Influence of Inhomogeneity on the Estimation of Mean and Extreme Temperature Trends in Beijing and Shanghai①

Yan Zhongwei (严中伟) and Yang Chi (杨 赤)
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029

Phil Jones
CRU, University of East Anglia, Norwich NR4 7TJ, UK

(Received May 31, 2000; revised August 3, 2000)

ABSTRACT

Inhomogeneities in the temperature series from Beijing and Shanghai are analyzed, using the detailed histories of both sets of observations. The major corrections for different periods range from −0.33 to 0.6°C for Beijing and −0.33 to 0.3°C for Shanghai. Annual mean and extreme temperature series are deduced from the daily observations and trends in the adjusted and unadjusted series are compared. The adjusted yearly mean temperatures show a warming trend of 0.5°C / century since the turn of this century and an enhanced one of 2.0°C / century since the 1960s. In contrast, the unadjusted data show a twice this value trend for Shanghai but little trend for Beijing at the long−term scale and overestimate the recent warming by 50%−130%. Beijing experienced a decrease of frequency of the extremes together with a cooling during the 1940s−1970s and an increase of frequency of extremes together with a warming since then. The trends of frequency of extremes at Shanghai were more or less opposite. It is implied that the regional trends of strong weather variations may be different even when the regional mean temperatures coherently change.

Key words: Inhomogeneity, Daily temperature series, Climatic warming, Extreme temperature

1. Introduction

Inhomogeneities in meteorological time series are mainly due to the change of observing sites and times. Urbanization induces another kind of systematic bias to temperature series. It is crucial to adjust for these inhomogeneities before any estimation of long−term climate change can be made. The difficulty in correcting the inhomogeneous series arises from the fact that climate change may result in similar behaviour. Thus any adjustment must correct the series but retain as much as possible of the true course of climate change.

The daily temperature series for Beijing 1915−1997 and Shanghai 1873−1997 are among the longest in China. They provide a base for some recent research projects that explore the details of the climate changes at the longest possible time scales. However, both time series may contain serious inhomogeneities as recorded in the station histories (Tao et al., 1991). In deed, Beijing was rejected from a list of suitable stations in some fine studies of regional climate changes (e.g., Portman, 1993). The present paper aims to reduce the effects of inhomogeneities in the series due to changes in observation systems and urbanization influence and to reconstruct as homogeneous time series as possible for further study.

① The study was supported by the China NKBRSF Project G1999043400, IAP / DF and CAS project (KZ951−A1−402).

Previous homogeneity studies have mainly been based upon monthly or annual series, (e.g., Jones et al. 1986). Recent studies deal in greater detail with the daily series (e.g., the IMPROVE project for long–term daily meteorological data series in Europe and the CLIMB project of extreme climate changes in China). Unfortunately, for the Beijing and Shanghai series, comparable daily data are not always available from nearby regions. This paper illustrates some monthly–based statistical calculations with the studied series and compares these with observations from adjacent sites. The results may provide a base to suggest likely corrections to the studied series (Sections 2 and 3). The urbanization effect during recent decades is considered based on a regional average estimation (Section 4). The adjusted series is therefore of regional mean character. Linear trends in some mean and extreme climate conditions are calculated, in order to see how large a bias the inhomogeneity may induce in the estimation of long–term climate change (Section 5). Section 6 gives a summary.

2. Adjusting the Beijing series

2.1 *Observation history*

Table 1 summarizes the information of the observation history at Beijing (details in Tao et al., 1991). The times of possible discontinuity due to the changes in observing sites and schedules are marked along the daily temperature anomaly series (Fig. 1). An anomaly here is defined as a departure from a mean seasonal cycle (Jones et al., 1999). As showed in Fig. 1, the daily variability is overwhelming so that the discontinuity induced by a site relocation or an observing time change, if any, is not visible. Nor is it effective to study the series with statistical tools for detecting change points. The analysis and the correction, if necessary, should be carried out for each period that is self–consistent within the series.

Table 1. History of Beijing daily temperature observations during 1915–1997

Period	Observing schedule	Height of thermometer and site
1915.4–1925	24 hourly	37.5 m at Pao Zi He, 39°54′N, 116°28′E
1925.1–1925.2	(Max.+min.) / 2	same site
–1928	24 hourly	same site
1929.7	3(6,14,22)	same site
1930–1932	8(3,6,9,12,14,18,21,24)	same site
1933–1937	24 hourly	not known
1940–1945	6 (2,6,10,14,18,22)	51.3m at West Suburb Park, 39°56′N, 116°20′E
1946–1953.5	24 hourly	same site
1953.6–1953.12	24 hourly	52.3 m at Five Tower Temple, 39°57′N, 116°19′E
1954–1960.7	4 (1,7,13,19)	same site
1960.8–1964	4 (2,8,14,20)	53.3 m same site
1965–1968	4 (2,8,14,20)	29.4 m at Daxing County, 39°35′N, 116°19′E
1969–1970.6	4 (2,8,14,20)	53.3 m at Zhanghua, 39°56′N, 116°16′E
1970.7–1980	4 (2,8,14,20)	31.2 m at Daxing County, 39°48′N, 116°28′E
1981–	4 (2,8,14,20)	54 m at Bei Wa Road, 39°56′N, 116°17′E

In the following analysis, the data from three nearby stations, Tianjin, Baoding and Jinan, are used for correcting the Beijing series. Previous studies found that the data from these stations were coherent within the region where Beijing is located (Portman, 1993).

