Trends in temperature extremes during 1951–1999 in China

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[1] Based on the daily surface air temperature data from about 200 stations during 1951–1999 in China, changes in the frequency of some extreme temperature events were studied with a focus on trends. For China as a whole, the number of hot days (Tmax over 35°C) displays a slightly decreasing trend, while the number of frost days (Tmin below 0°C) exhibits a significant decreasing trend. Meanwhile, increasing trends were detected in the frequencies of warm days and warm nights. In addition, decreasing trends was found in the frequencies of cool days and even stronger decreasing trend was found in frequencies of cool nights in China. *INDEX TERMS:* 0325 Atmospheric Composition and Structure: Evolution of the atmosphere; 1610 Global Change: Atmosphere (0315, 0325); 1630 Global Change: Impact phenomena; 3309 Meteorology and Atmospheric Dynamics: Climatology (1620). **Citation:** Zhai, P., and X. Pan, Trends in temperature extremes during 1951–1999 in China, *Geophys. Res. Lett.*, *30*(17), 1913, doi:10.1029/2003GL018004, 2003.

1. Introduction

[2] In the last few decades, climate change, especially global warming has received wide attention from governments and general public throughout the world. *IPCC* [2001] indicated that the global averaged surface temperature has been increased over the 20th century by about 0.6°C and the warming of the recent 50 years is largely attributed to human activities. Change in the mean temperatures may be related to change in extremes events, which is more closely related to the impacts of climate on human society and environment. Starting from *IPCC* [1996], many scientists have stressed the importance of study on climate extremes [*Karl et al.*, 1999, *Folland et al.*, 1999, *Manton et al.*, 2001]. Recently, *Easterling et al.* [2000] summarized the analyses of change in climate extremes around the world. He indicated that one of the biggest problems in performing analyses of extreme events for most of the globe is a lack of access to high-quality, long-term climate data with the appropriate time resolution. Based on the available daily surface data from many different sources, *Frich et al.* [2002] depicted the global picture of the change in many climate indicators during the second half of the 20th century and pointed out the importance in increasing global collaboration for climate extreme studies.

[3] China is a big country that occupies a significant portion of land territory of the world. Its regional daily dataset needs to be carefully examined to reveal regional climate changes so as to support studies on scenario construction and impacts of specific regions. This examination is useful to call awareness of local government and to compare China's results with those in other parts of the world thus contributing to the global study.

[4] Consistent with the global warming background [*IPCC*, 2001], China has also experienced warming in the 20th century [*Wang and Gong*, 2000]. Recently, China's daily surface air temperature data with a dense observation network and consistent observation practices have become available to the scientific community. In this paper, we attempt to study changes in temperature extremes based on a daily temperature dataset of about 200 stations in Mainland China during the second half of the 20th century.

2. Data and Analysis Method

2.1. Data Source and Quality Control

[5] A Chinese daily dataset from CMA/National Meteorological Center including daily maximum, minimum and mean surface air temperatures of 196 stations in Mainland China during the period 1951–1999 was used in this study.

[6] A quality control procedure based on the internal and spatial consistency between the daily mean, maximum and minimum temperatures was designed [*Pan and Zhai*, 2002] and applied before calculating all the extreme indices.

[7] To minimize the problems associated with temporal inhomogeneity, stations with serious relocation problems were removed [*Zhai and Ren*, 1999].

2.2. Analysis Method

[8] Two kinds of temperature extremes were chosen in this study: one kind for absolute extremes and the other for relative extremes. Shown in Table 1, the first two are absolute extreme indices, which would be easily related to the impact study but not effective in any season and in any place. Frost day is calculated based on minimum air temperature below 0°C and hot day is defined as maximum temperature over 35°C in China. The other four are relative extreme indices which can reflect extremes in each season and in every place.

[9] All China mean annual time series for warm day (night) and cool day (night) were calculated based on area-weighted average of station values in grid boxes of 2° latitude by 2° longitude. The anomaly time series for hot day and frost day as shown in Figure 1 were estimated based on area weighted averages for the anomalies relative to mean values of 1961–1990 at each station.

[10] Linear trends were estimated and their statistical significance was tested at 5% confidence level using the non-parametric Kendall's tau based on slope estimator

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Table 1. Six Temperature Indices Calculated Based on Daily Temperatures

Index	Description
Hot day	Days with Tmax above 35°C
Frost day	Days with Tmin below 0°C
Warm day	Days with Tmax above the 1961–1990 mean 95th percentile of the same day
Cool day	Days with Tmax below the 1961–1990 mean 5th percentile of the same day
Warm night	Days with Tmin above the 1961–1990 mean 95th percentile of the same day
Cool night	Days with Tmin below the 1961–1990 mean 5th percentile of the same day

[*Kendall and Gibbons*, 1981]. In case the trends would be biased due to existence of auto-correlation in the time series, the time series were pre-whitened [*Zhang et al.*, 2000].

