Interaction between the Baroclinically Unstable Wave and the Subtropical and Polar-frontal Jets

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1. Introduction

In the upper troposphere, two westerly jets exist in both of the Northern and Southern Hemispheres: the subtropical jet and the polar-frontal jet. In the North Hemisphere, the subtropical jet is stably located near 30 degrees north latitude at 300 hPa level. The polar-frontal jet is mainly located near 60 degrees north latitude at 200 hPa level.

The strength and location of the polar-frontal jet is variable, whereas that of the subtropical jet is relatively steady. The subtropical jet is formed by the transportation of angular momentum associated with Hadley circulation. On the other hand, the polar-frontal jet is formed by the temperature gradient at mid-latitude. The climate of mid-latitude, including Japan, is under the influence of the variation of polar-frontal jet. The variation of these westerly jets is related to the baroclinically unstable wave.

By Tanaka and Tokinaga (2002), it is confirmed that two different kinds of baroclinic instability exist: one is Charney mode and the other is polar mode. The Charney mode is excited by the baroclinicity of the subtropical jet and the polar mode is exited by the baroclinicity of the polar-frontal jet.

These baroclinic instabilities have different feedback process that makes the polar-frontal jet weaker or stronger. Figure 1 shows the example of Charney mode (left) and polar mode (right). The horizontal phase structure of the polar mode is characterized by the eastward phase tilt with respect to latitudes, and this structure indicates the northward eddy momentum flux all the way. On the other hand, the phase structure of Charney mode indicates that the eddy momentum flux is northward at lower-latitude while it is southward at high-latitudes, so it converges at mid-latitude around latitude of 45 degree north. This means that the polar-frontal jet is intensified by the polar mode, and weakened by Charney mode.

The polar-frontal jet is identified as a polar vortex when we look it from above the North pole. Arctic Oscillation (AO) advocated by Thompson and Wallace (1998) is confirmed to be the variation of the strength of polar vortex, so the index of AO, Arctic Oscillation index (AOI), can be confirmed to be the index of the velocity of the polar-frontal jet.

In this study, baroclinic instability of the Northern Hemisphere is investigated, using a method of expansion in 3D normal mode function introduced by Tanaka and Kung (1989).

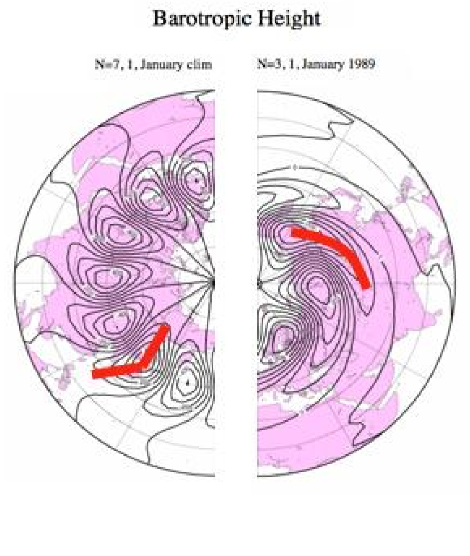

Fig. 1. The example of the horizontal structure of Charney mode (left) and polar mode (right).

2. Linear instability analysis

By using the 3D normal mode functions, we obtain a system of 3D spectral primitive equations in terms of the spectral expansion coefficients. Next, the equation is linearlized with respect to the monthly mean zonal basic state in order to study the barotropic-baroclinic instability.

Disregarding the external forcing of the perturbation, we can assume a wave-type solution of the equation. Then, from the solution of the eigenvalue problem, we can obtain eigenvectors ξ and eigenvalues ν.

From these eigenpairs, we can get the growth rate, phase speed, and modal structure of each solution of the linear instability analysis.

3. Result for January 1989

Figure 2 is monthly and zonal mean zonal wind in January 1989, when the AOI was the highest in the last 50 years. There is a sub-tropical jet near 30 degrees north latitude at 300 hPa level, and a polar jet near 60 degrees north latitude at 200 hPa level.

Figure 3 shows the growth rates (1/day) of the unstable modes computed for the zonal mean basic state of January 1989 (lower), compared with that for January climate data (upper). In climate data, the most unstable mode at zonal wave number n = 8 may be identified as Charney mode, which appears for n = 3 to 12. The most unstable mode is replaced by another different mode for the zonal wavenumbers n = 1 to 4, which clearly has different modal structure. According to Tanaka and Kung (1989), those unstable modes are labeled as shallow Charney modes Mc, dipole Charney modes M2, and tripole Charney modes M3, observing their structures as below.

