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Implications of temporal change in urban heat island intensity observed at Beijing and Wuhan stations

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[1] Temporal change in urbanization-induced warming at two national basic meteorological stations of China and its contribution to the overall warming are analyzed. Annual and seasonal mean surface air temperature for time periods of 1961∼2000 and 1981∼2000 at the two stations of Beijing and Wuhan Cities and their nearby rural stations all significantly increase. Annual and seasonal urbanization-induced warming for the two periods at Beijing and Wuhan stations is also generally significant, with the annual urban warming accounting for about 65∼80% of the overall warming in 1961∼2000 and about 40∼61% of the overall warming in 1981∼2000. This result along with the previous researches indicates a need to pay more attention to the urbanization-induced bias probably existing in the current surface air temperature records of the national basic stations.

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1. Introduction

[2] Urbanization may have affected the surface air temperature (SAT) records at many city stations in continents, especially in industrial regions like Europe, North America and East Asia. However, this issue is still under debate at present. It is generally hold that urban heat island effect is of secondary importance, and it is unlikely to surpass 0.05°C in the past a hundred years on global average, a magnitude lower than the optimal estimation of the global average annual mean SAT change of 0.6°C [*Jones et al.*, 1990; *Intergovernmental Panel on Climate Change*, 2001; *Peterson*, 2003; *Li et al.*, 2004a]. On the other hand, some researches have shown that the urban heat island effect may play a significant role in the global and regional SAT trend estimated up to date, which should be paid more attention to and should be emended [*Hansen et al.*, 2001; *Kalnay and Cai*, 2003; *Zhou et al.*, 2004; *Zhou and Ren*, 2005].

[3] We have analyzed the possible effect of urbanization on region-averaged SAT trends for various categories of city station groups in North China and Hubei Province of Central China using a most complete SAT data set up to now, and we are able to find the significant contribution of urban warming to the overall SAT rends as estimated for the city station groups and the national reference and basic stations [*Zhou and Ren*, 2005; *Chen et al.*, 2005; *Ren et al.*, 2005]. Here we choose two of big city stations, Beijing and Wuhan stations with a hope to obtain an insight into the temporal details of the urbanization effect. Both are national reference and basic stations, and together with other national basic stations, they have been usually used for analyzing regional climate change.

2. Study Areas, Data, and Methods

[4] Figure 1 shows the locations of the two city stations. Both Beijing and Wuhan are mega cities, with former owning a population of over 8 million and latter a population of over 5 millions. Being the capital of Hubei Province, Wuhan is the largest city in the middle reaches of the Yangtze River. In the past 50 years, especially since the end of 1970's, the two cities witnessed a rapid urbanization like many other big cities in China, leading to not only a fast growth of population but also a swift expansion of the built areas. Presently, Beijing and Wuhan have built areas of almost 600 km^2 and 400 km^2 respectively. There is no doubt that such a rapid urbanization must have resulted in large modification of the landscape within the built areas and the nearby suburbs, including enhancement of urban heat island (UHI) effect.

[5] Beijing Station now is located in the southeastern rim of the city proper, and Wuhan Station is located in Dongxihu District, western part of the city proper (Figure 1). Being in transition belts between city proper and suburban areas, the two sites witness significant UHI effect during the past half century, especially during the past two decades. Beijing Station has relocated for 6 times since 1960 (Table 1) due to the deterioration of observational settings, but Wuhan Station has remained at the same location since 1960. Thus the choices of the two city stations are representative for big city stations within national reference and basic station network. Most of the big city stations have undergone the deterioration of observational environment and frequent relocations for the last 40 years due to the unprecedented urbanization in the country.

