Influence of Stratospheric Potential Vorticity on Baroclinic Lifecycles

Abstract

The aim of this work is to investigate the dynamical coupling between the stratosphere and the troposphere. We consider the effect of perturbations to stratospheric potential vorticity on the evolution of baroclinic instability in the troposphere in simple lifecycle experiments. Both axisymmetric and non-axisymmetric perturbations are examined.

Model

The numerical model used is the Contour Adveective Semi-Lagrangian (CASL) algorithm developed originally by Dritschel and Ambaum (1997) and extended to cylindrical geometry by Macaskill et al. (2003). The model is a representation of the main dynamics on a polar $f$-plane:

$$\frac{Dq}{Dt} = v \cdot \nabla q = 0$$

(1)

Quasi-geostrophic framework:
- dominant balance in the atmosphere (large-scale, low-frequency motions)
- filters out small scales e.g. gravity waves
- layerwise 2D

Time evolution:

Eddy Kinetic Energy:

Results

The extreme case in which the stratospheric potential vorticity is exactly zero is used as a control. We then consider the effect of perturbations to the stratospheric potential vorticity that may be zonal (a crude representation of a strong vortex) or highly asymmetric (a crude representation of a vortex following a stratospheric sudden warming). Although the background tropospheric winds may change as a result of the stratospheric perturbations, changes to the vertical shear near the tropospheric jet are small. Both types of stratospheric perturbation result in dramatic changes to the baroclinic development of the control case.

(1) Control
- two way breaking is observed

(2) Axisymmetric Perturbation
- one way breaking observed

(3) Split Vortex
- wave-2 dominates evolution

Conclusions

- This response is found in:
  - synoptic scale development
  - zonal and global means e.g. EKE, $u$, geopotential
  - latitudinal heat transport

- The stratospheric PV anomalies considered affect a dipolar pattern of surface pressure that is qualitatively similar to the dominant variability of the troposphere (Arctic Oscillation). (See adjacent Figure)

Potential Vorticity

Troposphere
- interior: assume uniform interior PV (Eady-type model).
- surface: surface temperature $\theta_s$ can be considered as a sheet-like distribution of PV.
- tropopause: jump in stratification leads to sheet-like distribution of PV at the tropopause, $\theta_t$.

Stratosphere
- PV dominated by the polar vortex, represented by a volume of uniform PV.

Therefore the total PV is expressed by

$$q = \theta \delta(z - H_1) + \theta_s \delta(z) + q_{\text{strat}}$$

The latitudinal dependence of $\theta_s$ and $\theta_t$ is given by

$$\theta_s = \Delta \theta_s \tan(r/R)$$

where $R = L_R/2$ and $L_R$ is the deformation radius. $\Delta \theta_s$ represents (half) the pole-equator temperature difference.

The stratospheric PV is defined by

$$q_{\text{strat}}(r, \theta, z) = \begin{cases} q_{\text{lin}} & \text{if } r < r_0(\theta, z) \\ q_{\text{lin}} + \Delta q_{\text{strat}} & \text{if } r > r_0(\theta, z) \end{cases}$$

where $r_0(\theta, z)$ represents the location of the vortex edge (which may depend on longitude).