What kind of sudden stratospheric warming does propagate to the troposphere?

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1. Introduction

A sudden stratospheric warming (SSW), a sudden breakdown of the stratospheric polar vortex, is caused by dynamical forcing of upward propagating planetary waves from the troposphere [*Matsuno*, 1971]. Recently, a growing body of evidence is accumulated for that a change in the stratospheric circulation affects the tropospheric circulation. The change in strength of the stratospheric polar vortex propagates into the troposphere within a few weeks and the influence of the stratospheric circulation on the troposphere persists up to two months [*Baldwin and Dunkerton*, 1999, 2001]. The negative phase of the Arctic Oscillation (AO) [*Thompson and Wallace*, 1998, 2000] in the troposphere tends to be formed after SSW events [*Limpasuvan et al.*, 2004]. However, a negative phase of the AO, i.e., weak tropospheric polar vortex is not always formed after the stratospheric event. For instance, the SSW in December 1998 did not propagate to the stratosphere and strong tropospheric vortex is formed, although the subsequent SSW in February 1999 propagated into the troposphere [*Baldwin and Dunkerton*, 2001]. It is useful to examine what kind of SSW events propagate to the troposphere. The present paper tries to clarify factors which affect the downward propagation of a SSW event to the troposphere by a composite analysis of reanalysis data.

2. Data and analysis

The data we used in this study are from the reanalysis data of the European Centre for Medium-Range Weather Forecasts (ERA-40). We used daily averages calculated from 4th daily data for full 45-year period (September 1957 to August 2002). Daily climatological values are calculated by applying 20-day low-passed filter on 45-year average values. All anomalies presented in this study are deviations from the daily climatological values. The occurrence of a SSW is determined by using the polar temperature defined as an area-mean temperature poleward of 80°N. When a warming rate of the polar temperature exceeds 20K per 6-day period either at 10, 20, 30 hPa, we define it as a SSW event as the first criterion. When a warming satisfies the criterion only one day at 10 hPa, the warming is discarded. A key-day is defined as the day when the warming rate is the maximum at 10 hPa. Strength of a SSW event is defined as the maximum temperature rise at 10 hPa during 6 days centered at the key-day. When two SSW events occur with an interval less than 30 days, the stronger SSW event is selected and the weaker one is discarded. Finally, 51 SSW events were selected based on the above criteria.

We classified 51 SSW events into 2 groups based on whether the stratospheric polar temperature anomalies propagate into the troposphere or not using 30-day averaged anomaly in the polar temperature at 500 hPa (PT500). When the 30-day mean anomaly of PT500 after the key-day is positive, the event is classified as a tropospheric warm event. When the anomaly is negative, the event is called a tropospheric cold event. Among 51 events, 28 events are tropospheric warm events and 23 events are cold ones. A composite analysis from day -60 to day 60 is made to clarify differences between the tropospheric warm events and the cold events.

3. Results

Associated with SSWs, a polar night jet is decelerated. Figure 1 shows the composite anomalies of zonal mean high-latitude (50-80°N) zonal wind from day -40 to day 40 both for tropospheric warm and cold events. In the stratosphere, both cases show preconditioned positive anomalies before day -5, rapid decreasing of the zonal wind around the key-day with the minimum anomalies at day 5, downward propagation of negative anomalies and gradual recovery from the upper stratosphere. Features of SSWs in the middle and upper stratosphere are common in both composites.

Below 100 hPa, the difference is obvious. In the tropospheric warm composite, negative anomalies appear around day -7 and they persist beyond day 40. On the other hand, in the tropospheric cold event, positive anomalies are seen from day -8 to day 28 and the stratospheric negative anomaly does not propagate below 150 hPa. It is reasonable that the difference in zonal wind appears in the troposphere because 30-day means PT500 is used for classification. It should be noted, however, the difference starts well before the key-day, during the growing stage of SSWs. While the high-latitude tropospheric zonal winds are similar until day -10, the wind in the cold composite increases and that in warm composite decreases through the key-day. Anomalies are maintained until around day 30. The tropospheric anomalies are established during growing stage before the key-day.

To analyze the dynamical cause of change in zonal wind during the growing stage, anomalies in EP flux and its divergence averaged from day -10 to day -1 are shown in Figure 2. In both composites, enhanced upward EP fluxes into the stratosphere are evident. The differences are clearly seen in the troposphere. In the warm composite, waves propagate more poleward, while in the cold composite, waves propagate more equatorward. Therefore, in the warm composite, weak decelerating anomalies are caused in the high-latitude middle troposphere, while, in the cold composite, strong accelerating anomalies are produced in the high-latitude upper troposphere due to divergent anomalies of EP flux. The difference in wave forcing is mainly attributable to difference in planetary waves' forcing. In both composites, upward propagation of wavenumber 1 wave (wave-1) is enhanced, but the enhancement is stronger in the cold composite. For wavenumber 2 wave (wave-2), upward propagation is enhanced in the warm composite and reduced in the cold composite. Wave-1 and wave-2 made a difference in the tropospheric wave forcing and generated the westerly wind anomalies during the growing stage.

