



## Trends in hail in China during 1960–2005

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[1] The annual variation and trend in hail frequency during a 46-yr period from 1960 to 2005 in China are documented in this study. All analyses are based on a comprehensive collection of observational hail data and operational atmospheric sounding data released by the National Meteorological Information Center (NMIC) of China. The results show no trend in the mean Annual Hail Days (AHD) from 1960 to early 1980s but a significant decreasing trend afterwards. The different trend of the AHD at each station displays a marked regional dependence across China, however. Convective Available Potential Energy (CAPE), strength of vertical wind shear, and mean Freezing-Level Height (FLH) are analyzed to understand the observed long-term trends in hail frequency. **Citation:** Xie, B., Q. Zhang, and Y. Wang (2008), Trends in hail in China during 1960–2005, *Geophys. Res. Lett.*, 35, L13801, doi:10.1029/2008GL034067.

### 1. Introduction

[2] By definition, hail is precipitation in the form of balls or irregular lumps of ice produced by convective clouds [Changnon, 1978]. Studies on hail climatology, especially the long-term variation of Annual Hail Days (AHD, defined as the sum of hail days of all individual stations per year in China), are very important for understanding the regional climate change. In China, hail occurs almost everywhere except for a few areas of the south and east plains [Liu and Tang, 1966; Zhang *et al.*, 2008]. Liu and Tang [1966] documented the annual and seasonal variations of hailstorms from 1951 to 1960 using 811 surface meteorological observations in China. The limitation of their work was the use of data that only covered 10 years (7 years for some stations). Nevertheless, Liu and Tang was the first to have produced the hail climatology for the whole of China. A brief review of the early effort on the studies of hail climatology in China is given by Xu [1983]. A recent study on hail climatology in China has been recently done by Zhang *et al.* [2008], who documented the spatial distribution and seasonal and diurnal variations of hail occurrence based on the hail observations since 1961. However, a study of the country-wide hail temporal climatology in China with long-term hail observations is yet to be carried out. The purpose of this study is to use the observed hail data at all stations in China to analyze the long-term temporal climatology of hail in China with the focus on the linear long-term trend.

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### 2. Data and Analysis Method

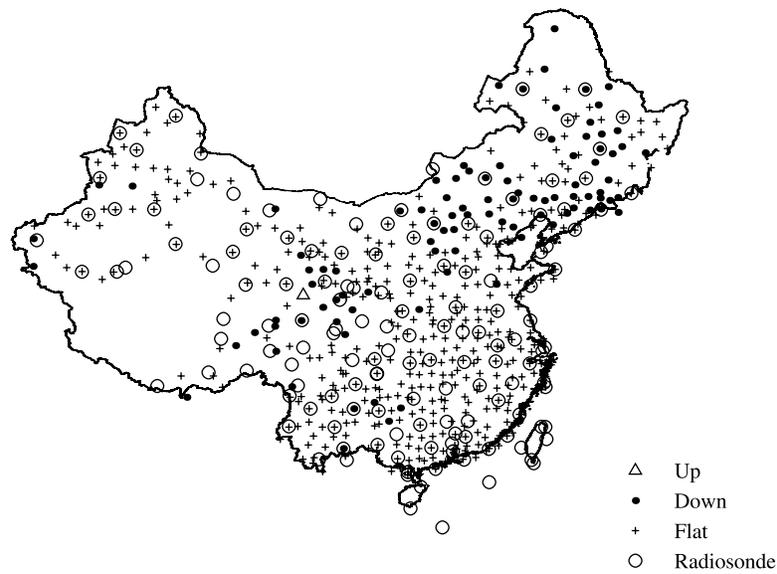
[3] The National Meteorological Information Center (NMIC) of China has compiled a complete historical hail dataset of 753 stations, which includes hail data for all weather stations in the surface meteorological observational network over the whole of China from 1951 to 2005. Because of some unexpected and historical reasons, for instance, some stations were relocated and some were established during this period, not all stations have the complete records of hail. In our study, a station with one year data missing, the year is regarded as an invalid year. Data in an invalid year are not considered in our analysis. To ensure a relatively large and continuous data records, we chose 523 stations with complete observations from 1960 to 2005 in this study (Figure 1). We focus on the annual variations and trend of hail frequency across mainland China during 1960–2005. According to the trend of the AHD at each station, the considered stations were classified into three types, namely, with up trend, down trend, and flat (no) trend.

