Climatic Change (2014) 122:595–608
DOI 10.1007/s10584-013-1013-z

Detection of urbanization signals in extreme winter minimum temperature changes over Northern China

Qingxiang Li • Jiayou Huang • Zhihong Jiang • Liming Zhou • Peng Chu • Kaixi Hu

Received: 28 February 2013 / Accepted: 19 November 2013 / Published online: 8 December 2013

Abstract Although previous studies show that urbanization contributes to less than 10 % of the long-term regional total warming trend of mean surface air temperature in northeast China (Li et al. 2010), the urban heat island (UHI) impact on extreme temperatures could be more significant. This paper examines the urbanization impact on extreme winter minimum temperatures from 33 stations in North China during the period of 1957–2010. We use the Generalized Extreme Value (GEV) distribution to analyze the distribution of extreme minimum temperatures and the long-term variations of the three distributional characteristics parameters. Results suggest that among the three distribution parameters, the position parameter is the most representative in terms of the long-term extreme minimum temperature change. A new classification method based on the intercommunity (factors analysis method) of the temperature change is developed to detect the urbanization effect on winter extreme minimum temperatures in different cities. During the period of rapid urbanization (after 1980), the magnitude of variations of the three distribution parameters for the urban station group is larger than that for the reference station group, indicating a higher chance of occurrence of warmer weather and a larger fluctuation of temperatures. Among different types of cities, the three parameters of extreme minimum temperature distribution of the urban station group are, without exception, higher than those of the reference station group. The urbanization of

---

Electronic supplementary material The online version of this article (doi:10.1007/s10584-013-1013-z) contains supplementary material, which is available to authorized users.

Q. Li (✉) • K. Hu
China Meteorological Administration, National Meteorological Information Center,
46 Zhongguancun South Avenne, Haidian District, Beijing, China 100081
e-mail: liqx@cma.gov.cn

J. Huang
Department of Atmospheric and Oceanic Science, School of Physics, Peking University,
100872 Beijing, China

Z. Jiang • P. Chu
School of Atmospheric Science, Nanjing University of Information Science and Technology,
Nanjing 210044, China

L. Zhou
Department of Atmospheric and Environmental Sciences, University at Albany,
State University of New York, Albany, NY 12222, USA

different types of cities all show a warming effect, with small-size cities have the most evident effects on extreme minimum temperatures.

1 Introduction

Associated with the escalation of global warming, the frequency and intensity of extreme weather/climate events and resulting climatic disasters have been increasing during the past several decades (IPCC 2012). Existing studies have found significant changes in temperature-related indices worldwide in the last 50 years. For instance, extreme minimum temperature has shown an evidently increasing trend, with more warm nights, fewer frost days, and a decline in the annual diurnal temperature range (Easterling et al. 1997; Alexander et al. 2006; IPCC 2007). The change of extreme temperature in China generally coincides with that in the world, but exhibits apparent seasonal and regional differences (Zhai and Pan 2003; Zhou et al. 2009; Li and Huang 2012). Over the 40 years 1951~1990, the minimum winter temperature across China rose by 2.5 °C on average (Zhai and Ren, 1997). Studies using a longer record suggest that the annual mean minimum temperature in China displays a general upward trend by 0.28 °C/10 years from 1951 to 2002, and the annual mean minimum temperature in winter has grown by 0.49 °C/10 years (Tang et al. 2005).

Marked progress has been made internationally in the study of impacts of urbanization on mean surface air temperatures. At the global scale, it is generally agreed that the contribution of urbanization to global warming is limited (Jones et al. 1990; Peterson 2003; Parker 2004; Hansen et al. 2010; Brohan et al. 2006). At the regional scale, the climatic impact of UHI is more significant. In the US, urbanization contributed to an average increase of surface air temperature of ~0.06 °C between 1901 and 1984 (Karl et al. 1988), ~0.07 °C between 1900 and 2009 (Hansen et al. 2010) and ~0.12 °C/10 years during the mid-20th century (Kukla and Gavin 1986).

The methods used to quantify the contribution of urbanization to climatic warming fall into four categories: the first method is to use the difference of the time series between urban and nearby rural (non-urban) stations as a measurement of urbanization (e.g., Li et al. 2004a); the second method is to use the difference between the data collected at ground observation stations and the reanalysis data that are not obtained from ground stations (e.g., Kalnay and Cai 2003; Zhou et al. 2004; Zhang et al. 2005a, b); the third method is to use other data (e.g. upper air temperature or sea surface temperature) as a proxy for non-urban stations to compare with urban stations (e.g., Jones et al. 2008); and the fourth method is to use satellites to estimate the rate of urban growth then relate this to temperature increases (Yang et al. 2011) . Results from these four methods differ greatly across China: 0.01 °C/10 years (Li et al. 2004a, 2010), 0.02 °C/10 years (Fang et al. 2007), 0.03~0.05 °C/10 years (Hua et al. 2008), 0.05 °C/10 years (Zhou et al. 2004), 0.07 °C/10 years (Du et al. 2007; Fang et al. 2007), 0.10 °C/10 years (Jones et al. 2008), 0.11 °C/10 years (Ren et al. 2008), 0.12 °C/10 years (Zhang et al. 2005a, b), 0.14 °C/10 years (Yang et al. 2011) and 0.33 °C/10 years (Chu and Ren 2005).