2.2 *For the early period before* 1937

The observing site was the same from the beginning up to 1932 or even 1937, when a period of totally missing observation occurred. During most of this early time, daily temperature was calculated from 24 hourly observations, except for some shorter periods as discussed as follows.

In January–February 1925, daily temperature was calculated as the mean of the daily maximum and minimum. We calculate the mean and variance of daily temperature anomalies for January–February during the early years before 1929, after which breaks of observation occurred. The mean January–February temperature anomaly during the early years is about −0.1°C. The 1925 value, −0.0, was slightly warmer. The same quantity at Tianjin is 0.2°C higher than the mean level of the period 1916–1928. This regional difference can be accepted at the monthly timescale. The different schemes of daily temperature calculation did not cause any serious bias in mean temperature level of January–February 1925. On the other hand, the standard deviation (square root of variance, noted later as STD) of daily temperature anomalies in January–February 1925 (1.9°C) appears smaller than the mean level of that period (3.1°C). It could be possible that the daily temperature variance in 1925 was low, because in general the mean of 2 records should not be less variable than the real daily mean. Daily records from nearby locations are not available. Fortunately, this problem influences only two months. A factor of 1.6 to inflate the deviation of the two months' data is suggested. Similar adjustment can be found in previous studies (e.g., Parker et al., 1992).

For July 1929, observing time changed. We compare the mean and STD of this month against those of July during 1915–1927. The STD of July 1929 (2.2°C) is near to the mean level of 1915–1928 (2.1°C). The mean anomaly of July 1929 (0.6°C) is slightly higher than the mean level of the early period (0.3°C). The nearest station, Tianjin, recorded 26.9°C in July 1929, about 0.6°C warmer than the mean level of that period. Thus, the different scheme of daily temperature calculation did not significantly alter the records of July 1929.

In 1930–1932, daily observations changed again. In 1933–1936, there was not site information. We take 1915–1928 as a reference period and calculate the departure of mean temperature for each calendar month of the possibly biased periods. The monthly mean data of Tianjin are compared, in order to judge if there were relevant natural climate changes.

Table 2. Monthly mean temperature departures from 1915–1928 reference level (M_1 for 1930–1932, M_2 for 1933–1936) of Beijing, comparing those of Tianjin (underlined). Units: °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
M_1	1.2	−2.1	0.4	−0.5	0.4	0.4	0.2	−0.1	0.4	−0.3	−0.6	0.7	0.0
	0.5	−1.7	0.2	−0.2	0.8	0.7	0.2	0.0	0.5	−0.2	−0.8	0.3	0.0
M_2	−2.0	−0.9	−2.6	−1.3	0.5	−0.7	0.3	−0.7	0.1	−1.1	−0.4	1.8	−0.6
	−2.5	−0.8	−2.7	−1.1	0.9	0.0	0.5	−0.9	0.9	−0.9	−0.6	1.6	−0.5

As showed in Table 2, the monthly departures from the reference period in Beijing are quite coherent with those in Tianjin for both the studied periods. Due to regional climate differences at a monthly scale, the absolute values for different calendar months in Beijing do not match exactly those in Tianjin. But at an annual scale, the two adjacent stations show almost the same departures for both periods. Annual variances of daily temperature anomalies also show more or less the same value for the different periods. It is suggested that the bias induced by the 8–observations per day in 1930–1932 should be negligible, and so should that by the resumed 24–observations per day in 1933–1936.

2.3 *For* 1940–1953

In this period, the site remained the same, but observing time changed in 1946. We check whether this induces a bias, by calculating for each period the mean and STD. The STD of the daily temperature anomalies in 1940–1945 (2.9°C) is almost the same as that in 1946–1952 (2.8°C). The mean level in 1940–1945 is 0.4°C warmer than that in 1946–1952. Tianjin also shows a warmer record in 1940–1945, but with a departure as large as 0.9°C. The observations in 1940–1945 might underestimate the daily temperature level in Beijing. However, it is found that 1944–1945 was 0.3°C warmer than the later period at Baoding and 0.7°C warmer at Jinan. We suggest that Beijing's records during 1940–1945 were possibly reduced by 0.2°C, which equals the average anomaly to the 3 nearby stations.