[4] The atmospheric sounding observations from 146 weather stations (see Figure 1) also obtained from NMIC are used to calculate the following three variables to understand the variation of AHD: (1) Convective Available Potential Energy (CAPE): calculated as the buoyant energy to accelerate an air parcel from the surface; (2) Freezing-Level Height (FLH): defined as the height at which temperature becomes below zero above this level; and (3) Vertical Wind Shear (VWS): defined as the magnitude of the vector difference between 500 hPa and 850 hPa winds.

[5] Each station has sounding data twice daily at 0800 LT (local time) and 2000 LT, respectively. In the data preprocessing, any days with only one sounding record or any stations with the data less than 46 years were discarded from the analyses. Since the wind observations in our sounding data are available from 1980, only the variation of the mean vertical wind shear strength from 1980 to 2005 is considered in this study. As the hail events mainly occur in warm seasons, we only analyze the dynamical and thermodynamic factors between April and October.

### 3. Results

[6] We first calculated the trend of the AHD at each station from 1960 to 2005. The trend at each station was then classified into one of the three groups: up trend and down trend (both significant at 95% confidence level), and no trend (Figure 1). Only one station in northwest of China shows up trend of AHD. About 25% stations (131 stations) show distinct down trend of AHD. They are mainly in northwest and northeast of China. The remaining 391 stations (accounting for about 74% of all stations) show no significant trend from 1960 to 2005. Most of these stations are located in south of China.

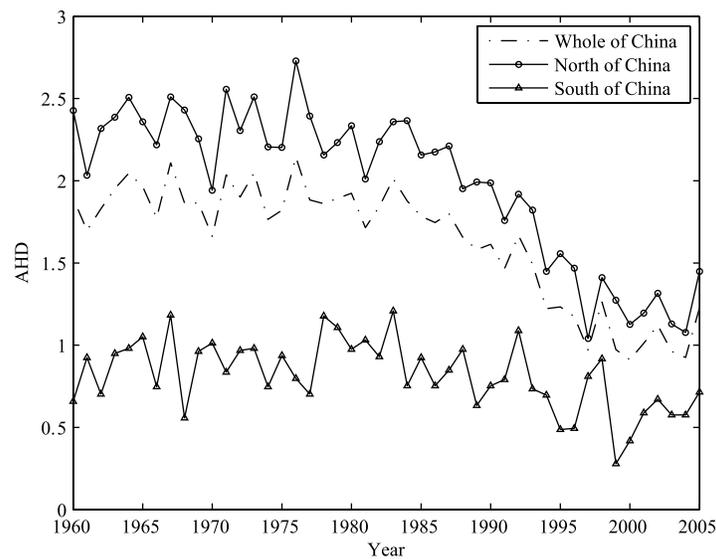


**Figure 1.** Locations of the 523 surface stations and their annual hail day (AHD) trends in China with high-quality hail-day records during 1960–2005. Circles indicate the locations of 145 radiosonde stations with sounding data.

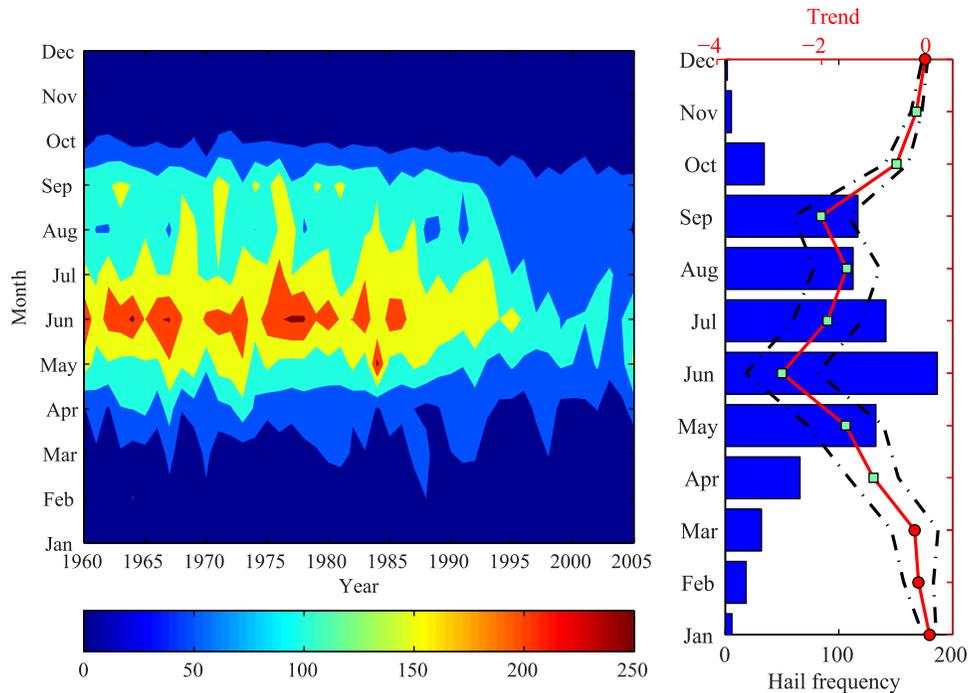
[7] Considering the different trends in north of China and south of China, we show in Figure 2 the mean AHD of south of China, north of China, and the whole of China, respectively. In addition to the short-term interannual variations, the mean AHD experienced relatively long-term trends. As we can see from Figure 2, two distinct periods can be easily identified. In the first period from 1960 to early 1980s, there is no statistically significant up or down trend in the mean AHD (significant at 95% confidence level). In the second period from early 1980s to 2005, the mean AHD exhibits a significant down trend. The mean AHD across China was almost halved during the second period (from 1.9 to 1.0). Interestingly, the trend shown in Figure 2 bears a similarity to that of AHD in the United

