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ANALYSIS OF THE EFFECTS OF URBAN HEAT ISLAND BY SATELLITE REMOTE SENSING

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Abstract Chengdu is located in Chengdu plain within the interior of our country and has rather unique geographic and climatic characteristics. The phenomena of its urban heat islands is visually and vividly demonstrated by use of NOAA meteorological satellite AVHRR data obtained in four observations in the side, two-dimensional and three-dimensional views in this paper. The regional distribution differences of the heat island regions between day and night in Chengdu city (a super-large city) are compared. The urban heat island characteristics in 10 and more its suburb towns are analyzed statistically.

Key words Satellite remote sensing and urban heat island

1. INTRODUCTION

A series of the urban meteorological and urban environmental questions have been brought about by urbanization. China is a large traditional agricultural country with a large agricultural population and the underdeveloped cities and towns in its vast territory. With its economic development and modernization drive step quickening a large amount of surplus rural labour forces move to the cities and towns, accelerate the urbanization progress and this is certainly to cause the urban climatic and urban environmental changes. Therefore, it is vital for urban construction planning and urban environmental improvement to study the urban climatic conditions and forecast the urban climatic variation trends.

The urban heat island phenomena is one of the key subjects to be studied for the urban climate. The urban heat island phenomena has been studied for a long time both abroad and home since its characteristics vary in the different locations, meteorological conditions and unique features of the cities and towns. It was observed by some researchers for a long time in the points set up both in the city proper and out of it and analyzed by a climatic method; it was observed many days continuously and many times a day to analyze the daily variation law of the heat island effects. As for a city with an area of hundreds square kilometers the ground observation is not able to reflect in detail the urban heat island distribution characteristics, whereas the satellite remote sensing technique can make up for the deficiency of other detection methods. The urban heat island phenomena was analyzed by use of the thermal infrared data obtained by meteorological satellite sensing. An atmospheric attenuation was corrected for the satellite remote sensing data by use of the meteorological sounding and ground observation data on the basis of a boundary layer theory[1]. This method can be used for reference. However, the heat island effect study results of a city is generally not able to represent the heat island effect conditions of another city.

Chengdu plain is situated in the west of Sichuan basin within the interior of our country and has rather unique geographic and climatic characteristics. Chengdu plain runs from NNE to SSW. In the west of the plain there is Qionglai mountain range with an altitude mostly of 2000~4000 m and in the further west of it there is western Sichuan plateau. In the east of the plain there is Longquan mountain range with an altitude generally below 1000 m. The region analyzed by this paper is 30.4~31.0°N and 103.7~104.3°E with an area of about 3800 km^2. The topography of this region is roughly that its north-west part is higher (its altitude between 600 and 700 m) and its south-east part is lower (its altitude below 500 m). The cities and towns are scattered like stars in the sky within the region (see figure 1). In centre of the region there is Chengdu city with an altitude of 500 m, about 60 km west to Qingcheng mountain and 20 km east to Longquan mountain. Chengdu city has an area of about 60 km^2 within the second ring road and an area of about 180 km^2 within the third ring road. The average area of its suburb middle & small towns is generally 5~15 km^2. Chengdu plain is a moist subtropical climatic region. Its yearly average wind velocity is 1.3 ms^{-1}, yearly average most of wind directions is NNE, the most of wind direction frequencies is 12% and the calm wind frequency is 39%.