So far, the early data before 1953 have all been adjusted to the 24 hourly reading, but with a site–change after the missing data period 1937–1939. We now compare the mean levels of the corrected temperature anomalies before and after the discontinuity. The records show little difference between the two periods at Beijing. However, Tianjin and Baoding both recorded a nearly 0.5°C cooler period in 1915–1936. Jinan was also cooler but to a lesser extent (0.3°C). It is clear that the region should be cooler in 1915–1936 than 1940–1953. The early observation site of Beijing, located about 20 km southeast of the new site, might overestimate the daily temperatures relative to the new site. We suggest a correction of –0.4°C to the earlier data, based on the mean departure of the 3 nearby stations' records.

2.4 *For* 1953–1964

The site moved in June 1953. The 24 hourly observation scheme was still in effect for the first 7 months. For 1954 up to July 1960, observations were made at 0100, 0700, 1300, 1900 hours local time. The new system of 4 observations a day at 0200, 0800, 1400, 2000 hours local time began in August 1960. Because the observations up to now have kept the new 4 observations a day, we will adjust the earlier records to those of 1961–1964. The variance of daily variability remains more or less unchanged with the new observation system. The mean level of temperature anomalies in 1954–1960 was 0.9°C below the reference level. In contrast, that of Tianjin was 0.7°C below the reference. Baoding and Jinan had even less cold records during the same time. Therefore, the old 4–observation system might underestimate the daily temperatures in Beijing. It can be imagined that the old system (4 observations at 0100, 0700, 1300, 1900 hours local time) tends to miss the daily maximum, which occurs around or after 1400 local time in general. A correction of 0.2°C is suggested.

The mean of Jun.–Dec. 1953, when 24 observations were taken, was 0.1°C below the reference level, while that of Tianjin was 0.6°C beyond the reference. Such a large difference can hardly be purely due to the change in observation system, because climate change may also result in an inter–station difference at the short time–scale such as a few months. In fact, Baoding recorded 0.1°C and Jinan recorded 2.1°C above their reference level for the same period. It was surely warm in 1953 over the region, however. A possible correction, 0.2°C, is suggested, so that Beijing's records during Jun.–Dec. 1953 became slightly warmer than the reference level. This implies that the old 4–observations–per–day system is quite near to the 24–hour observation system, while the new one records slightly warmer values.

2.5 *For the period after* 1965

The site moved in 1965, 1969, and in July 1970, before moving to the present site in 1981. We analyze the three parts of records in order to produce a self–consistent series for the period. The reference period is chosen as 1971–1980. The first period has a temperature anomaly the same as that of the reference. Tianjin also exactly recorded a zero departure during the same time from its reference 1971–1980. The other nearby station, Baoding, had a nearly zero departure, too. Therefore, the records during the two stages at the site of Daxin were quite homogeneous. In contrast, the records during 1969 and the first half of 1970 failed to have as cold anomalies as in Tianjin (–0.7 versus –1.1°C). The other nearby station Baoding also recorded an anomaly of –1.1°C in the same time. A correction of –0.4°C is likely.

The site was moved in 1981. The 4 observations a day schedule has been kept the same up to the present. To estimate the bias due to the site moving, we calculate the differences from reference (1971–1980) of the later periods as Table 3 shows. Because an urban bias might have become larger with time during the most recent years, the site–induced bias should exist only during some short windows adjacent to the reference period. From 1981 onwards, the temperature departure in Beijing has a systematic bias of about 0.6°C against the Tianjin records. Natural climate cannot be the cause of such a regular difference between two adjacent cities. The bias must be due to the site moving in Beijing. A correction of –0.6°C is added to the data of 1981–1997. This large discontinuity is even recognizable in the daily series (Fig. 1).

Table 3. Temperature departures from 1971–1980 level in Beijing (Units: °C, bracketed are Tianjin values)

1981–1982	1981–1983	1981–1984	1981–1985	1981–1986	1981–1987	1981–1988
1.21 (0.59)	1.36 (0.78)	1.15 (0.57)	0.96 (0.39)	0.93 (0.37)	0.92 (0.39)	0.97 (0.43)

As shown in Table 3, the bias does not increase with the length of time window used for comparison. This fact implies that there is no stronger urbanization effect in Beijing than in Tianjin, because, otherwise, the bias should increase with time. However, both cities have developed rapidly since the 1980s. The listed results suggest that the urban bias in Beijing should be comparable to that in Tianjin.

Now we can recognize 3 periods, 1915–May 1953, June 1953–1964 and 1965 onwards, during which the data have been self–consistent. Before correcting for the urban bias, we need to adjust the 3 major periods to each other. We only need to compare the three reference periods, 1946–1952, 1961–1964 and 1971–1980, to which the data of the three major periods have been adjusted, respectively. Taking the mean level of 1961–1964 as a reference, we found that both the earlier and later periods were cooler in both Beijing and Tianjin. However, the departure of Beijing in the later period is much larger (–0.9°C) than in the earlier period (–0.5°C). In contrast, Tianjin's records show almost the same departure for the earlier and later periods (–0.4°C). The records of Jinan and Baoding also show a similar pattern. Therefore, the cooler part of Beijing records in the later period is probably due to a site change. A correction of 0.4°C is added to the data of 1965–1997. Finally, for the convenience of updating the series, we add 0.2°C to whole series, so that all the series are adjusted to the recent observations.

