to the combined effects of planetary wave drag ($\bar{u}_{PWD}$), Newtonian cooling ($\bar{u}_{NC}$), and ozone heating ($\bar{u}_{OH}$).

Model

We extend the Holton and Mass (1976) model to include zonally asymmetric ozone and zonal-mean ozone. The quasigeostrophic model dynamics are governed by perturbation and zonal-mean equations for potential vorticity, wind, temperature, ozone, and the meridional circulation.

Experiments

Three experimental scenarios are considered: steady wave forcing; transient wave forcing; and a localized momentum pulse that mimics the wave drag exerted by wave breaking. For each scenario we distinguish the relative importance of zonal-mean ozone (ZMO) and zonal asymmetries in ozone (ZAO) in affecting downward signal propagation.

Results

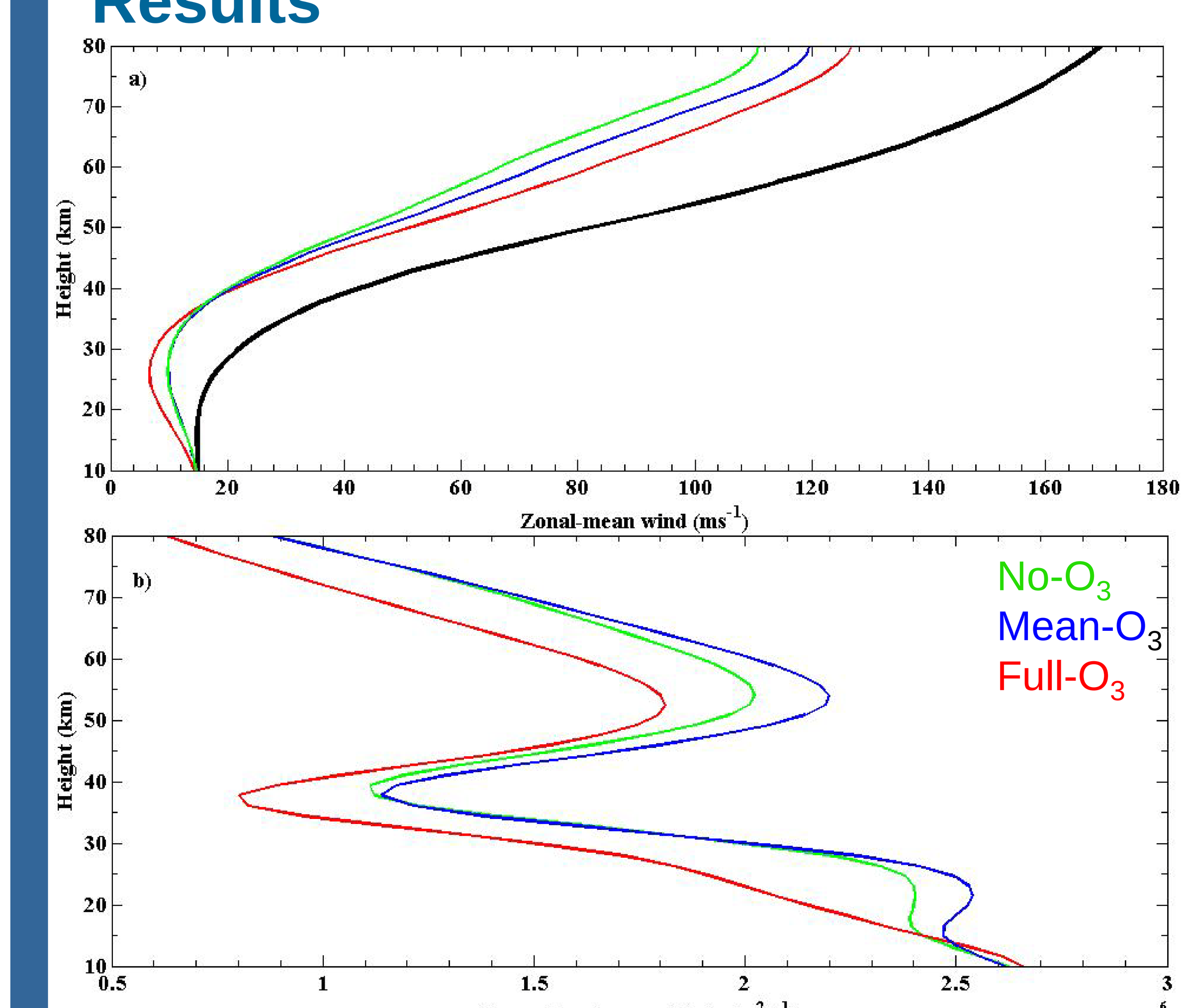

Figure 3. Response of (a) zonal-mean wind and (b) streamfunction amplitude to steady wave forcing. Radiative equilibrium is shown as the thick, solid, black line.

