Observational Analysis of the Local Structure of the Wave Activity Flux Associated with Maintenances of the Arctic Oscillation

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1. INTRODUCTION

The spatial structure of the primary mode of the empirical orthogonal functions (EOF-1) for the wintertime sea level pressure (SLP) anomaly in the Northern Hemisphere has a negative (positive) anomaly in the Arctic Ocean and two positive (negative) anomalies in the North Atlantic and the North Pacific. The Arctic Oscillation Index (AOI) defined by the score time series of EOF-1 is related to the zonal mean polar jet anomaly. Regarding the maintenances in polar jet or AO, DeWeaver and Nigam (2000) found that the stationary wave component is important for the maintenances of the AO, although the transient component is not negligible.

The AO has locally characteristic structures over Pacific and Atlantic. However, the maintenances of the AO is generally analyzed in a latitude-height section, and the local structure of the wave-mean flow interaction in these maintenances has not been analyzed.

In this study, we analyzed the local structure of quasi-stationary and transient wave activity flux associated with maintenances of the AO by separating it in positive and negative phase of the AOI. Note that we used the wave activity flux defined by Plumb (1986) for transient waves and by Takaya and Nakamura (2001) for quasi-stationary waves.

2. DATA AND ANALYSIS METHOD

The dataset used for our analysis is the National Centers for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR) reanalysis data library for January 1970 to December 2003. We used monthly mean fields of SLP and daily mean fields of geopotential height, horizontal wind.

To derive the AOI, we applied EOF analysis for monthly mean SLP anomalies, with solving eigenvalue problem of a covariance matrix. The analysis domain was poleward of 20°N. Here, the monthly mean anomaly was defined as the deviation from climatology during the 34 years of the analysis period.

We computed the 3-month moving average of normalyzed AOI and defined the positive/negative polarity of the AOI when this index exceeded one standard deviation for more than 3 months. There are 6 cases of positive AO (AO+) and 4 cases of negative AO (AO-) during the analysis period. These cases were almost the same periods. Excluding summer and autumn cases, 4 examples were chosen for each phase: from November 1988 to March 1989, February 1990 - May 1990, November 1991 - February 1992, December 1992 - February 1993 for AO+, December 1976 - February 1977, January 1979 - April 1979, November 1985 - January 1986, November 2000 - February 2001 for AO-. In this study, we analyzed first monthes of these periods, when the absolute value of the index show a tendency to increase.

We divided the wave forcing into a quasi-stationary component and a transient component. In case of the quasi-stationary component, we derived a barotropic component from monthly mean fields, using the same method as Tanaka (1991). Then, we computed the climatology and deviation from the climatology. In contrast, for the transient component, we applied 30 day moving averages for the daily mean fields, and deviations from these datas were obtained thereafter.

We analyzed the quasi-stationary (Takaya and Nakamura, 2001) and the transient (Plumb, 1986) wave activity fluxes at the first months of each 4 examples, and each 4 fluxes were composited. These fluxes describe the transport of wave activity density under a quasi-geotropic assumption, and the divergence represents local wave forcings. For the quasi-stationary fluxes, we used the climatology and deviation from the climatology, while the transient fluxes we used the 30 day moving average fields and the deviations.

3. RESULT AND DISCUSSION

3.1 In case of AO+

In Fig. 1, we show the wave activity flux for the barotropic quasi-stationary component and the barotropic height anomaly associated with the AO+ maintenances. Positive anomalies are found over North Pacific, Europe and the east coast of North America, and negative anomaly is shown in polar region, corresponding to the AO+ structure. Fluxes toward the southeast are found from North Atlantic to Europe and the Caspian Sea, and the flux from East Siberia to Japan is seen. These fluxes show the convergence in the North Africa, Caspian Sea and the northwest Pacific. In addition, the former flux appeared in the Atlantic storm track makes a distinct contribution to the negative anomaly over North Atlantic and the positive anomaly over Europe, enhancing the AO+ maintenance.

In Fig. 2, we show the radiative wave activity flux (M_R) for the transient component and the variance of the stream function in the upper troposphere (200 hPa). Note that the typical wave forcing pattern of zonal mean for the transient component appears at this altitude. A southeastward flux from South Alaska to the east coast of North America is found, converging over the east coast of North America. This transient wave may form the positive anomaly shown in Fig. 1. In addition, the southeastward flux over Europe are seen. These patterns in the transient fluxes are similar to that in the quasi-stationary fluxes.

