NOTES AND CORRESPONDENCE

The Influence of the Equatorial QBO on the Northern Hemisphere Winter Circulation of a GCM

By Masanori Niwano¹

*Division of Ocean and Atmospheric Sciences, Graduate School of Environmental Earth Science,
Hokkaido University, Sapporo 060-0810, Japan*

and

Masaaki Takahashi

Center for Climate System Research, University of Tokyo, Tokyo 153-8904, Japan

(Manuscript received 7 January 1997, in revised form 2 April 1998)

Abstract

The influence of a simulated equatorial quasi-biennial oscillation (QBO) on the Northern Hemisphere winter was studied by analyzing output data from a general circulation model (GCM). The differences between the 7–50 hPa equatorial QBO phases of the January–March (JFM) averaged zonal wind composite exhibit a weaker polar-night jet during the easterly phase of the equatorial QBO and a stronger polar-night jet in the westerly phase. The Eliassen–Palm flux of planetary waves is stronger and more convergent in the high latitude stratosphere for the easterly phase, while it exhibits similar characteristics in the mid latitude stratosphere during the westerly phase. These results are nearly consistent with observed results. Zonal wind deceleration anomalies are located slightly north of the zonal wind anomalies. It is likely that the JFM time-mean zonal wind anomalies develop from the small zonal wind anomalies during the early winter and propagate northward with time. The anomaly pattern in the troposphere coupled with that in the stratosphere reveals a tripole structure among equatorial, middle, and high latitudes, similar to the North Atlantic oscillation (NAO) pattern.

1. Introduction

It is fairly well known that the equatorial quasi-biennial oscillation (QBO) modulates the extratropical circulation during the Northern Hemisphere winter. The pioneer work of Holton and Tan (1980, 1982) (hereafter referred to as HT80 and HT82, respectively), analyzing a 16-year data set, showed that the polar-night jet was weaker during the easterly phase of the 50-hPa equatorial QBO. The composite of the 50-hPa equatorial QBO (westerly phase minus the easterly phase) exhibited a dipole pattern; that is, westerly anomalies appear in high latitudes

and easterly anomalies in the middle latitudes. Later, it was suggested that the interannual occurrences of stratospheric sudden warming (SSW) might be influenced by the lower stratospheric equatorial QBO (Labitzke, 1982). In more recent work, Dunkerton and Baldwin (1991) (hereafter referred to as DB91), and Baldwin and Dunkerton (1991) expanded the study of Holton and Tan and investigated the physical mechanism for the modulation of planetary-wave propagation. Several studies of numerical simulations examining the QBO modulation of planetary wave transport, on the other hand, were presented by O'Sullivan and Salby (1990) and O'Sullivan and Young (1992). These researchers found results consistent with the observed response.

In this study, we examine planetary wave behavior and its influence on the mean flow of the Northern

¹ Corresponding author: Masanori Niwano, Division of Ocean and Atmospheric Sciences, Graduate School of Environmental Earth Science, Hokkaido University, Sapporo 060-0810, Japan. E-mail: niwano@ees.hokudai.ac.jp
©1998, Meteorological Society of Japan

Fig. 1. Time-height cross section of the simulated equatorial zonal-mean zonal wind for 14 years and 9 months. The contour interval is 7.5 m/s, and negative values are indicated by dashed contours.

Hemisphere winter, by comparing the two phases of the equatorial QBO found in a general circulation model (GCM) where the QBO is fairly well simulated (Takahashi, 1996; Takahashi *et al.*, 1997). A stratosphere-troposphere coupling pattern, as it relates to the equatorial QBO, is also explored.

2. Model output

The model output data are from a QBO simulation performed using the first version of the atmospheric GCM developed at the Center for Climate System Research/National Institute for Environmental Studies (CCSR/NIES). The horizontal resolution is T21, which translates to a grid spacing of about 600 km. There are 60 layers in the vertical, having an approximate 500-m vertical resolution in the upper troposphere and lower stratosphere. The top level of the model is located at about 0.5 hPa (approximately 50 km, the 0.0005-sigma level). A scheme of moist convective adjustment is used as the cumulus parameterization. The damping time for the maximum wavenumber in the fourth-order horizontal diffusion is 20 days, being about one-order of magnitude longer than that usually employed in GCMs (*cf.* Boville, 1991). Here, it should be noted that the model has no externally varying forcing terms apart from the annual cycle. Namely, the sea surface temperature (SST) is climatological and annually cyclic. The model is, therefore, a purely internal system except for the diurnal and annual forcings. See Takahashi (1996) for a more detailed description of the model. In the present note, the simulation was extended to 14 years and 9 months. In the analyses, use was made

of 5-day averaged data to focus only on planetary wave activity.