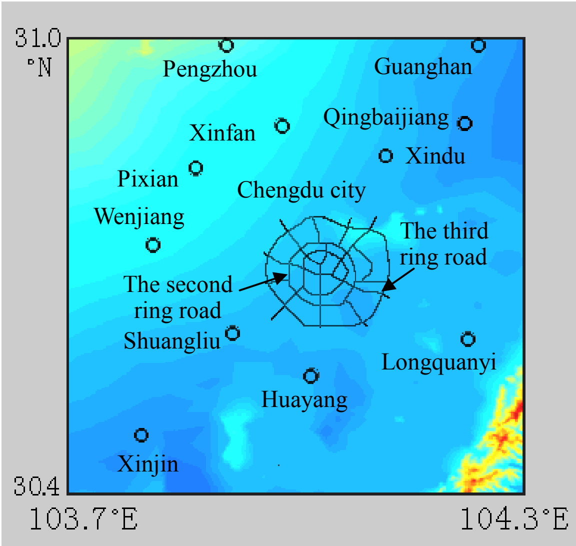


Figure 1 The distribution chart of main cities and towns

The NOAA14,16/AVHRR data are used in this paper. The AVHRR has totally 5 scanning and radiation channels. A comparison shows that the radiative brightness temperature measured in the fourth channel (its wave length is 10.3-11.3 μm) is closed to that in the fifth channel (its wave length is 11.5-12.5 μm), whereas the brightness temperature measured in the third channel (its wave length is 3.55-3.93 μm) is higher than that in the fourth channel by over 4℃ in the same quadrant at rather high ground temperature (the reason is that the third channel is more sensitive than the fourth and fifth channels in the high-temperature section). The data in the fourth channel have been selected for analysis. The sub-satellite points resolution is 1.1×1.1 km^2. The selected AVHRR data obtained in all four observations belong to a large-range clear weather in Sichuan basin, among which three observations took place around 17 o'clock (NOAA14) and one observation in the deep of night (NOAA16). The equivalent radiative brightness temperature has been calculated after data calibration and radiation correction for the used data. The urban heat island phenomena is demonstrated in the side, two-dimensional and three-dimensional views for analysis, the regional distribution differences of the heat islands between day and night in Chengdu city are compared and the urban heat island characteristics in ten and more middle and small towns are analyzed statistically.

2. DETERMINATION OF THE URBAN HEAT ISLAND REFERENCE POINT

The ground temperature is approximately replaced by the radiative brightness temperature in the first stage of this work. Strictly speaking, the radiative brightness temperature obtained by use of AVHRR can not be equal to the air temperature measured during ground-based meteorological observation. As the earth is taken as a black body the radiative brightness temperature is calculated on the basis of Planck's black-body radiation law, i.e.:

$$B(v,T) = \frac{c_1 v^3}{e^{c_2 v/T} - 1}$$

Where C_1 and C_2 are the Boltzman's constants determined experimentally, v is the wave number and T is the absolute temperature (called the black-body temperature and shortly called "TBB"). Since the temperature measured during meteorological observation is referred to the temperature of thermometer inductor in the shelter located at a height of 1.5 m above the ground the brightness temperature is different from the air temperature. However, for preliminary analysis of the relative change in the urban heat island intensity the urban heat island temperature (the heat island intensity) is represented by the temperature difference ΔT between the maximum brightness temperature T_{max} in the city proper and the minimum brightness temperature T_{min} in suburb in this paper.

The heat island intensity is related to a reasonable selection of the temperature reference point (i.e. T_{min}). If it is selected improperly it is possible to cause the heat island temperature ΔT to be on the high or low side. The background temperature characteristics in Chengdu plain are firstly analyzed by use of the satellite sensing radiative brightness temperature diagram in order to objectively reflect the urban heat island intensity. It was found out through analysis that the ground background brightness temperature in the selected region is low in its north-west part and high in its south-east part if the urban surface features such as buildings and roads influence on the brightness temperature is excluded. This is identical to the topography in the region, i.e. the background temperature is low in the case of higher north-west part topography and is high in the case of lower south-east part topography. If the temperature reference point is selected in the north-west of the city it is possible to cause the urban heat island temperature to be on the high side; if the temperature reference point is selected in the south-east of the city it is possible to cause the urban heat island temperature to be on the low side. The T_{min} selection method has been finally decided in such a way that the T_{min} in Chengdu city should be the minimum brightness temperature within the range of 10-15 km to the west of the city geographic centre, the T_{min} in Longquanyi district should be the minimum brightness temperature within the range of 5-10 km to the south-west of it and the T_{min} in other towns and townships should be the minimum within the range of 3-6 km to the west of them. On this basis the urban heat island effect characteristics are analyzed in the selected regions.