The aforementioned studies have been focused primarily on the impacts of urbanization on mean temperatures but very little on the changes in extreme temperatures, while urbanization has the strongest impacts on night (minimum) temperatures, particularly in winter in China, as discussed previously (Zhou et al. 2004; Hua et al. 2008; Li et al. 2010; Yang et al. 2011; Li and Huang 2013). Although Li et al. (2004a), Hua et al. (2008), Li et al. (2010) indicated that urbanization in north and northeast China contributes to less than 10 % of the regional total warming during last 50 years, the urbanization impact on winter extreme temperatures could be more significant. As Northern China is one of the regions which have experienced rapid urbanization, it can be used as a good case study to investigate how urbanization affects extreme winter minimum temperatures. Hence, the present study starts by identifying urban versus rural stations by developing a new classification approach. It is followed by a detailed investigation about the effect of urbanization on extreme winter minimum temperatures in Northern China from the perspective of the probability distribution of temperature and its long-term variations of characteristic parameters.

2 Data and methods

As noted in Li et al. (2004a), it is more reasonable to focus on a small region where the rural and urban stations likely share the same regional or large-scale meteorology. After carefully assessing the data quality, reliability, and homogeneity, we focus our study in a region in North China centered on the larger area of Beijing-Tianjing-Tangshan where rapid urbanization has occurred. This region represents the northeast part of the rapid urbanization zones in China and thus has the most likely urbanization impact on the minimum winter extreme temperatures. It consists of 33 spatially well distributed stations (Fig. 1).

The observed surface air temperature data set we used here are derived from the Chinese meteorological National station network (reference and basic stations) for January 1, 1957 to December 31, 2010, as processed by the China National Meteorological Information Center (NMIC). This dataset has been adjusted for homogeneity and abrupt discontinuities (Li et al. 2004b; Li et al. 2009). The adjustments improved the reliability of the data and decreased uncertainties in the study of observed climate change in China but to some extent kept the gradual urbanization signal in the time series (Li and Dong 2009; Li 2011).

A change in temperature is manifested not only by the mean value which is only one of the characteristic parameters of the probability distribution of temperatures, but also by other parameters. Unlike previous studies, the present study focused on the change in the probability distribution of extreme minimum temperature. There are various definitions of extreme weather events (Alexander et al. 2006). Here we define the extreme winter minimum temperatures in each year as the 3 lowest values of daily minimum temperatures in winter (Zhang et al. 2005a, b).

Extremes generally can be studied by fitting a GEV distribution to block maxima (e.g., annual maxima) or by fitting a generalized Pareto distribution (GPD) to excesses of peaks-over-threshold (Coles 2001). Wang et al. (2013a) find that two fitting approaches are comparable in terms of stability when the sample size is moderate. Here in this paper, we fit the GEV distribution to 30 samples (the 3 most extreme values in each of 10 blocks (the most extreme, 2nd most extreme and 3rd most extreme)). We first checked the samples and found that the 3 lowest daily minimum temperatures always happen in each of the 3 winter months (December and following Jan and Feb) in this region, which is like a block maxima (monthly maxima) GEV fitting. In addition, the Walker's test is performed as done in Wang et al. (2013b), the results suggest that the changes in extreme minimum temperature are field significant at the 5 % level, in the field of 33 stations, which would not impact the estimation errors of the 3 parameters of GEV.

Estimating the GEV distribution parameters generally consists of two major methods, maximum likelihood methods and L-moments methods. After comparing the fitted optimal results, Chen et al. (2010) found that among these two methods, the latter is easier to calculate and also is more accurate for smaller samples. Therefore we adopt the L-moments method to estimate the three parameters of the GEV distribution for the extreme minimum temperatures for different 10-year windows (Coles 2001; Chen et al. 2008; Supplementary Information(SI)).

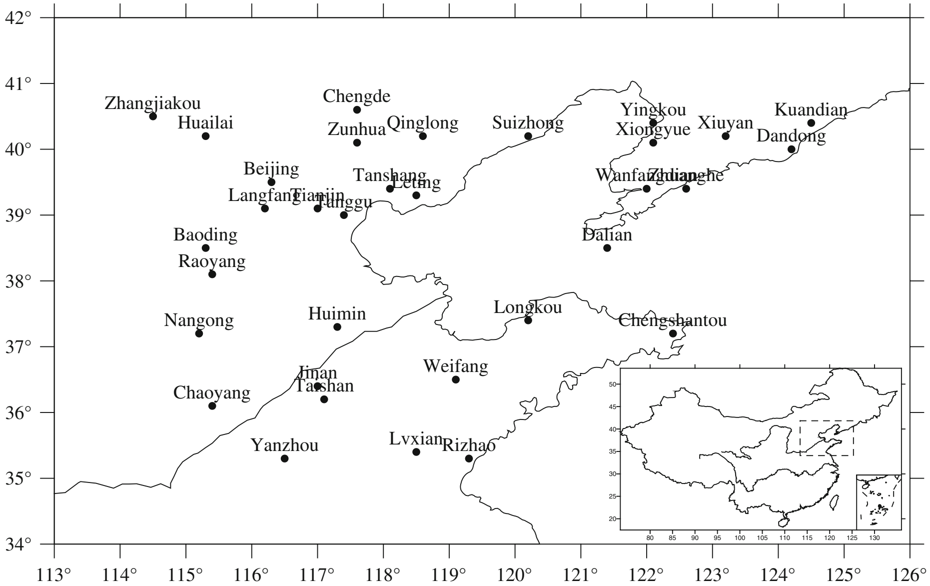

Fig. 1 Geographic location of stations over the study region

3 Climate features of extreme winter minimum temperature distribution parameters and their application in stations classification

For each of the 33 stations, the 3 daily extreme winter minimum temperatures in each year are used to estimate the GEV distribution parameters (using equations (5)-(7) in SI) over different 10-year windows successively shifted by 1 year. We divide the 54 years of data into 44 10-year periods, 1957–1966, 1958–1967, 1959–1968, and 2001–2010. The median year in each 10-year period is used as the representative year for each 10-year window (or each climatic stage), and as a result, we obtain 44 GEV parameters representing the period of 1963–2006, which are referred to as time series of the three distribution parameters.

