Diagnosis on the Northern Hemisphere circulation in December 2005
– linkage between the Arctic Oscillation and the tropical convective activity –

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1. Extreme climate events in December 2005

Japan and some East Asian countries, including Korea and northeastern part of China, suffered extremely cold weather, which persisted from late November 2005 through early January 2006. In Japan, monthly mean temperature averaged over Japan was the lowest for December since 1948 (Figure 1). Moreover significantly heavy snow fell broadly in the Japan Sea side of Japan, and the records of maximum snow depth in December were set at about one-third of the meteorological observatories of JMA. On the other hand, heavier-than-normal precipitation was observed through the month in Southeastern Asia, and significant damage by floods and landslides were reported in the Philippines, Vietnam, Thailand and Malaysia.

2. Atmospheric circulation anomalies

At 500-hPa height field, positive anomalies in the Arctic area and negative anomalies in the mid-latitudes in the Northern Hemisphere were observed in December 2005. It was the predominantly negative phase of the "Arctic Oscillation" (AO), which persisted through the month. (Figure 2). It is well known that the behavior of the AO, which is considered a phenomenon explained by internal dynamics of the extra-tropical atmosphere and inevitably involving chaotic nature, is related to the strength of the East Asian winter monsoon.

In the tropics, convective activities, inferred from Outgoing Longwave Radiation (OLR) fluxes, were much stronger than normal over the Bay of Bengal, the South China Sea and the Philippine Sea (Figure 3). The anomalies of the active convection were about three times of its standard deviation and the largest for the December since 1979.

In the upper troposphere north of the active convection areas, there was an anti-cyclonic circulation anomaly, followed by cyclonic and anti-cyclonic ones centered east off Japan and over the mid-Pacific, respectively. The set of the anomalies seems to form a stationary Rossby wave train which was forced by the strong convection in the tropics and propagated along the strong Asian Jet. Wave activity fluxes (Takaya and Nakamura, 2001) clearly show that the wave energy propagated eastward from the anti-cyclonic circulation anomaly north of the active convection areas to the Pacific, supporting this hypothesis. The hypothesis is also strongly supported by the result that quite similar circulation anomalies to those observed was found as the linear steady response to hypothetical heating anomalies over the Southeastern Asia (Watanabe, 2006)

It is concluded that besides the influence of the persistency of the negative phase of the AO, the active convection over the areas brought the extremely cold weather in and around Japan by exciting the stationary Rossby wave train along the Asian Jet, which caused the persistent and large-amplitude meandering of the jet. The striking atmospheric circulation related to the cold weather is drawn as a schematic diagram in Figure 4.

3. Review of the operational one-month forecast

Although it was very hard to predict such an extreme event with a few months' lead time, the operational one-month ensemble predictions system (EPS) could well predict general features of the anomalous circulation observed in early 2005/2006 winter with a few weeks lead time. As an example, the results of the EPS from 1st December are described. As shown in Figure 5, the predominant negative phase of the AO and corresponding strong Siberian High and Aleutian Low, and the stationary Rossby wave along the Asian Jet are well predicted. Time series of predicted 7-day running mean AO indices defined by EOF1 scores of DJF 500hPa height field in the Northern Hemisphere clearly show that the persisted negative phase of the AO was well predicted by the EPS (Figure 6). Since these large scale anomalous circulation fields were well predicted, the cold spell in Japan during the early winter was predicted satisfactorily. The probabilistic forecast guidance for second week (day: 9-15) showed high probability around 60% of below normal temperature in Western Japan correctly during the December. These suggest some possibility of issuing early warning for this extreme event with a few weeks in advance.

4. Concluding remarks

To inform the government and the public about reasons for the extremely cold event as a NHMS, JMA issued a quick diagnostic report on this extreme event in the middle of January 2006, and the report was frequently referred by mass media. However it still remains to reveal the reason for the cold month: the maintenance mechanisms of the active convection in the tropics, interaction between the AO and the active convection, influence of La Nina like SSTA, and so on. An intensive study on the extreme event in collaboration with meteorologists, climatologists, and oceanographers in and out of JMA is required to improve accountability of JMA on such extreme events. One month forecasts issued every Friday by JMA were useful to mitigate the severe cold and snow fall damage. However, it seems the forecasts were not fully used because the one month forecast and its skill are not well known by the public. In addition to the improvement of the EPS, more active publicity activities are required to enhance making use of the one month forecast in collaboration with potential users.

