The Possible Influence of Stratospheric Sudden Warming on East Asian Weather

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ABSTRACT

By analyzing the linkage of the Northern Annular Mode (NAM) anomaly to the East Asian jet and the East Asian trough during Stratospheric Sudden Warming (SSW), the influence of SSW on East Asian weather is studied. The results show that the East Asian jet is strengthened and the East Asian trough is deepened during SSW. With the downward propagation of SSW, the strengthened East Asian jet and the East Asian trough would move southward, expand westward and gradually influence the area of north and northeastern China. This implies that the winter monsoon tends to be enhanced over East Asia during SSW.

Key words: stratospheric sudden warming, northern annular mode, the East Asian jet, the East Asian trough

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1. Introduction

In the last decades, especially, since the research project "Stratospheric Processes And their Role in Climate Research Program (SPARC)" established by the joint scientific committee of the WCRP (World Climate Research Program) in 1992, more and more attention has been paid to stratosphere-troposphere interactions. Stratospheric sudden warming (SSW) is the outcome of the stratosphere-troposphere interactions. Accompanying SSW, the downward propagation of the stratospheric anomalies precedes the tropospheric anomalies (**??**; **?**; **?**; **?**; **?**).

While studying the stratosphere-troposphere interactions, **?** found the Atlantic Oscillation (AO) and pointed out that it is the lead EOF pattern of the Northern Hemisphere winter Sea Level Pressure (SLP) (**?**) anomalies north of 20°N, which is characterized by synchronous fluctuation in pressure of one sign over the polar caps and of opposite sign at middle latitudes. Also, this fluctuation resembles a meridional seesaw which was noticed by by Lorenz (1951) as early as 1951. The meridional seesaw was investigated later by **?**, **?**, **?**. **?** provided a clearer look; they indicated that this fluctuation exists from the surface to the lower stratosphere and behaves as a barotropic structure. **?** indicated that AO is closely related to the index cycle of zonal wind in extratropical regions. The oscillation of westerly wind intensity in the north-south direction in the middle latitude is regarded as NAM and the surface signature of NAM is regarded as AO. **??** showed that AO severely affects the winter weather in the Northern Hemisphere and it is closely related to the variation of the zonal circulations in the mid-high latitude regions.

Several recent studies of NAM indicate that the circulation anomalies propagate downward in the stratosphere under certain condition and affect the troposphere (**?**; **?**; **?**), therefore NAM is regarded as the propagation signal from the stratosphere to the troposphere. As is well known, NAM as a signal of the stratospheric anomalies propagating down to the

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troposphere is associated with SSW (**?**). NAM not only propagates downward, but also has large amplitude and maintains when NAM propagates downward into the troposphere. **?** examined the composites of NAM for 18 weak vortex events and 30 strong vortex events, respectively, and their results suggest that these stratospheric harbingers may be used as a predictor of tropospheric weather regimes. Furthermore many results showed that the negative phase of the winter NAM corresponds to a weak stratospheric polar vortex and is often accompanied by SSW, while the positive phase of the winter NAM is associated with a zonally quasi-symmetric polar vortex in the stratosphere (**?**, **?**; **?**). However, the results mentioned above are mainly for the effects of the stratospheric anomalies on the weather of Western Europe and North America, and we have seldom seen similar work on East Asia. In this paper, we shall discuss the possible influence of SSW on the weather of East Asia.

2. The relationship between SSW and NAM

The data used in this study are from the daily analysis of the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis I covering the period of 1 January 1958 to 31 December 2006. NAM indices are provided by Baldwin (http://www.nwra.com/resumes/baldwin/nam.html) and particular arithmetic of NAM is referred in Baldwin's article (**?**).