3. Adjusting the Shanghai series

3.1 *Observation history*

Table 4 summarizes the information of the observation history at Shanghai (details in Tao et al., 1991). The times of possible discontinuity due to the changes of observing sites and schedules are marked along the daily temperature anomaly series (Fig. 2). Similarly, we analyze the series section by section before adjusting the whole. The monthly data from three nearby stations, Nanjing, Hangzhou and Anqing, will be referenced for adjustment.

Table 4. History of Shanghai daily temperature observations during 1873–1997

Period	Observing schedule	Height of thermometer and site
1873–1874	(Max.+min.) / 2	7.0 m, Xujiahui, 31°12'N, 121°26'E
1875–1878	Unknown	Same site
1879–1900	24 hourly	Same site
1901–1950	24 hourly	4.6 m, same site
1951–1953	4 (2,8,14,20)	Same site
1954–1955	4 (1,7,13,19)	Same site
1956–1960.7	4 (1,7,13,19)	4.5 m, Longcao Road, 31°10'N, 121°26'E
1960.8–	4 (2,8,14,20)	Same site

3.2 *For the early period before* 1950

During 1873–1900, observing site remained the same. The observing schedule was not clear for the years 1875–1878. Unfortunately, there were not comparable data from nearby regions until the 1900s. We calculate the monthly mean and STD of daily anomalies. The annual mean STDs for 1879–1900 are between 2.1–2.9°C (averagely 2.4°C). Those before 1879 are between 2.1–2.7°C (averagely 2.5°C). The annual mean temperature anomalies for 1879–1900 range from −1.0 to 0.2°C (averagely −0.4°C). Those before 1879 are between −0.8 and 0.2°C (averagely −0.5°C). Statistically, there is no strange reading during the early years. Although the analysis does not ensure a self–consistent series, correction is unlikely.

The site remained the same but facility seemed changed in 1901, without details. We compare the average temperature anomalies of decades before 1900 and after 1901. The average value for 1881−1900 is almost the same as that for 1901−1920, both about −0.4°C. That for 1891−1900 remains about −0.4°C, while that for 1901−1910 is −0.5°C. It is likely that the whole early period remains at a quite stable cooler level, though the protocol change in 1901 may induce some small bias. We would regard the early data series as a nearly homogeneous one.

3.3 *For the* 1950s–1960s

Observing time changed from 1951−1953 to 1954–July 1960 with a site change in 1956. The departures of mean temperature anomalies for the different periods against the reference level of 1931−1950 are listed in Table 5. The mean values of the nearest stations, Nanjing and Hangzhou, are compared to see if those departures are natural in the region.

Table 5. Departures of mean temperature anomalies of Shanghai against the reference level of 1931–1950. Bracketed are the average mean values of Nanjing and Hangzhou. Units: °C

1951–1953	1954–1955	1956–1959	1961–1965	1961–1970
0.3 (0.0)	−0.1 (−0.4)	−0.4 (−0.7)	0.1 (−0.2)	−0.1 (−0.4)

Table 5 shows a systematic bias of 0.3°C in the records of Shanghai, relative to the nearby stations. The bias seems persistent through the series since the 1950s. A correction of −0.3°C is likely for the Shanghai series after 1950. For the convenience of updating new data, we add 0.3°C to the early series before 1950. This implies that the reference level of 1931−1950 in Shanghai should be underestimated. Indeed, another nearby station Anqing also shows, albeit with fewer records, warmer anomalies during 1931−1950 than Shanghai.

4. Urbanization correction

So far, the series have been adjusted with respect to all observing scheme and site−induced biases. The resultant series should represent some regional trends, because adjacent stations are taken as references for adjustment. It is noted that all the adjacent stations used here are located in large cities as well. Assuming that urbanization effects are more or less the same among these cities as implied in Tables 3 and 5, the so−far−corrected series will retain any urban bias. A few authors used to analyze the urban−induced warming trend in China (e.g., Wang and Zang, 1990; Zhao, 1991; Portman, 1993). Especially, Portman (1993) estimated a regional mean urban bias for China. Due to the lack of proper rural site data, we can hardly make further quantitative analysis. However, the results of the previous studies may help us to estimate an additional adjustment to the studied series.

Three points are summarized here from the study of Portman (1993). (a) The mean trend induced by urbanization effect in annual temperature series of major cities in China since the 1950s to the 1980s was about 0.26°C / 30 years. (b) Seasonal urban bias variations were not important, though spring might suffer slightly more. (c) The urbanization−induced trend became significant since the middle 1960s. Considering that both cities expanded rapidly since the 1980s, a slightly larger urban trend is estimated to be 0.30°C / 30 years (or 0.01°C / year) for Beijing and Shanghai during 1965−1997. Before 1965, the urban bias is considered to be negligible.

