The relationship between the stratospheric quasi-biennial oscillation (QBO) and tropospheric circulation from the Northern hemisphere autumn to winter

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1. Introduction

The influence of the stratospheric quasi-biennial oscillation (QBO) on tropospheric circulation over the Northern hemisphere is studied over a 25-year period (1980-2004), using NCEP/NCAR reanalysis data. Seasonal evolution of the interaction between the stratospheric QBO and tropospheric circulation is focused from the Northern hemisphere autumn till winter.

2. Data

- U, V, ω, z, T ・・・ NCEP/NCAR Reanalysis data
- analysis period ・・・ autumn (Sep-Oct-Dec) and winter (Dec-Jan-Feb) in March 1980 – Feb 2005

3. Classification by QBO

50 hPa zonal-mean zonal wind averaged for 5S-5N was calculated. And then, all 25 years were divided into easterly years and westerly years of the QBO in each season.

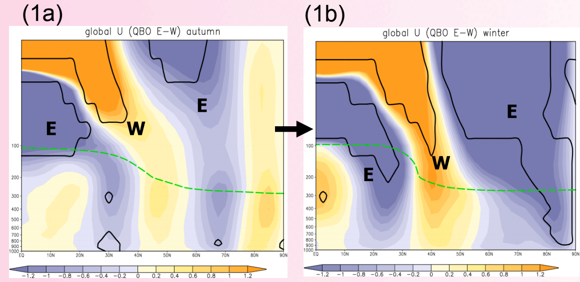

Fig.1 Zonal-mean zonal wind differences between the easterly phase and the westerly phase (easterly minus westerly) of the QBO in (a) autumn and (b) winter. The unit is m s^{-1}. Black and bold lines indicate reaching the 95% significant level. A dashed line shows the tropopause.

4. Result

4-1 The distribution of zonal-mean zonal wind

Figure 1 shows zonal-mean zonal wind differences between easterly years and westerly years in autumn and winter. Significant easterly anomalies are seen at high latitudes in winter. This is just exactly Holton-Tan oscillation. And there are westerly anomalies in mid-latitudes and easterly anomalies around 20-30N near the tropopause in not only winter but also autumn. This indicates that a part of Holton-Tan oscillation starts to form during autumn. These anomalies strengthen shifting southward with seasonal march.

4-2 Effects of waves

To clarify the formation process of these zonal wind anomalies, the effects of waves were investigated using the Transformed Eulerian-mean equation:

$$\frac{\partial \bar{u}}{\partial t} = -\bar{v}^*\left[\frac{1}{a\cos\phi}\frac{\partial}{\partial\phi}(\bar{u}\cos\phi) - f\right] - \bar{w}^*\frac{\partial \bar{u}}{\partial z} + \frac{1}{\rho_0 a\cos\phi}\nabla\cdot\mathbf{F} + \bar{X}$$

Westerly acceleration in mid-latitudes and easterly acceleration in the low latitudes are observable in the troposphere (Fig. 2a). Figures 2c and d show stationary (10-30 days) and transient (< 10 days) components of EP flux divergence, respectively. This means that both transient eddies and stationary waves are dominant in westerly acceleration in mid-latitudes, while easterly acceleration in the low latitudes depends only on stationary waves.

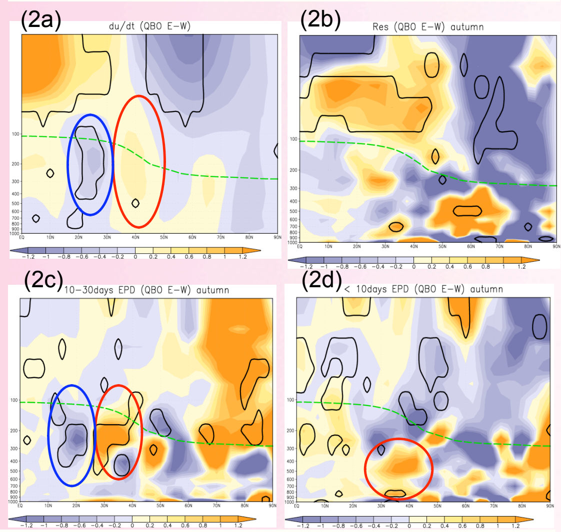

Fig.2 (a) The local time change of zonal-mean zonal wind, (b) the residual circulation, (c) stationary and (d) transient components of EP flux divergence in autumn. All figures are evaluated as easterly years minus westerly years of the QBO. The unit is $\times10^{-6}$ m s^{-2}. Black and bold lines indicate reaching the 95% significant level. A dashed line shows the tropopause.