3. ANALYSIS OF THE URBAN HEAT ISLAND CHARACTERISTICS

3.1 Heat island temperature ΔT

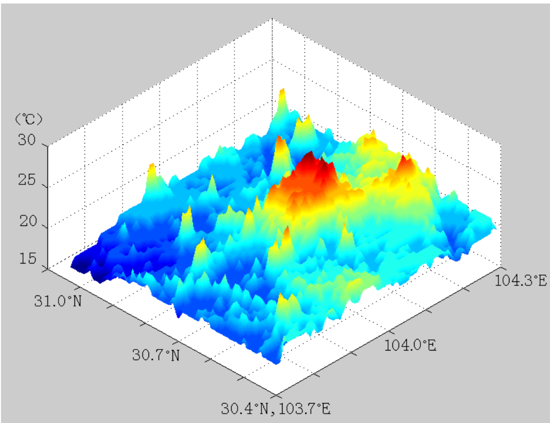
For the statistic results of heat island temperature ΔT see table 1. The ΔT in Chengdu city (a super-large city) is analyzed independently and the ΔT in other districts, cities (towns) and townships is analyzed statistically as in the middle and small towns in the table. It can be seen from table 1 that the urban heat island phenomena is obvious both in large cities and small towns. A comparison of ΔT average values shows that the average is 7.35℃ in Chengdu city and the average is 4.39℃ in the middle and small towns, among which the maximum is 5.18℃ in Xindu and the minimum is 3.10℃ in Xinfan township. The ΔT in Chengdu city was the maximum (up to 9.4℃) at 17:15 (Beijing time, BTC, similarly hereinafter) on 31 July 2000 and the minimum (5.0℃) at 3:18 on 22 May 2001. A comparison of ΔT average values in the middle and small towns shows that the average was 5.55℃ (among which it was higher than 7.0℃ in Xindu and Guanghan) at 17:15 on 31 2000 July and 2.88℃ (among which it was 1.7 ℃ in Xinfan township) at 3:18 on 22 May 2001.

The figures 2 and 3 are the urban heat island three-dimensional view and side view respectively. The figure 2 shows that most of the heat islands are in isolated conditions in middle and small towns. Although Longquanyi is located about 16 km away from Chengdu city proper they are linked sometimes by a rather high temperature ridge (see figure 2a, b and figure 3a, b) which is saddle-shaped approximately.

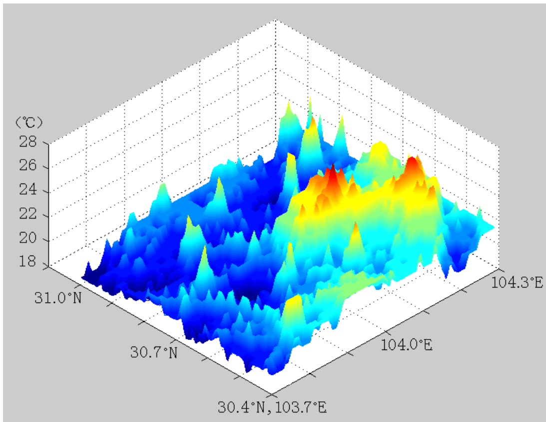
Table 1　A statistic table of the urban heat island temperature ΔT (℃)

Time(BTC) & date,	Chengdu city	Longquanyi	Qingbaijiang	Xindu	Guanghan	Pengzhou	Xinfan	Pixian	Wenjiang	Shuangliu	Xinjin	Huayang	Average in middle & small towns
16:40 on 26 March 2000	7.3	4.9	4.8	4.9	5.0	4.5	3.9	4.9	5.0	4.8	4.1	4.6	4.67
16:28 on 27 March 2000	7.7	4.2	5.2	4.8	4.7	3.7	3.8	5.2	4.4	4.5	4.6	3.9	4.45
17:15 on 31 July 2000	9.4	4.2	4.9	7.2	7.4	6.2	3.0	6.2	6.5	6.1	5.2	4.1	5.55
3:18 on 22 May 2000	5.0	3.3	3.2	3.8	3.4	2.5	1.7	2.3	2.3	3.3	2.8	3.1	2.88
Average	7.35	4.15	4.52	5.18	5.13	4.22	3.10	4.65	4.55	4.68	4.18	3.92	4.39

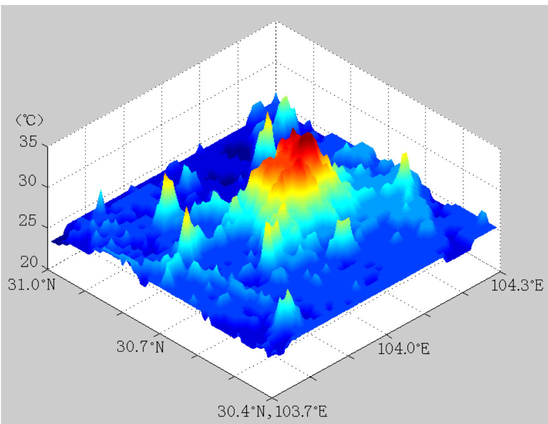
Note: The ΔT is corrected to be +3.0℃ in Pengzhou because it was effected partially by the cloud on 31 July 2000.