[6] There are other nineteen meteorological stations in Beijing Municipality of some seventeen thousands square kilometers (Figure 1a). Of the totally twenty stations, fifteen have a record length of at least 40 years before 2000, and the others began recording after mid 1960's. With reference to metadata of population and description of the specific locations, and length and continuity of the records, six rural stations near Beijing Station and four rural stations around Wuhan Station are chosen as reference sites for comparing with the urban stations [*Chu and Ren*, 2005; *Chen et al.*, 2005]. The rural stations of Beijing region are Xiayunling,

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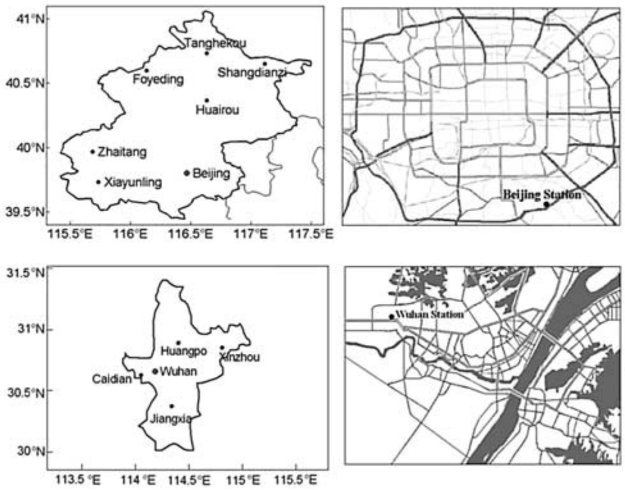

Figure 1. Locations of Beijing and Wuhan stations in (right) the two cities and (left) the nearby rural stations around the two cities. (a) Beijing region; (b) Wuhan region.

Zaitang, Foyeding, Tanghekou, Huairou, and Shangdianzi respectively (Table 1 and Figure 1), which are all located in relatively remote areas of the municipality. Except for Huairou Station, the rural stations were generally built in mountains, and all of them have undergone no relocation since the beginning of records. No rural station can be used in the south and southeast parts of Beijing Municipality according to the criteria mentioned above. The four rural stations around Wuhan City are Huangpo, Xinzhou, Jiangxia, and Caidian stations, respectively (Figure 1b). Xinzhou and Caidian stations are located in small towns, and they have been moved for two times and one time respectively during 1961~2005 though the changes are small with moving distances being less than 3km and almost no change in altitude.

[7] The data of all stations, including the two city stations and the ten rural stations, are checked for errors and in-homogeneities probably caused by relocation and other non-climatic factors, using the same method as that of *Easterling and Peterson* [1995]. Actually, the data of the stations had already been quality-controlled and corrected prior to this study, by the national and regional meteorological data centers of the China Meteorological Administration. No error is found for the data of the twelve stations in the re-examination done in this work. Discontinuous points, however, are found for the time series of Beijing Station in the in-homogeneity examination, and they are proved to be caused by relocation of observation sites. Adjustment is made for the in-homogeneities of Beijing Station temperature series [*Li et al.*, 2004b; *Chu and Ren*, 2005]. The changes of sites for Xinzhou and Chaidian stations are small, and no significant discontinuous points has been detected [*Chen et al.*, 2005]. The influence of change of instrumentation has been proved to be insignificant, and no adjustment has been made for instrumentation change.

[8] Average monthly and annual SAT anomalies of the all stations are calculated for each year, and linear trends of the SAT anomaly series are obtained by using the least square method. Base period for calculating temperature anomalies is 1971~2000. The difference between linear temperature trend of a city station and average of the nearby rural stations is defined as urban warming, and ratio of the urban warming and the overall warming for a city station indicates the contribution of enhanced UHI effect to the overall warming as recorded at the city station. In addition to annual mean SAT, annual mean minimum and maximum SAT is also investigated for Wuhan Station. Trends for two time periods, 1961~2000 and 1981~2000, are compared to look into the difference of the recent two decades from the previous two decades and the entire period.

3. Urban Warming and its Contribution to Overall Warming

[9] Figure 2 shows the annual SAT anomalies of the two city stations and the nearby rural stations for time period of 1961~2000. Both city stations and rural stations undergo a significant warming in terms of annual SAT. It is also evident that inter-annual and inter-decadal variability in the two regions is rather similar. A cooling trend from 1961 to 1969 and a reversal to averages in late 1970s can be