We calculated the climatology of the time series of the 3 GEV parameters: mean, standard deviation and coefficient of variation (CV), for the period of 1963–2006. It is evident that the shape parameter CK is between 0 and 0.5, representing the approximate shape of the probability dense distribution curve of the extreme minimum temperature in Northern China. The peak value of the curve is located on the right side of the position parameter CM. The distribution of the curve reflects the regularity of the extreme minimum temperature variations in Northern China, i.e. the probability of the occurrence of above −17.1 °C is relatively high, with the range of temperature fluctuation of 2.3 °C. We also noticed that the position parameter CM had the least dispersion coefficient, indicating that it has the best representativeness of long term extreme minimum temperature changes.

To find out the common characteristics of the 3 distribution parameters across the 33 stations in Northern China in terms of long term variations, a principal factor analysis is applied to the time series of the distribution parameters for the period of 44 years over the study region. Further, we checked the variance contribution explained by the first 3 common factors and their accumulated variance contribution. It is evident that the first common factor for all of the 3 distribution parameters has contributed ≥69 % of the total variance. Among the 3 parameters, the 1st common factor of the position parameter has a ~90 % variance contribution. Compared with the other two parameters, it represents the major common characteristics of year-by-year variations at different climatic stages.

It is generally believed that the linear trend of temperatures at rural stations is less evident than that at urban stations. Given the aforementioned uncertainties in classifying urban versus rural stations, here we first employ the classification method of factor analysis to classify the 33 stations into two groups: presumed "urban" and "rural" stations (Huang 2007). The above analysis shows that among the 3 GEV distribution parameters, the position parameter can best reflect the average state of most frequently occurring extreme minimum temperatures. So, the result of factor analysis can be utilized to classify the stations based on the characteristics of these parameters. Specifically, the 1st factor loading is used as the main criteria to classify the 33 stations into two groups. The first group consists of the stations whose 1st factor loading value is<0.88 (see Table 1). There are 3 stations belonging to this group (Taishan, Chaoyang and Xiuyan). The mountainous station, Taishan, can be regarded as having no urban impacts. Chaoyang and Xiuyan are two typical rural stations according to the metadata of the station. Another two stations, Weifang and Tangshan, are also classified into the "rural" group, but we regroup them subjectively into the "urban" station group as they are two typical urban stations. The remaining 30 stations with the 1st factor loading value greater than 0.88 (Table 1 and Fig. 5) are all defined as the "urban" station group.

The stations in the "urban" group can be further classified into different groups according to the loading distribution in the factor analysis of the extreme minimum temperature measured at the 33 stations in Northern China (Huang 2007). We divide the urban station group into 3 types of stations according to the loading of the 1st factor, while taking account of the loading distribution of the 2nd and 3rd factors as a reference (Fig. 2): the 1st type of station group is marked as group 'A', in which the 1st factor loading is 0.95~0.98, the 2nd factor loading is −0.3~0.1, and the 3rd factor loading is −0.4~0.3; the 2nd type of station group is marked as group 'B', in which the 1st factor loading is 0.88~0.95, the 2nd factor loading is −0.4~0.3, and the 3rd factor loading is −0.4~0.4; the 3rd type of station group is marked as group 'C', in which the 1st factor loading is 0.95~0.97, the 2nd factor loading is −0.1–0.3, and the 3rd factor loading is -0.2~0.0. The 1st, 2nd, and 3rd factor loadings and geographic locations of the stations in these groups are shown in Table 1 and Fig. 2.

The different urban types correspond roughly to the classification of the stations according to urban population. As shown by the classification in Table 1, the 'A' type consists of 11 stations, among which 10 are located in cities with a population smaller than 500,000. Therefore, the 'A' type stations can be seen as a station group located in small-size cities. The 'B' type comprises 8 stations, among which 6 lie in cities with a population between 500,000 and 1,000,000. Consequently, the 'B' type stations can be referred to as stations in medium-size coastal cities. Among the 11 'C' type urban stations, 6 are located in cities with a population over 1,000,000, and so they can be called large-size urban stations. This classification based on the factor analysis agrees well with our previous judgment of the station's circumstance.

4 Impacts of urbanization on extreme winter minimum temperature

For each year we aggregate spatially the extreme winter minimum temperatures at the 33 stations in our study region into the "urban" and "rural" groups, and then calculate the GEV parameters at different 10-year windows as described previously for the period of 1963–2006.