In summary, Figs. 1 and 2 show the corrections or adjustments for both series. For Beijing, the major positive correction culminates to about 0.6°C at the beginning of 1965, while the major negative correction culminates about −0.33°C in the end of 1997. The large negative correction in recent years is entirely due to the urban bias. The earlier adjustments are mainly due to site changes. For Shanghai, besides the same urban bias correction, a positive adjustment of 0.3°C is added to the early part of the series before 1951. The adjusted part is small relative to the large daily variations, but it may be important for estimating the long−term trend of climate change.

5. Trends in annual mean and extreme temperature series at Beijing and Shanghai

Trends in a few quantities are considered to describe climate changes, based on the daily

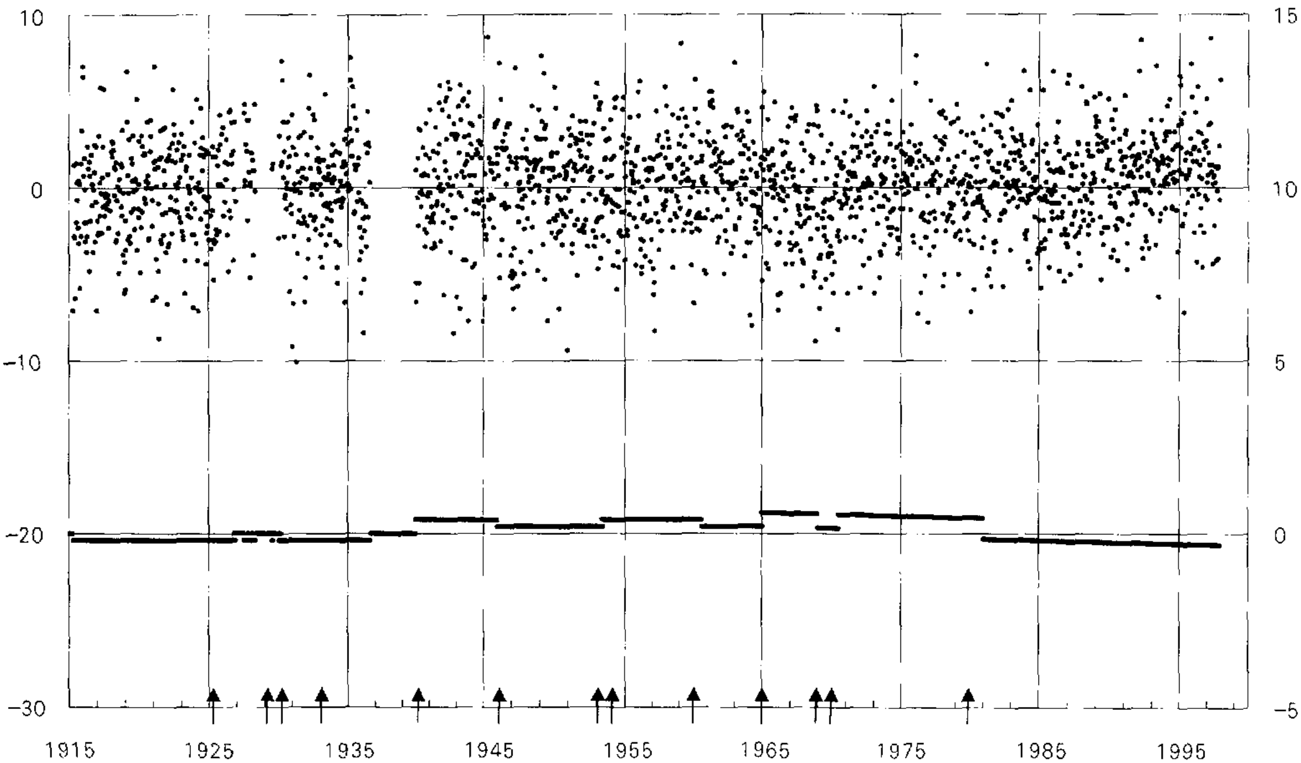

Fig. 1. Beijing daily temperature anomalies from the mean seasonal cycle 1915−1997 (upper panel, left coordinate: °C). For a succinct view, only one record each fortnight is plotted. Blank along the time axis means record missing. Arrows mark the changes of observing site and method to calculate daily temperature. The lower panel shows the adjustment (right coordinate: °C).