Table 1. Information of the Stations Used in the Study

Station Name	Station Code	Longitude, E	Latitude, N	Altitude, m asl[a]	Start Time of Record	Relocation Since 1960	Category
Beijing	54511	11628	3948	33	1913	01/1965 01/1969 07/1970 01/1981 04/1997	Basic
Xiayunling	54597	11543	3943	409	1959		Ordinary
Zaitang	54501	11540	3958	441	1974		Ordinary
Foyeding	54410	11608	4036	1217	1978		Ordinary
Tanghekou	54412	11637	4043	334	1974		Ordinary
Huairou	54419	11637	4022	76	1959		Ordinary
Shangdianzi	54421	11707	4039	287	1958		Ordinary
Wuhan	57494	11408	3037	24	1880		Basic
Huangpo	57491	11424	3052	33	1958		Ordinary
Xinzhou	57492	11448	3050	33	1958	09/1976 01/1995	Ordinary
Jiangxia	57493	11419	3021	38	1959		Ordinary
Caidian	57489	11400	3035	39	1959	12/1965	Ordinary

[a]Above sea level.

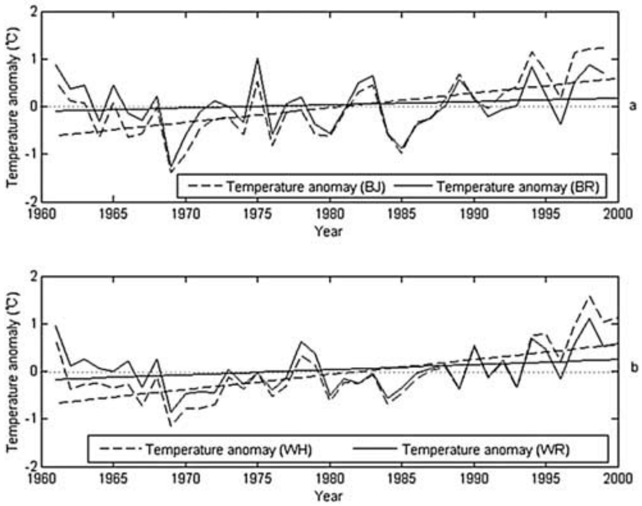

Figure 2. Annual mean air temperature anomalies for 1961∼2000: (a) Beijing Station (BJ) and the six rural stations (BR), and (b) Wuhan Station (WH) and the four rural stations (WR). Straight lines denote the linear trends for the period of 1961∼2000.

observed. 1969 is the coldest year in the record. The most significant warming for both urban and rural stations occurs after mid-1980, with 1998 being the warmest year in the records. The inter-annual and inter-decadal variability is generally consistent with that reported by *Hu et al.* [2003] and *Ren et al.* [2005] for the country-averaged annual SAT series of China. Seasonal feature of temperature variability for the two regions is also similar to the country averaged SAT series, with the warming in wintertime being more evident than in any other seasons, and a cooling trend in summer occurring in the Wuhan region.

[10] Large difference, however, is seen in annual SAT trends between city stations and the nearby rural stations.

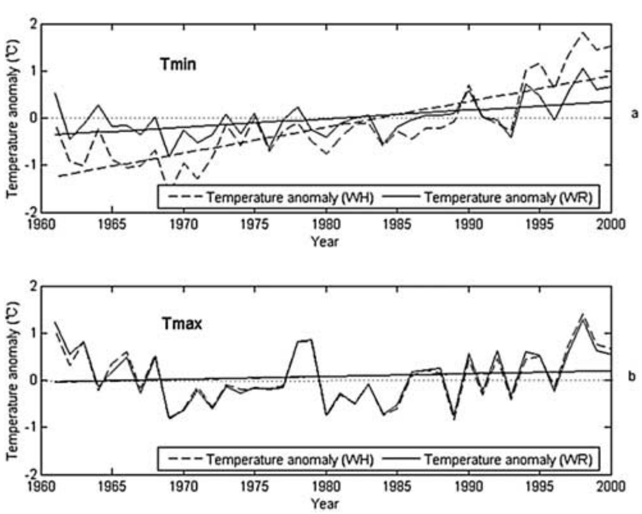

Figure 3. Annual mean (a) minimum and (b) maximum surface air temperature anomalies at Wuhan Station (WH) and the four rural stations (WR) for 1961∼2000. Straight lines denote the linear trends for the period of 1961∼2000.

