Interannual Variations of Cold Front Activity in Springtime Mongolia

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1. INTRODUCTION

The spatial distribution and temporal variations of frontal systems are important to both weather and climate in the extratropics. In East Asia, a well-defined cold front is frequently observed in the leading edge of cold air outbreaks as southeastward propagation of a cold airmass from Siberia (Boyle and Chen 1987; Ding 1994). Accompanied with the passages of a cold front, dramatic temperature decreases are observed (Fig. 1) and strong northerly wind causes a heavy dust storm event over the Mongolian Plateau and northern part of China in spring (Sun et al. 2001; Shao and Wang 2003).

Hayasaki et al. (2004) showed that seasonally averaged activity of cold surge in spring is apparently decreased in recent two decades. Based on their analysis, the weakening of cold surge activity in Mongolia was influenced by the reduction in cooling intensity. However, the temporal dependence shorter than season and acceptable interpretations for the decline of cooling intensity were not documented well.

The main objective of this paper is to examine interannual variations of cold front activity over the East Asia based on monthly mean fields. The difference in a cyclone activity is also evaluated in terms of the changes of cold front activity.

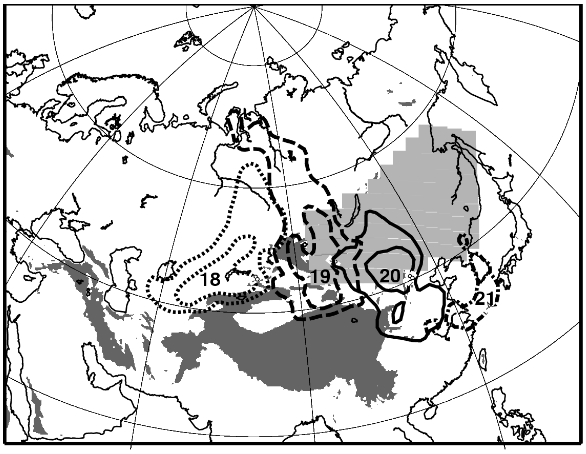

Fig. 1. Spatial distribution of daily mean temperature change from March 18 to 21 2002, this period corresponds to the record-heavy dust storm event occurred for March 19–20 in Mongolia and northern China. Daily mean temperature changes (below −4 K) at March 18 (short dashed), 19 (long dashed), 20 (solid), and 21 (dot-dashed) are plotted. Contour interval is 4 K. Other cooling areas, which may not be related to the dust storm event, have been omitted for clarity. Light shaded area is used to consider cyclone statistics in Fig. 5. Also shown are areas with elevations above 1500 m (dark shaded), based on ETOPO-2 data.

2. DATA AND ANALYSIS PROCEDURE

This study uses 6-hourly surface and pressure level data obtained from the European Centre for Medium Range Weather Forecasts (ECMWF) Reanalysis (ERA-40) from September 1957 through August 2002. The reanalysis output has a global resolution with 1.125° × 1.125° for surface data and 2.5° × 2.5° for pressure level data. Daily mean values are obtained by the averages of four times daily values.

To examine a cold front activity in Mongolia, same as Hayasaki et al. (2004), we use area-integrated frequency of cooling days ($[f_{cd}]$) which is determined by a rapid decrease in daily mean surface air temperature exceeding 5 K a day. The analysis area is set to 39.375° – 50.625°N, 102.375° – 120.375°E. Therefore, the $[f_{cd}]$ is determined by the total cooling days for all grid points in the analysis area divided by the total number of days.

The cyclone track data is obtained from the U.S. Climate Diagnostics Center (CDC) website. The detection and tracking algorithm of cyclone is essentially described by Serreze (1995) and Serreze et al. (1997). For this study, only

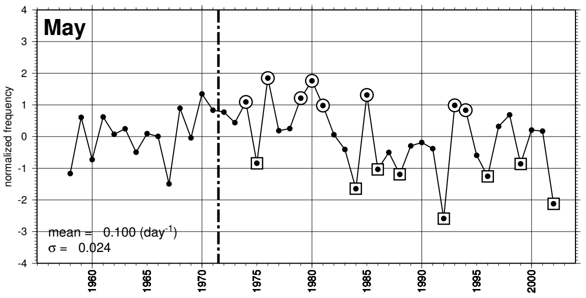

Fig. 2. Normalized anomaly of cold front activity for May 1958–2002 in Mongolia. Large circle and square symbols represent the highest and lowest 8 years, respectively, for the period 1972–2002.

cyclones that existed for four or more consecutive observation periods (i.e., at least one day) are used.

