Variations of Cold Surge Activity over East Asia

Masamitsu Hayasaki[1], Seiji Sugata[1], and H. L. Tanaka[2,3]

1: National Institute for Environmental Studies, Japan
2: University of Tsukuba, Japan
3: Frontier Research Center for Global Change, Japan

1. Introduction

Cold surge is one of the most dominant weather events over the East Asia during cold seasons. As the southeastward movement of a cold airmass from Siberia, an intense cold front is formed in the leading edge of the cold surge. Cold front passages are accompanied by dramatic temperature decreases and strong northerly wind (Boyle and Chen, 1987; Ding, 1994). In addition, cold surge over the East Asia has much influence on the long range transport of mineral dust (Sun, *et al.*, 2001). For example, Shao and Wang (2003) indicated that most of dust storm events observed in Mongolia and northern China are associated with the cold front passages. This result suggests that the cold surge activity may be a proxy index of atmospheric "potential" that relates to dust storm occurrences. Unfortunately, most of previous papers about cold surges have been studied mainly to the tropical-midlatitude interaction during winter season (e.g., Chen, *et al.*, 2004).

On the other hand, there have been many papers on long-term variations of dust storm frequency (Sun, *et al.*, 2001; Qian, *et al.*, 2002). Most of studies indicate that the frequency of dust weather tends to decrease in northern China and Mongolia in the last 20 years. However, such results were derived from the surface observations. As discussed in Shao and Wang (2003), surface weather report data may contain spatial/temporal inhomogeneities that are caused by different preferences of observers. Therefore, examinations about the cold surge activity should provide more reliable result concerned with the long-term variations of dust storm frequency.

In this study, we summarize a climatology of the cold surge activity over the Eurasia, particularly focus on the East Asia during spring. The interannual fluctuations of cold surge activity provide additional perspective of daily temperature variations.

2. Data and analysis method

We use 6-hourly surface fields from the European Centre for Medium Range Weather Forecast (ECMWF) Reanalysis (ERA-40) from September 1957 through August 2002. The data used in this study are obtained from the ECMWF data server (http://www.ecmwf.int/research/era/index.html). The field used here is 2-meter temperature (hereafter surface temperature).

To identify a cold surge as simple as possible, we use daily mean surface temperature and focus on the day-to-day temperature changes. Daily mean values are obtained by the averages of four times daily values. The occurrences of cold surge is identified when a daily mean temperature decrease exceeds 5 K in a day. Cases satisfying this criterion are called "cooling day" in the next section. The threshold value is based on the synoptic experience, however, it is reasonable compared with the previous studies about cold surges (e.g., Joung and Hitchman, 1982).

3. Spatial and temporal patterns of cooling day

Figure 1 shows geographical distribution of the seasonal mean frequency of cooling days for 1958–2002 spring (MAM). In the most part of the northern Eurasia, cooling day frequently occurs at least one time per month; correspond to 3% in Figure 1. There are two centers of cooling day frequency in the Eurasia continent. One is located in the West Siberian Plain; the other is located in Mongolia and

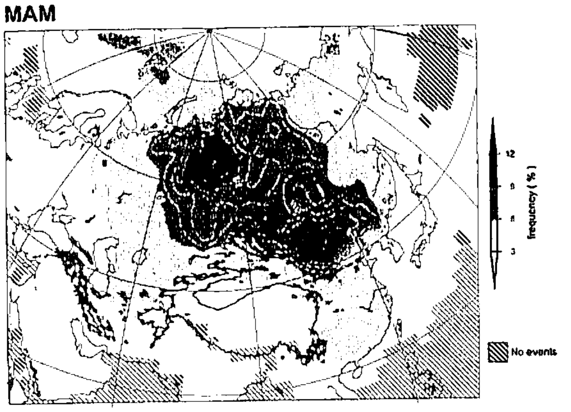

Figure 1: Seasonal mean frequency of cooling days for 1958–2002 spring. Thick sold lines represents 2000 m terrain height. Thick dashed line shows a study area (105–120°E, 40–50°N).