In 1989 data, on the other hand, Charney mode, dipole Charney mode and tripole Charney mode are weakened, and the most unstable mode at zonal wave number n = 2 to 9 may be identified as polar mode Mp. This mode was labeled as monopole Charney mode M1 in Tanaka and Tokinaga (2002), but this mode is different clearly from shallow Charney mode in their structure. So we'll not call this mode shallow Charney mode but polar mode.

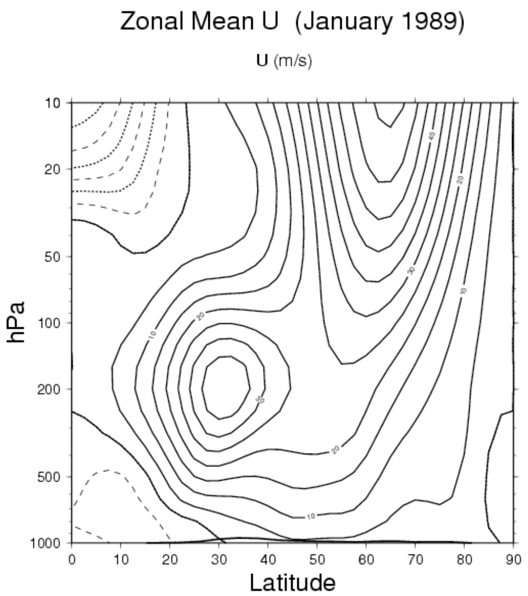

Fig. 2. Meridional-height section of zonal mean zoal wind (m/s) for January 1989 (high AO index) in the NH.

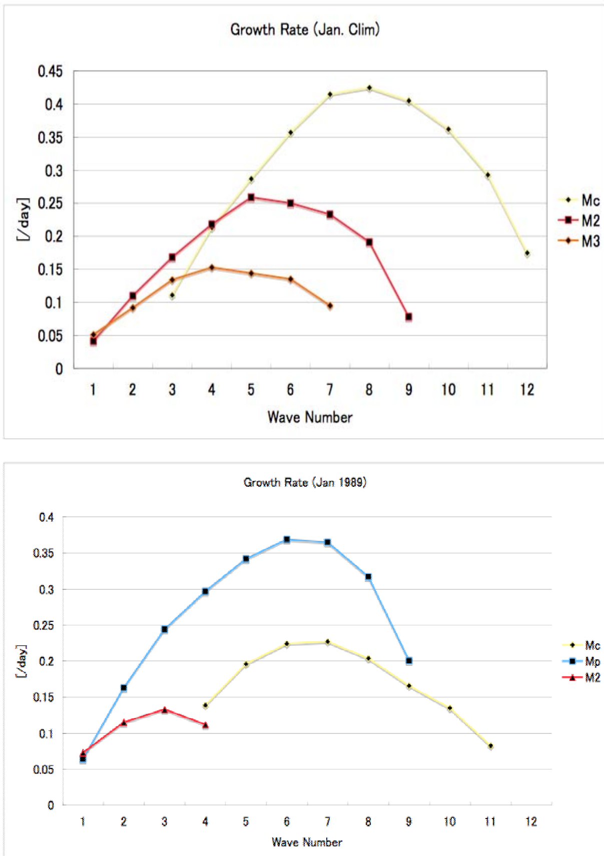

Fig. 3. Growth rates (/1day) of the unstable modes for the zonal mean basic state for January Climate (upper) and January 1989 (lower). The unstable modes are labeled Mc for ordinary Charney modes, M2 for dipole Charney modes, M3 for tripole Charney modes, and Mp for polar modes.

3. Result for virtual atmosphere

Figure 4 shows the distribution of the regression of the zonal mean zonal wind for the Arctic Oscillation index. The peak of the zonal wind anomaly is located in the stratosphere and the axis of polar-frontal jet is stretched around 50-60 degrees north latitude. This structure is associated with the Arctic Oscillation. We added this data on January climate in some stages, and used the linear instability analysis to find how the polar mode would be modified.

At first, in the January climate data, the peak of the growth rate is located at n = 8 and the most unstable mode is Charney mode. The maximum of the growth rate of Charney mode and dipole Charney mode is about 0.42 /day and 0.25 /day.