3. INTERANNUAL VARIATIONS OF COLD FRONT ACTIVITY

Figure 2 shows monthly mean normalized anomaly of cold front activity in Mongolia (enclosed by thick dashed line in Fig. 3) for May 1958–2002. It is apparent that monthly mean $[f_{cd}]$ indicates negative trend with statistical significance for the period 1972–2002. Most of the smaller $[f_{cd}]$ years can be seen after mid 1980s. In March and April, however, cold front activity has no obvious trend in this period (not shown).

Any variation in $[f_{cd}]$ is expected to be caused by differences in cold front activities such as differences in the cold air route, cooling intensity or temporal cycle of cold air outbreaks. In order to identify the dominant factor(s) in the differences in $[f_{cd}]$, we examined composite analyses of the 8 years with the highest $[f_{cd}]$ (active years) and the 8 years with the lowest $[f_{cd}]$ (inactive years) for the period 1972–2002. The years used in these composites are marked with circles and squares in Fig. 2.

Figure 3 shows mean frequency of cooling days based on the highest and lowest 8-years of cold front activity in May. The maximum frequency within analysis area in Fig. 3b ($\sim$ 0.11 $(\text{day})^{-1}$) is about 20% smaller than in Fig. 3a ($\sim 0.18(\text{day})^{-1}$). The most frequent area of cooling days is still located within analysis area. On the other hand, local frequency maximum of cooling days can be seen in the east of the Lena River for the inactive case (Fig. 3b). Overall, though the spatial distributions of cooling day frequency slightly shift poleward over northeastern Siberia, the displacement of the frequency

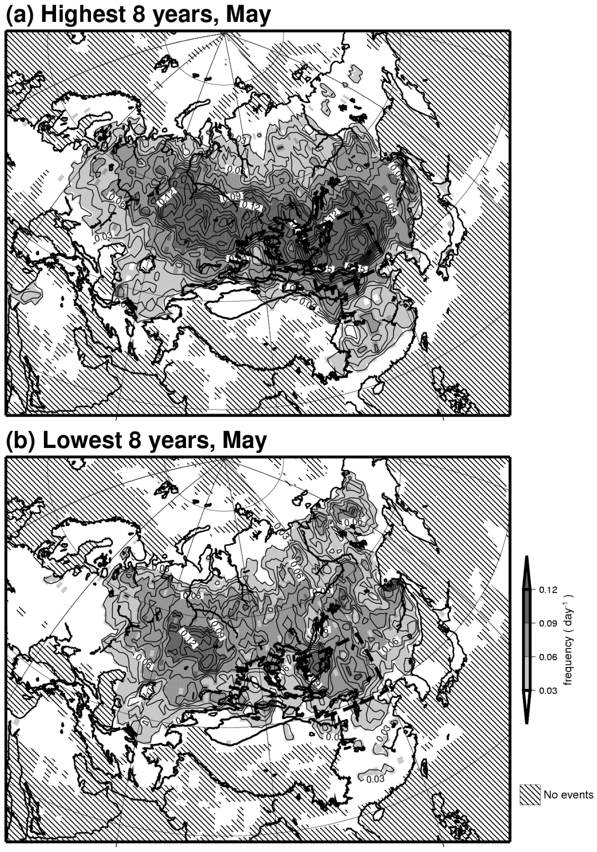

Fig. 3. Monthly averaged frequencies in cooling day for (a) the highest 8 years and (b) the lowest 8 years. Selected years are shown in Fig. 2.

Table 1. Statistics of 8-year composites of cooling events over Mongolia.

8-year composites	$[f_{cd}]$ (day^{-1})	Number of cooling events	Period (day)	$[\Delta T_{total}]$ (K)	$[\Delta T_0]$ (K)
		May			
Active	0.130	6.8	14.1	−5.01	−3.42
Inactive	0.065	6.5	13.0	−2.84	−1.81
mean	0.099	6.6	13.7	−4.18	−2.76

maximum in Mongolia is not clear. These results suggest that the $[f_{cd}]$ difference between the active and inactive years is not influenced by changes of cold surge tracks.