Figure 1 shows a time-height section of the equatorial zonal-mean zonal wind. The QBO is clearly visible in the middle stratosphere, between 5 and 80 hPa, with an approximate 1.3-year period, being shorter than that observed. The easterly phase of the QBO is weaker and of shorter duration than the westerly phase, especially in the 50–80 hPa layer. This feature is one deficiency in the simulation.

An examination was made of the spatial autocorrelation of zonal-mean zonal wind during the Northern Hemisphere winter, by setting the reference point in the polar-night jet, and correlating with other grid points (not shown). The reference point 1.0 hPa, 69.2°N is where the largest interannual variability of the mean zonal wind appears during late winter. The correlation revealed that the 7–50 hPa equatorial zonal-mean zonal wind was in phase with the interannual variability in the polar-night jet. The 7–50 hPa equatorial wind was, therefore, used to select the easterly and westerly years of the QBO, and composited differences are constructed between the QBO phases. In the easterly years 4, 5, 9, 13, and 14, and the westerly years 2, 3, 7, 11, and 12, for January–March (JFM), the equatorial winds between 7 and 50 hPa had anomalies beyond a level of about one standard deviation σ , except for year 14 when the anomaly was about the 0.8σ level. Composited figures in this manner exhibit larger anomalies than the corresponding anomalies determined by other definitions of the QBO. In this study, we focus on the JFM time-mean field, since not much difference exists between the

E-W 50hPa GPH (m) Jan-Mar

Fig. 2. Polar stereographic projection of the 50-hPa geopotential height (geopotential meters) differences between the easterly and the westerly phase (easterly minus westerly) of the QBO. The contour interval is 25 m and negative values are indicated by dashed contours. Values significant at more than the 0.1 level based on a one-sided *t* test are lightly shaded, and at the 0.05 level darkly shaded.

two phases during early winter.

The JFM time-mean zonally averaged quantities were obtained as follows. First, the 5-day averaged data were used to calculate zonal-mean quantities (*e.g.*, the Eliassen-Palm flux). Next, the calculated zonal-mean quantities were averaged over the JFM period to create JFM time-mean zonally averaged quantities.

3. Results

3.1 Differences in the geopotential height field and the zonal-mean wind

Figure 2 shows the difference in the easterly and westerly phase (easterly phase minus the westerly phase) of the JFM time-mean geopotential height at 50 hPa. Here, and in the remainder of this study, the westerly phase will always be subtracted from the easterly phase. Positive pressure anomalies are found around the north polar regions, surrounded by negative pressure anomalies in midlatitudes. This indicates a weaker polar vortex and stronger westerlies in the middle latitudes for the easterly phase of the QBO. This oscillation pattern between the

polar regions and midlatitudes coincides with observational analyses (HT80; DB91).

Local patterns exhibit wavenumber-3 negative anomalies over Europe, North America, and the Pacific at middle latitudes. Higher-latitude positive anomalies north of about 55°N, especially in the higher latitudes, exhibit a wavenumber-2 pattern with troughs near 100°E and 45°W. The wave-like pattern coincides rather well with that observed. The magnitudes of the positive and negative anomalies are comparable to those in Fig. 3c of DB91 for December–February. On the other hand, the analysis in HT80 for January and February, using a shorter 16-year data set than that used in DB91, reveals larger anomalies in the middle latitudes.

The composited differences in the JFM time-mean zonal wind fields in Fig. 3 are characterized by a dipole pattern in the stratosphere, with negative anomalies (maximum about -17 m/s) north of 40°N and positive anomalies south of 40°N, similar to Fig. 2. The anomalies have nearly the same amplitudes as those observed, as reported in DB91. Values examined by a *t*-test indicate that the dipole anomalies are statistically significant at the 0.1 level.

Fig. 3. Latitude-height cross section of the JFM time-mean zonal wind differences between the two phases of the QBO (easterly minus westerly). The contour interval is 2.5 m/s and negative values are indicated by dashed contours. Shading indicates significant values as in Fig. 2.

