The feature of atmospheric circulation in the extremely warm winter 2006/2007

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1. Introduction

In winter 2006/2007 (from December 2006 to February 2007), seasonal mean temperatures were extremely high over from southern Siberia to Japan (Figure 1). The features of the atmospheric circulation mainly over eastern Asia region are summarized and compared with those in winter 2005/2006 when northeastern Asia experienced extremely cold weather in December.

The Japanese 25-year Reanalysis (JRA-25) and JMA Climate Data Assimilation System (successor of JRA-25) data were used for this analysis. The ECMWF 40-year Reanalysis (ERA-40) data was used partly for EOF analysis.

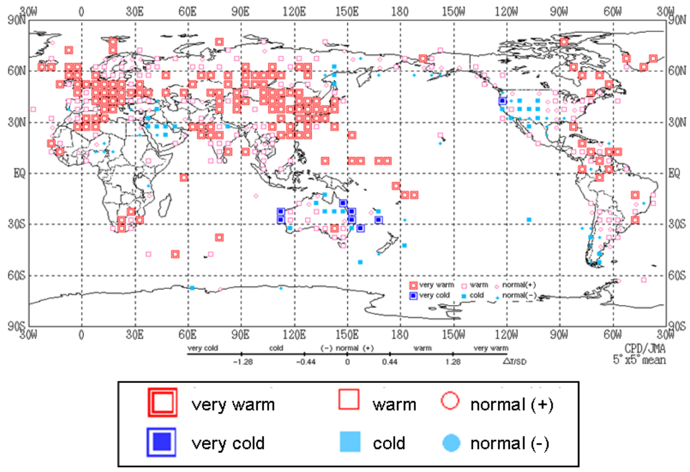

Figure 1 Monthly mean temperature anomaly (normalized) category (winter 2006/2007).

2. Arctic Oscillation and polar front jet

2.1 Comparison with winter 2005/2006

In winter 2006/2007, the seasonal mean polar front jet from Europe to Lake Baikal, which is unclear in the climatological condition, was remarkably clearer and stronger than normal (Figure 3). This condition persisted throughout the season.

The 1st eigen vector calculated from EOF analysis of 500-hPa height in winter (December - February) is the annular pattern which has the negative height anomalies over the polar cap and the positive height anomalies over the mid-latitude zone (Figure 2 left). In JMA, the score of the 1st eigen vector is used as the index of the Arctic Oscillation (AO). The positive score suggests that the AO is in the positive phase and the polar front jet is clear. The score was positive from December 2006 to middle January 2007 (Figure 2 right). This is approximately consistent with the features of the polar front jet mentioned above. On the other hand, the score was negative from late November 2005 to early January 2006. This indicates that the phase of the AO was remarkably negative and the polar front jet was weaker than normal in winter 2005/2006.