The change of cold front activity depends also on the other statistics of cooling events such as the number of events for the analysis period, intensity or persistence of each cooling event. To evaluate the above mentioned values, we use two indices of cooling intensity derived from area-averaged temperature changes in a specified date or period. One is the temperature change at key date ($[\Delta T_0]$); the other is the total temperature change during the cold surge period ($[\Delta T_{total}]$). The key date of a cooling event (Day 0) is distinguished by the maximum cooling date in each cooling event. A cooling

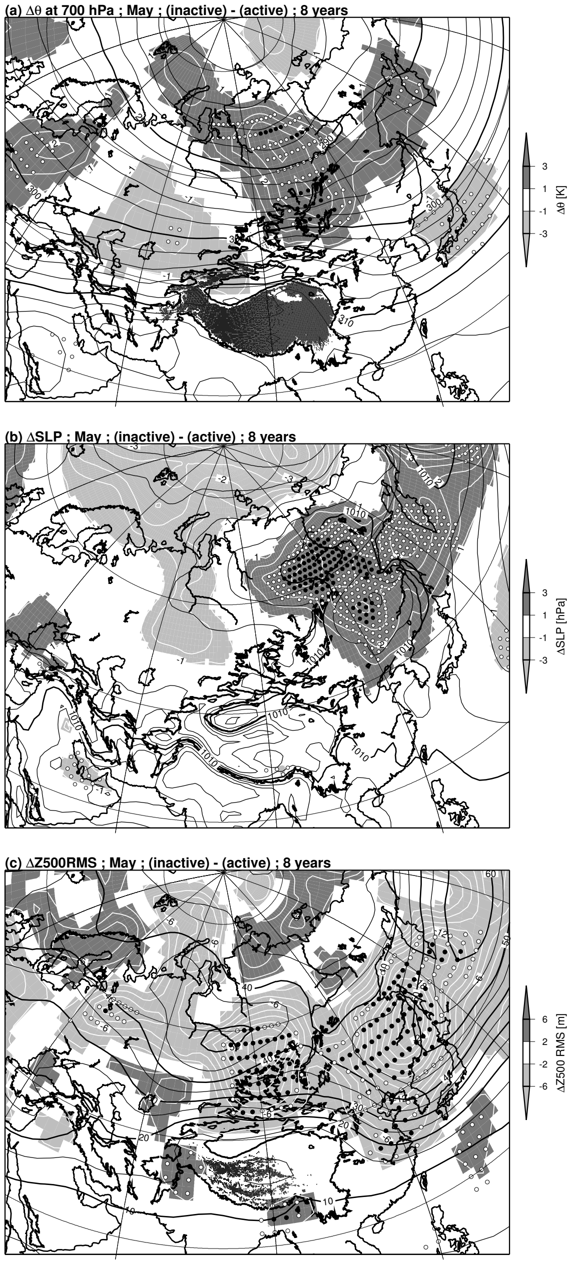

Fig. 4. Differences between active and inactive composites of (a) potential temperature at the 700-hPa level, (b) SLP, and (c) the root-mean-square of band-pass filtered (2–8 day) geopotential height at the 500-hPa level. Black contour represents monthly climatology for 1972–2002. Statistically significant differences are denoted in white and black circles at 0.05 and 0.01 significance level, respectively. Composite years are same as Fig. 3.

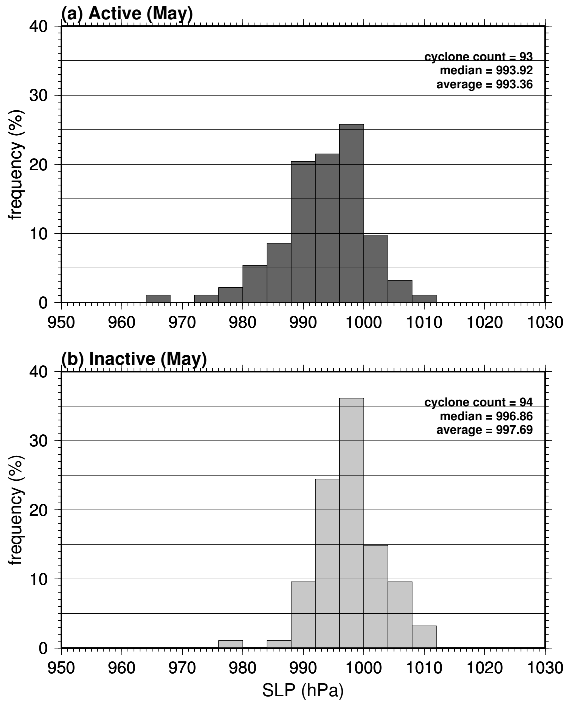

Fig. 5. Histogram of minimum SLP at cyclone center passed over Mongolia and northeastern China (see light shaded area in Fig. 1). (a) Active years and (b) inactive years.

period in each event defines successive cooling days, which are determined by negative values of the area-averaged daily temperature change.

