Positive Feedback between Polar Jet and Polar Mode of the Baroclinic Instability

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1 Introduction

The Arctic Oscillation (AO) is the dominant atmospheric mode characterized as opposing atmospheric pressure patterns between the middle and high latitudes. It is defined as the leading mode of the empirical orthogonal function (EOF1) of sea-level pressure (SLP) in the Northern Hemisphere winter. The theory was proposed by Thompson and Wallace (1998). The AO makes a profound impact on seasonal weather in mid to high latitudes in the Northern Hemisphere. The variation of the AO-index is assumed to correspond to the variation of the intensity of the polar jet.

The variation of the westerly jet is also related to the baroclinically unstable waves. Tanaka and Tokinaga (2002) confirmed the two different kinds of baroclinic instability; the Polar mode excited by the baroclinicity of the polar jet and the Charney mode excited by the baroclinicity of the subtropical jet. These baroclinic instabilities have opposite feedback processes making the polar jet stronger or weaker.

In the areas of strong baroclinicity, Rossby waves can amplify and eventually break; causing the potential vorticity (PV) gradient on the isentropicsurface invert. Four characteristic types of wave breaking exists. This includes the two types of equatorward breakings: LC1 and LC2; introduced by Thorncroft et al. (1993) and the two poleward breakings; P1 and P2, introduced by Peters and Waugh (1996).

In this study, we investigated the positive feedback between the polar jet and the Polar mode of the baroclinic instability by focusing on the north-south transport of eddy momentum and the rotational direction of the wave breaking.

2 Data and Method

We used the NCEP/NCAR reanalysis dataset for the winter time periods (DJF). A temporal resolution of 6 hours (00, 06, 12, 18 UTC), horizontal resolution of $2.5° \times 2.5°$ and 17 vertical layers were used in the analysis.

We selected a total of 10 seasons; with 5 positive AO-index seasons and 5 negatine AO-index seasons from 1965 to 2006 (Fig. 1). The positive AO winter seasons are 1971/72, 1975/76, 1988/89, 1992/93 and 1999/2000. The negative AO winter seasons are 1968/69, 1969/70, 1976/77, 2000/01 and 2003/04. The AO-index shows the minimum value in the 1976/1977 winter season and the maximum value in the 1988/89 winter season. Rapid changes of the AO-index sach as these winters are known as "climate shifts".

We calculated the north-south transport of the westerly eddy momentum $\overline{u'v'}$ and the acceleration of the zonal mean wind. Then we mapped the 315 K isentripic surface potential vorticity (Hoskins et al. 1985) to investigate the rotational direction of the wave breaking. Additionally, for the composite analysis, we calculated the meridional negative PV gradient to examine the distribution of the wave breaking.

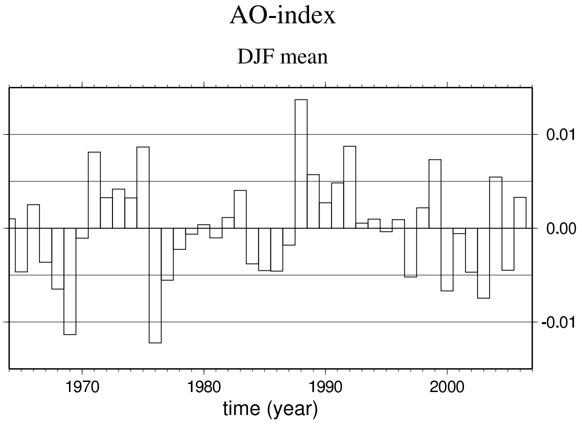

Fig. 1: DJF mean of AO-index.

