GEOPHYSICAL RESEARCH LETTERS, VOL. 17, NO. 12, PAGES 2377-2380, DECEMBER 1990

URBAN HEAT ISLANDS IN CHINA

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Abstract. We used 1954-1983 surface temperature from 42 Chinese urban (average population $1.7*10^6$) and rural (average population $1.5*10^5$) station pairs to study the urban heat island effects. Despite the fact that the rural stations are not true rural stations, the magnitude of the heat islands was calculated to average 0.23 °C over the thirty-year period with a minimum value during the 1964-1973 decade and maximum during the most recent decade. The urban heat islands were found to have seasonal dependence which varied considerably across the country. The urban heat islands also had a strong regional dependence with the Northern Plains dominating the magnitude of the heat islands. The changes in heat island intensity over three decades studied suggest a general increase in heat island intensity of about 0.1°C, but this has not been constant in time. These results suggest that caution must be exercised when attributing causes to observed trends when stations are located in the vicinity of metropolitan areas.

Introduction

In recent years concerns were raised about whether the observed increase in atmospheric greenhouse gases was the main cause for the observed increases in the global mean surface temperature of ~ 0.5 °C during the last hundred years (see WMO/UNEP, 1990 for a review). These concerns intensified after the 1988 abnormal weather of record high temperature and drought conditions in many regions of the United States and record storms sweeping over Europe. In addition, the 1980's have been documented as the warmest decade on record. Many of these weather anomalies are not inconsistent with the simulations from the general circulation models, which also predict a substantial global warming in the next few decades if the current increasing trends for greenhouse gases continue. A global warming will have serious implications on regional weather and climate with subsequent effects on economic and social activities. Active research has been focused on climate model development to improve regional climate prediction and on observations to detect the greenhouse warming signals (CES, 1989).

One area of the detection issue has focused on the credibility of greenhouse warming attribution in the global temperature trend when many stations are located in the vicinity of major urban areas (Wood, 1988; Karl and Quayle, 1988; Karl et al., 1988; Jones et al., 1990). Regional studies indicate that there exists a significant urban heat island effect in the United States; in some cases it can introduce bias of 0.1-0.3 °C per decade in the temperature trend.

Karl et al. (1988) and Balling and Idso (1989) have studied the relationship between population change and urban warming bias in the United States and the correlations were found to be statistically significant. Karl et al. (1988) have developed an empirical relation to correct the urban warming bias in the United States Historical Climate Network (HCN). Even in this mostly rural network of stations, a warm bias of about 0.06 °C occurs during the twentieth century due to population growth around observing sites.

Both the United States and China are located in mid-latitudes with comparable land areas. However, the climates of the two countries are different due to the different topographical and geographic conditions. In addition, there are considerable differences in the non-climatic factors such as the energy consumption, industrialization and population density, which may affect the temperature trends and the magnitude of the urban bias. Consequently, the urban warming bias in China may have a different pattern than that found in the United States.

Several empirical studies have already been conducted to study the urban heat island effects in China (see Zhou and Zhang, 1985 for a review). However, these studies focused on either the big cities such as Shanghai or the comparative study between a big city and the suburbs for one or two selected cities (see Chow, 1986). Here we perform a study of the urban warming bias in the Eastern half of China using many stations. Our work differs from the recent study by Jones et al. (1990). They have shown that any urban bias in their data has been mitigated over Eastern China. The reasons for this are not clear. Our intent is to determine the magnitude and scope of heat islands in China and determine whether there is evidence of any change in their intensity over the past few decades.

Analysis

The temperature data used in this study are based on 42-pairs of urban-rural stations from a 260-station temperature data set recently compiled under the United States' Department of Energy and People's Republic of China's Academy of Sciences joint research program on the greenhouse effect (Koomanoff et al., 1988). The temperatures cover the period up to 1983. For some stations, the data dated back to the nineteenth century, for example, Beijing from 1841 and Shanghai from 1873.