Table 1 The values of the 1st, 2nd, and 3rd factor loadings of different types of stations in the urban group

Group	Station number	1	2	3	Station name	Province	Latitude (N)	Longitude(E)
Ref	54486	0.83	−0.39	0.39	Xiuyan	Liaoning	40.2	123.2
	54808	0.88	0.08	0.06	Chaoyang	Shandong	36.1	115.4
	54826	0.88	0.28	0.16	Taishan	Shandong	36.2	117.1
A	54405	0.98	−0.02	−0.07	Huailai	Hebei	40.2	115.3
	54429	0.95	−0.25	−0.09	Zunhua	Hebei	40.1	117.6
	54436	0.97	−0.04	0.05	Qinglong	Hebei	40.2	118.6
	54454	0.97	−0.15	0.05	Suizhong	Liaoning	40.2	120.2
	54476	0.97	0.02	0.11	Xiongyue	Liaoning	40.1	122.1
	54493	0.97	−0.08	0.11	Kuandian	Liaoning	40.4	124.5
	54563	0.97	−0.07	0.13	Wanfangdian	Liaoning	39.4	122.0
	54584	0.95	0.04	0.25	Zhuanghe	Liaoning	39.4	122.6
	54725	0.98	0.03	−0.02	Huimin	Shandong	37.3	117.3
	54936	0.96	−0.23	0.05	Lvxian	Shandong	35.4	118.5
	54945	0.97	−0.05	0.07	Rizhao	Shandong	35.3	119.3
B	54497	0.92	0.04	0.34	Dandong	Liaoning	40.0	124.2
	54534	0.88	−0.41	−0.11	Tanshang	Hebei	39.4	118.1
	54539	0.94	−0.28	−0.12	leting	Hebei	39.3	118.5
	54602	0.92	0.09	−0.37	Baoding	Hebei	38.5	115.3
	54623	0.91	0.19	0.33	Tanggu	Tianjin	39.0	117.4
	54753	0.93	−0.23	−0.25	Longkou	Shandong	37.4	120.2
	54776	0.95	0.26	0.03	Chengshantou	Shandong	37.2	122.4
	54843	0.88	−0.41	−0.01	Weifang	Shandong	36.5	119.1
C	54401	0.96	0.23	0.01	Zhangjiakou	Hebei	40.5	114.5
	54423	0.95	0.17	−0.18	Chengde	Hebei	40.6	117.6
	54511	0.96	0.23	−0.10	Beijing	Beijing	39.5	116.3
	54471	0.97	0.20	0.00	Yingkou	Liaoning	40.4	122.1
	54518	0.96	0.02	−0.25	Langfang	Hebei	39.1	116.2
	54527	0.96	−0.19	−0.10	Tianjin	Tianjin	39.1	117.0
	54606	0.95	0.27	−0.06	Raoyang	Hebei	38.1	115.4
	54662	0.96	0.26	−0.01	Dalian	Liaoning	38.5	121.4
	54705	0.95	0.17	−0.16	Nangong	Hebei	37.2	115.2
	54823	0.96	0.23	−0.06	Jinan	Shandong	36.4	117.0
	54916	0.95	−0.09	−0.11	Yanzhou	Shandong	35.3	116.5

Given that among the 3 parameters, the position parameter can best reflect the characteristics of extreme minimum temperature distribution at different climatic stages, we focused on the long term variations of the position parameter of the urban station group. Evidently there is an upward trend in the position parameter in Northern China, and such a trend is also seen in the position parameters of the "reference" station group (Fig. 3). The correlation coefficient of the two series (i.e., the urban versus reference groups) is 0.96, and the coefficients for other two parameters are 0.69 for CK and 0.88 for CF. The high correlations suggest the similar inter-annual variability and high spatial autocorrelation among the stations.

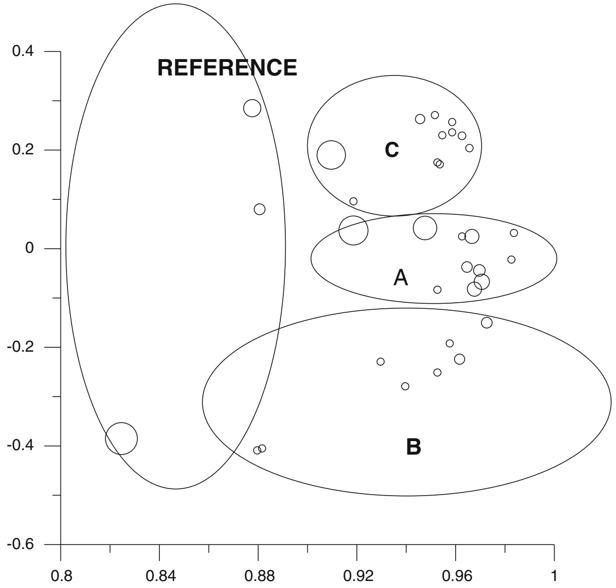

Fig. 2 The scattering distribution plots of the first 3 weighing factors of CM

However, the magnitude of the trends differs between the urban and reference station groups and also among the 3 distribution parameters, with a strong year-by-year variability (Fig. 4). Again, the common upward trend for all of the 3 parameters reflects regional/global warming trends. The shape and position parameters of the urban station group are larger than those of the reference station group while the dispersion parameter of the urban station group is smaller than that of the reference station group (Table 2). Table 2 indicates that the probability distribution curve of the urban extreme minimum temperature is located on the right side of the corresponding distribution curve of the reference station group, but the former is narrower than the latter. This suggests that the occurrence probability of relatively warmer extreme minimum temperature of the urban station group is higher than that of the reference station group, with a magnitude of fluctuation smaller than that of the reference station group (Fig. 5). Figure 4 also shows strong year-by-year variations of the 3 distribution parameters for the difference between the urban and the reference station groups. The position parameter exhibits the largest difference and the variations also display a periodic characteristic.