Next, as shown in Fig.5 (upper), we add the regressed data (Fig. 4) on the climate data. The difference between it and climate data is little. The maximum of the growth rate of Charney mode is about 0.41 /day and the maximum of dipole Charney mode is same.

Then, we doubled the regression data and add on the climate data. The values of Charney mode and dipole Charney mode is reduced nearly 1.0 /day, and polar mode appear with the maximum located at 0.28 /day.

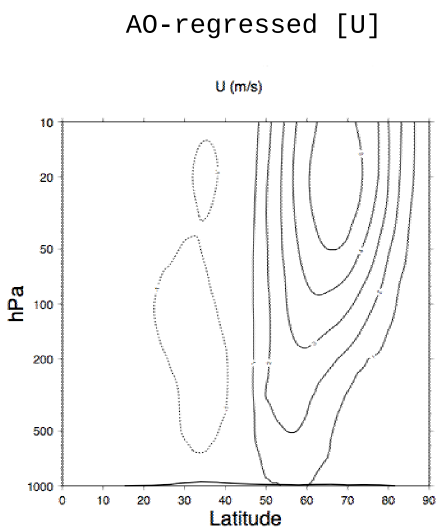

Fig. 4. Meridional-height section of regressed value of zonal mean zonal wind (m/s) for Arctic Oscillation index.

Next, 1.5 times of the regressed data is added on the climate data. Then, the growth rate of Charney mode increases a little and polar mode decreases a little. But, the dipole Charney mode is in same position. So, it isn't likely to be connected continuously to the position of Fig. 5 (upper). It is unchanged for the case of 1.2 times of the regressed data too (Fig. 5 lower).

Figure 6 shows the growth rate of the maximum instability of each mode with respect to velocity of polar-frontal jet. Charney mode is gradually reduced, but dipole Charney mode is suddenly decreased and polar mode appeared suddenly at the case of 1.2 times. It seems that the tri-pole Charney mode changes to dipole Charney mode, and the dipole Charney mode changes to the polar mode.

Figure 7 shows the horizontal and vertical structures of the dipole Charney mode in Fig. 5 (upper) and the polar mode in Fig. 5 (lower).

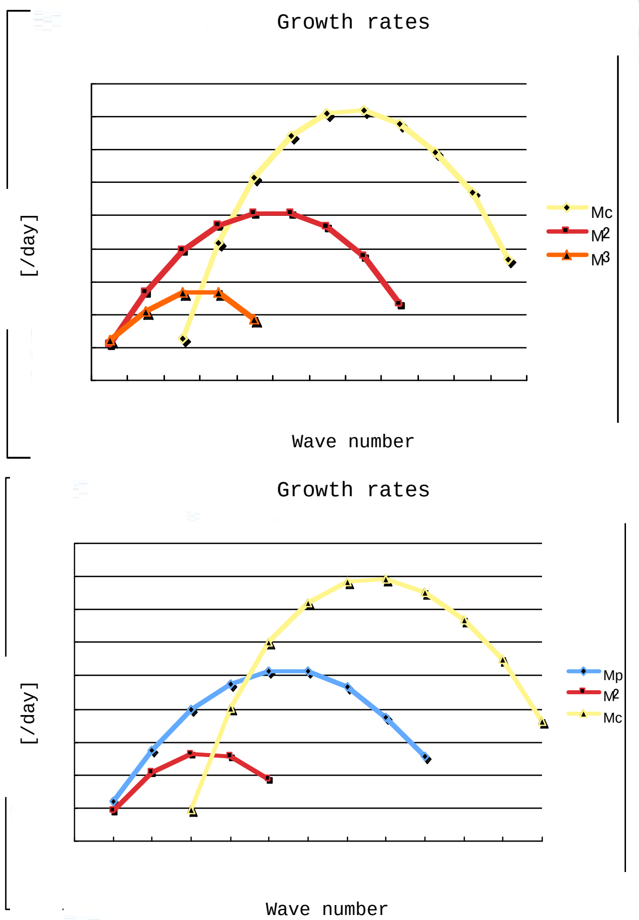

Fig. 5. Growth rates (1/day) of the unstable modes for the zonal mean basic state for January Climate added with the regressed AO structure (upper) and that with 1.2 times of the regressed structure (lower).

It seems that if the south part of the polar mode is divided, it becomes southern peak of the dipole Charney mode and polar mode changes to dipole Charney mode. So, the polar mode is expected to be connected continuously to the dipole Charney mode.