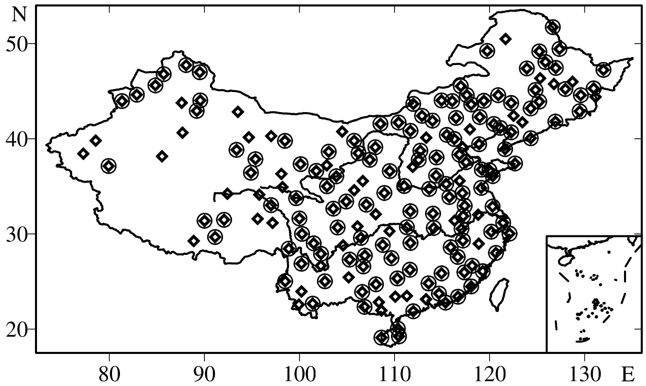

Figure 2. Spatial distribution of trends (diamond signs mean decrease trends and the circle signs indicate statistical significant at 0.05 level) for annual number of frost days in China during 1951–1999.

3. Trends in Temperature Extremes

3.1. Hot Day

[11] In Figure 1, variation of the number of hot days is displayed. There is a slightly decreasing trend of 0.5 day/10a for China as a whole. Some high anomalies in early 1950s are consistent with warm climate reflected by many above normal maximum temperatures [*Zhai and Ren*, 1999] and anomalous high mean surface temperatures [*Wang and Gong*, 2000] in the same period.

[12] Results of spatial distribution of trends indicate significant deceasing trends in the number of hot days mainly in the central and southern parts of eastern China. However, significant increasing trends were found in some areas in western China.

3.2. Frost Day

[13] The number of frost days decreased with a rate of 2.4 days/10a during 1951–1999. The average number of frost days in 1990s is about 10 days per year fewer than those in 1960s (Figure 1). For most parts of the world, the annual number of frost days also shows a near global decrease during the second part of the 20th century [*Frich et al.*, 2002]. Compared with the results of the North American continent, the decrease rate of frost days in China is larger than that in the USA as given by *Easterling* [2002].

[14] As shown in Figure 2, significant decreasing trends in the annual number of frost days were found in most parts of China. The sharpest decreasing trends occurred in northwestern and eastern China. This result is consistent with the decreasing trend in cold days defined by the days with minimum temperature below −20°C over northern China [*Zhai et al.*, 1999].

3.3. Warm Day

[15] As Figure 3 shows, the warm days displayed a slightly decreasing trend prior to mid-1980s but a sharply increasing trend appeared since mid-1980s. From 1950s to mid-1960s, the number of warm days was 20–25days per year, while up to 1999, warm days even reached 35 days per year. The increasing trend in warm days in China is consistent with that of the same index in the neighboring countries such as Japan and Vietnam, etc. [*Manton et al.*, 2001].

[16] The number of warm days slightly increased in northern China, western China and the southeast coast, with

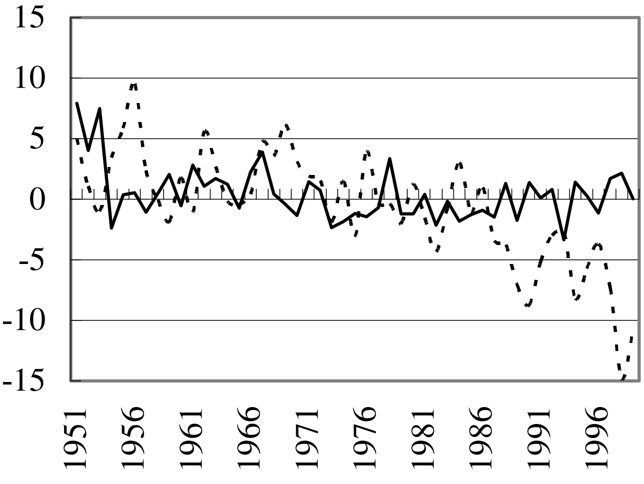

Figure 1. Anomalies of China's averaged numbers of hot days (solid line) and frost days (dash line) during 1951–1999.

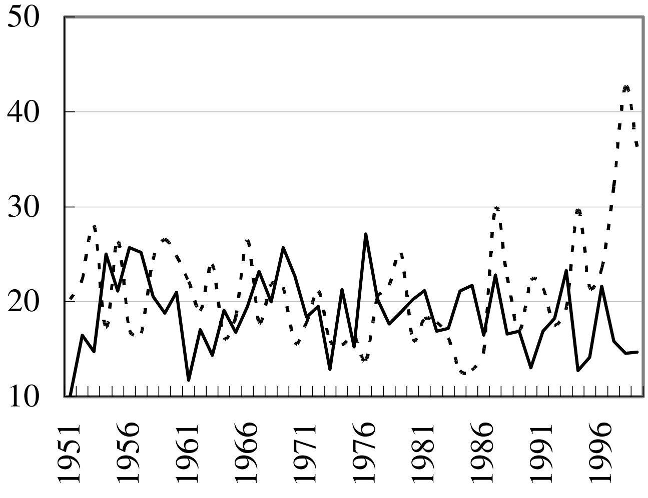

Figure 3. China's averaged numbers of warm days (dash lines) and cool days (solid lines) during 1951–1999.

significantly increasing trends in western China. However, a total different picture with decreasing trends was clearly shown in the areas in the central and southern parts of eastern China.