Like Zhou et al. (2004) and Li et al. (2010), here we also take the year 1980 as the cut-point to divide our study period into two different periods to examine the UHI effect on the extreme minimum temperature in Northern China. We calculated the mean values of the 3 distributional parameters of both the urban and reference station groups for two different periods, before and after the year 1980 (marked as Period ‘I’ and ‘II’ respectively in Table 2). The “Difference” column in Table 3 lists the difference between the mean values of the parameters of the urban and reference stations during the same period. Evidently during the rapid urbanization, the 3 distributional parameters of the urban stations are all higher than those of the reference stations. The difference in the shape and dispersion parameters between the urban and reference station groups changes from the negative value in Period ‘I’ to the positive value in Period ‘II’ (Table 2), which suggests that before the year 1980, the probability distribution curve of extreme minimum temperature of the urban station group is located on the right side of that of the reference station group. Its dispersion range is smaller than that of the reference station group. However, during the period of rapid

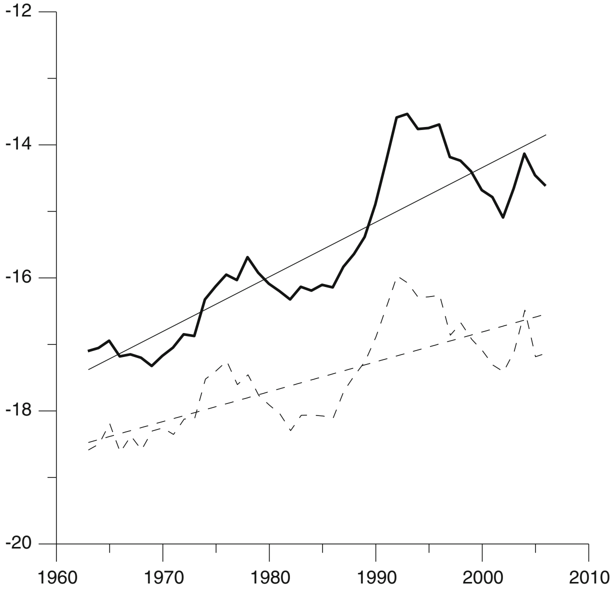

Fig. 3 Long term variations of the CM parameter for the "urban" (*solid line*) and "reference" (*dashed line*) station group. Tthe linear trends of CM series, 0.75/10 years and 0.39/10 years, respectively, are both statistically significant at the 5 % level

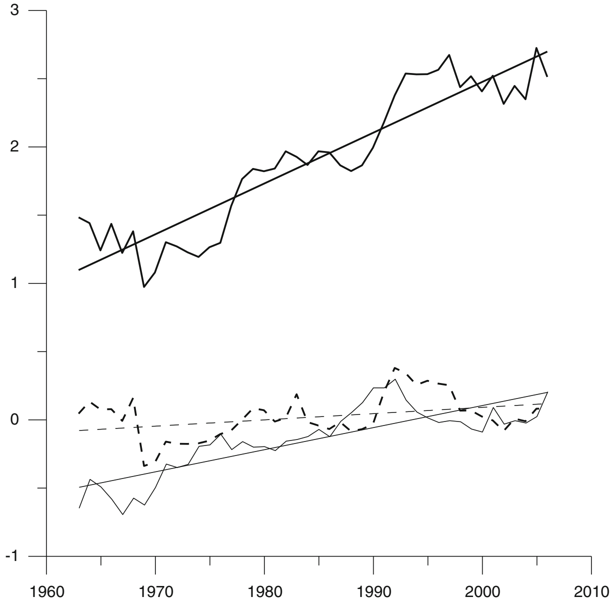

Fig. 4 Long term variations of the difference between the urban and reference station groups in terms of the 3 GEV parameters (*dotted line*: CK—fine *solid line*; CF—*bold dotted line*; CM—*bold solid line*). Note that CK has no unit and the unit of CF and CM is °C). Tthe linear trend of CM series, 0.37/10 years, is statistically significant at the 5 % level

Table 2 Comparison between the urban and reference station groups in terms of the mean values of the 3 extreme minimum temperature distribution parameters (Period I: 1957–1979; Period II: 1980–2010)

Parameter	Climatic stage	CK			CF			CM		
Category		Urban	Reference	Difference	Urban	Reference	Difference	Urban	Reference	Difference
Mean value	All	0.30	0.27	0.03	1.80	1.94	−0.14	−15.6	−17.5	1.9[a]
Mean value	I	0.18	0.24	−0.06	1.56	1.93	−0.37[a]	−16.6	−18.1	1.5[a]
Mean value	II	0.38	0.30	0.08	1.97	1.95	0.02	−14.8	−17.1	2.3[a]

([a]) means that the differences between the urban and rural stations are statistically significant at the 5 % level Note that CK has no unit and the unit of CF and CM is °C

