Diagnostic Tool of Zonally Symmetric Structure of the Global Atmosphere Based on the Pressure-Isentrope Hybrid Vertical Coordinates (Extended Abstract)

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Diagnostic Tool of the Zonally Symmetric Structure of the Global Atmosphere Based on the Pressure-Isentrope Hybrid Vertical Coordinates (Extended Abstract)

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1. Introduction

A set of zonal mean equations is formulated in the pressure-isentrope hybrid vertical coordinates, which diagnoses the mean-meridional circulation and wave, mean-flow interaction (Iwasaki, 1989 and 1998, hereafter called as I89 and I98). This is to generalize the nonacceleration theorem (*e.g.*, Andrews and McIntyre, 1976) toward finite-amplitude and/or nongeostrophic (fully primitive) expression, where the vertical component of the Eliassen-Palm flux is expressed as the from drag over the isentropic or the ground line. The formulation leads us to a consistent view of the meridional transports of mass, angular momentum, heat and minor constituents. It gives the nondivergent mean-meridional mass circulation and solves the lower boundary conditions. We demonstrate the performance of the scheme as a diagnostic tool of the global atmosphere.

Next, we derive rate equations of potential energy and kinetic energies of zonal means and eddies. We find significant differences from conventional Eulerian mean view (Lorenz, 1955). The zonal mean available potential energy directly transforms with the eddy available potential energy but the zonal mean kinetic energy directly transforms with the eddy available potential energy. Particular attention is paid to the energetics of ideal baroclinic waves based on the above formulation.

Polar vortexes have sharp edges around the polar night jetstream. The thermodynamic structure of the atmosphere suggests large differences in the meridional heat transport between the inside and outside of the polar vortex. Here, we apply the new formulation to the mean meridional circulation and its relation to the maintenance mechanisms of the polar vortex.

2. Basic formulations

Isentropic zonal means of pressure $p_\dagger \equiv \bar{p}$ are used as the vertical coordinate. The zonal means of arbitrary variables are defined with the mass weight $\partial p/\partial p_\dagger$

$$\overline{A^*} \equiv \overline{A\frac{\partial p}{\partial p_\dagger}} \tag{1}$$

and eddies are defined as departures from the mass weighted zonal means

$$A' \equiv A - \overline{A^*} \tag{2}$$

The mass weight is required to satisfy conservation constraints. Cartesian coordinate is chosen for simplicity. The zonal mean zonal momentum equation is written by

$$\left(\frac{\partial \overline{u^*}}{\partial t}\right)_{p_\dagger} + \frac{\overline{v^*}}{a\cos\phi}\left(\frac{\partial \overline{u^*}\cos\phi}{\partial\phi}\right)_{p_\dagger} + \overline{\omega_\dagger^*}\frac{\partial \overline{u^*}}{\partial p_\dagger} = f\overline{v^*} + \boldsymbol{D}_F + \overline{X^*}, \tag{3}$$

where Eliassen-Palm flux and its divergence are

$$\boldsymbol{F} \equiv (F_\phi, F_{p_\dagger}) = a\cos\phi\left(-\overline{(u'v')^*}, -\overline{(u'w_\dagger')^*} - \frac{1}{a\cos\phi}\overline{p\left(\frac{\partial\phi}{\partial\lambda}\right)_{p_\dagger}}\right)$$

and

$$\boldsymbol{D}_F = \frac{1}{a\cos\phi}\left\{\frac{1}{a\cos\phi}\left(\frac{\partial}{\partial\phi}F_\phi\cos\phi\right)_{p_\dagger} + \frac{\partial F_{p_\dagger}}{\partial_{p_\dagger}}\right\},$$

respectively. The $\overline{\omega_\dagger^*}$ is the mean-vertical $p_\dagger$-velocity and others are conventional notations. The vertical component of Eliassen-Palm flux is expressed as the form drag over isentropes. The thermodynamic equation without any eddy terms

$$\left(\frac{\partial\theta}{\partial t}\right)_{p_\dagger} + \frac{\overline{v^*}}{a}\left(\frac{\partial\theta}{\partial\phi}\right)_{p_\dagger} + \overline{\omega_\dagger^*}\frac{\partial\theta}{\partial p_\dagger} = \overline{\left(\frac{Q}{\Pi(p)}\right)^*} \tag{4}$$

More details are found in I89 and I98.