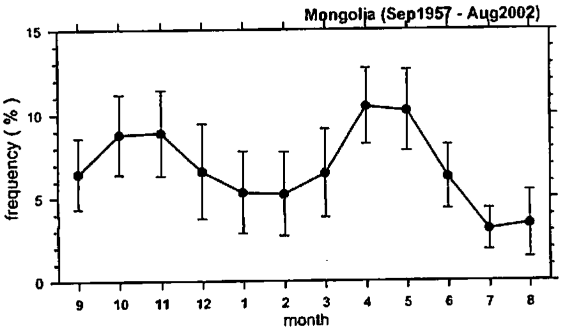

Figure 2: Area-averaged monthly mean frequency of cooling days in Mongolia region (see Figure 1) for September 1957 through August 2002.

northern China. In Mongolia, frequency peak area corresponds to the major dust storm area (Sun, *et al.*, 2001; Shao and Wang, 2003; Kurosaki and Mikami, 2003). This frequency peak in Mongolia is observed in almost fixed area (105–120°E, 40–50°N) throughout a year (not shown).

To provide more detailed information about cooling day frequency in Mongolia, Figure 2 shows monthly climatology of area-averaged frequency in Mongolia (see Figure 1). It is clear that cooling day frequency has two peaks in late autumn (October and November) and late spring (April and May). These spatial and temporal features of cooling day frequency are similar to the typical cold surge activity (Ding and Krishnamurti, 1987; Zhang, *et al.*, 1997).

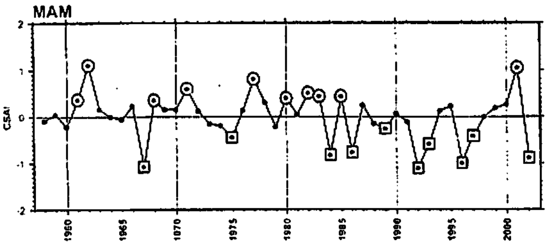

Figure 3: Seasonal mean cold surge activity index (CSAI) for 1958–2002 spring (MAM) in Mongolia. Large circle and square symbols represent the highest and lowest 10 years, respectively, for this period.

Overall, our definition of cooling day seems to detect a typical cold front passages in association with the cold air outbreaks of continental airmass.

4. Interannual variations in Mongolia

In this section, we use a cold surge activity index (CSAI) which is derived from normalized anomaly of area-averaged cooling day frequency in Mongolia.

Figure 3 shows seasonal mean CSAI in Mongolia for 1958–2002 spring. Seasonal mean frequency fluctuates from 6% to 13%. CSAI tends to have negative anomalies, particularly in the last two decades. Weakening of cold surge activity in recent 20 years is consistent with several previous studies (Zhai, *et al.*, 1999; Qian, *et al.*, 2002).

Interannual CSAI variation should be caused by following factors: 1) geographical differences of cold surge tracks, 2) differences of cooling intensity, and 3) modulations of cold surge cycle. In the first case, changes of cold surge tracks result in differences of cooling day frequency in a fixed area. In the second case, weakening of cooling intensity would provide decreases a number of grids in study area and/or shorter persistency of each cold surge event. In the third case, changes of cold surge cycle might have caused a differences of total number of cold surge events in spring season.

First, we examine a cold surge tracks using spatial composites classified by CSAI. Figure 4 shows composite of cooling day frequency based on the highest and lowest 10-years in