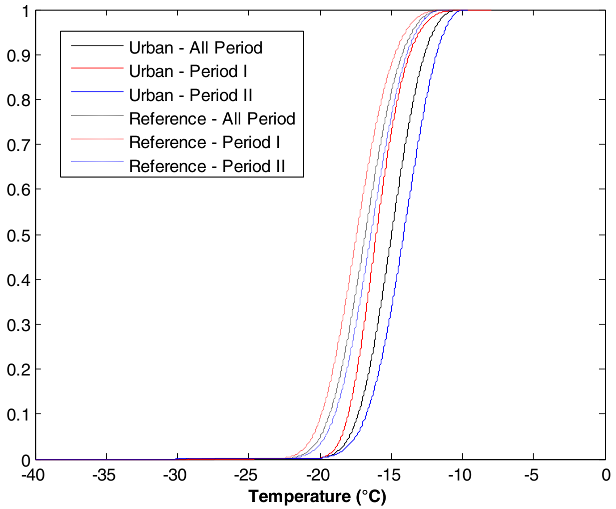

Fig. 5 Comparisons of the theoretical distribution functions between the urban and reference station groups in different periods (Period I: 1957–1979; Period II: 1980–2010)

development of urbanization, relatively higher extreme minimum temperature at urban stations occurs more frequently (Fig. 5). As a result, the probability distribution curve of extreme minimum temperature of the urban station group shifts to the right side of that of the reference station group. Its dispersion range is larger than that of the reference station group. There are also considerable changes in the position parameter. During the period after the year 1980, the position parameter of the urban station group is higher than that of the reference station group by 2.3 °C, while during the period of low-level urbanization; the position parameter of the urban station group is higher than that of the reference station group by 1.5 °C. If we use the former value as a measure of the intensity of urban heat island, then in each 10-year climatic stage, the value of the urban station group is higher than that of the reference station group by 0.8 °C; in each 10-year climatic stage, the value of the urban station group is higher than that of the reference station group by 0.80 °C, i.e. the effect of urban heat island on extreme minimum temperature is about 0.80 °C/10 years.

Table 3 The mean values of the distributional parameters of different types of urban stations and of their differences from the reference station group (Period I: 1957–1979; Period II: 1980–2010)

City type		A		B		C	
Parameter	Period	Mean value	Difference	Mean value	Difference	Mean value	Difference
CK	I	0.12	−0.12[a]	0.30	0.06	0.37	0.13[a]
	II	0.43	0.13[a]	0.32	0.02	0.40	0.10[a]
CF	I	1.60	−0.34[a]	1.63	−0.30[a]	1.84	−0.09
	II	2.16	0.21	1.87	−0.08	1.97	0.01
CM	I	−19.1	−1.0[a]	−14.3	3.8[a]	−16.3	1.7[a]
	II	−17.2	0.0	−12.8	4.3[a]	−14.5	2.6[a]

([a]) means that the differences between the urban and rural stations are statistically significant at the 5 % level
Note that CK has no unit and the unit of CF and CM is °C

The above analysis indicates that the effect of urbanization on the extreme minimum winter temperature in Northern China is very significant, and the urban heat island effect due to urbanization has increased the magnitude and variation of the extreme minimum temperature in cities.

5 Effects of different urbanization types on extreme winter minimum temperature

To assess impact of the rapid expansion of the different types of cities on extreme minimum temperatures, two historical periods are considered with the year 1980 as the cut point as described in Section 4. The period after 1980 represents a rapid development of urbanization. The relevant parameters of the urban station group during these two periods are compared with those of the reference station group. Table 3 lists the mean values of the 3 distributional parameters of different types of urban stations in the two periods as well as the difference between these mean values of the urban station group and the corresponding values of the reference station group. Table 3 and Fig. 6 indicates that during the period of rapid urban expansion (Period II), there is a positive difference of 0.13 between the shape parameter of the 'A' type urban stations and that of the reference stations, compared with a negative difference during Period I. This suggests that during the period of rapid expansion of small-size cities in Northern China, higher extreme minimum temperatures in the cities occur more frequently. The shape parameters of the stations in 'B' and 'C' type cities show little change. The mean trends of the position parameters of the 'A', 'B' and 'C' type cities are higher than those of the reference station group by 1.00, 0.50 and 0.90 °C/10 years, respectively. This suggests that the UHI effect is relatively strong in small- and medium-size cities. In other words, the urbanization in small-size cities exerts the greatest impact on extreme minimum temperature during the period of rapid expansion, possibly related to its faster urban expansion, consistent with the result that the urban size has an impact on the UHI effect (Mohsin and Gough 2012).

6 Conclusions

Although in north/northeast China, the urbanization contributions to the long-term trends are less than 10 % of the regional mean temperature change during the past 50 years (Li et al. 2010), the UHI impact on extreme temperature is more signifcant. In the present study, we classify the weather stations in Northern China into urban and non-urban stations by the winter minimum temperature change features and quantify the contribution of urbanization to the rise in winter minimum temperature by differentiating between urban and non-urban time series from 33 weather stations in Northern China for the period of 1956–2010. The Extreme Winter Minimum Temperatures from these stations are used to estimate the GEV distribution parameters over forty-four 30-year windows successively shifted by 1 year from 1963 to 2006. The 3 parameters of the GEV distributional characteristics are analyzed to examine their long term variations and to quantify the urbanization effects on extreme minimum temperature change. We have the following conclusions:

1. Among the 3 GEV distribution parameters of extreme minimum temperatures, the position parameter has the best representativeness in terms of year-by-year variations. There is an evidently upward trend in extreme minimum temperatures, indicating increasingly higher extreme minimum temperatures with time.