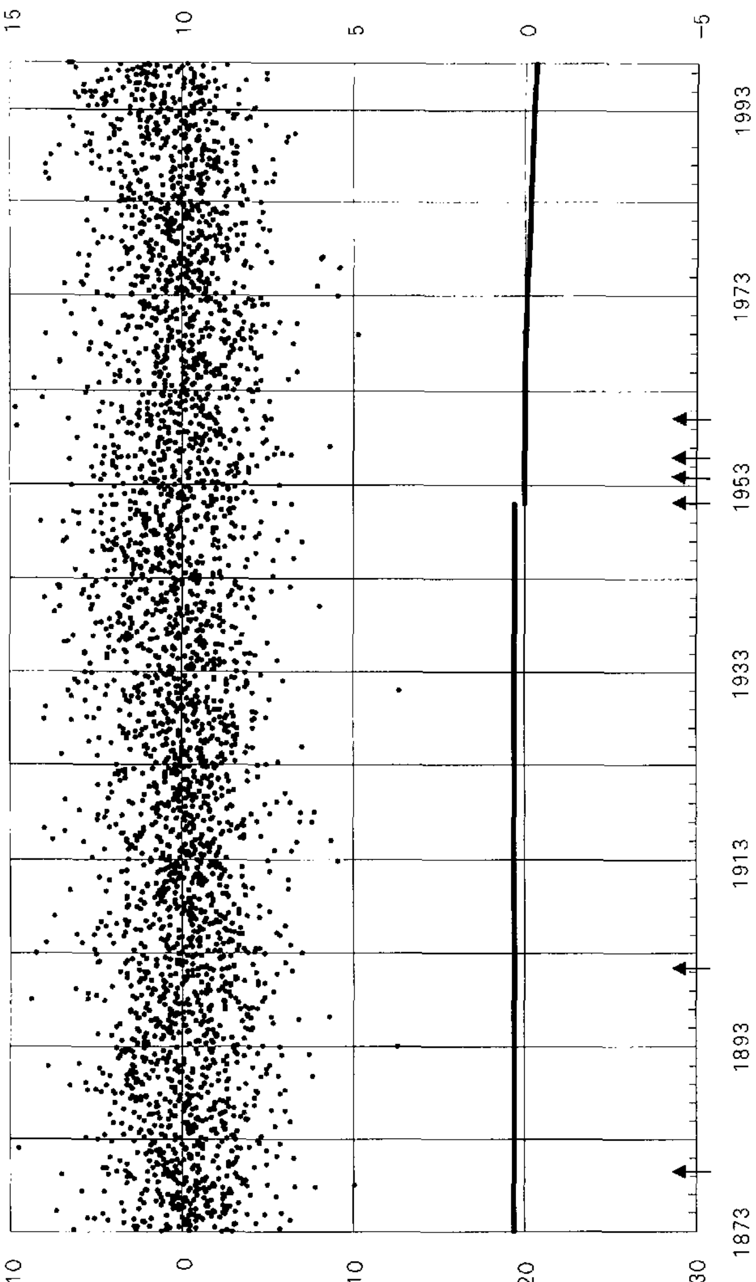

Fig. 2. Same as Fig. 1 but for Shanghai 1873–1997.

temperature observations. Besides the most common quantity, the annual mean temperature anomaly, we are interested in some extreme climate changes. Here we define the annual extremely low (high) temperature as the average of 5% coldest (warmest) daily records among the total ones of the year. Another important quantity is the frequency of relatively extreme events. For each year, there are some unusually warm and cold events, with respect to the normal for the time of year. They reflect strong weather–timescale disturbances. For each calendar day, a frequency distribution is defined by all the observed daily temperature anomalies of that day and four adjacent calendar days (Jones et al., 1999). For each year, the number of the days with temperature anomaly beyond the 5 / 95 percentile limits of the climatological distribution defines the annual frequency of extremely cold / warm events. For convenience of discussion, all the frequencies are unified into days per hundred days, i.e., percentages (%).

Table 6 lists the linear trends of the different quantities at Beijing and Shanghai, based on the adjusted and unadjusted data series. The trends are calculated for the whole series (referred to thereafter as the long–term) and the part since 1961 (referred to thereafter as the short–term), in order to compare the different influences of the inhomogeneities on different time–scale series. The Mann–Kendall's test (Sneyers, 1990) is used to judge if there is a significant trend in the series, with a significance level of 0.01. Figures 3 and 4 depict the trends in annual mean temperatures (T_m) and the annual frequencies of extremes ($F_c + F_w$).