3.2 Wave behavior

Planetary wave activity is investigated by examining the computed Eliassen-Palm flux (EP flux) vector and its divergence. The meridional and vertical fluxes are defined in spherical coordinates ($\lambda, \phi, z \equiv -H \ln(p/p_s)$) as

$$\begin{aligned} F^{(\phi)} &\equiv -\rho_0 a \cos \phi \overline{v' u'}, \\ F^{(z)} &\equiv \rho_0 f a \cos \phi \overline{v' \theta' / \theta_z}, \end{aligned} \quad (1)$$

respectively, where a is the radius of the earth and ρ_0 the density of the basic state defined by $\rho_0 \equiv \rho_s \exp(-z/H)$.

The EP flux divergence is related to the westerly deceleration by the transformed Eulerian-mean (TEM) equations (Andrews and McIntyre, 1976) given in spherical coordinates as

$$\frac{\partial \bar{u}}{\partial t} = f \bar{v}^* + \frac{\nabla \cdot \mathbf{F}}{\rho_0 a \cos \phi} + \bar{X}, \quad (2)$$

where

$$\nabla \cdot \mathbf{F} \equiv \frac{1}{a \cos \phi} \frac{\partial}{\partial \phi} (\cos \phi F^{(\phi)}) + \frac{\partial F^{(z)}}{\partial z}, \quad (3)$$

and $\bar{X}$ designates the contribution from small-scale waves and unresolved processes.

The residual mean circulation ($\bar{v}^*, \bar{w}^*$) is defined by using the Eulerian-mean circulation ($\bar{v}, \bar{w}$) as

$$\bar{v}^* \equiv \bar{v} - \frac{1}{\rho_0} \frac{\partial}{\partial z} \left(\rho_0 \frac{\overline{v' \theta'}}{\theta_z} \right), \quad (4a)$$

$$\bar{w}^* \equiv \bar{w} + \frac{1}{a \cos \phi} \frac{\partial}{\partial \phi} \left(\cos \phi \frac{\overline{v' \theta'}}{\theta_z} \right). \quad (4b)$$

During each QBO phase, the EP fluxes propagate from the midlatitude lower stratosphere into the upper stratosphere (not shown). The vectors indicate movement toward lower latitudes, becoming convergent over the entire stratosphere south of 60°N .

Figure 4 shows the composited difference in the two phases of the EP flux (vectors, in the scaled form suggested by Palmer (1981)) and the flux divergence (contours, divided by $\rho_0 a \cos \phi$) averaged for JFM. In the middle stratosphere, upward flux anomalies are found north of 60°N , while downward anomalies are seen south of 60°N . These results demonstrate that planetary waves extend to higher latitudes in the stratosphere during the easterly phase, while propagating into the stratospheric middle latitudes south of 60°N for the westerly phase of the QBO. These fluxes correspond to the mean zonal wind dipole structure shown in Fig. 3.

The dipole pattern of flux divergence is qualitatively similar to the observed results (DB91), although the convergent anomalies in the upper

Fig. 4. Cross section of the composited differences in the Eliassen-Palm flux vectors and flux divergence of the QBO phases (easterly minus westerly). Both components of the vectors have been divided by ρ_0 . The divergence contour interval is $5.0 \times 10^{-6} \text{ m/s}^2$, with negative values shaded.

stratosphere north of 55°N have slightly smaller amplitudes than those observed. The divergent anomalies above 10 hPa near 50°N , however, have the opposite sign of those in Fig. 16 of DB91, while the EP flux anomalies in the mid-latitude stratosphere do not resemble the observed results, which display upward anomalies over the entire stratosphere.

The EP flux vectors in low latitudes exhibit more convergence in the layer between 10–50 hPa for the easterly phase, whereas near the equator they propagate to the south of the convergent anomalies during the westerly phase. These results appear to demonstrate that the behavior of the critical layer for planetary waves is more reflective for the easterly phase of the QBO than the westerly phase.

The upper-tropospheric EP flux pattern for each phase (not shown) reveals that planetary waves propagate upward and equatorward. A maximum in the flux convergence exists at about 60°N and 400 hPa, having a magnitude comparable to that observed (DB91). The equatorward propagating planetary waves appear to converge in the low latitudes south of the maximum in the subtropical jet.