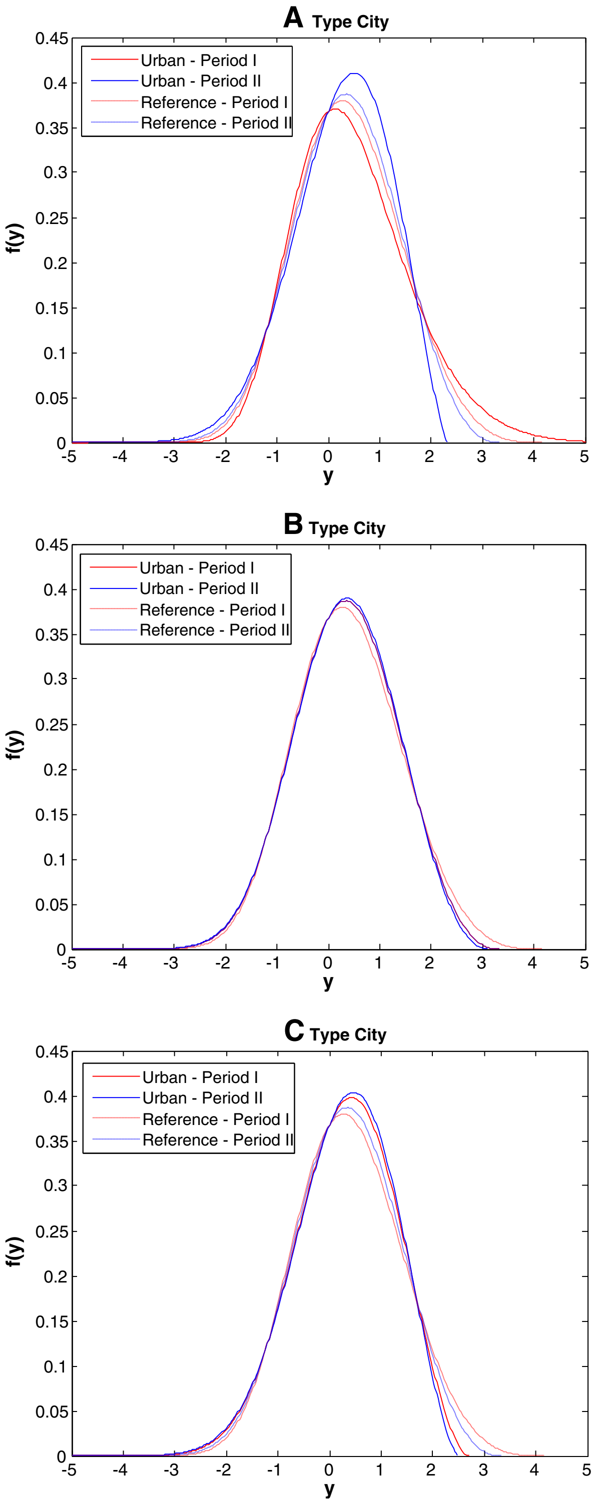

Fig. 6 Comparisons of the probability density functions between the urban and reference station groups for different periods and different types of urban stations (Period I: 1957–1979; Period II: 1980–2010)

2. The stations can be classified into the urban and rural station groups by the mean values of the loading values based on factor analysis. During the period of rapid urban expansion, the 3 distribution parameters for the urban station group show an evidently upward trend, with a higher chance of warmer weather and larger variations in cities, than those for the reference station group.
3. During the rapid urbanization period, the 3 parameters of extreme minimum temperature distribution of the city station group are higher than those of the reference station group. The urbanization at different types of cities all contributes to the increase in extreme minimum temperature. The extreme minimum temperature in small-, medium- and large-size cities increases by 1.00, 0.50 and 0.90 °C/10 years respectively, with small and medium cities having a stronger UHI effect on winter extreme minimum temperature.
4. It is worth noting that different methods and datasets would result in different estimations. It is clear that the signal extracted by our new method is likely primarily due to the UHI effect. In this paper, the estimated contribution of urbanization on extreme minimum temperature based purely on the calculation of the change in temperature series is still only a theoretical maximum value.

Acknowledgments The study is supported by: the State Key Development Program of Basic Research of China (2010CB951600; 2010CB428505), the National Science and Technology Supporting Plan of the Twelfth Five-Year (2012BAC22B05), National Natural Science Foundation of China (grant 40605021),China Meteorological Administration Special Foundation for Climate Change (CCSF201224). The first author has made an in-depth discussion with Dr. Wang Xiaolan on the separation of urbanization signal by GEV method during his visit to the Ministry of Environment in Canada. Dr. Yang Xuchao of Zhejiang Provincial Metrological Bureau provided data on nocturnal illumination and also technical support for the present study. And we would like to thank Prof. Phil Jones and Mr David Parker for their kindly reviewing an early version of this manuscript and their helpful comments to it.

References

Alexander LV et al (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res 111, D05109. doi:10.1029/2005JD006290

Brohan P, Kennedy JJ, Harris I et al (2006) Uncertainty estimates in regional and global observed temperature changes: a new data set from 1850. J Geophys Res 111, D12106. doi:10.1029/2005JD006548

Chen Y, Li X, Chen M et al (2008) Research on general exteme value distribution linear matrix which takes account of historical data on floods. J China Hydrol 28(3):8–13 (in Chinese)

Chen Z, Liu Z, Lu J (2010) Comparative analysis of parameter estimation methods of generalized extreme value distribution. Acta Sci Nat Univ Sun Yat-sen 48(6):105–109 (in Chinese)

Chu Z, Ren G (2005) The impact of change in Beijing metropolis heat island intensity on regional temperature series. Trans Meteorol 63(4):534–540 (in Chinese)

Coles SG (2001) An introduction to statistical modeling of extreme values. Springer

Du Y, Xie Z, Zeng Y et al (2007) Impact of urban expansion on regional temperature change in the Yangtze River Delta. J Geogr Sci 17(4):387–398. doi:10.1007/s11442-007-0387-0