Data from selected 84 rural and urban stations includes monthly mean temperatures for the period 1954-1983. The period was chosen mainly because most stations were established by 1954 and continuous records exist. We grouped the 42-pairs into six regions: (I) Northeast, (II) Northern Plains, (III) Middle-Lower Changjiang and Huaihe Basin, (IV) Southeast Coast, (V) Southwest and (VI) Northwest; each region had seven station pairs (see Figure 1). Discussion of the geophysical features and climate characteristics of these regions can be found in Domros and Peng (1988). Figure 1 also shows the locations of the station pairs, and the averaged station heights, populations and linear trends over separate urban and rural stations for the individual regions. These stations primarily cover the Eastern part of China. They were chosen based on station histories: selected stations have relatively few, if any, changes in instrumentation, location, or observation times over this period. Additional criteria used to choose the 42-pairs urban-rural stations are: as small as possible spatial distance between the individual pair; most stations with 1985 population of over one million for urban sites (average 1.71 million) and less than 0.2 million for rural sites (average 0.147 million); and suitability of topography, geographical location and the spatial location of the station network.

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Paper number 90GL02300
0094-8276/90/90GL-02300$03.00

Region	Urban (U)/ Rural (R)	Height (m)	Population (1000)	Linear Trend (°C/30 years)
I	U	172	1697	0.82
	R	142	241	0.51
II	U	67	2494	0.64
	R	41	89	0.35
III	U	47	1382	0.11
	R	45	188	0.21
IV	U	31	2025	0.10
	R	29	59	0.05
V	U	726	1490	-0.21
	R	647	162	-0.14
VI	U	1143	1212	0.70
	R	1073	144	0.44
China				
	U	363	1717	0.36
	R	330	147	0.24

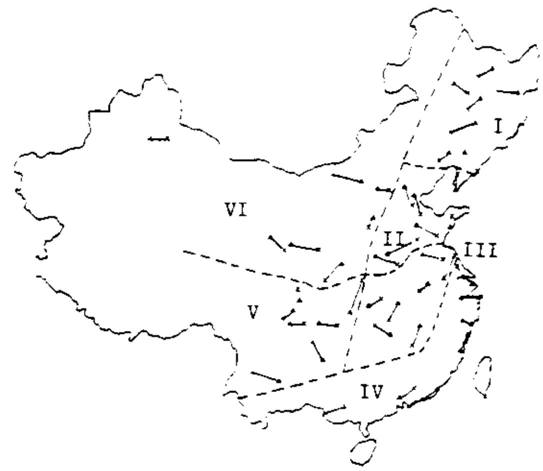

Fig.1: The 42-pairs urban (in Δ) and rural (in X) stations used to study the urban heat islands. The values of station heights, populations, and 30-year linear trends averaged over the separate urban and rural stations are calculated for six regions: (I) Northeast, (II) Northern Plains, (III) Middle-Lower Changjiang and Huaihe Basin, (IV) Southeast Coast, (V) Southwest, and (VI) Northwest. Note that the population statistics used are 1981 - 1985 averages for urban stations and 1984 - 1985 averages for rural stations.

We first examined the spatial pattern of the temperature trends for the individual stations and the results of the regional average are included in Figure 1. In general, the regions of the Northeast, and Northern Plains and Northwest showed large positive trends for both the urban and rural stations while negative trends were observed in the Southwest. Note that these results imply a tendency for a decrease in the north-south temperature gradient. The thirty-year trends averaged over the Eastern half of China were 0.36 °C for the urban stations and 0.24 °C for the rural stations.

Figure 2 shows the 1954-1983 annual mean temperatures averaged over the 42 urban and rural stations separately. In general, three stages are observed for both the urban and rural temperatures: a warming trend before 1961; a cooling trend between 1961-1969; and a warming trend after 1969. The temperatures averaged over the thirty years for rural and urban stations are calculated to be 12.61°C and 12.80 °C, respectively.

These urban-rural temperature differences however, include factors such as differences in geography and topography, which will have influences on the temperature differences. To minimize the effect of topography and geography, we used multiple regression techniques. The differences in altitude, latitude and longitude between the paired urban and rural stations were used to predict the urban-rural temperature difference. The residuals between these

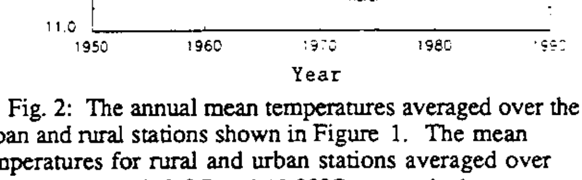

Fig. 2: The annual mean temperatures averaged over the urban and rural stations shown in Figure 1. The mean temperatures for rural and urban stations averaged over 1954-1983 are 12.61°C and 12.80°C, respectively.

predictions and the actual urban-rural temperature differences were used to refine the urban-rural differences. The differences are referred to as "corrected" differences. Using the F-test, we find that the regressions are statistically significant at the 0.01 significance level for the annual averages and at the 0.05 level for the seasonal averages.