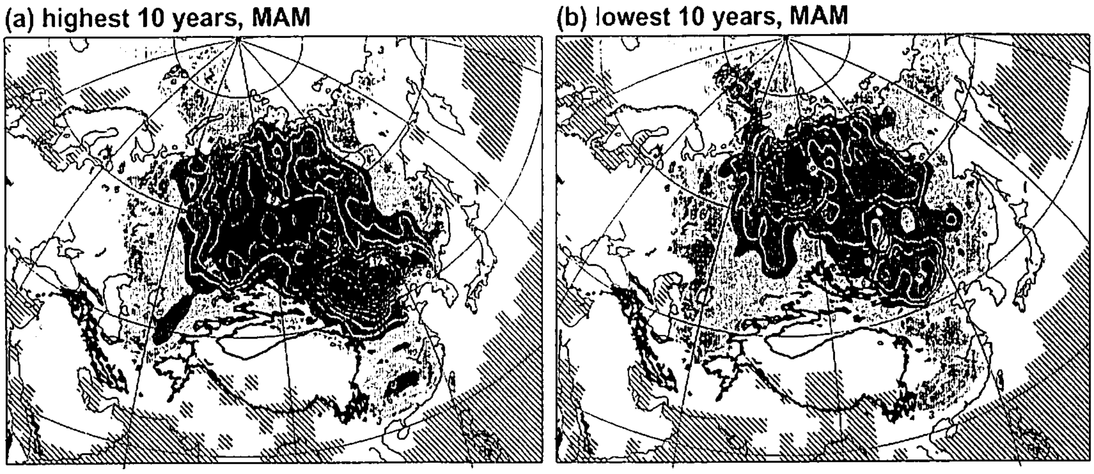

Figure 4: Seasonal mean cooling day frequency composites for the highest 10 years (a) and the lowest 10 years (b). Selected years are shown in Figure 3.

Table 1: Statistics of 10-year composites of cooling events over Mongolia.

	frequency (No. of events)	$[\Delta T_0]$ (K)	$[\Delta T_{total}]$ (K)	persistency (day)
highest 10 years	177	−3.31	−4.36	2.47
lowest 10 years	172	−2.56	−3.15	2.07

spring CSAI for 1958–2002 (selected years are marked in Figure 3). Peak frequency (~ 9%) in Figure 4b is 40% smaller than Figure 4a (~ 14%). However, geographical location of the frequency peak area has no significant differences in Mongolia. At the outside of Mongolia, frequency decreases have also seen over Siberia in total, though its peak frequency is nearly same in each other. Therefore, it is suggested that CSAI differences between more frequent and less frequent years do not depend on the changes of cold surge tracks.

Second, we focus on several statistics of cold surge activity. We use two indices of cooling intensity that is derived from area-averaged temperature changes in a specified date or period. One is temperature changes at Day 0 ($[\Delta T_0]$); the other one is total temperature changes during cold surge period ($[\Delta T_{total}]$). Starting date of cold surge event (Day 0) is distinguished by the maximum cooling date in each cold surge event. A cold surge period defines successive cooling days. Continuity of cold surge event identified by an existence of cooling day at least one grid-point inside the study area.

As shown in Table 1, despite the CSAI differences between two composite reaches to 40% in total, the total number of events has no significant differences (177 versus 172 events). On the other hand, there are 16-28% differences in $[\Delta T_0]$, $[\Delta T_{total}]$, and mean persistency of cold surge. These results suggest that interannual CSAI differences are caused by the changes in cooling intensity. Zhai et al. (1999) has also reported a decrease of extreme cold day in China, although their study was based on surface observations for 1951–1995.

Since a cooling day is identified by day-to-day temperature differences in each grid-point, cooling intensity corresponds to horizontal temperature gradient across a cold front. Therefore, recent CSAI weakening does not depend on the modulation of cold surge cycle and tracks, but is caused by the weakening of horizontal temperature gradient of cold front.

5. Summary

We define a simple index of cold surges using ERA-40 for the period 1957–2002. Cold surge (cooling day) is simply defined by the temperature decrease exceeds 5K in a day.

Cooling days are frequently observed over Eurasia continent, particularly in the north of 40°N. Two distinct frequency maxima are seen in the continental area; the West Siberian Plain and Mongolia. In Mongolia, there are two frequency peaks in late autumn (October and November) and late spring (April and May). Frequent area is geographically fixed throughout the seasons in Mongolia (not shown). Results of spatial pattern and seasonal evolution of cooling day frequency are consistent with the well-known features of cold surges.