NAM is the useful tool for diagnosing the intensity of the polar vortex. The negative phase of the winter NAM coincides with the weak polar vertex which represents the positive anomaly of polar geoptential height, and usually accompanied by SSW, while the opposite situations tend to occur in the winter of the positive NAM phase (**?**). In this paper, SSWs and the distributions of NAM were statistically analyzed in the Northern Hemisphere winter of 49 years from 1958/59–2005/06 and the relationship between NAM and SSW was verified. Figure 1 illustrates the time-height sections for the temperature difference between 60°N and the pole during the SSW from December 2003 to January 2004 and NAM indices in the Northern Hemisphere winter in the same period. It can be seen from Fig. 1a that SSW began on December 16 when the meridional temperature gradient changed from the negative to the positive. The tropospheric temperature began to rise with strengthen of SSW; at the same time, NAM indices began to change from the positive to the negative (as shown in Fig. 1b), and with the strengthen of SSW, the negative NAM indices gradually propagated down to the lower troposphere. NAM indices changed from the negative to the positive with the ending of SSW.

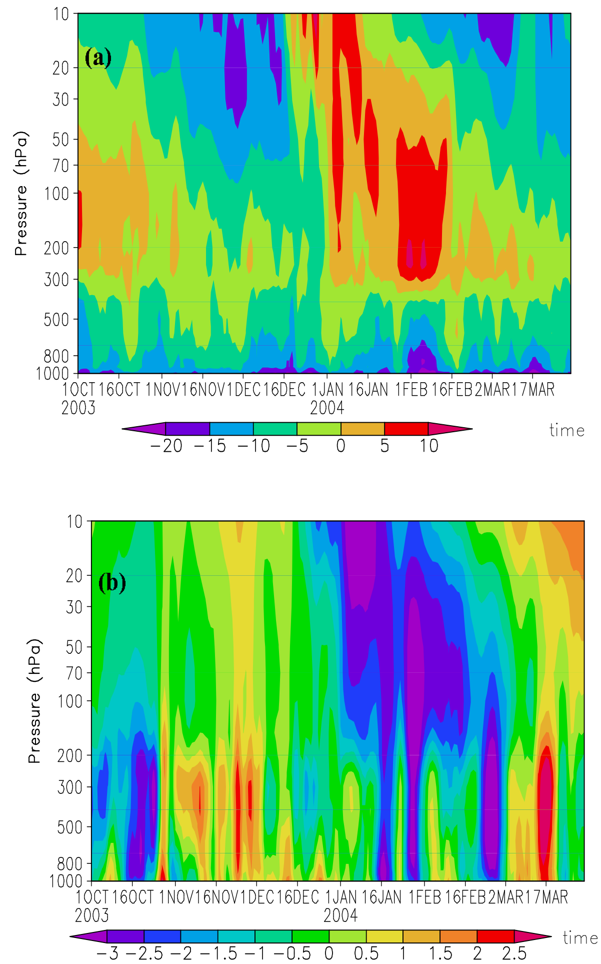

Fig. 1. The time-height sections for (a) the temperature difference between 60°N and the pole (units: K) during the SSW from December 2003 to January 2004 and (b) NAM indices in the Northern Hemisphere winter in the same period.

The NAM indices composite analysis for 38 strong SSW and 30 weak SSW have been made and shown in Fig. 2a and Fig. 2b, respectively. The results imply that the stratospheric anomalies can propagate down to the troposphere and have important influences on the lower troposphere when strong SSW occurs (Fig. 2a), whereas NAM in the weak SSW period (Fig. 2b) hardly affect the troposphere. NAM anomalies in the