States [Changnon, 2000]. This may be an indication of the global climate change.

[8] Figure 3 shows the mean hail frequency as a function of month and year over China. Consistent with the results of Zhang *et al.* [2008], hail events occur most frequently in warm seasons during June–September with the highest frequency of occurrence in June in most regions of China. November and December show the lowest mean hail frequency of hail occurrence. Large down trends in monthly mean hail frequency during the 46 year period coincide with the high long-term mean monthly hail frequency of occurrence (Figure 3). On the contrary, the months with the low mean hail frequency show different long-term trends. As we can see in Figure 3, there is a small down trend in November, and no trend in December, January, February



**Figure 2.** Mean AHD variations and trends, respectively, in the whole of China, south of China, and north of China during 1960–2005. Note that here and hereafter, north of China and south of China refer to regions north and south of 30°N in China.



**Figure 3.** (left) The mean hail frequency against month and year (filled color) and (right) mean seasonal variation (blue bar) of hail frequency and their trends (red curve, and each green square indicates that the down trend is significant at 95% confidence level) in China from 1960 to 2005. Note that the dashed lines in Figure 3 (right) show the 95% confidence intervals.

and May (significant at 95% confidence level). Since the monthly mean hail frequencies and their trends in these months are both small, we will focus on our following analyses in warm seasons to understand the large-scale atmospheric conditions that may control the long-term changes in hail frequency of occurrence across China.

[9] Hail is favored by both low freezing level in the ambient atmosphere and strong updrafts to allow ice particles to grow [Dessens, 1986]. Hail occurs mostly in association with thunderstorms in a convectively unstable environment with abundant low-level moisture supply [Longley and Thompson, 1965]. Localized unstable air masses, vertical shear of horizontal wind, baroclinic instability of frontal systems, lake/topographic effects, and even cloud microphysics may play important roles in triggering hailstorms [Changnon, 2000]. However, when considering causes of the long-term trend, especially the significant down trend in annual hail frequency of occurrence after early 1980s, it is impossible to examine the local/regional and weather conditions favoring the hail events. We thus focus on some climatic parameters that are considered to be related to the formation process of hail.