The cold surge activity index (CSAI) is defined by normalized anomaly of area-averaged cooling day frequency in Mongolia (105–120°E, 40–50°N). The interannual variations of CSAI show weakening in the last two decades during spring. This result is consistent with observed warming trends in China (Zhai, *et al.*, 1999; Qian, *et al.*, 2002). To understand the reasons about CSAI differences, we investigate the cold surge activity using composite analysis. The highest and lowest 10 years of CSAI are composited for 1958–2002 spring. CSAI fluctuations depend on the three parameters: 1) difference of cold surge tracks, 2) cooling intensity, and 3) cycle of cold surge event.

In low CSAI (less frequent) composite, total number of cooling days are 40% smaller than high CSAI case. But its peak position has no significant differences in space. On cooling intensity and persistency, there are significant differences between high and low CSAI cases. Difference reaches to 16–28% in these variables. In contrast, the number of cold surge events in each composite is almost same. The weakening of cooling intensity in Mongolia may be a manifestation of global warming.

We document the weakening of cooling intensity, but it is not clear in the physical process(es) of cold air weakening. Warm anomaly is seen in high-latitude area, particularly for daily minimum temperature (Karl, *et al.*, 1991; Karl, *et al.*, 1993). Further studies are required to understand the linkage between the global warming and weakening of cooling intensity.

References

Boyle, J. S. and T.-J. Chen, 1987: Synoptic aspects of the wintertime east Asian monsoon. *Monsoon Meteorology*, Oxford Univ. Press, 125–160.

Chen, T.-C., W.-R. Huang and J.-H. Yoon, 2004: Interannual variation of the East Asian cold surge activity. *J. Climate*, **17**, 401–413.

Ding, Y., 1994: *Monsoons over China.* Kluwer Academic Publishers, 432pp.

Ding, Y. and T. N. Krishnamurti, 1987: Heat budget of the Siberian high and the winter monsoon. *Mon. Wea. Rev.*, **115**, 2428–2449.

Joung, C. H. and M. H. Hitchman, 1982: On the role of successive downstream development in East Asian polar air outbreaks. *Mon. Wea. Rev.*, **110**, 1224–1237.

Karl, T. R., G. Kukla, V. N. Razuvayev, M. J. Changery, R. G. Quanyle, J. Richard R. Heim, D. R. Easterling and C. B. Fu, 1991: Global warming: Evidence for asymmetric diurnal temperature change. *Geophys. Res. Lett.*, **18**, 2253–2256.

Karl, T. R., P. D. Jones, R. W. Knight, G. Kukla, N. Plummer, V. N. Razuvayev, K. P. Gallo, J. Lindseay, R. Charlson and T. C. Peterson, 1993: A new perspective on recent global warming: Asymmetric trends of daily maximum and minimum temperature. *Bull. Amer. Meteor. Soc.*, **74**, 1007–1023.

Kurosaki, Y. and M. Mikami, 2003: Recent frequent dust event and their relation to surface wind in East Asia. *Geophys. Res. Lett.*, **30**, 1736, doi:10.1029/2003GL017261.

Qian, W., L. Quan and S. Shi, 2002: Variations of the dust storm in China and its climatic control. *J. Climate*, **15**, 1216–1229.

Shao, Y. and J. Wang, 2003: A climatology of Northeast Asian dust events. *Meteorol. Zeits.*, **12**, 187–196.

Sun, J., M. Zhang and T. Liu, 2001: Spatial and temporal characteristics of dust storms in China and its surrounding regions, 1960-1999: Relations to source area and climate. *J. Geophys. Res.*, **106D**, 10325–10333.

Zhai, P., A. Sun, F. Ren, X. Liu, B. Gao and Q. Zhang, 1999: Changes of climate extremes in China. *Clim. Change*, **42**, 203–218.

Zhang, Y., K. R. Sperber and J. S. Boyle, 1997: Climatology and interdecadal variation of the east Asian winter monsoon: Results from the 1979-95 NCEP/NCAR reanalysis. *Mon. Wea. Rev.*, **125**, 2605–2619.