It is apparent in Fig. 4 that downward flux anomalies exist north of 55°N , below about 200 hPa, while upward flux anomalies are found around 45°N in the troposphere. This pattern reveals that plan-

etary wave fluxes in the troposphere are stronger and more convergent at high latitudes, and propagate upward and southward to the middle-latitude stratosphere during the westerly phase of the QBO. For the easterly phase, planetary waves propagate from the middle-latitude troposphere to higher latitudes in the lower stratosphere.

3.3 Mean zonal wind acceleration anomalies estimated using the TEM equations

Next, an investigation is conducted of the sum of the first term $f\bar{v}^*$ and the second term (defined as the quantity D_F) on the right-hand side of Eq. (2), which is a more accurate indication of the mean flow deceleration.

The sum of the JFM time-mean $f\bar{v}^*$ and D_F for each phase of the QBO reveals that the deceleration of the mean zonal wind occurs in the stratosphere, poleward of about 50°N (not shown). The region of westerly acceleration in the lower latitudes south of about 50°N , can be found in the stratosphere for each phase, except for the equatorial QBO regions south of 20°N . These patterns imply that the temporal changes of the stratospheric mean zonal wind mainly result from $f\bar{v}^*$ larger than D_F in the lower latitudes and from D_F larger than $f\bar{v}^*$ in the higher latitudes.

Figure 5 shows the difference between the east-

Fig. 5. Cross section of the composited differences in the $f\bar{v}^* + D_F$ of the QBO phases (easterly minus westerly). The contour interval, shading, and the Eliassen-Palm flux vectors are the same as in Fig. 4.

erly and the westerly phases of the JFM sum of $f\bar{v}^*$ and D_F . The pattern displays negative anomalies (shaded regions) in latitudes greater than 65°N , and large positive anomalies between $35\text{--}65^\circ\text{N}$ above 20 hPa connected with lesser positive values at $50\text{--}65^\circ\text{N}$ below 20 hPa. It is of interest that the upper stratospheric dipole anomalies and the tripole anomalies below 20 hPa exist at slightly higher latitudes than the zonal-mean zonal wind anomalies shown in Fig. 3. This difference may be explained by taking into account the seasonal march of the mean zonal wind. The movement of the developing polar vortex anomaly to higher latitudes with time during the winter can also be seen in the present data, especially at midlatitudes (*cf.* Kodera, 1991; James and Dodd, 1996).

Negative anomaly maxima of $f\bar{v}^* + D_F$ in the polar regions can be found near the latitude of the maximum mean zonal wind anomalies, so that the negative anomalies are likely to explain the difference found in the polar-night jet between the QBO phases. If a value of $dt = 40$ days is considered, the zonal-wind deceleration anomaly estimated by $f\bar{v}^* + D_F$ ($= -5.0 \times 10^{-6} \text{ m/s}^2$) at 10 hPa and 75°N is -17.3 m/s . This value is near that found in the same region of the difference between the JFM

averaged zonal winds of the QBO phases (Fig. 3).

3.4 Stratosphere-troposphere coupling mode with respect to the equatorial QBO

As was shown in Fig. 3, the stratospheric mean zonal wind dipole between the higher and lower latitudes is connected with the tropospheric tripole pattern spread over the high, middle, and low latitudes. Negative polar-night jet anomalies and negative tropospheric anomalies near $45\text{--}70^\circ\text{N}$ are linked together. In addition, positive anomalies from the upper-stratospheric equatorial QBO to the low-latitude stratosphere are connected with the positive anomalies near $30\text{--}45^\circ\text{N}$ in the troposphere. Negative anomalies appear in low latitudes of the troposphere, which are in phase with the QBO anomalies.

This zonal mean dipole pattern in the stratosphere is very similar to the observed results of HT80 and DB91, and the EOF 2 stratospheric mode discussed by Nigam (1990). On the other hand, the tripole pattern in the troposphere resembles the EOF 1 pattern (Nigam, 1990). In addition, the stratosphere/troposphere coupling pattern corresponds well to the correlation pattern between the December–February mean zonal wind and the NAO-related mode (Baldwin *et al.*, 1994).

E-W 500hPa GPH (m) Jan-Mar

Fig. 6. The same as in Fig. 2, except at 500 hPa with a contour interval of 10 m.