References

Takaya, K., and H. Nakamura, 2001: A formation of a phase-independent wave-activity flux of stationary and migratory quasi-geostrophic eddies on a zonally-varying basic flow, J. Atmos. Sci., 58, 608-627.

Watanabe, M., 2006: personal communication

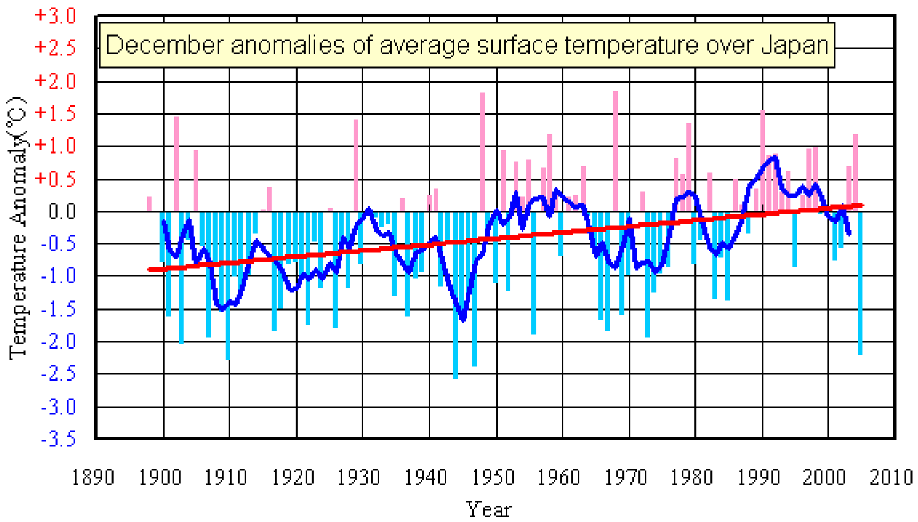

Figure 1 The time series of December anomalies of average surface temperature over Japan from 1898 to 2005

The bars indicate anomalies from the climatological normal (1971-2000 average). The Blue line shows five-year running mean anomalies and the red line indicates the long-term linear trend.

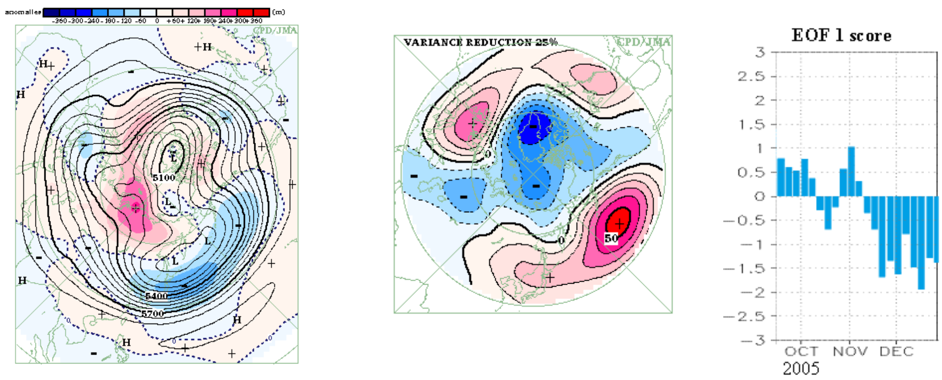

Figure 2 Monthly mean 500-hPa height and anomaly in December 2005 (left panel), EOF-1 of three-month (DJF) mean 500-hPa height (middle panel), and the series of its scores (right panel)

In the left panel, contours show 500-hPa heights in an interval of 60m, and shading indicates anomalies. Middle panel shows the distribution of eigen vector multiplied by root of its eigen value. In the right panel, blue bars denote EOF-1 scores derived from projecting five-day mean heights onto three-month mean ones. The EOF-1 scores are used as the Arctic Oscillation index in JMA's monitoring.