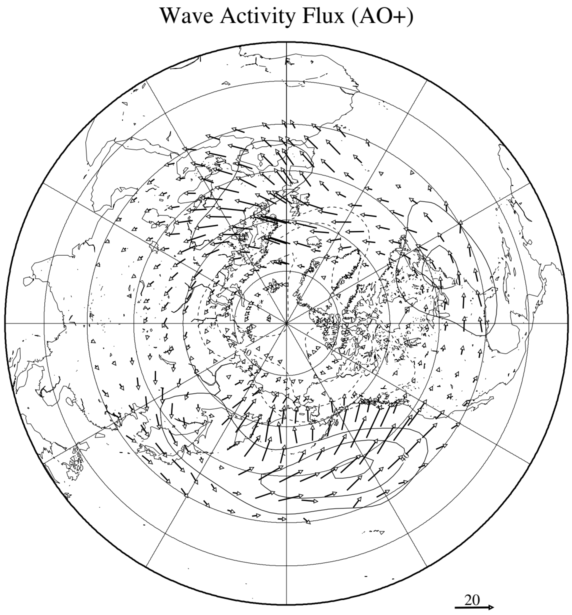

Fig. 1. Composite map of the barotropic quasi-stationary wave activity flux and barotropic height anomaly associated with the AO+ maintenance. Solid lines indicate a positive barotropic height anomaly and broken lines indicate a negative anomaly (contour interval; 20 m).

3.2 In case of AO-

In Fig. 3, we show the wave activity flux of the barotropic quasi-stationary component and the barotropic height anomaly related to the

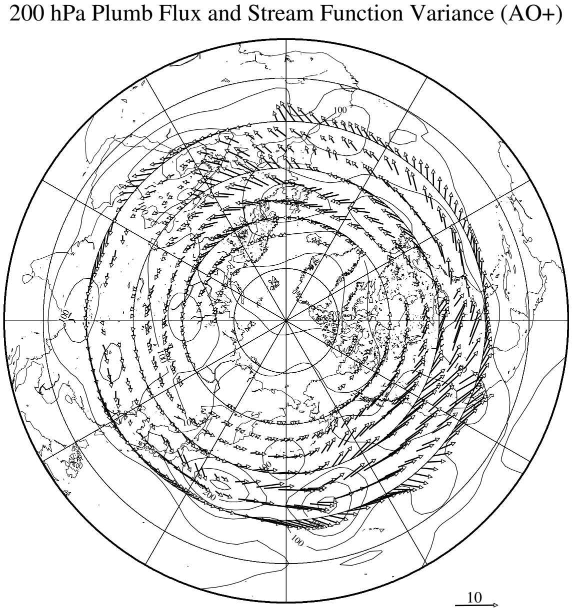

Fig. 2. Composite map of the transient wave activity flux (M_R) and variance of the quasi-geotropic stream function in the upper troposphere (200 hPa) associated with the AO+ maintenance. Contour lines show the variance of the stream function (contour interval; 50×10^{10} (m^4s^{-2})).

AO- maintenance. In the polar region, a positive anomaly is found, while negative anomalies is seen over North Atlantic, Aleutian, Siberia and North America, corresponding to the AO- structure. The local structures of wave propagation by the quasi-stationary component seen in Fig. 3 show two northeastward fluxes: from the North Pacific to Alaska, from North America to Greenland. These fluxes converge in Alaska and Greenland, corresponding to the AO- maintenance. In addition, the former flux appeared in the Pacific storm track leads to the formation of a negative anomaly over the North Pacific and a positive anomaly in the polar region. The later flux may form a positive anomaly over Greenland. An eastward flux from Europe to Siberia is seen, and may contribute to the formation of a positive anomaly over the Caspian Sea and negative anomalies over Europe and Siberia.