3. Mass stream function

Figure 1 shows the mass stream functions analyzed by the conventional Eulerian mean, TEM and $p_\dagger$ analysis (I89). The $p_\dagger$ analysis is very different from the conventional analysis based on pressure coordinates. The tropospheric circulation consists only of single direct cell with a kink near the subtropical jet stream in contrast with the well-known three cell structure of the conventional Eulerian mean circulation. The stratospheric circulation diagnosed by the new scheme is more consistent with the observation of minor constituents and with trajectory simulations than that by the TEM. These results suggest practical advantages of the scheme as well.

4. Energy cycle

The global atmospheric energy cycle is formulated meeting with the context of the non acceleration theorem. As shown in fig. 2, it is significantly different from the conventional Eulerian mean view (Lorenz, 1955). The zonal mean available potential energy do not directly transforms with the eddy available potential energy but the zonal mean kinetic energy directly transforms with the eddy available potential energy. The latter is contributed to by the vertical divergence of the Eliassen-Palm flux divergence.

Figure 3 shows the energy flow of the baroclinic instability waves. The zonal mean available potential energy is released to the zonal mean kinetic energy by driving mean meridional wind. Simultaneously the kinetic energy of mean zonal wind transforms into the eddy available potential energy through wave, mean-flow interactions. Under the geostrophic equilibrium

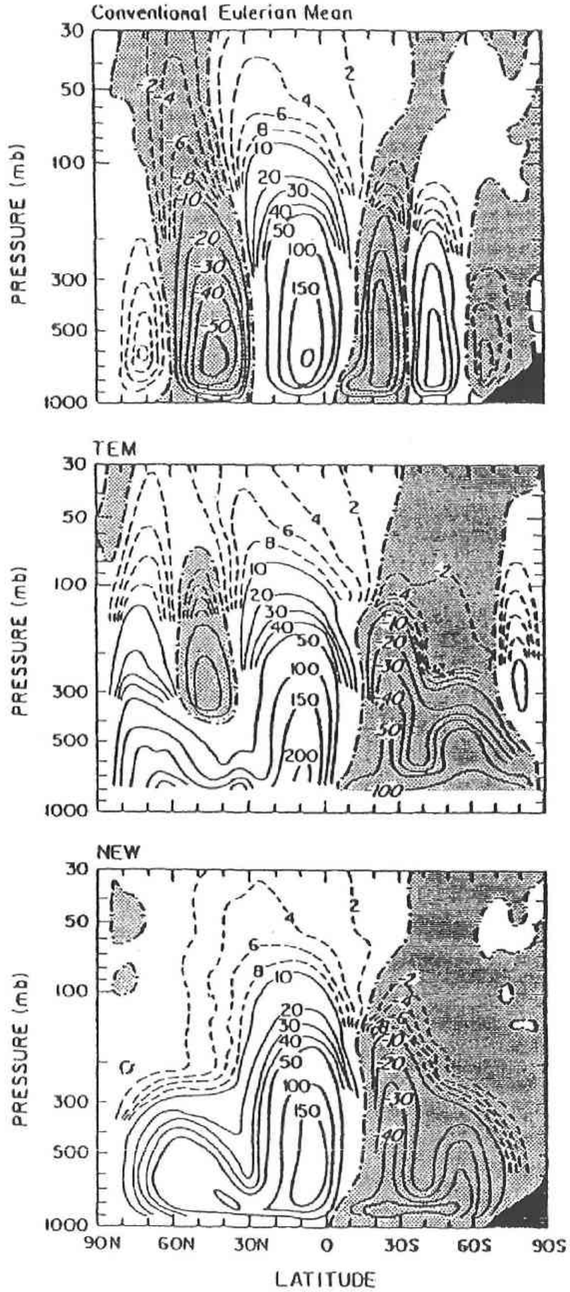

Fig. 1. Mass streamfunctions of the perpetual January simulation by NCAR CCM1, diagnosed with the conventional Eulerian mean, the TEM and the p_t analyses. (After Iwasaki, 1989).

condition, these two transformation rates are almost equal to each other. Geostrophic adjustments may assist transformations from the eddy available potential energy into the eddy kinetic energy. All the processes might be the main stream of dynamical energy flows in mid- and high latitudes.