Table 6. Linear trends in annual series of temperature changes at Beijing and Shanghai, compared between adjusted and original data. The insignificant positive (negative) trends are marked with+(–). T_m: annual mean temperature; T_c: extremely cold temperature; T_w: extremely warm temperature; F_c: frequency of extremely cold events; F_w: frequency of extremely warm events. Units are °C / century for temperatures and percentage / century for frequencies

For	Beijing 1915–		Beijing 1961–		Shanghai 1873–		Shanghai 1961–	
	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original
T_m	0.5	+	1.9	4.4	0.5	1.0	2.0	3.0
T_c	2.8	2.6	6.7	9.2	0.7	1.2	6.6	7.6
T_w	–1.0	–1.2	–	+	+	1.0	+	+
F_c	–	–	–	–	–1.4	–3.5	–	–6.7
F_w	–	–	+	16.2	1.8	3.9	+	+
$F_c + F_w$	–2.5	–	+	+	+	+	–	+

The adjusted annual mean temperatures at Beijing and Shanghai both show a long–term warming of 0.5°C / century. This is near to the recent estimated global average warming of about 0.6°C / century based on global data (IPCC, 2000) and that over whole China about 0.4°C / century based on multi–types of data (Wang and Gong, 2000). We can even see from Figs. 3 and 4 some coherent inter–decadal variations between Beijing and Shanghai annual mean temperature series. As Beijing and Shanghai are both located in the mid–low latitudes within the same climate regime such as eastern Asian summer and winter monsoons, the similar long–term trends are not unreasonable.

In contrast, the unadjusted series show a long–term trend twice this at Shanghai but little at Beijing. This incoherence is clearly due to the inhomogeneities induced by the recent urban bias and the early observing protocol changes (Figs. 1 and 2). Indeed, previous studies using unadjusted data series could hardly find such coherence of temperature changes between

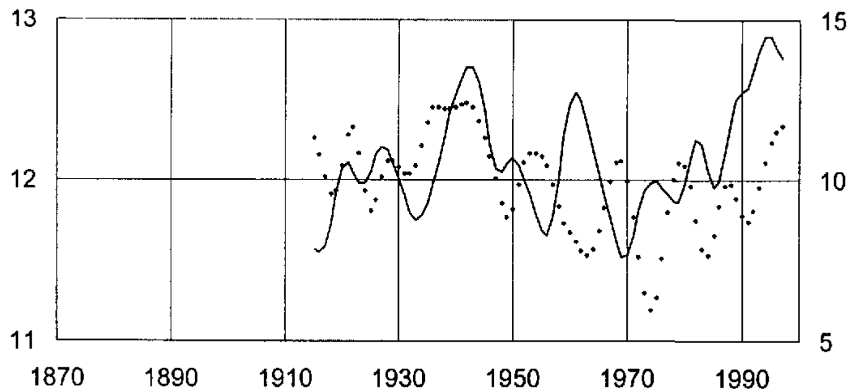

Fig. 3. The 11–year–binomial smoothed annual mean temperature series (thin) and the annual frequency of extremes (dot) for Beijing. The right axis is for frequency (%) and the left for temperatures (℃).

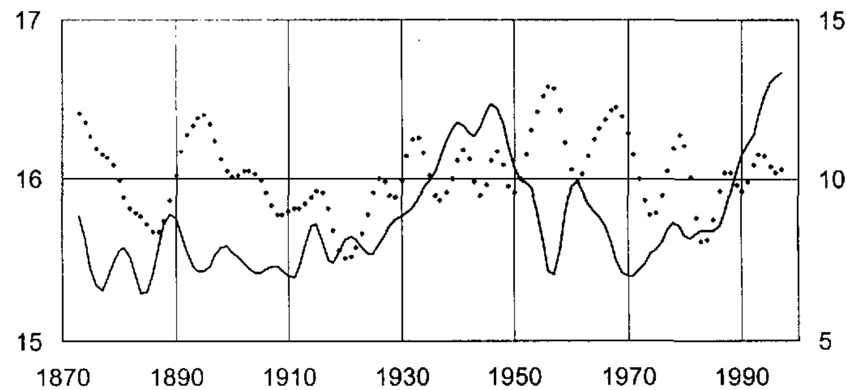

Fig. 4. Same as Fig. 3 but for Shanghai.

Beijing and Shanghai (e.g., Yan and Zhang, 1993).

Since the 1960s, the adjusted annual mean temperatures at Beijing and Shanghai show again a similar but enhanced warming trend of 1.9–2.0°C / century. The original data overestimate this trend by 50% at Shanghai due to urban bias and 130% at Beijing due to both urban bias and a site change from suburb to more–urban location.

The extremely cold temperatures at Beijing and Shanghai both have significantly warmed. At the long–term scale, the original data keep almost the same trend at Beijing (2.8°C / century) but overestimate the trend at Shanghai (0.7°C / century) by 0.5°C / century. The annual coldest temperature in China is mainly controlled by the winter cold surges from Siberia. When Siberia became warmer and therefore the cold surges became weaker, North China might be earlier and more influenced. If it is the case, the stronger warming in the coldest temperature in Beijing than in Shanghai is understandable (Yan and Yang, 2000).

Since the 1960s, however, the coldest temperatures at both Beijing and Shanghai have exhibited a warming about 6.6–6.7°C / century. The original data overestimate the trend by 37% at Beijing and 15% at Shanghai. The larger increase of the coldest temperatures at Shanghai implies that the area of influence of the weakened winter cold surges has much expanded southward in the recent decades.