3 Results

3.1 Momentum Flux and Zonal Wind

Figure 2 illustrates the north-south transport of westerly eddy momentum and acceleration of the zonal mean U at 00Z 5 January 1977. The eddy momentum is transported from low-latitudes to high-latitudes at the vicinity of the tropopause. At the area of convergence of eddy momentum near 50°N, the westerly jet is accelerated. In the higher latitudes, the westerly flow is decelerated and the direction of the eddy momentum becomes equatorwards. Figure 3 shows the potential vorticity of the 315 K isentropic surface on the same day. Over the eastern North Atrantic, the low-Q at the low-latitudes intrude towards the northeast and the Rossby wave seems to just about to break with an anticyclonic rotation. In the same way, in the eastern North Pacific region, the low-Q intrudes toward the northern high-Q area.

In contrast, on 00Z 13 January 1977, the eddy momentum is transported from high-latitudes to mid-latitudes and converges at the vicinity of 40°N (Fig .4). Additionally in this area, the westerly jet is accelerated. In the high-latitude areas, eddy momentum diverges and the jet is decelerated. On the same day over the North Atrantic region, the low-Q from the southern area reaches the polar region and the Rossby wave seems to just about to break with a cyclonic rotation at mid-latitudes (Fig. 5).

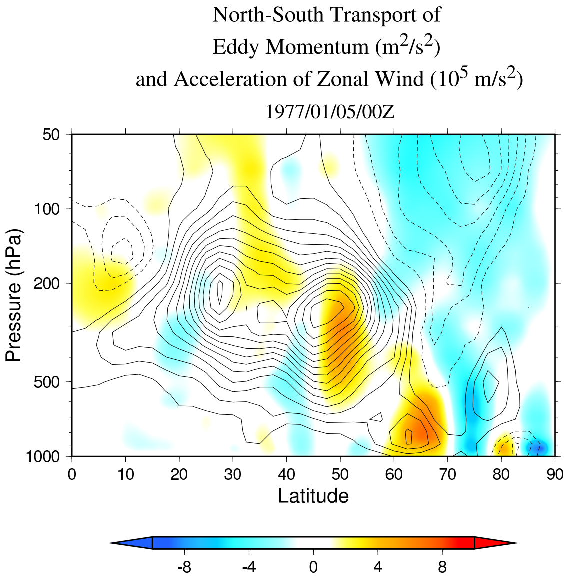

Fig. 2: North-south transport of eddy momentum and acceleration of zonal mean wind (1977/01/05/00Z).

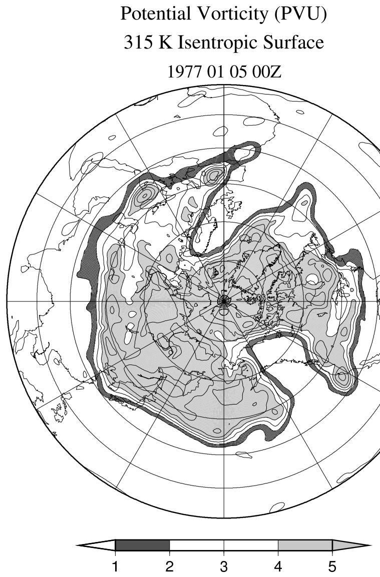

Fig. 3: PV on 315 K isentropis surface (1977/01/05/00Z).

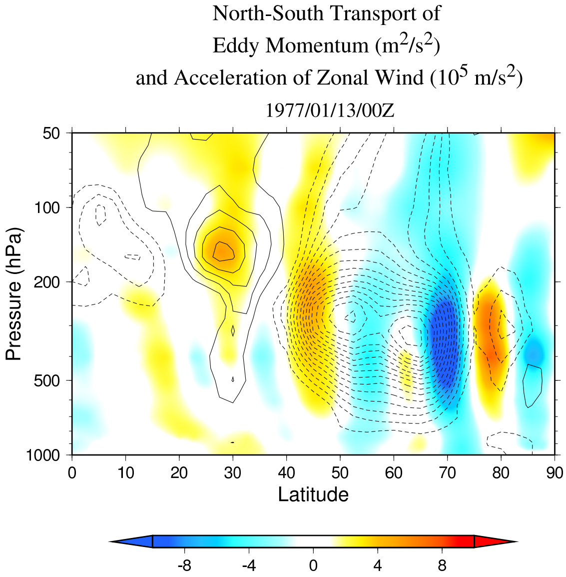
North-South Transport of
Eddy Momentum (m^2/s^2)
and Acceleration of Zonal Wind (10^5 m/s^2)
1977/01/13/00Z

Fig. 4: Same as Fig. 2 except for 1977/01/13/00Z.