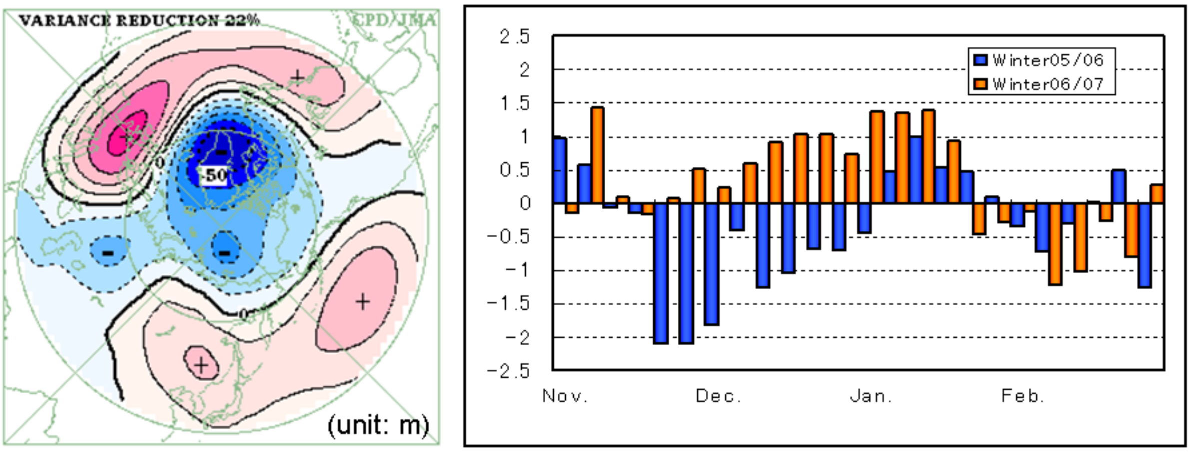

Figure 2 Distribution of eigen vector of the first component calculated from EOF analysis of winter mean 500-hPa height in the northern hemisphere (left) and time series of the scores calculated by projecting 5-day mean data onto EOF1 (right).
EOF analysis is conducted with covariance matrix for 47 samples of seasonal mean 500-hPa height from 1958 to 2004. Original data before 1979 are provided by courtesy of ECMWF.

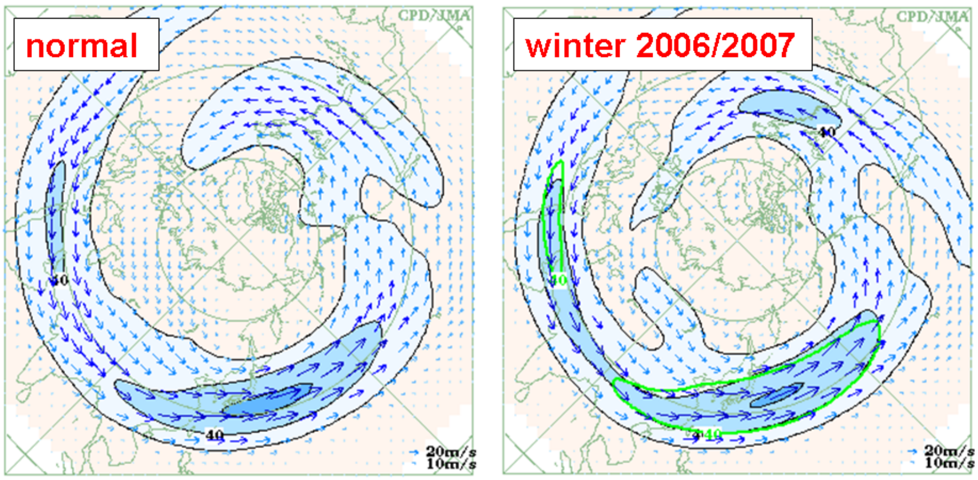

Figure 3 Winter mean 300-hPa wind speed and vectors in the northern hemisphere (left: normal, right: 2006/2007).
Black lines show wind speed at intervals of 20 m/s. Blue shading shows values greater then 40 m/s. Green lines show normal wind speed at intervals of 40 m/s. Base period for normal is 1979-2004.

2.2 Diagnosis of the acceleration/deceleration of polar front jet using EP-flux

One of the important processes that maintained the anomalous westerly is considered from the point of view of the eddy mean flow interaction. The Eliassen Palm flux (EP-flux) based on mass-weighted isentropic zonal means (Tanaka et al. 2004) was used to confirm the general momentum budget. The direction of EP-flux is parallel to the direction of energy propagation and its horizontal and vertical components represent westward momentum and heat transport by eddy, respectively. This means eastward momentum is transported to the opposite direction of EP-flux. In addition, the total eddy forcing can be diagnosed by the divergence (accelerate westerly) and convergence (decelerate westerly) of EP-flux. In this isentropic diagnosis, the momentum flux near the lower boundary can be adequately estimated.

In December 2006, upward anomalies and divergence anomalies of EP-flux were clearly seen at 50 to 60 degrees north in the lower troposphere (Figure 4 right). This indicates, in higher latitudes, baroclinic waves were more active than normal and transported eastward momentum from the upper troposphere to the lower. In the upper troposphere, equatorward anomalies at 50 to 60 degrees north were seen. This indicates that eddies transported eastward momentum poleward by deflecting and propagating equatorward.