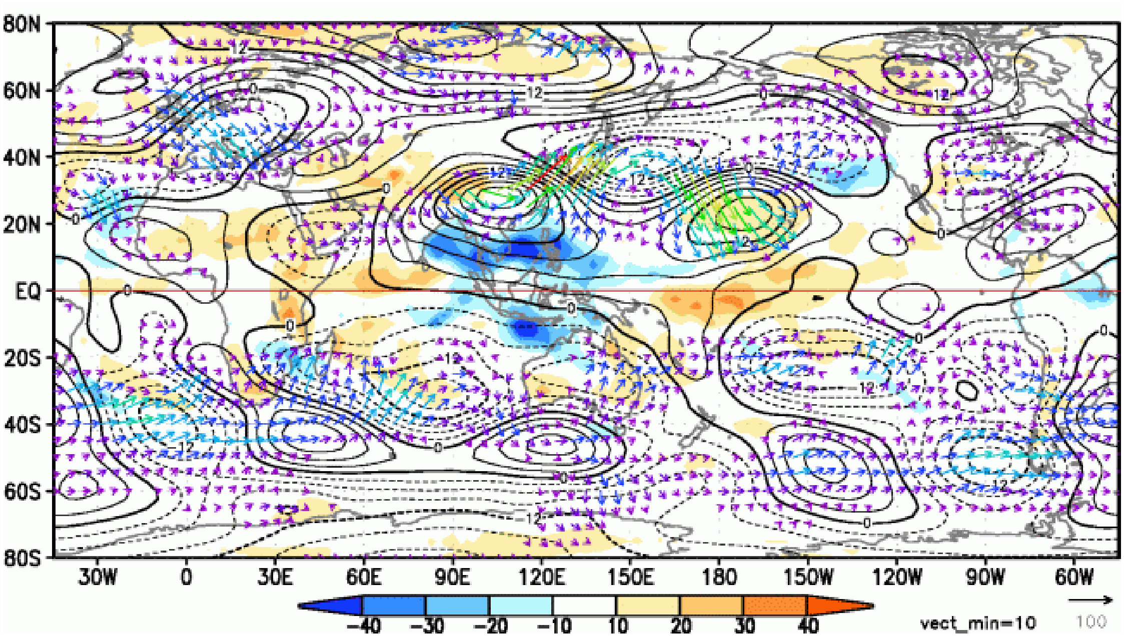

Figure 3 Outgoing Longwave Radiation (OLR) anomalies and 200-hPa stream function anomalies (December 2005)

Cold-(warm-)color shading shows negative (positive) OLR (W/m^2) anomalies, meaning stronger-than-normal (weaker-than-normal) convective activities. Contours denote stream function anomalies at 200-hPa with an interval of $3x10^6 m^2/s$. Vectors show wave activity fluxes (m^2/s^2) after Takaya and Nakamura (2001). Directions of the vectors are consistent with those of the group velocity.

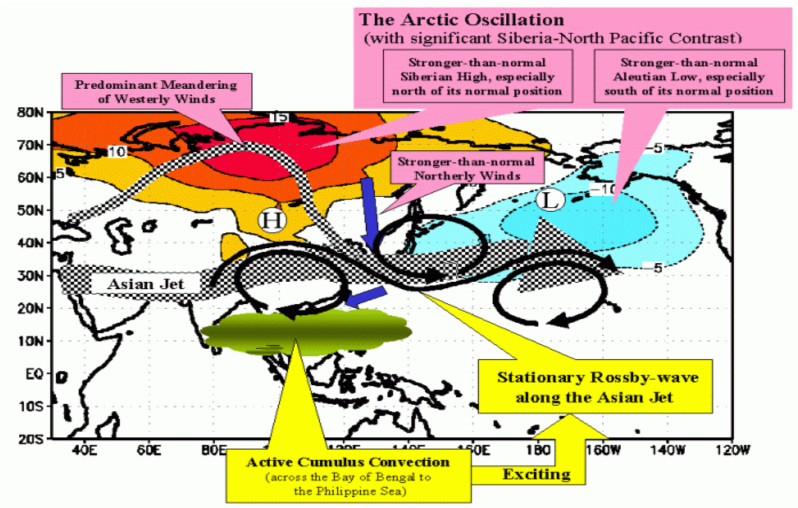

Figure 4 The schematic diagram of the atmospheric circulation related to the extremely cold weather in and around Japan during December 2005

Both striking surface and atmospheric circulation in the upper troposphere are lapped over the map. Contours with warm- and cold-color shading show sea level pressure anomalies. "H" and "L" marks show the center of the Siberian High and the Aleutian Low, respectively. Thick blue-colored vectors denote stronger-than-normal monsoon surface winds over East Asia and Southeast Asia. Thicker checked-pattern shows the Asian jet working as a wave-guide, on which black vectors indicates anomalous circulation related to the stationary Rossby wave, and thinner one shows predominantly meandering westerly jet in the upper troposphere over Siberia.