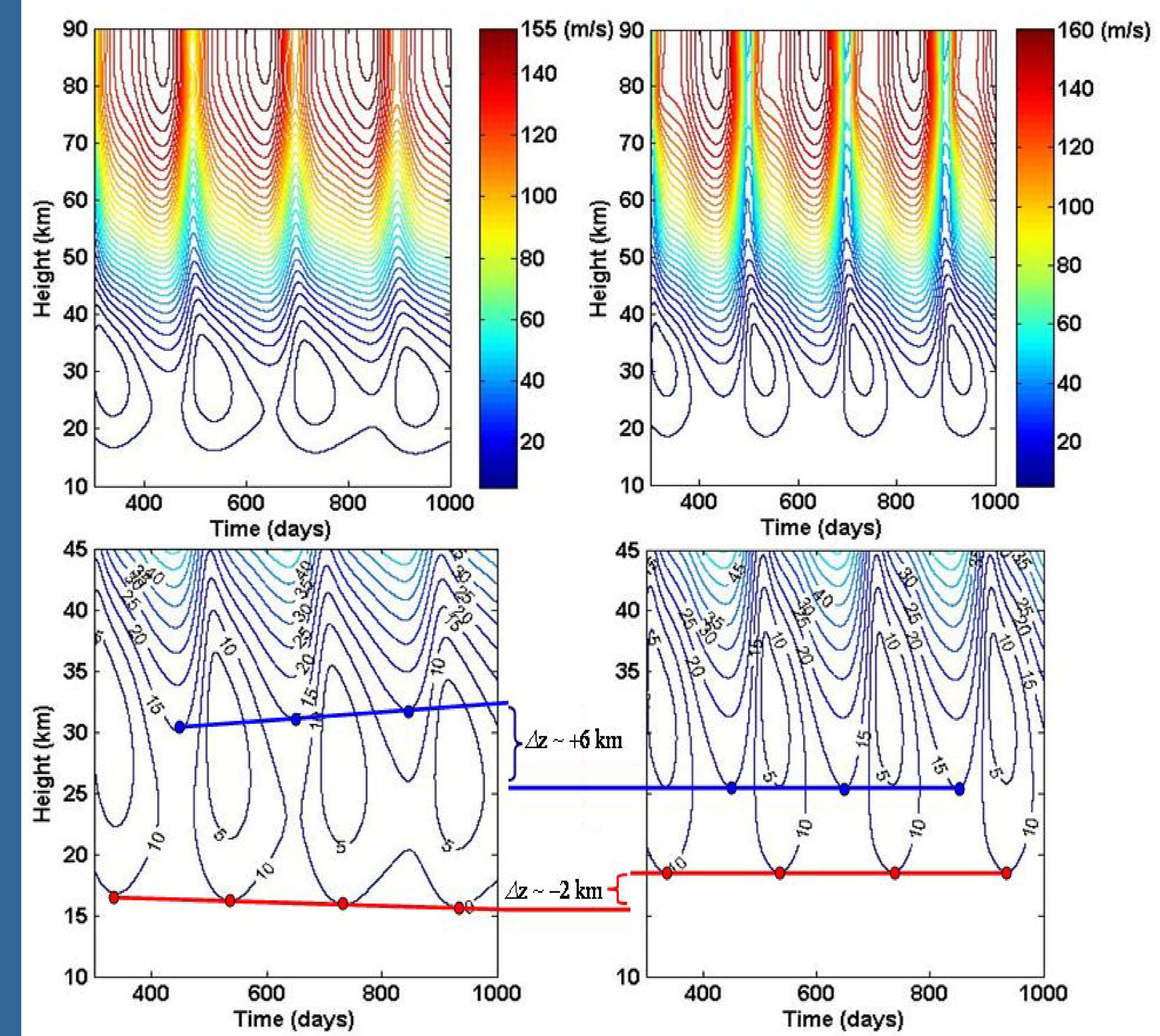

Figure 4. Response of zonal-mean wind to 200 day period transient wave forcing (contour interval 5 ms^{-1}) for model run including both zonally asymmetric ozone and zonal-mean ozone (left column) and with zonal-mean ozone only (right column). Blue line marks the height that the 15 ms^{-1} zonal wind contour descends to during the maximum zonal wind phase; red line marks the height that the 10 ms^{-1} zonal wind contour descends to during the minimum zonal wind phase.