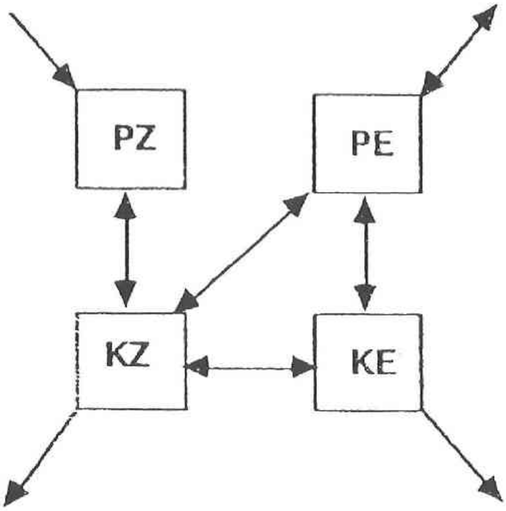

Fig. 2 Energy cycles of the global atmosphere.

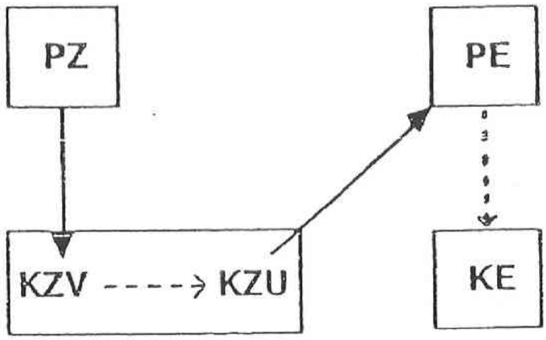

Fig. 3 Energy cycle of baroclinic instability waves.

5. Mean meridional circulation associated with the polar vortex

The SH polar vortex, which is more axisymmetric than the NH one, is studied by using an annual run of the NCAR CCM1 (Iwasaki, 1992). Figure 4 shows the seasonal variation of stratospheric wind and temperature at 54.1 hPa. In SH winter, the temperature has a local maximum at mid-latitudes and minimum at high latitudes. This agrees well with the observation. The meridional temperature gradient is in thermal wind balance with the polar night jetstream. The stratospheric temperature balance is reached by the radiative cooling and adiabatic heating due to downward motions. Figure 5 shows the mean vertical velocity in the stratosphere. In SH winter, the fast downward velocity may cause significant adiabatic heating at mid-latitudes. The mid-latitudes are the main passages of downward branch of the Brewer-Dobson circulation. On the other hand, the downward velocity is so slow that the temperature is close to the radiative equilibrium at high latitudes. The lack of adiabatic heating may be one of the reasons why the temperature becomes very low within the polar vortex.

As is well-known, the extratropical mean-meridional circulation is driven by wave-mean