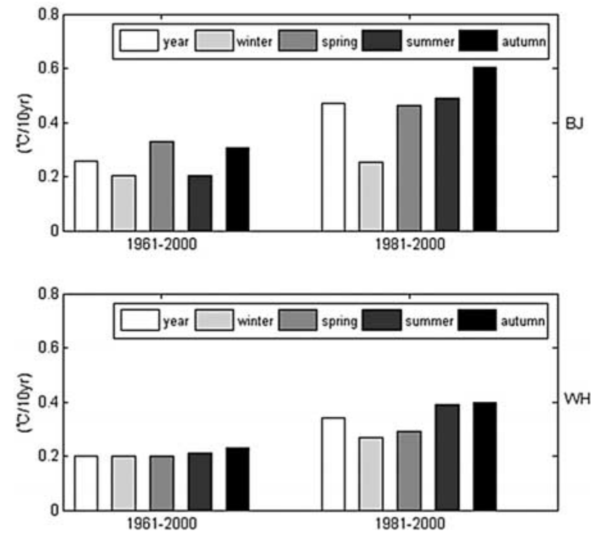

Figure 4. Urban warming at Beijing and Wuhan stations for time periods of 1961∼2000 and 1981∼2000.

Increase in annual mean SAT during 1961∼2000 reaches 0.32°C/10 yr. and 0.31°C/10 yr. respectively for Beijing Station and Wuhan Station, but it is only 0.06°C/10 yr. and 0.11°C/10 yr. for averages of the rural stations around the two cities, indicating that the temperature increase at the two city stations is mostly caused by urban warming. Furthermore, the significant difference of annual mean SAT between the city stations and the nearby rural stations results from the large warming of the cities at night, as seen from annual mean minimum SAT anomalies compared to annual mean maximum SAT anomalies at Wuhan Station and the four rural stations (Figure 3). Both increase of annual mean maximum SAT at Wuhan Station and the difference of annual mean maximum SAT between the urban and rural stations are small.

[11] Figure 4 shows urban warming at Beijing and Wuhan stations, as estimated on basis of difference of annual and seasonal mean SAT between the two city stations and the nearby rural stations, for two time periods of 1961∼2000 and 1981∼2000. Yearly temperature rise at Beijing and Wuhan stations related to the nearby rural temperature change is estimated to be 0.26°C/10 yr. and 0.20°C/10 yr. respectively for 1961∼2000, and 0.47°C/10 yr. and 0.34°C/10 yr. respectively for 1981∼2000. More rapid urban warming is underdone for the late period of 1981∼2000, with Beijing Station being even more remarkable than Wuhan Station. In comparison to 1961∼2000, urban warming during 1981∼2000 increases by 81% for Beijing Station and 70% for Wuhan Station. Therefore, larger impact of urbanization occurs at the two city stations during the last 20 years when urbanization and economic growth of China are unprecedented in history.

[12] Urban warming is generally significant in each of the four seasons (Figure 4). The largest urban warming at Beijing Station, 0.33°C/10 yr., occurs in spring for the entire period analyzed, but autumn witnesses the most significant urban warming reaching as high as 0.60°C/10 yr. for the time period of 1981∼2000. Summer of Beijing Station undergoes the second largest seasonal urban

warming during 1981∼2000, but summer and winter record the least seasonal urban warming during the 1961∼2000. More evident urban warming in autumn and summer than in other seasons at Wuhan Station appears in both 1961∼2000 and 1981∼2000, though the late period sees a larger urbanization effect for the two seasons. It is interesting to note that urban warming in spring, summer and autumn is becoming more obvious with time at the two city stations.