Figure 6 shows the JFM time-mean 500-hPa geopotential height field differences between the QBO phases. This composite has strong negative anomalies east of North America and in the northwest Pacific, with weak anomalies found from high latitudes around 80°E to Europe. Positive anomalies are found over Greenland, eastern Siberia, and the Gulf of Alaska. The pattern found from eastern North America to Arabia is similar to the NAO-like pattern of the 500-hPa geopotential (Baldwin *et al.*, 1994), and the 500 hPa geopotential field pattern associated with the first mode of 50-hPa geopotential height (Perlwitz and Graf, 1995; Kodera *et al.*, 1996).

There are, however, differences between the pattern investigated here and the observed patterns. Namely, the present pattern reveals that the anomaly over Europe has a smaller value than that over eastern North America. In addition, the negative anomalies over the Beaufort Sea and the positive anomalies over the Gulf of Alaska are opposite of those observed. In spite of these differences, however, Fig. 6 may suggest that influences of the QBO and NAO on the mean flow in the Northern Hemisphere are linked.

4. Conclusions

It has been demonstrated that the interannual variability of the JFM Northern Hemisphere circulation associated with the 7–50 hPa equatorial QBO could be simulated by the CCSR/NIES GCM. The analyses of the 50 hPa-geopotential height and mean zonal wind indicated that the polar-night jet was weaker in high latitudes and stronger in the midlatitudes during the easterly phase of the QBO. Stratospheric planetary wave activity was shown to be stronger in high latitudes and weaker in the middle latitudes during the easterly phase of the QBO. On the other hand, tropospheric planetary wave activity was weaker in the high latitudes and stronger in the midlatitudes, also during the easterly phase. This suggests that planetary waves propagate from the middle latitude troposphere to the high latitude stratosphere in the easterly phase, and from the high latitude troposphere to the midlatitude stratosphere during the westerly phase. These results were rather consistent with observational studies by Holton and Tan (1982), and Dunkerton and Baldwin (1991). Composited differences of $f\bar{v}^* + D_F$ in the TEM equations were likely to explain the zonal-mean zonal-wind anomalies by taking into ac-

count the seasonal march. That is, the zonal wind anomalies in early winter move to higher latitudes with time. The higher- and lower- latitude anomalies of the stratospheric zonal-mean zonal wind appeared to be produced mainly by planetary wave convergence and the mean meridional circulation, respectively.

The critical layer for planetary waves appeared to exhibit a more reflective behavior for the easterly phase of the QBO. This, to some extent, may explain the modulation of planetary waves by the equatorial QBO. This modulation, however, should be clarified by examining the temporal development of the mean zonal wind and planetary wave activity.

The stratosphere/troposphere coupling mode related to the equatorial QBO displayed a stratospheric dipole and a tropospheric tripole structure. The pattern of this mode was found to be similar and possibly associated with the NAO-like pattern (Perlwitz and Graf, 1995), which was partly confirmed by the geopotential heights at 50 and 500 hPa, and the zonal-mean zonal flow oscillation patterns. The tropospheric tripole pattern of the coupling mode was also similar to the mode of the tropospheric tripole pattern produced by a model simulation (James *et al.*, 1994). This coupling mode between the stratosphere/troposphere appears to be an important mode of the interannual variability in the Northern Hemisphere winter.

Acknowledgments

The authors would like to thank Dr. F. Hasebe for helpful discussions and encouragement, and Drs. K. Kodera, M. Shiotani, and K. Yamazaki for valuable discussions. They are also grateful to anonymous reviewers for helpful comments on an earlier version of this paper. For the graphics, use was made of the GFD-DENNOU library, and GTOOL which was compiled by A. Numaguti. A portion of this study was supported by a Grant-in Aid for Scientific Research from the Japanese Ministry of Education, Science, and Culture (No. 06452083).