3.4. Cool Day

[17] For China as a whole, the number of cool days displayed a slightly decreasing trend of 0.5 day/10a. The decreasing trend was especially obvious since mid-1980s. Although differences exist in defining cool days, a decreasing trend is consistent with those in most Southeast Asian countries as revealed by *Manton et al.* [2001]. Moreover, inter-annual and inter-decadal variability for the number of cool days are also obvious during the past 50 years in China (Figure 3).

[18] Spatially, the number of cool days displayed significant decreasing trends (about 4 days/10a) in most parts of northern China, but slightly increasing trends in much of southern China.

3.5. Warm Night

[19] From Figure 4 it is clear that the average number of warm nights for all of China increased with a rate of 3 day/10a. This rate is consistent with that in China's neighboring countries [*Manton et al.*, 2001]. Prior to the mid-1980s, there were about 10–20 warm nights per year, compared with 20–40 warm nights per year after the mid-1980s. *Frich et al.* [2002] revealed that the global warming trend in warm nights is clearly reflected by the Tn90 indicator, with the exception of parts of Canada, Iceland, China and around the Black Sea. In this study, the number of warm nights was found significantly increasing in most parts of China. The biggest increasing trends are in parts of southwest China.

3.6. Cool Night

[20] The number of cool nights in China displayed a decreasing trend with a rate of 3 day/10a. This rate is more obvious since mid-1970s (Figure 4).

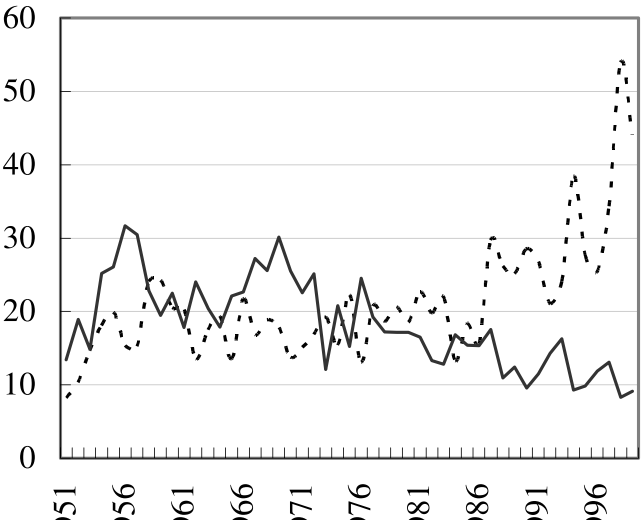

Figure 4. China's averaged numbers of warm nights (dash lines) and cool nights (solid lines) during 1951–1999.

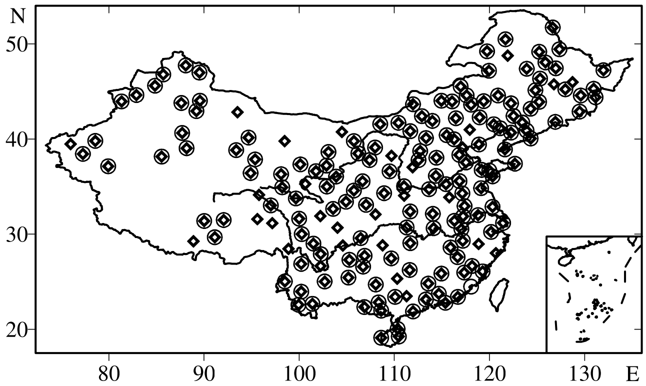

Figure 5. Spatial distribution of trends for annual number of cool nights, other are the same as Figure 2.

[21] The number of cool nights decreased significantly. The decreasing trends in northern China are greater than those in southern China (Figure 5).

[22] The result that decreasing trends in China's cold nights are much greater than those in cold days is consistent with those of many other countries in SE Asian areas [*Manton et al.*, 2001] and it also supports the fact that the increase of nighttime temperature is quicker than that of daytime temperature [*Karl et al.*, 1991].

4. Conclusions

[23] Based on Chinese daily temperature data from 1951–1999, the numbers of days that experienced extreme temperature events were studied. The major conclusions are summarized as:

[24] (1) The number of days with daily maximum temperature above 35°C showed a slightly decreasing trend for China as a whole. The decreasing trends were especially obvious in eastern China. Additionally, the number of frost days displayed a significant decreasing trend, suggesting that the frost-free season in China has been significantly prolonged.

[25] (2) Increasing trends were detected in the frequencies of warm days and warm nights, and the major increases were found to occur since the mid-1980s. The increasing trend in the frequency of warm nights was greater than that of warm days. A decreasing trend was found in the mean number of cool days for all of China, and an even stronger decreasing trend was found in the number of cool nights. Spatially, the frequency of warm days increased in northern and western China but decreased in much the central and southern parts of eastern China. However, frequency of warm nights increased significantly in most of China, and cool nights decreased over almost all China.

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