[13] Table 2 shows urbanization-induced change in annual mean maximum (T_M) and minimum (T_m) SAT at Wuhan Station for 1961∼2000 and 1981∼2000. Trends of T_m and T_M are 0.37°C/10 yr. and 0°C/10 yr. respectively for 1961∼2000, but they increase to 0.66°C/10 yr. and 0.08°C/10 yr. respectively for 1981∼2000, indicating a much more evident warming at nights (T_m) and an enhanced urban warming in the later 20 years. The largest urban warming trend of 0.70°C/10 yr. occurs in winter T_m for 1981∼2000. Less significantly negative trends are seen for winter T_M for both 1961∼2000 and 1981∼2000, implying that urbanization might have made the observation site to become cooler in daytime compared to the rural areas. It is also worth noting that the later period of the last two decades witnesses a much stronger urban warming of T_M for summer and of T_m for winter, than before or in the entire period. As expected, the enhancement of urban warming during 1981∼2000 as compared to the earlier years dominantly occurs in nighttime (T_m) of winter and daytime (T_M) of summer.

[14] Relative contribution of urban warming to the overall warming observed at the two city stations is shown in Table 3. With regard of annual mean SAT, the contribution reaches to 80.4% for 1961∼2000 and 61.3% for 1981∼2000 at Beijing Station, and comes to 64.5% for 1961∼2000 and 39.5% for 1981∼2000 at Wuhan Station. The contribution generally increases from winter and spring to summer and autumn, with an exception of Beijing Station for 1981∼2000. During 1961∼2000, the overall warming observed in summer and autumn at Beijing Station and in summer at Wuhan Station can be entirely accounted for by the urbanization effect. Seasonal warming of 1981∼2000 in spring at Beijing Station is also entirely caused by enhanced UHI effect. Although winter registers the largest overall warming at the two city stations, and urban warming in winter is also very significant, the cold season witnesses the lowest contribution of urban warming to overall warming at both city stations. Except for spring of Beijing Station, the contribution of urban warming to overall warming for year and all seasons drops with time, implying that, although urbanization has speeded up, an increased part of warming observed at the city stations is caused by baseline climate change during the last 20 years as compared to the previous two decades.

Table 2. Urban Warming Trend Recorded by Annual Mean Maximum and Minimum Temperature at Wuhan Station for 1961∼2000 and 1981∼2000[a]

	Winter	Spring	Summer	Autumn	Year
		1961∼2000			
Minimum	0.39	0.33	0.34	0.39	0.37
Maximum	−0.05	0.03	0	0.03	0
		1981∼2000			
Minimum	0.70	0.58	0.57	0.44	0.66
Maximum	−0.01	0.08	0.22	0.04	0.08

[a]Unit: °C/10 yr.

Table 3. Contribution of Urban Warming to the Overall Warming at Beijing and Wuhan Stations for Time Periods of 1961∼2000 and 1981∼2000[a]

	Winter	Spring	Summer	Autumn	Year
		1961∼2000			
Beijing	35.3	76.7	100	100	80.4
Wuhan	35.1	57.1	100	76.7	64.5
		1981∼2000			
Beijing	22.2	100	60.2	81.8	61.3
Wuhan	21.6	35.4	81.3	46.0	39.5

[a]Unit: %.

4. Conclusions and Discussion

[15] In summary, temporal trends of annual and seasonal mean SAT for time periods of 1961∼2000 and 1981∼2000 at Beijing and Wuhan stations and their nearby rural stations are all significantly positive, and the annual and seasonal urban warming for the two periods for Beijing and Wuhan stations is also positive and significant. The annual urban warming at the city stations can account for about 65∼80% of the overall warming in 1961∼2000, and about 40∼61% of the overall warming in 1981∼2000. The quality control and the in-homogeneity examination and adjustment for the data of the stations used for the analysis have been made.

[16] The impact of urbanization on observed SAT trend for the two city stations is much larger than reported for North China as whole and for Hubei Province [*Zhou and Ren*, 2005; *Chen et al.*, 2005]. The two city stations are all of national basic stations, as many other city stations in the country, and the records from the stations are generally used in regional climate change analyses. It is likely that a larger part of SAT increase in the country as obtained from data set of the national reference and basic stations has been caused by enhanced UHI effect during the past decades. As both city stations are not located in the central area the city, the findings reported here are not necessarily representative for the downtown area where maximum UHI effect should usually be felt. However, the findings along with the previous researches do indicate a need for paying more attention to the selection of observational sites, and for further detecting and adjusting the urbanization-induced bias probably existing in SAT records of city stations, in analysis of observed regional climate change.

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