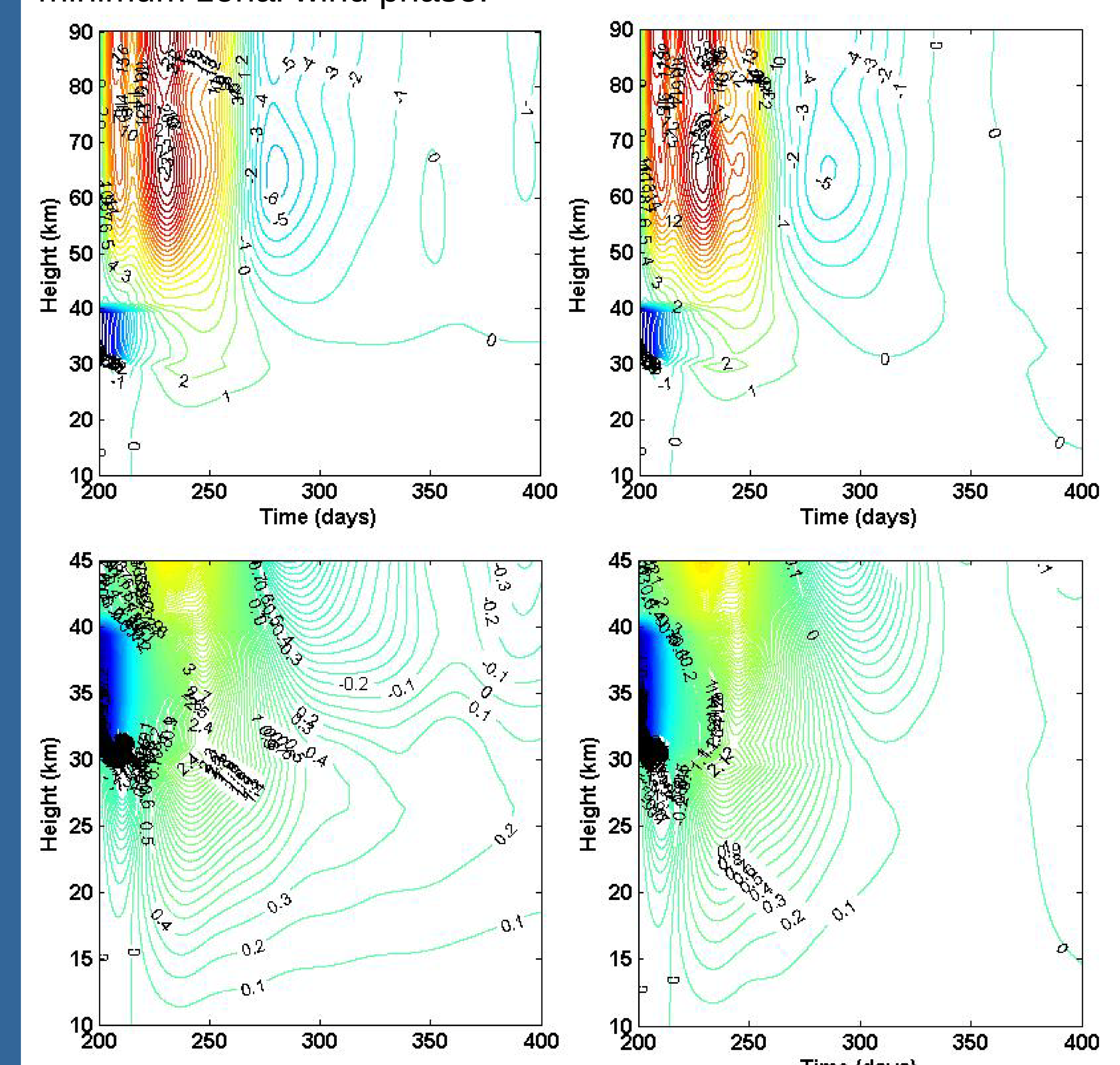

Figure 5. Response of zonal-mean wind to instantaneous -10 ms^{-1} zonal-mean wind pulse between 30 and 40 km in height for model run with both zonally asymmetric ozone and zonal-mean ozone (left column) and with zonal-mean ozone only (right column) (contour interval 0.1 ms^{-1}). The wind pulse (which is intended to mimic the effect of breaking planetary waves) is imposed after the model has equilibrated to a steady state at day 200 of the model run.

Conclusions

EXPERIMENT ONE (steady wave forcing)

- The combined effects of pathways P1 and P2 lead to a stronger and colder polar vortex in the middle stratosphere to lower mesosphere and a slightly weaker and warmer vortex in the lower stratosphere when zonal asymmetries in ozone are included.

EXPERIMENT TWO (transient wave forcing)

- Preliminary results show that for transient (periodic) wave forcing, zonal asymmetries in ozone modulate the strength, duration, and downward migration of zonal-mean wind signals.
- Minimum (maximum) zonal-mean wind signals migrate more deeply (less deeply) into the lower stratosphere when zonal asymmetries in ozone are included in the model versus zonal-mean ozone only.
- Zonal-mean wind signals persist for longer durations when zonal asymmetries in ozone are included in the model.

EXPERIMENT THREE (wave pulse forcing)

- For a localized momentum pulse placed in the middle stratosphere, zonal asymmetries in zone enhance downward signal propagation and increase its temporal persistence.

Implications for climate variability