As shown in Table 1, despite $[f_{cd}]$ for active years is twice as large as that for inactive years, the mean number of events has no clear difference (6.8 versus 6.5 events per month). Mean period of a cooling event for inactive years is slightly shorter than that for active years, the difference in mean period is not enough to explain the difference in $[f_{cd}]$. The noticeable differences can be seen in $[\Delta T_0]$ and $[\Delta T_{total}]$. These results suggest that interannual variations of $[f_{cd}]$ depend on the changes in cooling intensity.

4. IMPACT ON CIRCULATION FIELD AND CYCLONE ACTIVITY

To evaluate an impact of the reduction in $[f_{cd}]$ upon circulation field, we examine composite analyses for temperature, SLP, and cyclone activity in May.

The difference charts obtained by subtracting the high composites from the low composites are displayed in Fig. 4 for potential temperature at the 700-hPa level, SLP, and the storm track activity. The storm track activity is evaluated by root-mean-square (RMS) of band-pass filtered (2–8 day) geopotential height at the 500-hPa level.

The potential temperature field (Fig. 4a) shows that positive (warm) diffrences can be seen in eastern Eurasia, the statistically significant positive differences extend southward or southeastward from northern part of the West Siberian Plain to norhtern Mongolia. The positive differences are also observed from surface to mid-troposphere (not shown), and the spatial pattern is similar to the strong warming trend reported by Folland et al. (2001).

In the SLP field (Fig. 4b), strong positive (high) differences are observed from northeastern Siberia through northeastern China and the Sea of Okhotsk.

Figure 4c shows that the reduction in storm track activity for the inactive case is statistically significant over central Eurasia and from northeastern China through northwestern Pacific.

The decline of storm track activity can also be seen in the intensity of individual cyclone. Figure 5 shows composite frequencies of the minimum SLP for each cyclone in Mongolia and northeastern China, corresponding to the light shaded area in Fig. 1. As noted by Chen et al. (1991), cyclone activity is most pronounced in this area during spring season. Comparison between Fig. 5a and Fig. 5b reveals some interesting differences in frequency distribution. Consistent with the results of Figs. 4b and 4c, the number of strong cyclones in active years is relatively frequent compared to the inactive years.

5. DISCUSSION AND CONCLUSIONS

As in Hayasaki et al. (2004), the weakening of cold front activities in Mongolia is apparent, particularly in May. Additionary, composite analyses of cold front activity show that the weakening of cold front activity correspond to the reduction in cooling intensity ($[\Delta T_0]$ and $[\Delta T_{total}]$). There are no obvious differences in the number of cooling events and mean cooling periods (Table 1).

Since $[\Delta T_0]$ is determined by the maximum temperature drop in each cooling period, $[\Delta T_0]$ corresponds to the horizontal temperature gradient across the cold front. Therefore, the weakening of $[f_{cd}]$ in recent years is mainly influenced by the weakening of the horizontal temperature gradient across the cold front.

The reduction in cold front intensity may be related to form shallower cyclone in the downstream of Mongolia. As noted in section 1, strong cold front systems are frequently observed in the leading edge of a cold air outbreak. In the East Asia, rapidly developing cyclones are frequently observed associated with the southward or southeastward progress of cold air (Boyle and Chen 1987). The smaller occurrences of strong cyclones for the composite of inactive years (Fig. 5) may correspond to the weakening of baroclinicity caused by the reduction in cold front intensity (see Table 1 and Figs. 4a, 4c).

In the composite differences in temperature field, the spatial distribution of positive temperature differences is similar to the strong warming trend in recent years (Fig. 4a). As shown in Fig. 2, the interannual variations of cold front activity have a negative trend since mid 1980s. The zonally asymmetric features of warming trend may be interpreted by the changes of cold front activity as shown in this study. Further studies are required to understand the linkage between the global warming and weakening of the cooling intensity.

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