The corrected annual and seasonal urban heat islands are given in Table 1. The results indicate that temperatures averaged 0.23 °C warmer in the urban areas across all regions and seasons (as opposed to 0.19 °C for the uncorrected urban-rural difference). Averaged across all of China, the strongest urban heat islands, 0.29 °C, occurred in winter and the weakest, 0.14 °C, in summer. Considerable variability exists from region to region however, and a portion of this variability is unlikely to be related to heat island effects. For example, if we omit the Northern Plains which has a very large difference between summer and winter, then the results are similar to those observed in the United States: stronger heat islands occur in summer compared to winter (Table 1). As such, the summer to winter differences may not be significant. Further study of the characteristics in the region of Northern Plains, including the data quality, is warranted. The Middle-Lower Changjiang and Huaihe Basin and the Northwest also showed a large annual urban heat islands (about 0.35 °C), but the seasonal variation is relatively small; in fact, these two regions together with the Northern Plains dominate the annual average urban-rural temperature difference of 0.23 °C for all of China. The urban-rural temperature differences in other areas were small. The large difference between regions suggests that more data would be desirable to determine whether the regional differences are sampling errors or real physical characteristics.

The interannual variability of the annual and seasonal mean urban-rural temperatures is shown in Figure 3. This is of particular interest with respect to potential urban heat island biases in long-term temperature series derived from urban stations in China. For the annual-mean case (Figure 3a), the changes in the urban-rural temperature difference had two stages, a decreasing trend before 1966 and an increasing trend afterwards. The magnitude of the increase is particularly large after 1977. These trends may be associated with energy consumption and population movement resulting from economic and political activities during the periods of the Great Leap Forward before 1966 and the Cultural Revolution afterward. During those periods, many factories were closed and production halted through a reduction of the staff. Since 1972, industry functions gradually returned to normal and after

Table 1. Annual and seasonal urban heat islands (°C) in China averaged over the period 1954-1983

Region	Spring	Summer	Autumn	Winter	Annual
Northeast	0.18	0.03	-0.09	0.06	0.04
Northern Plains	0.20	-0.18	1.07	1.42	0.63
Middle-Lower Changjiang and Huaihe Basin	0.44	0.42	0.38	0.21	0.36
Southeast Coast	-0.13	0.20	0.03	-0.08	0.01
Southwest	0.24	0.04	-0.05	-0.22	0.00
Northwest	0.32	0.35	0.36	0.35	0.35*
China—Mean	0.21 (0.21)†	0.14 (0.21)	0.28 (0.13)	0.29 (0.06)	0.23 (0.15)
Standard Deviation	0.19 (0.21)	0.22 (0.17)	0.44 (0.22)	0.59 (0.22)	0.26 (0.18)

* The annual value is 0.28 °C if the Hohhot-Urad Zhongqi pair in the far west is excluded (see Figure 1); this will have a small effect on the annual mean over China, reducing to 0.22 °C.† Values in the parentheses are the averages without including the Northern Plains.

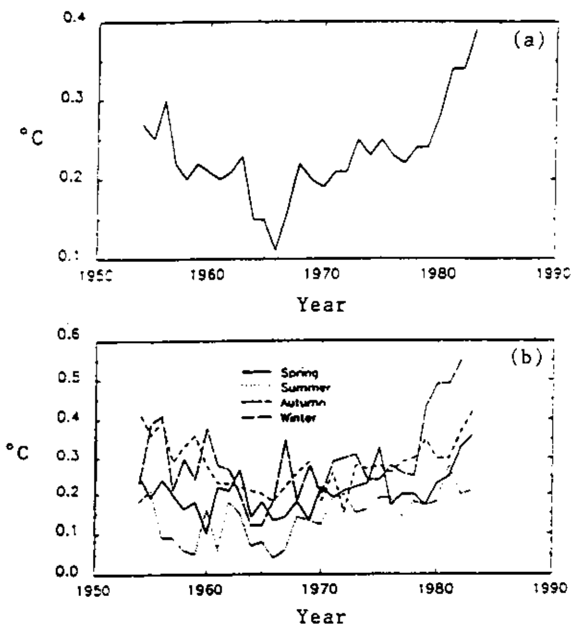

Fig. 3: Urban-rural temperature difference in China during 1954-1983 for (a) annual mean and (b) seasonal mean values.