4. Summary

Factors which affect the downward propagation of a SSW event to the troposphere are studied by composite analysis of 45-year reanalysis data of the ERA-40. During a growing stage of SSW, the SSW which propagates into the troposphere shows enhanced upward wave-2 EP flux, while that without downward propagation shows reduced flux. For wave-1 flux, non-propagating events show stronger upward flux than propagating events. As for the horizontal geopotential anomalies in the troposphere, the composite of propagating events show a negative phase of the Eurasian pattern during the growing stage and a negative phase of the Arctic Oscillation pattern after the event, while that of non-propagating events show a positive phase of the Eurasian pattern during the growing stage (Figures and discussions are omitted because of space limitation). In both composites, the tropospheric anomalies are already generated by tropospheric planetary wave forcing before SSWs.

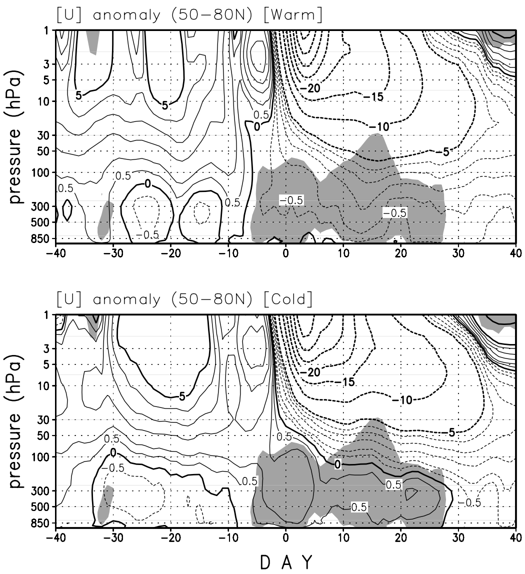

Figure 1: (Top) Time-height composite of zonal mean zonal wind anomalies averaged over 50-80N for tropospheric warm events Abscissa denotes days from the key-day. Thick contour interval is 5 m/s. Negative contours are dashed. Thin contours are drawn with 1 m/s interval where absolute values are less than 5 m/s. In addition, contours of 0.5 and -0.5m/s are drawn.
(Bottom) Same as the top panel except for tropospheric cold events. Shadings denote regions where the differences between tropospheric warm events and cold events are statistically significant at 95% level based on *t*-test.

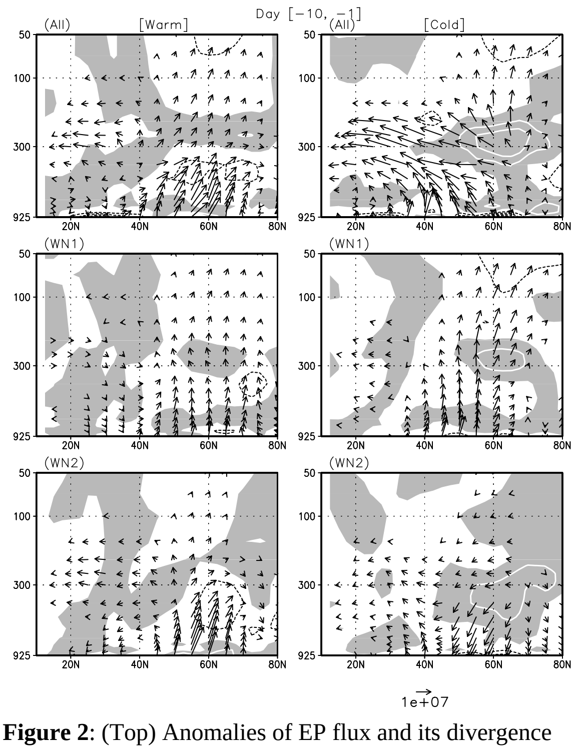

Figure 2: (Top) Anomalies of EP flux and its divergence for warm tropospheric polar temperature composite (left) and cold composite (right). A scale of arrow is shown at bottom right for $1.x10^7$ kg/s^2. Contours denote EP flux divergence with contour interval of 1 m/s/day.
(Middle) Same as in top panels except for wave-1.
(Bottom) Same as in top panels except for wave-2.