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Transformed Eddy-PV Flux and Positive Synoptic Eddy Feedback onto Low-Frequency Flow

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ABSTRACT Interaction between synoptic eddy and low-frequency flow (SELF) has been a subject of many studies. In this study, we further examine this interaction by introducing a transformed eddy-potential-vorticity (TEPV) flux that is obtained from eddy-potential-vorticity flux through a quasi-geostrophic potential-vorticity inversion. This TEPV flux combines the effects of the eddy-vorticity and heat fluxes into the net acceleration of the low-frequency flow. We show that the anomalous TEPV fluxes are preferentially directed to the left-hand side of the low-frequency flow in all vertical levels throughout the troposphere for monthly flow anomalies and for climate modes such as the Arctic Oscillation (AO). Furthermore, this left-hand preference of the TEPV flux direction is a simple indicator of the positive reinforcement of the low-frequency flow by net eddy-induced acceleration. By projecting the eddy-induced net accelerations onto the low-frequency flow anomalies, we estimated the eddy-induced growth rates for the low-frequency flow anomalies. This positive eddy-induced growth rate is larger (smaller) in the lower (upper) troposphere. The stronger positive eddy feedback in the lower troposphere may play an important role in maintaining an equivalent barotropic structure of the low-frequency atmospheric flow by balancing off some of the strong damping from surface friction..

1. Eddy-vorticity and heat flux patterns associated with AO

In Fig. 1, winter-mean eddy-vorticity flux anomalies are predominately directed to the left of the AO flow anomalies and enhance the AO. The in-phase relationship between eddy forcing and the AO flow means a positive eddy feedback with an up-gradient vorticity transport. Also, eddy-heat fluxes follow the left-hand preference in their direction with a down-gradient heat transport.

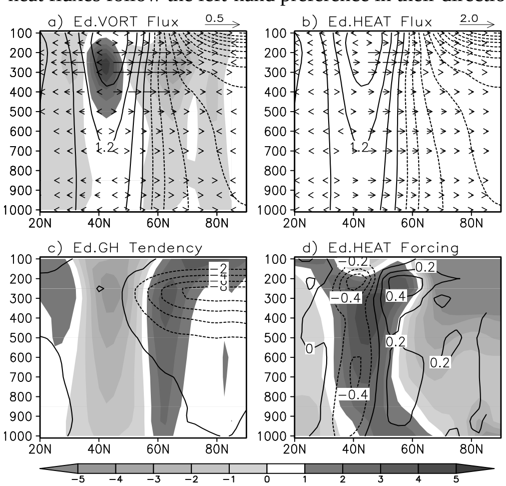

Fig. 1. Panel (a) is zonal-mean vertical cross section for monthly-mean geopotential height anomalies (contours, unit: 10 gpm), eddy-vorticity fluxes (vectors, unit: 1×10^{-5} ms^{-2}) and their divergence (shade, unit: 1×10^{-17} m^{-1}s^{-2}). Panel (b) is the same as panel (a) except the vector is for eddy heat flux (unit: 1×10^{-6} Km^{-1}s^{-1}). Panel (c) is monthly-mean vorticity anomalies (shade, unit: 0.5×10^{-6} s^{-1}) and geopotential height tendencies (1×10^{-5} gpm/s) induced by eddy-vorticity fluxes. Panel (d) is monthly-mean potential temperature anomalies (shade, unit: 0.1 K) and the convergence of eddy-heat fluxes (1×10^{-6} Km^{-1}s^{-1}). Each field is obtained by regression onto the AO index and then averaged during boreal winter (DJF). Contour intervals are 0.6 in (a) and (b), 2.0 in (c), and 0.2 in (d). The two eddy fluxes are defined as $F_{irro}^{HEAT} \equiv \nabla\Delta_2^{-1}\left(\nabla\cdot\vec{F}^{HEAT}\right)$, and $\vec{F}_{irrot}^{VORT} \equiv \nabla\Delta_2^{-1}\left(\nabla\cdot\vec{F}^{VORT}\right) = -\nabla\chi_2^{VORT}$.

2. Definitions of TEPV flux

The question is how to diagnose the combined effect of the eddy-vorticity and the eddy-heat fluxes on the acceleration of low-frequency flow. We derive a new transformed eddy-PV flux:

$$\vec{F}^{TEPV} \equiv \nabla\Delta_3^{-1}\left(\nabla\cdot\vec{F}^{PV}\right) = \Delta_2\Delta_3^{-1}\vec{F}^{PV}.$$

Fig. 2 presents pattern of the AO-related TEPV flux, where the TEPV fluxes are preferentially directed to the left-hand side of the low-frequency flow on all vertical levels in the troposphere.