On the other hand, in December 2005, in the lower troposphere, upward anomalies at 40 degrees north and downward anomalies at 60 degrees north were seen (Figure 4 left). This indicates that the storm track were located in an equatorwardly shifted position and eddies were less active at 60 degrees north than their normal. This indicates eddy eastward momentum transport from the upper troposphere to the lower was less than normal at 60 degrees north. In the upper troposphere, poleward anomalies of EP-flux and the convergence anomalies in the higher latitudes were clearly seen. This indicates that eddies transported eastward momentum equatorward and decelerated the polar front jet.

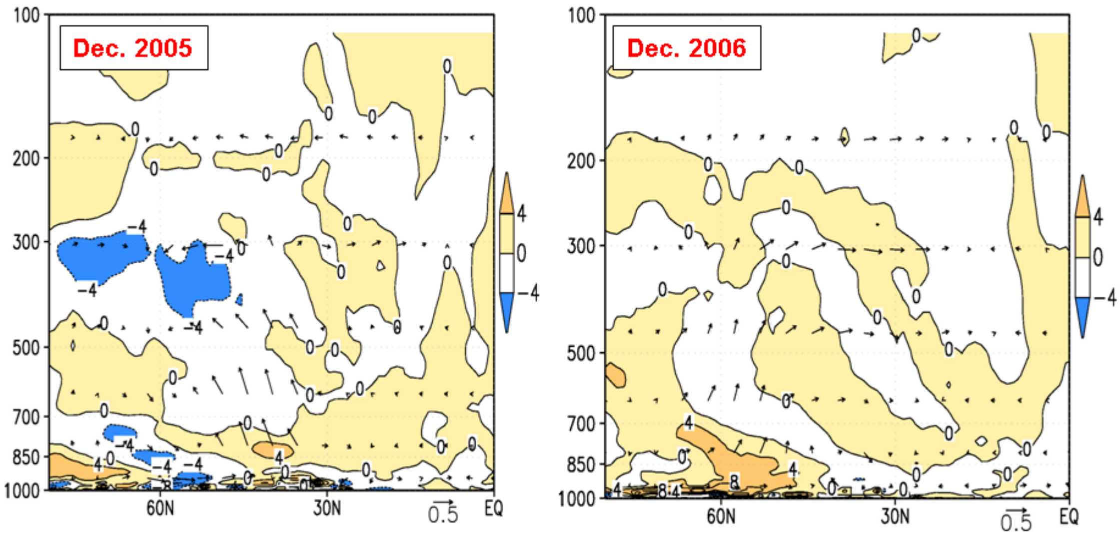

Figure 4 Eliassern-Parm flux (EP-flux) and divergence anomaly based on mass weighted isentropic zonal means in the northern hemispheric troposphere (left: December 2005, right: December 2006).
Vectors show EP-flux anomaly (m^2/s^2). Shadings show divergence of EP-flux anomalies (m/s/day). Base period for normal is 1979-2004.

3. Eastward shift of Aleutian low and convective activity in the tropics

The center of the Aleutian Low shifted north-eastward from its normal position and the Siberian High was weak from its center to eastern Siberia (Figure 5 left). This indicates that northeastern Asian winter monsoon was weak and the cold surge occurred less frequently.

Statistically, eastward shift of the Aleutian low is associated with Pacific North American (PNA) pattern, which is featured in El Nino events (Figure 5 right). But it is thought that the pattern in winter 2006/2007 was formed by different mechanism.

In December 2006, the contrast between enhanced convections in the western Indian Ocean and suppressed convections in the Maritime Continent was so remarkable. In the upper troposphere, anticyclonic circulation anomalies and wave activity flux (Takaya and Nakamura, 2001) associated with the quasi-stationary Rossby wave packet propagation were clearly seen over northern India (Figure 6). Weak cyclonic circulation anomalies in southern China and strong anticyclonic circulation anomalies in the east of Japan were also observed. These indicate that the northwesterly flow was weaker than normal over Japan. Moreover, cyclonic circulation anomalies near the Gulf of Alaska were clearly seen. It is consistent with the eastward shift of Aleutian low.