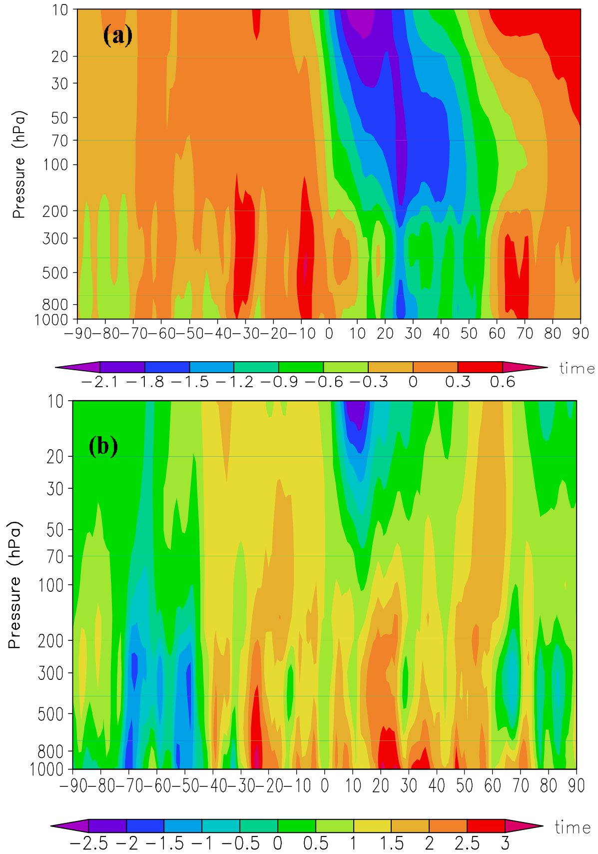

Fig. 2. Composite analysis of the time-height sections of NAM indices for (a) 38 strong SSW and (b) 30 weak SSW.

strong SSW period reach Earth's surface in 3–4 weeks and last 2 months there. This result agrees with Baldwin's (Baldwin and Dunkerton, 2001).

3. The linkage of NAM to the winter weather anomalies over East Asia

In section 2 we showed that the negative phase of NAM is linked with SSW, however only strong SSW can influence the lower troposphere. The stratospheric anomalies can lead to the variation of the atmospheric circulation in the troposphere and has important influence on tropospheric weather systems (**?**; **?**; **?**). We have mentioned this point in our previous paper (**?**). It was even suggested that the signal of NAM anomalies in the stratosphere can be used to predict tropospheric weather (**?**). In order to clarify this relationship over East Asia, the present paper analyzes the linkage of NAM anomalies to the East Asian atmospheric circulation.

The remarkable characteristics of the East Asian atmospheric circulation include the East Asian jet in the upper level and deep East Asian trough (**?**). Therefore the linear regression coefficients for the zonal wind field at 200 hPa and geopotential height field at 500 hPa on NAM were calculated independently at various levels in the Northern Hemisphere winter from 1959–2006, respectively, and then composite analysis of both kinds of regression coefficients in 48 winters were done respectively. Since the relationship between stratospheric NAM anomalies and the East Asian atmospheric circulation is studied, only the composite regression coefficients for the zonal wind field at 200 hPa on NAM indices at 10 hPa, 30 hPa, 50 hPa are given in Fig. 3. As shown in Fig. 3a, the regression coefficient for the zonal wind field at 200 hPa on NAM at 10 hPa is positive to the north of 65°N while it is negative in the range from 30°N to 60°N. Hence, the zonal wind weakened to the north of 65°N and strengthened in the range from 30°N to 60°N in the negative phase of NAM (with SSW). In the meantime, the westerly wind is also strengthened over East Asia in the range from 35°N to 50°N, 110°E to 150°E, i.e., the East Asian westerly jet becomes stronger. In a word, the negative phase of NAM at 10 hPa leads to the strengthening of the East Asian westerly jet. The opposite situations tend to occur in the winter of the positive NAM phase. In Fig. 3 the shading indicates that the correlation is significant above the 95% level (dark) and 99% level (light) (the same below). For the distribution of the regression coefficients between the zonal wind at 200 hPa and NAM at 30 hPa (Fig. 3b), the positive correlation range in the high latitude is augmented and expands southward. At the same time, the negative correlation field in the range from 30°N to 60°N also moves southward and extends eastward and westward. Therefore the positive (negative) phase of NAM coincides with the weakened (strengthened) East Asian jet moving southward and expanding, whereas the distribution of the regression coefficients between the zonal wind at 200 hPa and NAM at 50 hPa (Fig. 3c) is approximately the same. The results indicate that the positive (negative) phase of stratospheric NAM corresponds with the East Asian jet weakening (strengthening) at 200 hPa in the upper troposphere. The enhanced East Asian jet would move southward, expand westward and gradually influence the area of north and northeast China with the downward propagation of SSW

Displayed in Figs. 4a–4c are the composite regression coefficients for the geopotential height field at 500 hPa on NAM indices independently at 10 hPa, 30 hPa, 50 hPa. It is seen that the regression coefficient for geopotential height field at 500 hPa on NAM at 10 hPa (Fig. 4a) is positive in the range from 60°N to