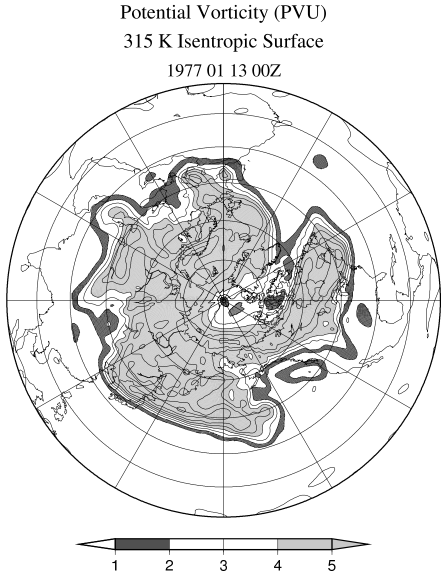
Potential Vorticity (PVU)
315 K Isentropic Surface
1977 01 13 00Z

Fig. 5: Same as Fig. 3 except for 1977/01/13/00Z.

3.2 Composite Analysis

Figure 6 displays the mean value of the eddy momentum transport and the anomalies of zonal mean U for each composite period. During the positive AO phase, the eddy momentum is transported from low-latitudes to high-latitudes and converges near 60°N. The equatorward momentum transport at high-latitudes is very small. This structure is consistent with the Polar mode. Indeed, the anomaly of the polar jet at the convergence area of the eddy momentum is positive and that of the subtropical jet is negative. On the other hand, during the negative AO phase, the eddy momentum is transported from both high and low latitudes to the mid-latitudes and converges near 50°N. This structure is consistent with the Charney mode. The polar jet at the divergence area of the eddy momentum is weak and the subtropical jet is strong.

Figure 7 shows the distribution of the wave breaking. During the positive AO phase, the significantly enhanced frequency of the wave breaking is seen over Europe and the western North Pacific. In the western North Atrantic region, the frequency of the wave breaking is significantly low. During the negative AO phase, the area of enhanced frequency of the wave breaking is expanded from the North Pacific to the polar regions and over the western North Atrantic region.

According to the zonal mean of the wave breaking frequency, the mean value is large during the positive AO phase at 30°N-40°N, where the peak of the subtropical jet is located. On the other hand, the mean value is large during the negative AO phase at 55°N where the peak of the polar jet is located.

4 Discussions

In this study, we analyzed the north-south transport of westerly eddy momentum and the potential vorticity on the 315 K isentropic surface during the positive and negative AO winter seasons. When the anticyclonic wave breaking occurs, the eddy momentum is transported towards the high-latitudes. In contrast, for the cyclonic wave breaking, the eddy momentum is transported towards the low-latitudes. At the region where the eddy momentum converges, the westerly flow is accelerated.