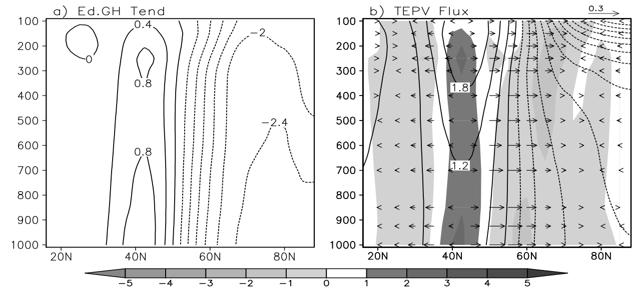

Fig. 2. Panel (a) is zonal-mean vertical cross section for monthly-mean geopotential height tendency (contours, unit: 1×10^{-5} gpm/s). Panel (b) is for geopotential height anomalies (contours, unit: 10 gpm), associated meridional TEPV fluxes (vectors, unit: 1×10^{-5} ms^{-2}) and their divergence (shade, unit: 1×10^{-17} m^{-1}s^{-2}) during DJF. Latitude-pressure cross sections are obtained by averaging the AO-index-regressed fields at [0°, 360°E]. Contour intervals are 0.4 in (a) and 0.6 in (b).

3. Left-hand directing TEPV fluxes and positive eddy feedback

Fig. 3 further gives horizontal pattern of the AO-related TEPV fluxes, confirming this left-hand preference. In terms of theoretical demonstration by Jin et al. (2006a) and Jin (2010), by expressing a part of eddy forcing as a linear function of the mean flow itself, we can derive the relationships between the eddy flux and low-frequency flow as follows:

$$-\vec{k}\wedge\vec{F}_{irrot}^{VORT} = \lambda_2\overline{\vec{V}}^a + \vec{k}\wedge\nabla R_2.$$

$$-\vec{k}\wedge\vec{F}^{TEPV} = \lambda_3\overline{\vec{V}}^a + \vec{k}\wedge\nabla R_3,$$

It can be seen in the two equations that the left-hand preference in eddy fluxes is corresponding to λ_2 and λ_3 greater than 0. Further, we define an eddy-induced growth rate:

$$\lambda_j = \frac{\iint_S f\,\overline{\Phi}^a\chi_j\,dxdy}{\iint_S \overline{\Phi}^a\,\overline{\Phi}^a\,dxdy}. \quad (j=2,3)$$

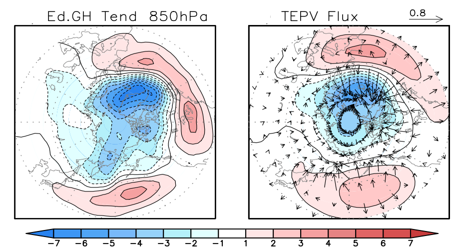

Fig. 3. AOI-regressed patterns for geopotential height tendency (contours and shading, unit: 1×10^{-5} gpm/s) in a), and geopotential height anomalies (shading, unit: 10 gpm) and anomalous TEPV fluxes (vectors, unit: 1×10^{-5} ms^{-2}) in b) at 850hPa.

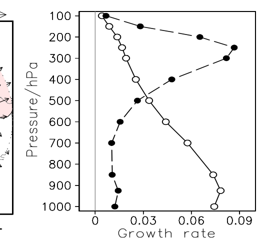

Fig. 4. Vertical profiles of the eddy-induced growth rate (unit: 1/day) derived from the TEPV fluxes (open circle line) and eddy-vorticity flux (solid dot line) for all months during the entire period from Jan. 1978 to Dec. 2007.

Both of the growth rate profiles in Fig. 4 are clearly positive at all levels, indicating that the low-frequency variability has a positive eddy-induced growth in the entire troposphere, consistent with the fact that the eddy-vorticity and TEPV flux follows the left-hand directing preference. Also, the differences between the two profiles reflect the net effects of the eddy-heat flux on total eddy feedback.

4. Summary

This TEPV flux proposed here combines the effects of the eddy-vorticity and heat fluxes into the net acceleration of the low-frequency flow. We show that the anomalous TEPV fluxes are preferentially directed to the left-hand side of the low-frequency flow in all vertical levels, thus which is a simple indicator for the positive reinforcement of the low-frequency flow. The left-hand preference in the eddy flux direction implies that the eddy-vorticity or TEPV fluxes are systematically organized by low-frequency flow and thus induce a positive feedback onto the flow itself. A schematic diagram for positive eddy feedback is summarized in Fig. 5.

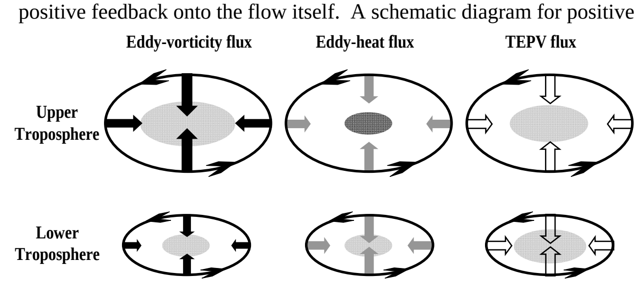

Fig. 5. Schematic illustration for SELF feedback processes related to eddy-vorticity flux (a), eddy-heat flux (b) and TEPV flux (c). Black solid circles with clockwise arrows indicate anomalous cyclonic circulation (such as the north action center of the AO). Shaded areas denote the eddy-induced geopotential height tendency of negative (light gray) and positive (dark gray) signs, where the size of areas indicates the strength of the tendency. Due to the cyclonic circulation, the negative (positive) geopotential height tendencies induced by eddy fluxes reflect the positive (negative) eddy feedback.

Refer to: Ren, H.-L., F.-F. Jin, J.-S. Kug, L. Gao. 2010, *Clim. Dyn.*,10.1007/s00382-010-0913-0.