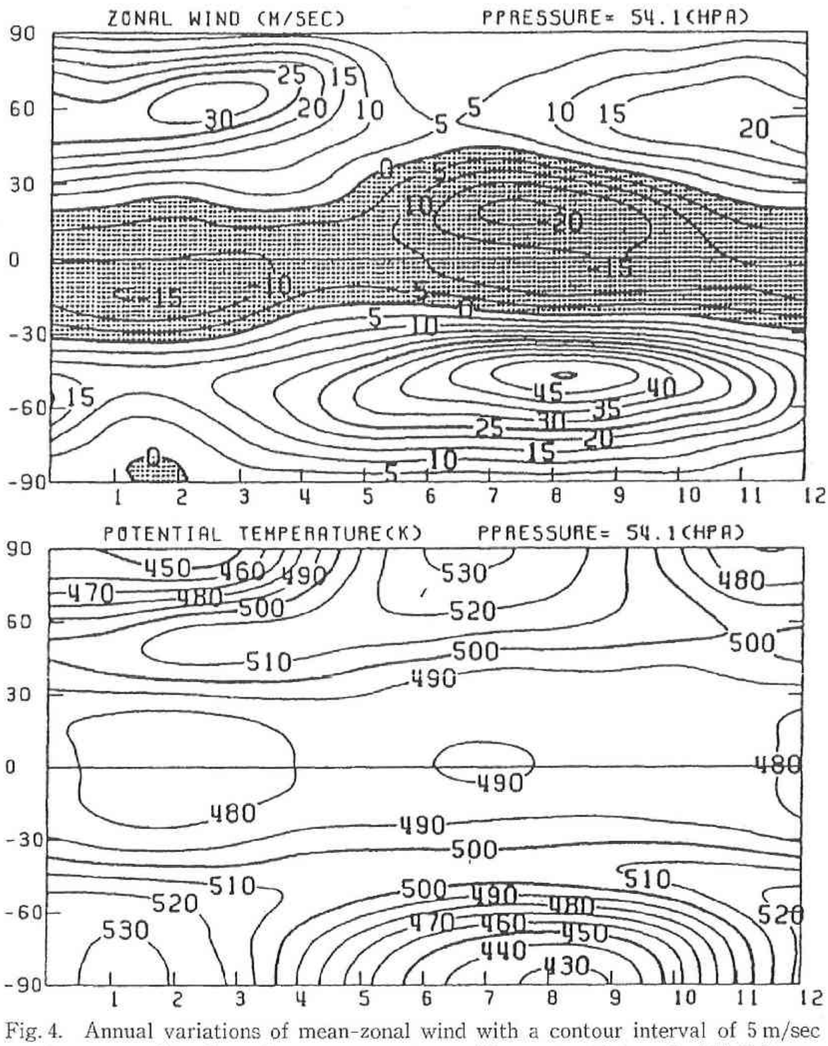

Fig. 4. Annual variations of mean-zonal wind with a contour interval of 5 m/sec (upper panel) and zonal mean temperature with a contour interval of 10 K (lower panel) at 54.1 hPa. Vertical and horizontal axes indicate latitudes and months, respectively. (After Iwasaki, 1992).

flow interactions and the vertical motions are induced by the meridional gradients of the Eliassen-Palm flux divergence above this level (Haynes *et al*, 1991),

$$\overline{\omega_{\dagger}^{*}} \approx \int_{0}^{p_{\dagger}} \frac{1}{a \cos\phi} \frac{\partial}{\partial\phi}\left(\frac{\cos\phi}{f} \boldsymbol{D}_{F}\right) dp_{\dagger}. \tag{5}$$

Thus, the different thermodynamic structure between the inside and outside is attributed mainly to wave, mean-flow interactions. Ditailed wave characteristics associated with polar night jet stream will be studied in the future.

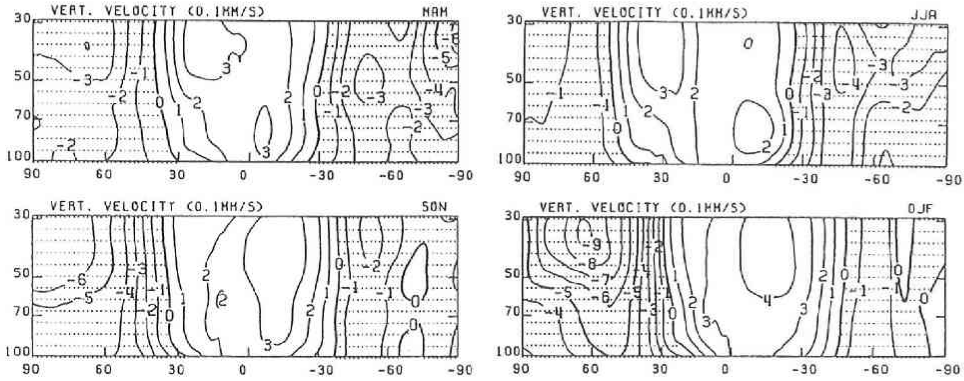

Fig. 5. Meridional cross section of mean vertical velocity in the stratosphere. Each panel is averaged over three months, MAM (March, April and May), JJA (June, July and August), SON (September, October and November) or DJF (December, January and February). (After Iwasaki, 1992).

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