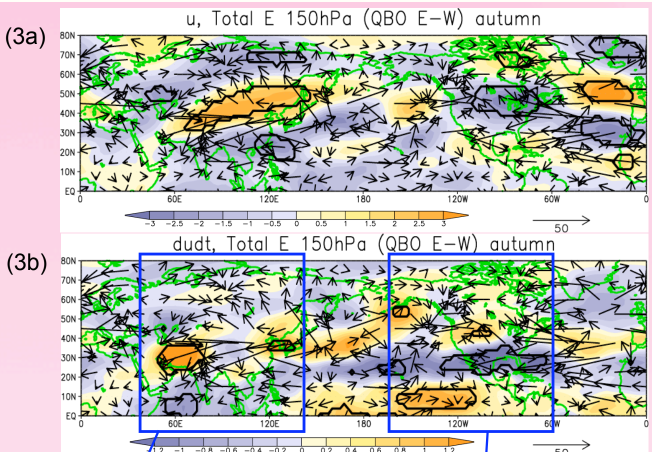

Fig.3 (a) Zonal wind and total component of extended EP flux at 150 hPa in autumn. Each unit is m s^{-1} and m^2 s^{-2}. (b) The local time change of zonal wind and total component of extended EP flux at 150 hPa in autumn. Each unit is $\times10^{-6}$ m s^{-2} and m^2 s^{-2}. All variables are evaluated as easterly years minus westerly years of the QBO. Black and bold lines indicate reaching the 95% significant level.

$$\mathbf{E} = \left(\overline{v'^2} - \overline{u'^2}, -\overline{u'v'}, \frac{f_0^2}{N^2}\overline{v'\theta'}\right) \qquad \nabla_3\cdot\mathbf{E}$$

4-3 Horizontal distribution

The horizontal distribution of zonal wind was examined. Figure 3a shows zonal wind anomalies at 150 hPa in autumn. The vectors mean total component of extended EP flux by Hoskins *et al.* (1983). Significant westerly anomalies in mid-latitudes and easterly anomalies in the low latitudes can be seen over Asia. These anomalies are reflected in Fig. 1a which shows zonal averaged zonal wind. However, western hemisphere has noisier anomaly distribution compared to eastern hemisphere.

Next, the local time change of zonal wind is focused (Fig. 3b). Westerly acceleration in mid-latitudes is found around the west of India and Japan. And fluxes seem to be divergent in the regions. On the other hand, the tendency of zonal wind anomalies over the American regions differs from that over Asian regions.

4-4 Roles of waves in Asia and America

Figure 4 shows latitude-pressure cross-section of stationary and transient components of extended EP flux and their 3D divergence averaged on Asian region (40-140E) and American region (160-60W). Apparently, the convergence and divergence of extended EP flux by stationary waves are seen in the upper troposphere over Asia (Fig. 4a). In America, both transient and stationary waves seem to be associated with westerly acceleration near 30-40N, though the signals are weak (Figs. 4b and d). In addition, the correspondence of significant easterly acceleration near 20-30N (Fig. 3b) and flux divergence over America (Figs. 4b and d) is obscure.

These results indicate that easterly and westerly acceleration over Asia are related to stationary eddies, whereas wind anomalies over America are not likely to depend on waves deeply.

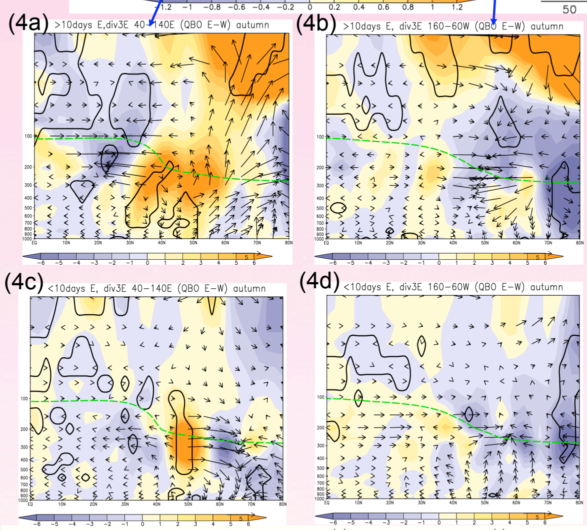

Fig.4 Latitude-pressure cross-section of (a) stationary and (c) transient components of extended EP flux and their 3D divergence in Asian region (40-140E). Latitude-pressure cross-section of (b) stationary and (d) transient components of extended EP flux and their 3D divergence in American region (160-60W). (units of flux: for y component m^2 s^{-2}; for vertical component$\times10^{-4}$ K m s^{-1}). And the unit of divergence is $\times10^{-6}$ m s^{-2} . Black and bold lines indicate reaching the 95% significant level. A dashed line shows the tropopause.

5. Conclusion

- Westerly (easterly) anomalies in mid-latitudes and easterly (westerly) anomalies in the low latitude are seen during the easterly (westerly) phase of QBO in not only winter but also autumn.
- Wave activities in autumn appear to affect the distribution of wind in winter. Both transient and stationary waves are dominant in westerly acceleration at mid -latitudes, while easterly acceleration in the low latitude is responsible for only stationary waves.
- In Asia, easterly and westerly anomalies are associated with acceleration by

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