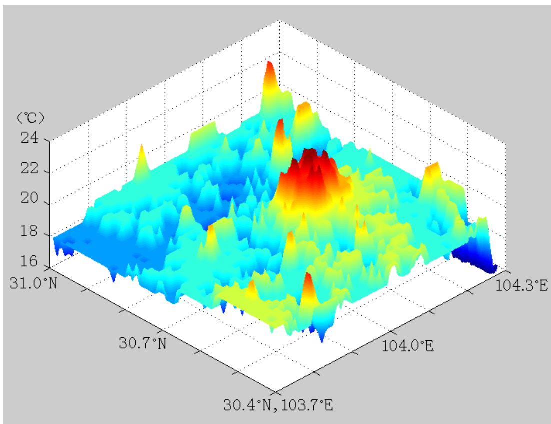
a.　16:40 on 26 March 2000



b.　16:28 on 27 March 2000

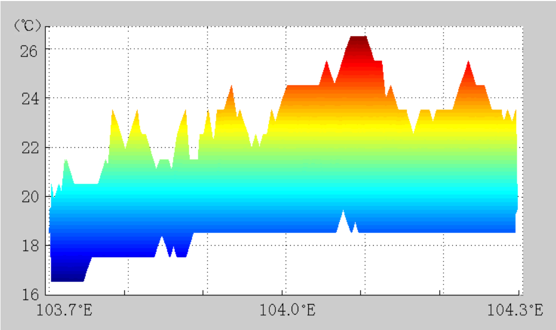


c.　17:15 on 31 July 2000

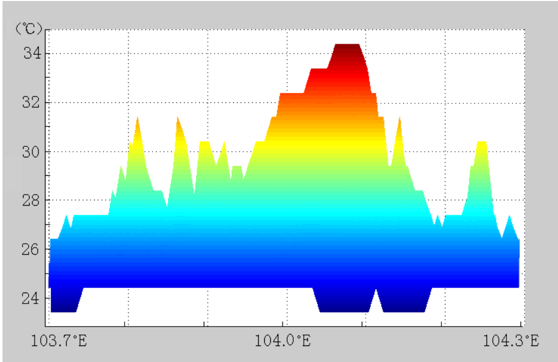


d.　3:18 on 22 May 2000

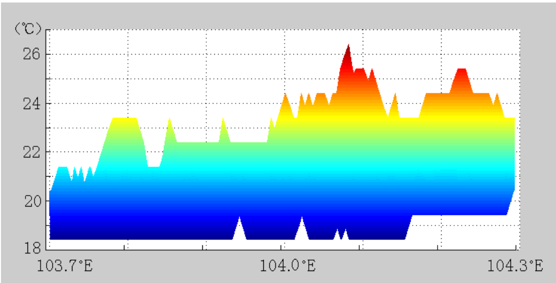
Figure 2　A free-space diagram of the urban heat island temperature