References

- Andrews, D.G. and M.E. McIntyre, 1976: Planetary waves in horizontal and vertical shear: the generalized Eliassen-Palm relation and the mean zonal acceleration. *J. Atmos. Sci.*, **33**, 2031–2048.
- Baldwin, M.P., X. Cheng and T.J. Dunkerton, 1994: Observed correlations between winter-mean tropospheric and stratospheric circulation anomalies. *Geophys. Res. Lett.*, **21**, 1141–1144.
- Baldwin, M.P. and T.J. Dunkerton, 1991: Quasi-biennial oscillation above 10 mb. *Geophys. Res. Lett.*, **18**, 1205–1208.
- Boville, B.A., 1991: Sensitivity of simulated climate to model resolution. *J. Climate*, **4**, 469–485.
- Dunkerton, T.J. and M.P. Baldwin, 1991: Quasi-biennial modulation of planetary-wave fluxes the Northern Hemisphere winter. *J. Atmos. Sci.*, **48**, 1043–1061.
- Holton, J.R. and H.-C. Tan, 1980: The influence of the equatorial quasi-biennial oscillation on the global circulation at 50 mb. *J. Atmos. Sci.*, **37**, 2200–2208.
- Holton, J.R. and H.-C. Tan, 1982: The quasi-biennial oscillation in the Northern Hemisphere lower stratosphere. *J. Meteor. Soc. Japan*, **60**, 140–148.
- James, P.M., K. Fraedrich and I.N. James, 1994: Wave-zonal flow interaction and ultra-low frequency variability in a simplified global circulation model. *Quart. J. Roy. Meteor. Soc.*, **120**, 1045–1067.
- James, I.N. and J.P. Dodd, 1996: A mechanism for the low-frequency variability of the mid-latitude troposphere. *Quart. J. Roy. Meteor. Soc.*, **122**, 1197–1210.
- Kodera, K., 1991: The solar and equatorial QBO influences on the stratospheric circulation during the early Northern-Hemisphere winter. *Geophys. Res. Lett.*, **18**, 1023–1026.
- Kodera, K., M. Chiba, H. Koide, A. Kitoh and Y. Nikaidou, 1996: Interannual variability of the winter stratosphere and troposphere in the Northern Hemisphere. *J. Meteor. Soc. Japan*, **74**, 365–382.
- Labitzke, K., 1982: On the interannual variability of the middle stratosphere during northern winters. *J. Meteor. Soc. Japan*, **60**, 124–139.
- Nigam, S., 1990: On the structure of variability of the observed tropospheric and stratospheric zonal-mean zonal wind. *J. Atmos. Sci.*, **47**, 1799–1813.
- O'Sullivan, D. and M.L. Salby, 1990: Coupling of the quasi-biennial oscillation and the extratropical circulation in the stratosphere through planetary wave transport. *J. Atmos. Sci.*, **47**, 650–673.
- O'Sullivan, D. and R.E. Young, 1992: Modeling the quasi-biennial oscillation's effect on the winter stratospheric circulation. *J. Atmos. Sci.*, **49**, 2437–2448.
- Palmer, T.N., 1981: Diagnostic study of a wavenumber-2 stratospheric sudden warming in the transformed Eulerian-mean formalism. *J. Atmos. Sci.*, **38**, 844–855.
- Perlwitz, J. and H.-F. Graf, 1995: The statistical connection between tropospheric and stratospheric circulation of the Northern Hemisphere in winter. *J. Climate*, **8**, 2281–2295.
- Takahashi, M., 1996: Simulation of the stratospheric quasi-biennial oscillation using a general circulation model. *Geophys. Res. Lett.*, **23**, 661–664.
- Takahashi, M., N. Zhao and T. Kumakura, 1997: Equatorial waves in a general circulation model simulating a quasi-biennial oscillation. *J. Meteor. Soc. Japan*, **75**, 529–540.

大気大循環モデル (GCM) に現れた赤道準 2 年振動 (QBO) の 冬季北半球大循環への影響について

庭野将徳

(北海道大学大学院地球環境科学研究科)

高橋正明

(東京大学気候システム研究センター)

赤道準 2 年周期振動 (QBO) が再現された大気大循環モデル (GCM) の出力データを使って、赤道 QBO が冬の北半球循環に及ぼす影響について調べた。1-3 月の帯状平均東西風について調べてみると、7-50 hPa の赤道 QBO が東風 (西風) の時に極夜ジェットが弱く (強く) なるような中高緯度間の双極子 (dipole) 構造が成層圏に現れた。惑星波の Eliassen-Palm フラックスは QBO 東風 (西風) の時に高緯度 (中緯度) 成層圏で強く、そこでより収束している。これらの結果は観測データの解析による結果と一致している。また、帯状平均帯状風減速の偏差は東西風偏差よりも北側に位置する。このことから冬季の東西風偏差は初冬における偏差が時間と共に高緯度側へ移動して作られているように思われる。成層圏の双極子構造は対流圏の赤道付近、中緯度、高緯度間で振動する 3 重極子 (tripole) と結び付いており、その連携したパターンは北大西洋振動 (NAO) パターンと似た子午面、経度構造をしている。