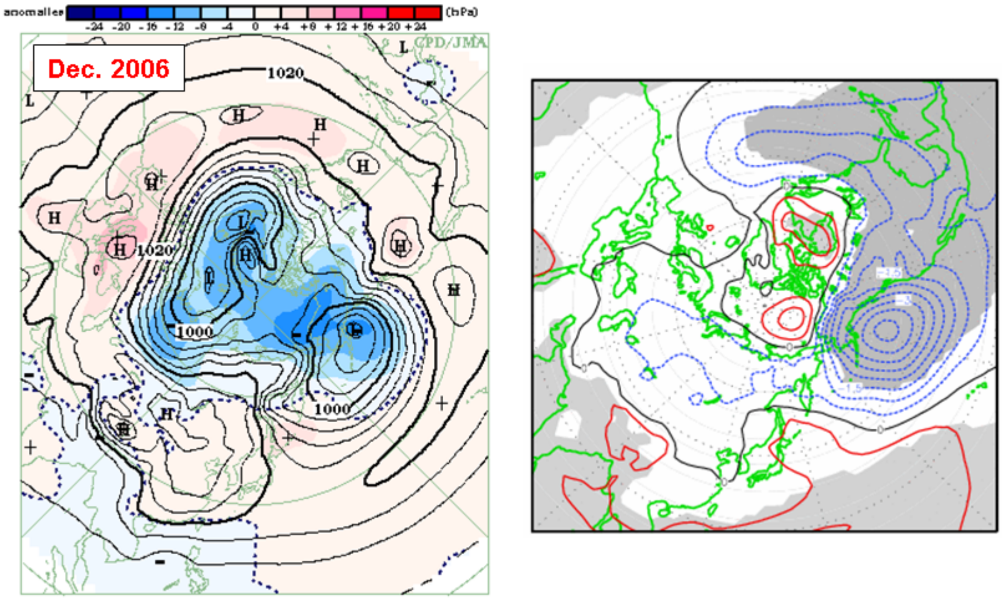

Figure 5 (Left) Monthly mean sea level pressure and anomaly
Contours show sea level pressure in an interval of 4 hPa. Shadings show anomalies.
(Right) Regression coefficient map between sea level pressure in winter and NINO.3-SST
Contours interval is 0.5 hPa. Gray shadings show 95 % confidence level.

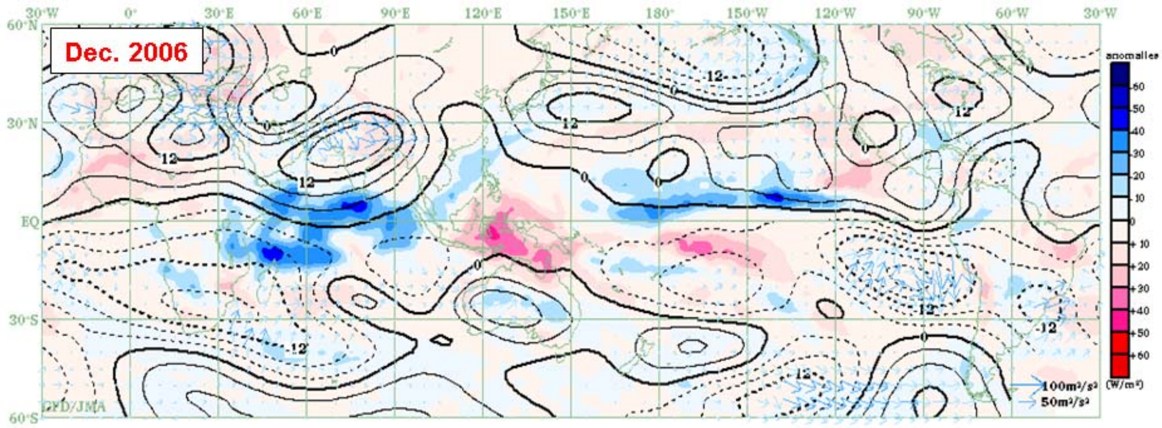

Figure 6 Monthly mean 200-hPa wave activity flux, stream function and outgoing longwave radiation (OLR) anomaly.
Vectors show horizontal component of wave activity flux (Takaya and Nakamura, 2001). Contours show stream function anomalies at intervals of $4x10^6m^2/s$. Shadings show OLR anomalies (W/m^2). Base period for normal is 1979-2004.