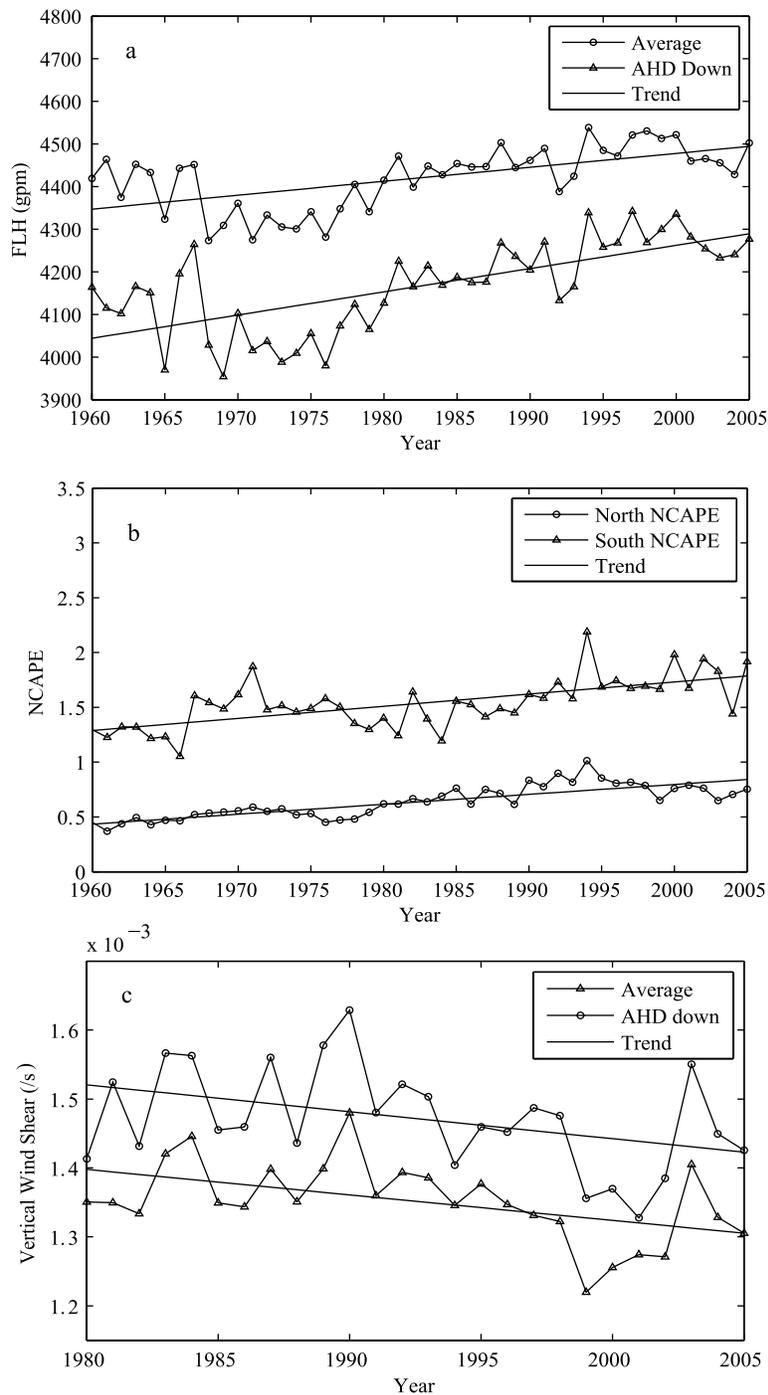
### 3.1. Freezing Level Height (FLH)

[10] Hail forms above the freezing level through complicated cloud microphysical processes. Whether the hail can occur in a convective thunderstorm partly depends on whether the liquid drops have sufficient momentum to go through the FLH. If the liquid drops cannot go above the freezing-level, they will remain liquid state. Therefore, Increasing FLH is generally unfavorable for the hail formation. Based on the sounding data, we show in Figure 4a both

the averaged FLH at all stations and that at stations with decreasing trend in AHD in China. In general, the FLH averaged at stations with AHD decreasing trend is lower than that averaged at all stations for any given year, indicating that low FLH favors the hail formation processes. Consistent with the down trend in AHD in China, the mean FLH shows an up trend during 1980–2005. The present mean FLH is about 200 meters higher than that averaged during 1960–1979 (Figure 4a). Santer *et al.* [2003] reported that the height of tropopause has increased by several hundred meters as a result of the warming trend in the whole troposphere since 1979 and they contributed the increase to the direct effect of the global warming. This also implies an increase in FLH, as what we can see over China in Figure 4a. To this point, the increasing trend in the mean FLH could be one of the important climatic factors that contributed to the down trend in the AHD in China.

### 3.2. Convective Available Potential Energy (CAPE)

[11] CAPE represents the amount of buoyant energy available to accelerate an air parcel vertically, or the amount of work an air parcel does on the environment. The higher the CAPE, the more energy is available to foster convective storm growth [Doswell and Rasmussen, 1994]. Therefore, long-term variation of CAPE presents changes in the instability of the atmosphere. Using the 46-yr sounding data, we calculated warm season mean CAPE in north of China and south of China (Figure 4b). Note that these are mean values calculated only for days when CAPE is positive and normalized by the long-term mean value across the whole of China. We can see that the mean atmosphere became more and more unstable in the past 46 years and the