1978, factory production and economic development rapidly expanded under the new Open Door policy. As a result, a large inflow of rural population to the cities occurred so that the urban heat islands in China may have increased as a result. This is evident beginning the year 1977 in Figure 3a. Much more detailed analyses of the attributes are needed however, before we can be certain of the causes for such trends.

On a seasonal basis (Figure 3b), similar features are also observed. It is quite clear that, for all four seasons, the magnitudes of the urban heat island bias after 1966 has been increasing. The trend is particularly strong during autumn and winter. Before 1966, except for autumn and winter, the urban-rural temperature differences showed little trend.

The annual and seasonal urban heat-island bias during the three ten-year periods are summarized in Table 2. The values reflect the heat island features discussed above: maximum during winter and minimum during summer for the average of all regions, but just the opposite when the Northern Plains is omitted from the sample. Increased heat islands occur during the most recent decade for all of Eastern China with and without the Northern Plains. We have also examined the urban heat island bias for the three ten-year periods on the regional basis, shown in Table 3. The general characteristics are similar to the annual features observed in Table 2. However, the decadal changes in urban-rural temperature differences are large in Northeast, Northern Plains, Southeast Coast, and the Northwest while the other two regions showed small changes.

Because of the lack of population statistics in China, in the analysis of the relation between population and heat island effects we used the available population data during 1981-1985 for the cities and 1984-1985 for the rural stations. The population difference versus the temperature difference for the individual urban-rural pairs were used to derive an empirical correlation. The relationship exists. However, the correlation is not statistically significant, which suggests that we would probably need many more station pairs before we could

Table 2. Annual and seasonal urban heat islands (°C) in China

Period	Spring	Summer	Autumn	Winter	Annual
1954-63	0.20 (0.21)*	0.12 (0.19)	0.31 (0.18)	0.29 (0.06)	0.23 (0.16)
1964-73	0.17 (0.19)	0.12 (0.18)	0.22 (0.06)	0.23 (0.01)	0.19 (0.11)
1974-83	0.25 (0.23)	0.19 (0.25)	0.31 (0.16)	0.36 (0.13)	0.28 (0.19)

*Values in the parentheses are the averages without including the Northern Plains.

Table 3. Annual urban heat islands (°C) in China

Region	1954-63	1964-73	1974-83	1954-83
Northeast	0.00	-0.03	0.16	0.04
Northern Plains	0.62	0.57	0.70	0.63
Middle-Lower Changjiang and Huaihe Basin	0.41	0.34	0.34	0.36
Southeast Coast	0.00	-0.05	0.06	0.01
Southwest	0.01	0.01	-0.01	0.00
Northwest	0.35	0.28	0.42	0.35
China	0.23	0.19	0.28	0.23

predict the magnitude of the urban heat islands on an annual basis.

Conclusions and Discussion

We used the 1954-1983 surface temperature data in Eastern China to examine the urban heat island effects. The average effect was calculated to be quite substantial in our data, about 0.23 °C for the last thirty years. The heat island effects also had strong seasonal and regional dependences with considerable variability.

Our focus in the present study has been mainly on the urban-rural temperature difference so that the choice of the station network was strictly based on the station pairs and their homogeneous distribution. Consequently, our rural stations are generally not the true "rural" stations; rather they are cities with fairly large populations (see Figure 1). Our results suggest that in the absence of other factors which could cancel the urban heat island bias, stations in China located in the vicinity of major cities have relatively large heat islands. The changes in the magnitude of the urban-rural temperature differences over the 1954-83 period indicate that since the late 1970's the rate of warming at urban stations is over 0.1 °C per decade relative to more rural stations. Although there has been rapid urbanization in China since the 1970's, it is not certain whether the trend from such a short period should be attributed solely to urbanization. An updated data set may clarify this situation. These results suggest that caution must be used when using trends from stations in the vicinity of major metropolitan areas.

Acknowledgments. Zhaomei Zeng participated in the study as a visiting scholar under the United States Department of Energy and the People's Republic of China's Academy of Sciences Joint Research on the Greenhouse Effect. This research was supported by the Atmospheric and Climate Division, Office of Health and Environmental Sciences, Department of Energy.

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(Received August 24, 1990;
revised October 12, 1990;
accepted October 15, 1990)