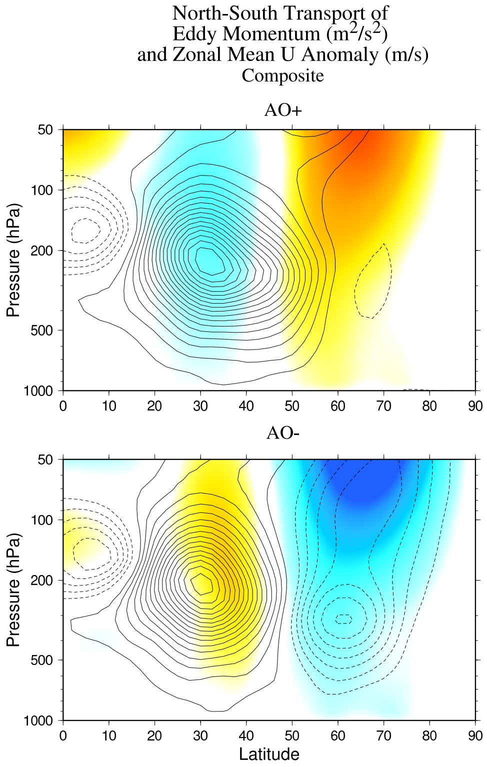

Fig. 6: Eddy momentum flux and zonal mean wind for the composite.

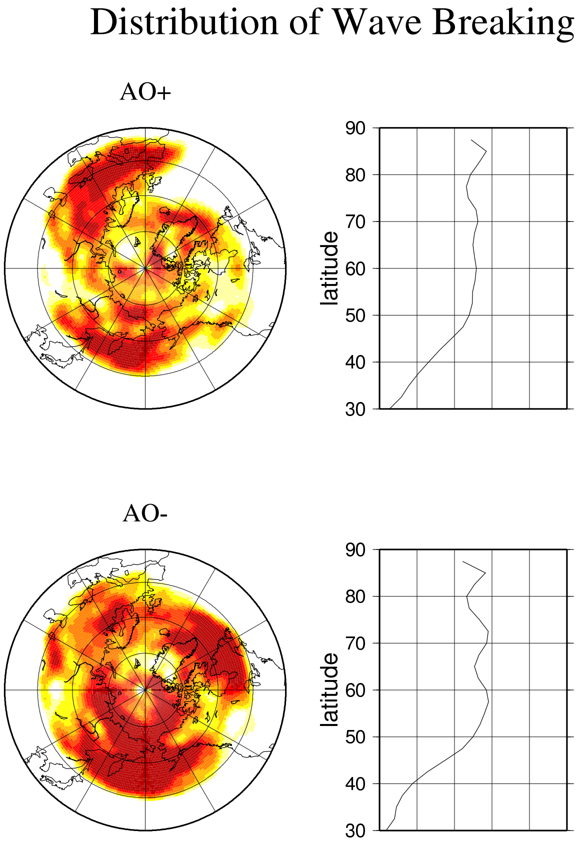

Fig. 7: Distribution of wave breaking frequency maps (left) and zonal mean wave breaking frequency (right).

During the positive AO phase, the polar jet is strong and wave breaking tends to occur in the mid-latitudes, around 30°N-40°N compared to the negative AO phase. The eddy momentum is transported from low-latitudes to high-latitudes. This structure is consistent with the Polar mode and tends to make the polar jet stronger. Therefore, the positive feedback operates between the polar jet and the Polar mode.

References

Hoskins, B. J., M. E. McIntyre, and A. W. Robertson, 1985: On the use and significance of isentropic potential vorticity maps. *Quart. J. Roy. Meteor. Soc.,* **111,** 877-946.

Peters, D. and D. W. Waugh, 1996: Influence of barotropic shear on the poleward advection of upper-tropospheric air. *J. Atmos. Sci.,* **53,** 3013-3031.

Tanaka, H.L. and H. Tokinaga, 2002: Baroclinic instability in high latitudes induced by polar-vortex: A connection to the Arctic Oscillation. *J. Atmos. Sci.,* **59,** 69-82.

Thompson, D. W. J. and J. M. Wallace, 1998: The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. *Geophys. Res. Lett.*, **25**, 1297-1300.

Thorncroft, C. D., B. J. Hoskins, and M. E. McIntyre, 1993: Two paradigms of baroclinic-wave life-cycle behaviour. *Quart. J. Roy. Meteor. Soc.,* **119,** 17-55.