Easterling DR et al (1997) Maximum and minimum temperature trends for the globe. Science 277(5324): 364–367

Fang F, Bai H, Zhao H et al (2007) The urbanization effect in Northwestern China and its contribution to temperature warming. Plateau Meteorol 26(3):579–585 (in Chinese)

Hansen J, Ruedy R, Sato M, Lo K (2010) Global surface temperature change. Rev Geophys 48, RG4004. doi:10.1029/2010RG000345

Hua L, Ma Z, Guo W (2008) The impact of urbanization on air temperature across China. Theor Appl Climatol 93(3):179–194

Huang J (2007) Methods of meteorological statistical analysis and forecast. Meteorology Press, Beijing

IPCC (2007) Climate change: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

IPCC (2012) Managing the risks of extreme events and disasters to advance climate change adaptation, a special report of working groups I and II of the intergovernmental panel on climate change. Cambridge University Press, Cambridge and New York

Jones PD, Groisman PY, Coughlan M et al (1990) Assessment of urbanization effects in time series of surface air temperature over land. Nature 347:169–172

Jones PD, Lister DH, Li Q (2008) Urbanization effects in large-scale temperature records, with an emphasis on China. J Geophys Res 113, D16122. doi:10.1029/2008/JD009916

Kalnay E, Cai M (2003) Impact of urbanization and land-use change on climate. Nature 423(6939):528–531

Karl TR, Diaz HF, Kukla G (1988) Urbanization: its detection and effect in the United States climate record. J Clim 1:1099–1123

Kukla G, Gavin J (1986) Urban warming. J Clim Appl Meteorol 250:1265–1270

Li Q (2011) Introduction to research on climatic data homogenization [M]. Meteorological Press, Beijing

Li Q, Dong W (2009) Detection and adjustment of undocumented discontinuities in Chinese temperature series using a composite approach. Adv Atmos Sci 26(1):143–153. doi:10.1007/s00376-009-0143-8

Li Q, Huang J (2012) Long-term change in the extreme climate events of minimum temperature in Beijing. Plateau Meteorol 31(4):1145–1150 (in Chinese)

Li Q, Huang J (2013) Effects of urbanization in surrounding Bohai area on extreme summer warmest night temperatures, Acta Meteorologica Sinica 71(4):668–676 (in Chinese)

Li Q, Zhang H, Liu X et al (2004a) UHI effect on annual mean temperature during recent 50 years in china. Theor Appl Climatol 79:165–174

Li Q, Liu X, Zhang H et al (2004b) Detecting and adjusting on temporal inhomogeneity in Chinese mean surface air temperature dataset. Adv Atmos Sci 21(2):165–174

Li Q, Zhang H, Chen J et al (2009) A mainland China homogenized historical temperature dataset of 1951-2004. Bull Am Meteorol Soc 90:1062–1065. doi:10.1175/2009BAMS2736

Li Q, Li W, Si P et al (2010) Assessment of surface air warming in northeast China, with emphasis on the impacts of urbanization. Theor Appl Climatol. doi:10.1007/s00704-009-0155-4

Mohsin T, Gough WA (2012) Characterization and estimation of urban heat island at Toronto: impact of the choice of rural sites. Theor Appl Climatol 108(1–2):105–117

Parker DE (2004) Large-scale warming is not urban. Nature 432:290

Peterson TC (2003) Assessment of urban versus rural in situ surface temperature in the contiguous United States: no difference found. J Clim 16:2941–2959

Ren G, Zhou Y, Chu Z et al (2008) Urbanization effects on observed surface air temperature trends in North China. J Climate 21:1333–1348

Tang H, Zhai P, Wang Z (2005) On the change in the mean maximum and minimum temperature and diurnal range from 1951 to 1990. Clim Environ Res 10(4):728–735 (in Chinese)

Wang XL, Trewin B, Feng Y et al (2013a) Historical changes in Australian temperature extremes as inferred from extreme value distribution analysis. Geophys Res Lett 40:573–578. doi:10.1002/grl.50132

Wang X, Feng Y, Vincent L (2013b) Observed changes in one-in-20 year extremes of Canadian surface air temperatures. Atmos Ocean (accepted)

Yang X, Hou Y, Chen B (2011) Observed surface warming induced by urbanization in East China. J Geophys Res 116, D14113. doi:10.1029/2010/JD15452

Zhai P, Pan X (2003) The change in extreme events of temperature and precipitation in Northern China over the past 50 years. Geogr Trans 58(Supplement):1–10

Zhai P, Ren F (1997) On the change of China's maximum and minimum temperature in the recent 40 years. Acta Meteorologica Sinic 55(4):418–429 (in Chinese)

Zhang J, Dong W, Wu L et al (2005a) Impact of land use changes on surface warming in China. Adv Atmos Sci 22(3):343–348

Zhang XB, Gabriele H, Francis WZ, et al (2005b) Avoiding inhomogeneity in percentile-based indices of temperature extremes. J Clim 18:1641–1651

Zhou L, Dickinson RE, Tian Y et al (2004) Evidence for a significant urbanization effect on climate in China. Proc Natl Acad Sci U S A 101(26):9540–9544

Zhou L, Dai A, Dai Y et al (2009) Spatial dependence of diurnal temperature range trends on precipitation from 1950 to 2004. Clim Dyn 32:429–440. doi:10.1007/s00382-008-0387-5