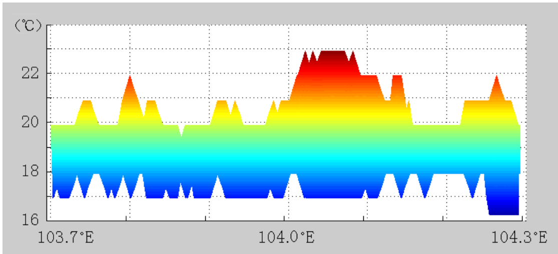
a. 16:40 on 26 March 2000



c. 17:15 on 31 July 2000

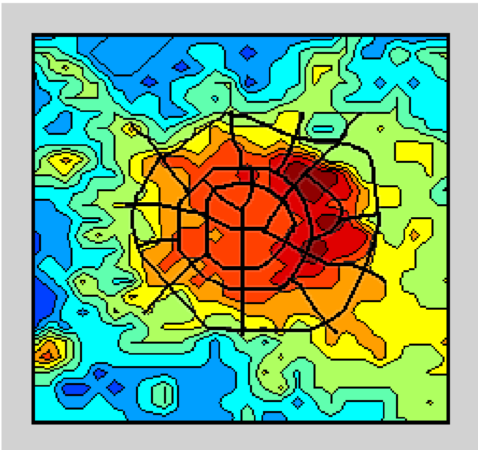


b. 16:28 on 27 March 2000

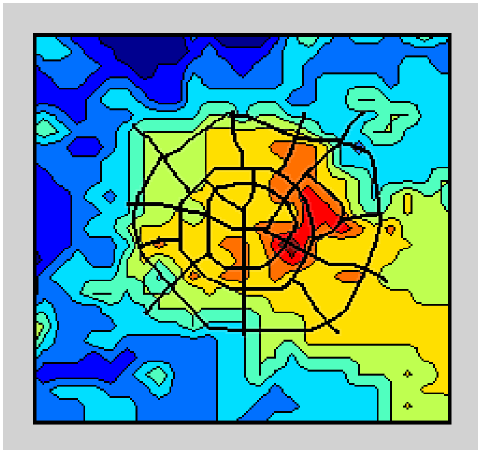


d. 3:18 on 22 May 2000

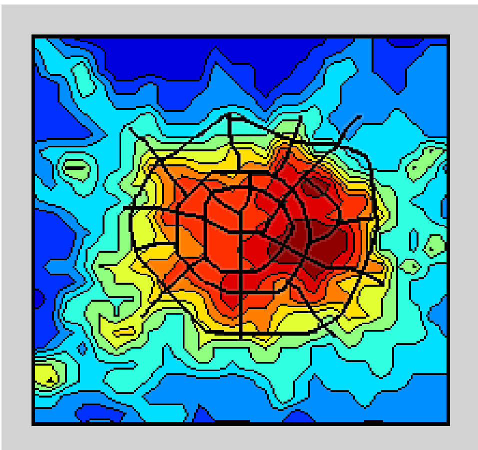
Figure 3 The side-face characteristics of the urban heat island temperature (from south to north)



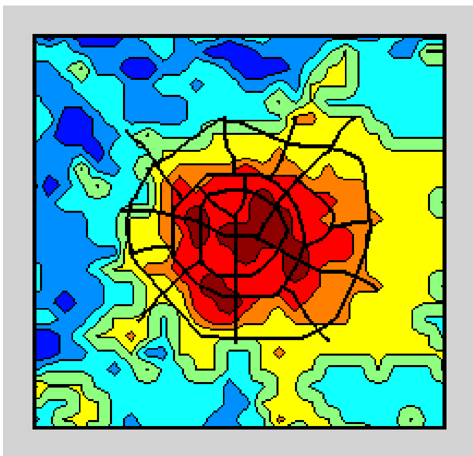
a. 16:40 on 26 March 2000



b. 16:28 on 27 March 2000



c. 17:15 on 31 July 2000



d. 3:18 on 22 May 2000

Figure 4 Chengdu city's urban heat island temperature plan

3.2 Distribution features of the heat island high-temperature zones in Chengducity

The urban heat island range and distribution features are consistent with the urban built-up areas as well as related to the urban functional areas, weather and time. Take Chengdu city as an example. The old urban areas in the city are characterized by a large population density, prosperous and bustling commerce, frequent human activities and quite a lot of waste heat generated there. The city's north-east part is an industrial area, a lot of large-&-middle-scale factories are concentrated on both internal and external sides of the north and east sections along the second and third ring roads and a large amount of waste heat is vented to atmosphere during their production. For example, the highest temperature was observed near the second ring road in the city's east part at 17:15 on 31 July 2000 (see figure 4c) and ΔT was up to 9.4℃ (see table 1); the highest temperature was observed between the second and third ring roads in the city's north-east part at 16:40 on 26 February 2000 (see figure 4a) and ΔT was 7.3℃ (see table 1). However, the human activities were relatively still, the urban heat island effect was rather weak at night (at three o'clock on 22 May) and the heat island peak zone occurred in the city's centre (See figure 3d), for example ΔT was 5.0℃ at 3:18 on 22 May 2001 (see table 1).

4. CONCLUSION

A reasonable selection of the urban heat island reference point is an important link for the urban heat island study. The urban heat island phenomena can be vividly described in detail by use of NOAA/AVHRR data. The heat island phenomena in Chengdu city is remarkable and the phenomena in the middle and small towns is also obvious.Our main works in next step are synchronous observation, correlation analysis and quantitative study of the air temperature at the urban meteorological observation points and satellite remote sensing radiative brightness temperature, and it is necessary to study how to determine the average intensity of the urban heat islands in the future,etc.

5. MAIN LITURATURE

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