In order to confirm whether the tropical convections served as a source of Rossby wave or not, the Rossby wave source (Lu and Kim, 2004) was calculated. From 16th to 25th December 2006, the convective activities in the Indian Ocean were most enhanced, in addition, the strongest Rossby wave propagation over Eurasia was observed. Focusing on vorticity advection by divergent wind (Figure 7 left), negative vorticity generations were clearly seen from Arabian Peninsula to northwestern India. In this region, the absolute values of negative vorticity generations by advection were larger than those by vorticity forcing. This indicates that the tropical convections in the Indian Ocean strengthened the Rossby wave propagation from Europe. As for vorticity forcing (Figure 7 right), negative vorticity generations around Japan were clearly observed.

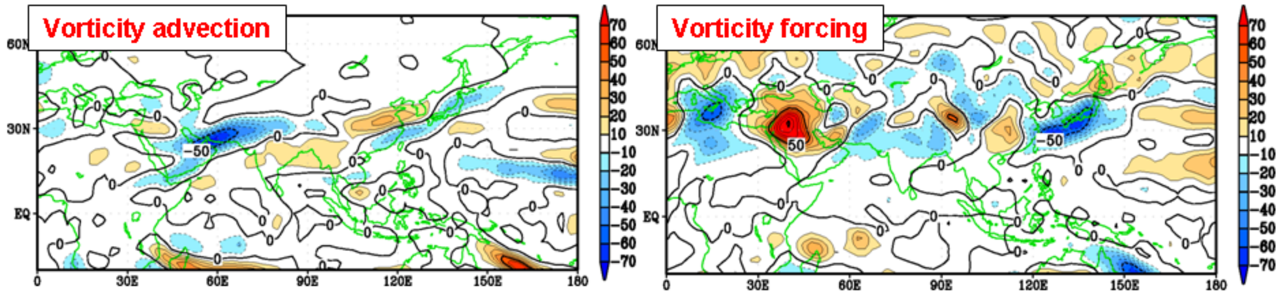

Figure 7 200-hPa Rossby wave source calculated by divergent wind and relative vorticity averaged from 16 Dec. 2006 to 25 Dec. 2006 (left: vorticity advection, right: vorticity forcing)
Red (Blue) shadings show that positive (negative) vorticities are generated ($10^{-11}s^{-2}$).

4. Conclusions

The factors which brought the strong polar front jet and weak East Asian winter monsoon in winter 2006/2007 are summarized as follows.

(1) The active eddies in the higher latitude developed and transported momentum from the upper troposphere to the lower. They deflected and propagated eastward in the upper troposphere and maintained the anomalous westerlies.

(2) Rossby wave packet propagations along the Asian jet brought anticyclonic anomalies to the south-east of Japan and the cycloninc anomalies in the Gulf of Alaska. This is one of the causes that the East Asian winter monsoon was weakened. It is considered that the tropical convections in the Indian Ocean strengthened the energy of the quasi-stationary Rossby wave along the Asian jet.

As a result of comparing the westerlies and EP-flux in winter 2005/2006 and with those in winter 2006/2007, it is found that the contrasts of convective activities and circulation patterns between both winters were clear in the first half of the season.

5. References

Lu, R., and B.J. Kim, 2004: The Climatological Rossby Wave Source over the STCZs in the Summer Northern Hemisphere. J. Meteorol. Soc. Jpn., **82**, 657–669.

Takaya and Nakamura, 2005: Mechanisms of intraseasonal amplification of the cold Siberian high. J.Atmos.Sci., **62**, 4423-4440.

Takaya, K., and H. Nakamura, 2001: A Formulation of a Phase-Independent Wave-Activity Flux for Stationary and Migratory Quasigeostrophic Eddies on a Zonally Varying Basic Flow, J.Atmos.Sci., **58**, 608-627.

Tanaka,D., T. Iwasaki, S. Uno, M. Ujiie and K. Miyazaki, 2004: Eliassen-Palm flux diagnosis based on isentropic representation. J.Atmos.Sci., **61**, 2370-2383.

Ujiie, M., 2008: Momentum budget analysis of zonal mean flow by using isentropic representation of EP-flux. Extended abstract of the 3rd WCRP, P2-13.