The trends in extremely warm temperatures are not significant, except the cooling of −1°C / century at Beijing at the long–term scale. The unadjusted data do not bias much but exaggerate the insignificant warming trend at Shanghai at the long–term scale as a significant one. Comparing the trends in the coldest and warmest temperatures, we may conclude that the seasonal cycle has weakened by 3.8°C / century during the last century for Beijing, but not so clearly for Shanghai.

The frequencies of relatively cold extremes have decreased, with a significant rate of −1.4% per century at Shanghai at the long timescale. The original data of Shanghai overestimate the long–term decreasing trend by more than double and exaggerate the recent insignificant trend as a significant one.

The frequencies of relatively warm extremes have experienced different changes between Beijing and Shanghai. For Beijing, a decreasing trend prevails until recent decades. During the recent decades, together with the enhanced warming, warm extremes have increased. For Shanghai, the increasing of warm extremes (1.8% per century) is significant at the long–term scale. The original data overestimate it by more than double. The increasing trend becomes insignificant during the recent decades due to large interannual variations.

Combining the frequencies of warm and cold extremes, we find a significant decreasing trend of −2.5% per century at Beijing at the long–term scale. A change to increasing frequency of extremes occurs during the recent decades. In contrast, an increasing trend is more dominant at Shanghai during the early time but tends to stop during the recent decades (Figs. 3 and 4). This suggests that the changes of strong weather–scale disturbances may be quite different between Beijing and Shanghai, though the mean temperatures have coherently increased.

6. Summary

The inhomogeneities in the daily temperature observations at Beijing and Shanghai are analyzed, according to detailed station histories. Likely adjustments are suggested, based on nearby stations' data and a regional average urban bias. The adjusted series may, therefore, be of some regional average character. Although further corrections are plausible, the present analysis should have suppressed the inhomogeneities as much as possible under the present data condition. The major corrections for the Beijing series range from −0.33 to 0.6°C and those for Shanghai from −0.33 to 0.3°C.

The adjusted annual mean temperature series show a warming trend of 0.5 °C / century since the turn of this century and an enhanced one of about 2.0°C / century since the 1960s at both stations. The unadjusted data overestimate the recent warming by 50% for Shanghai and 130% for Beijing, and they suppress the long–term warming trend at Beijing but double that at Shanghai.

The significant trends in extreme temperatures suffer less from the inhomogeneities, with biases ranging from 10% to 70%. The annual coldest temperatures have increased about 1–2°C during the last century. The increasing rate in the coldest temperature has enhanced to about 6–7°C / century at both Beijing and Shanghai during the last few decades. In contrast, the annual warmest temperatures have not much changed or even decreased by 1.0°C / century at Beijing during the last century. This has led to a weakening seasonal cycle during the last century (by 3–4°C / century at Beijing but less clearly at Shanghai).

The changes in frequency of relative extremes are different in different regions. Beijing experienced a decrease of frequency of the extremes together with a cooling during the 1940s–1970s and an increase of frequency of extremes together with a warming since then. The trends of frequency of extremes at Shanghai appeared more or less opposite to those at Beijing (Figs. 3, 4). This means that trends of strong weather variations may be different at different regions even when the mean temperatures coherently change.

Inhomogeneities in time series form a complicated problem in analyzing climate change. They induce various biases at different observation stations and periods. It is hard to thoroughly negate their influence in the studied time series. The present analysis may have provided a basis for quantitatively judging the extent to which the inhomogeneities bias the temperature series of Beijing and Shanghai. Further judgment needs more detailed information of observing history and comparable adjacent regional data.

This work is carried out at CRU, UEA under a Royal Society BP fellowship. Thanks are due to Prof. Zeng Zhaomei for her assistance in data.

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观测序列的不均一性对估算北京和上海的平均温度与极端温度变化趋势的影响

严中伟　杨　赤

摘　要

根据北京和上海气象观测站的详细历史资料，修正了两站逐日温度序列的不均一性，并分析这种不均一性对长期气候变化趋势估计的影响。对北京序列，不同时期的主要修正幅度在−0.33−0.6°C；对上海序列则为−0.33−0.3°C。从逐日序列计算出年平均温度和年极端温度序列，并把修正之前和修正之后的序列趋势进行比较。修正之后的两站年平均温度序列自20世纪初起呈现出0.5°C／百年的变暖趋势，自20世纪60年代起这一趋势增强为2.0°C／百年。相比之下，上海的未修正资料显示出两倍于此的趋势；北京的未修正资料几乎没有长期趋势，而对近期的变暖趋势则高估了50%−130%。北京温度序列在20世纪40年代至70年代呈变冷趋势，极端事件的频率降低；此后又呈变暖趋势，极端事件的频率增加。上海温度极端事件的变化趋势基本呈相反趋势。这意味着即使区域性平均温度变化一致，区域性强天气波动的变化趋势也会有所不同。

关键词：不均一性，逐日温度序列，气候变暖，极端温度