Because the interactions between the stratospheric ozone and planetary wave fields are central to the downward propagation of energy from the stratosphere into the troposphere, perturbations to the stratospheric ozone field may impact the circulation of the troposphere. For example, it is conceivable that this ozone-dynamics mechanism may serve as a means for communicating nature and human-caused changes in the stratospheric ozone field to changes in the global climate.

References

Hardiman, S. C., and P. H. Haynes (2008), Dynamical sensitivity of the stratospheric circulation and downward influence of upper level perturbations. *J. Geophys. Res.*

Haynes, P. H., C. J. Marks, M. E. McIntyre, T. G. Shepherd, and K. P. Shine (1991), On the “downward control” of extratropical diabatic circulations by eddy-induced mean zonal forces. *J. Atmos. Sci.*

Holton, J.R., and C. Mass (1976), Stratospheric vacillation cycles, *J. Atmos. Sci.*, ***33***, 2218-2225.

Nathan, T. R., and E. C. Cordero (2007), An ozone-modified refractive index for vertically propagating planetary waves. *J. Geophys. Res.*

Perlwitz, J., and N. Harnik (2003), Observational evidence of a stratospheric influence on the troposphere by planetary wave reflection. *J. Clim.*

Plumb, R. A., and K. Semeniuk (2003), Downward migration of extratropical zonal wind anomalies. *J. Geophys. Res.*

Correspondence:

John R. Albers
Atmospheric Science Program, One Shields Avenue
University of California
Davis, CA 95616
albersjohn@hotmail.com (e-mail); (608)469-3046