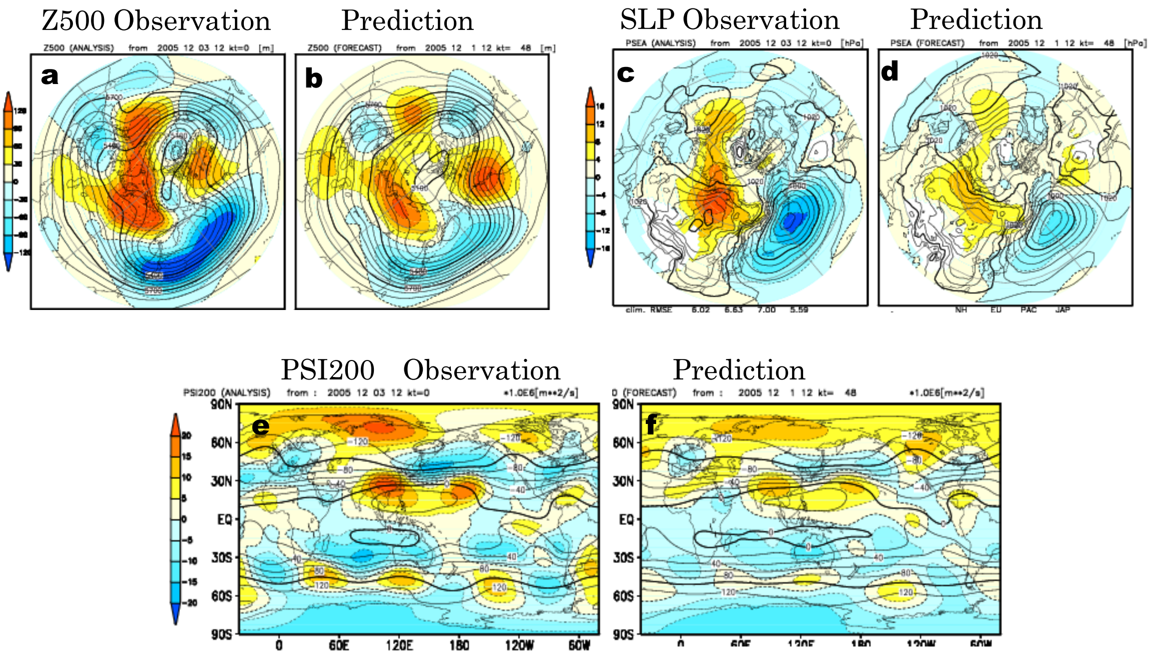

Figure 5 Observed and predicted fields for 28-day mean from 3rd to 30th December 2005. Initial date is 1st December 2005.

a)Observed 500hPa heights (contours with interval 60m) and anomalies (shade)

b)Same as a) but for prediction (ensemble mean)

c)Observed Sea level pressure (contours with interval 4hPa) and anomalies (shade)

d)Same as c) but for prediction (ensemble mean)

e) Observed 200hPa stream function (contours with interval $2x10^7 m^2/s$) and anomalies (shade)

f) Same as e) but for prediction (ensemble mean)

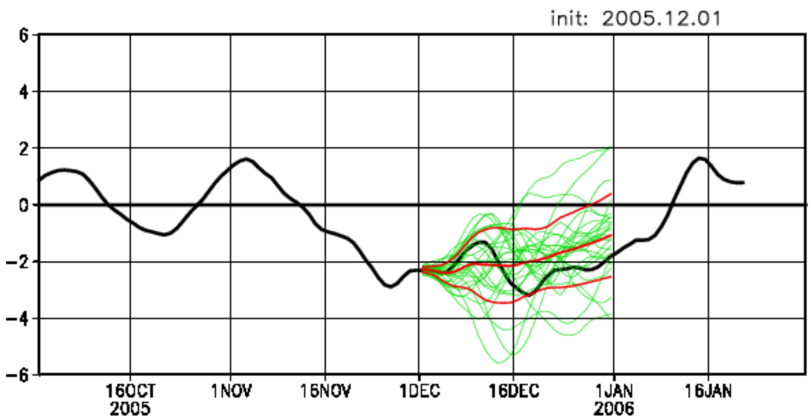

Figure 6 Observed and predicted AO indices defined by EOF-1 scores derived from projecting 7-day running mean heights onto EOF-1 of DJF 500hPa height field in the Northern Hemisphere. Initial date is 1st December 2005.

Black lines denote observed EOF-1 scores. Green lines denote prediction of each ensemble member. Red lines denote ensemble mean prediction and ± one standard deviation among ensemble member.