In Fig. 4, we show the wave activity flux of the transient component and the variance of the stream function at 200 hPa associated with the AO- maintenance. The distinct northeastward flux from North America to Greenland is found, and we can see the flux over North Pacific. These fluxes are similar to the quasi-stationary fluxes, enhancing the AO- maintenance. The flux over Atlantic may contribute to the formation of the negative anomaly over the North Atlantic and a positive anomaly over Greenland. While, the flux over North Pacific may form a negative anomaly over the Aleutians and a positive anomaly in the polar region. Zonal means of these fluxes show convergence in the high latitude, corresponding to weaker polar jet anomaly.

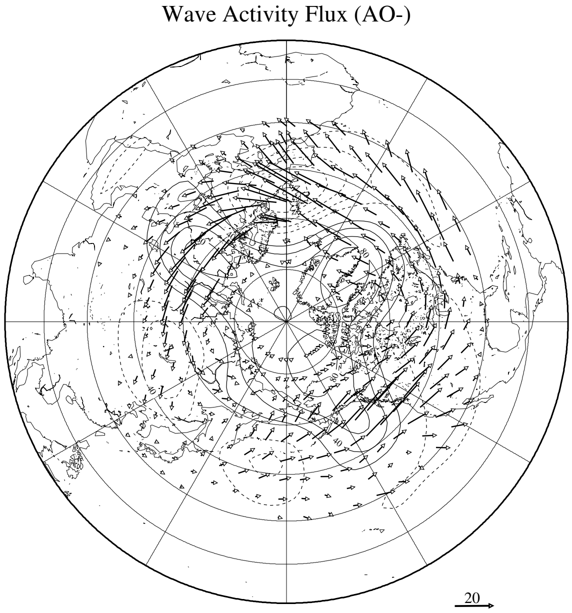

Fig. 3. The quasi-stationary wave activity flux and barotropic height anomaly of Fig. 2, but for the AO- maintenance.

4. CONCLUSION

In this study, we have described the quasi-stationary and transient wave activity flux associated with maintenances of each phase of the AOI, based on a composite analysis for observational data.

For maintenance to AO+, the quasi-stationary and transient wave activity fluxes toward the southeast appere from Atlantic storm track region, converging in the North Africa and Caspian Sea. These fluxes enhance the

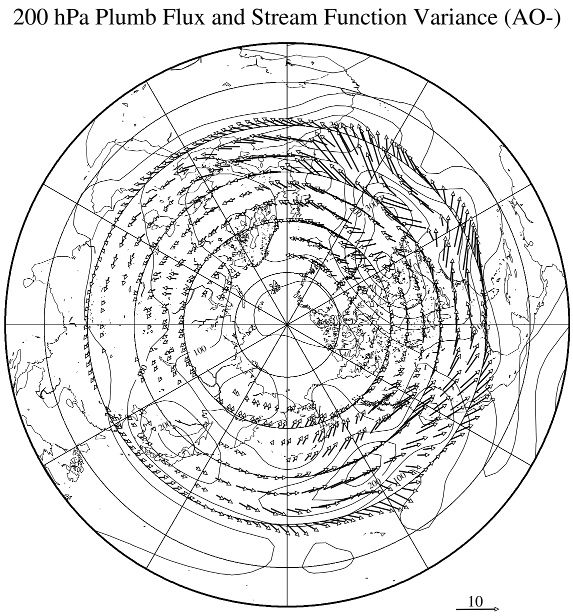

Fig. 4. The transient wave activity flux and variance of the stream function of Fig. 3, but for the AO- maintenance.

AO+ maintenance and contribute to a negative anomaly over North Atlantic and a positive anomaly over Europe. In contrast, the southeastward flux for the transient component indicates from South Alaska to the east coast of North America, enhancing the maintenance of the AO+.

For maintenance to AO-, the quasi-stationary waves propagate from the North Pacific to Alaska, while the transient waves propagate from North America to Greenland. These fluxes converge in the high latitude, corresponding the AO- maintenance. The flux for quasi-stationary component over the Pacific storm track region contributes to the pattern of a negative anomaly over Pacific and a positive anomaly over Arctic region. For the transient component, flux may form a negative anomaly over Atlantic and a positive anomaly over Arctic.

It is concluded that the wave activity flux is greatest over the Atlantic and Pacific storm track regions, enhancing the each phase of the AO and showing the positive feedback between wave activity flux and zonal mean flow.

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