**Figure 4.** (a) Variation and trend of the annual mean FLH during the period of 1960–2005. “Average” and “AHD Down” denote the averaged FLH values at the stations with flat and down AHD trends, respectively. (b) Same as in Figure 4a by for NCAPE (normalized CAPE) averaged north and south of China. Note that NCAPE in south of China is greater than that in north of China and both show an up trend. (c) Variations and trends of the annual mean vertical wind shear averaged at the stations with no trend and those with down AHD trend during the period of 1980–2005.

up trend in CAPE (Figure 4b) contrasts the down trend in hail frequency as shown in Figure 2. Interestingly, although hail events mainly occur in north of China, the CAPE in north of China is less than that in south of China, indicating that there is discrimination between severe convection and CAPE as presented by *Rasmussen and Blanchard* [1998]. Meanwhile, the result also indicates that CAPE is not the

unique ingredient in hail formation and that large CAPE does not always produce severe convection. This is in agreement with the findings by *Brooks et al.* [2007] for the United States.

[12] *Zhao et al.* [2006] analyzed the relation between precipitation and aerosol in eastern China and found that aerosols play an important role in the reduction of precip-

itation in eastern central China. Thus, because both the atmospheric instability and amount of aerosols increased, the negative effect of aerosols offset the positive effect of the former, causing the significant reduction of precipitation in the region. As one type of precipitation, hail could also be reduced due to the negative effect of atmospheric aerosols. On the other hand, Wang and Zhou [2005] found a general decreasing trend in annual mean precipitation and extreme precipitation events in central, north, and northeast of China but an increasing trend in Yangtze River basin during 1960 and 2001. They indicated that the long-term trend in precipitation was associated with a weakening trend in the southwesterly monsoon over East Asia. Therefore the down trends in hail in China could be a result of the reduction of precipitation in the predominant hail-producing regions, such as north and northeast of China (Figure 1). Although both annual precipitation and extreme precipitation events increased in the Yangtze River valley and south of China, the hail frequency shows no trend due to the increasing trend in FLH in the region (Figure 4a).

### 3.3. Vertical Wind Shear

[13] Strong vertical shear is a triggering mechanism for instability energy to release and for hail to form and also favors the growth of hail in thunderstorms [Longley and Thompson, 1965; Etkin and Brun, 1999]. To estimate the change in vertical wind shear, we calculated the mean vertical wind shear in warm season and analyzed its variation and trend. Since the wind observations in the sounding data are available from 1980, only the variation of the mean vertical wind shear in warm season during 1980–2005 is given in Figure 4c. Although there is strong interannual variability, a linear down trend is still clear in vertical wind shear both averaged at the stations with no trend and those with down AHD trend. This indicates a general weakening of the mean baroclinity associated with the meridional temperature gradient in the mid-lower troposphere over China in response to the global warming in the last 2–3 decades [Zhai and Eskridge, 1996]. Although it is stronger in any given year at the stations with down AHD trend than those with no trend, the mean vertical shear should not play a dominant role in the observed down AHD trend since the slopes of the trend in vertical shear for the stations with no trend and for those with down trend are similar.

## 4. Summary

[14] Hail records provided by NMIC from 1960 to 2005 were used to analyze the long-term trend in annual hail days in China. Two distinct periods in the 46 years were identified. In the first period (1960–early 1980s), AHD showed little linear trend, while in the second period (early 1980s and afterwards), there was a significant down AHD trend days. This down trend in AHD was mainly contributed by the down trend in warm season during June–September. Analysis of some climatic factors indicated that the rising trend in freezing-level height, which increased by about 200 m during 1960–2005 is responsible for the decreasing trend in hail frequency. Although it is considered

as a triggering factor for hailstorms, the vertical shear seems not to have played a dominant role in the observed down trend in hail frequency in China since a similar weakening trend in the annual mean vertical shear is found for the stations with and without down AHD trends. The long-term change in CAPE seems to have little correlation with the down trend in hail frequency, however. We considered that although the CAPE increased in the past, the annual mean precipitation and extreme precipitation events in north and northeast of China decreased as a result of the weakening of the East-Asian summer monsoon [Wang and Zhou, 2005], leading to a decreasing trend in hail frequency in these regions. On the other hand, the rising in freezing-level and the increase in aerosols may offset or even dominate the positive effect of CAPE, resulting in little trend in hail frequency in south China. The results from this study may imply a possible reduction of hail occurrence under the global warming due to the increase in freezing-level height in China.

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