4. CONCLUDING SUMMARY

In this study, we confirmed that the stronger the polar-frontal jet is, the more the polar mode stands out based on the result of the eigenvalue problem for various basic states. We also confirmed that the polar mode becomes the most unstable mode exceeding the Charney mode in each wavenumber when the polar frontal jet is strong enough. We find that the polar mode is not a new mode, but that the dipole Charney mode becomes the polar mode.

As a future subject, we need to investigate the characteristic of the dipole Charney mode and its activity in relation to subtropical jet and polar frontal jet, and how do they change due to the change from the dipole Charney mode to the polar mode. And finally, we need to quantify the feedback between their baroclinic instability and westerly jets.

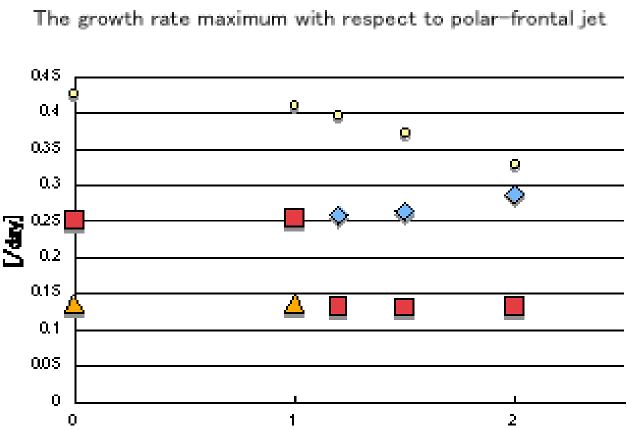

Fig. 6. Growth rate of the maximum instability of each mode with respect to various velocity of the polar frontal jet.

REFERENCES

Hartmann, D.L., 1980 : Baroclinic Instability of Realistic Zonal-Mean States to Planetary Waves, J. Atmos. Sci., 36, 2336-2349.

Tanaka, H.L. and E.C Kung, 1989 : A study of low-frequency unstable planetary waves in realistic zonal and zonally varying basic states, Tellus, 41A, 179-199.

Tanaka, H.L. and H. Tokinaga, 2002 : Baroclinic instability in high latitudes induced by polay 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, Geophy. Res. Let., 25, 1297-1300.

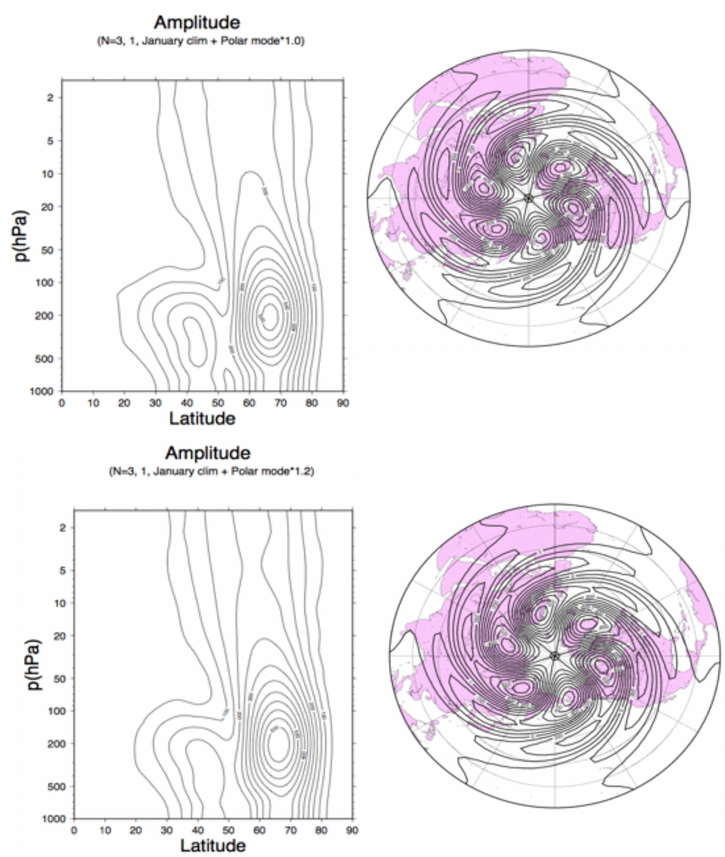

Fig. 7. Meridional-height section of the geopotential amplitude (left) and horizontal section of the barotropic height (right) for January Climate added with the regressed AO structure (upper) and that with the 1.2 times of the regressed structure (lower).