The Study on the Heat Island in Midsummer in Shanghai Area

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Abstract

Based on the temperature data of 18 meteorological stations and sites during 1960~1999, the intensive temperature observation data of added 13 sites and the satellite remote sensing brightness temperature data of NOAA-14 during TIO'9798, the distribution feature of high temperature in midsummer season in Shanghai region are analyzed. This paper brings out the principle for defining the heat island and presents the area and intensity of the heat island in Shanghai. The evolution of heat island reveals that the rapidly enlarging and enhancing of the heat island in Shanghai began just since 1980's, it coincides with the developing of the Shanghai urban construction. It is discussed in detail the relationship between the area and intensity of heat island and some urban factors such as the coverage of built-up urban district, the land use category, the population density and the fuel burned heat density and so on. Meanwhile some heat island mitigation measures are suggested in this paper.

Key words: hot wave, heat island, urban factors, heat island mitigation measure

1. Introduction

Shanghai is one of the biggest cities in the world. It is 6340.5 km^2 in area and 13.04 million in population. The hot wave in midsummer is a main calamitous weather from which Shanghai often suffers. In the last 20 years the hot wave in midsummer in Shanghai region exhibits aggravating tendency and has affected negatively the sustainable development of Shanghai. Apart from the climatic warning up, the enhancing heat island effect due to the rapid development of Shanghai proper construction and extension of the urban area is also an important reason. Hence it is necessary to study the factors contributing the heat island and the mitigation measures.

In order to gather more dense data in urban region to study the heat island effect, a temperature intensive observation project in Shanghai region was conducted in July~August during 1997~1998 (called as TIO'9798). During TIO'9798 were added 13 temperature observation sites, Besides the 18 meteorological stations and urban observation sites keeping the recent 40 year's meteorological record are employed in this study, too. The mean distance of 31 meteorological stations and intensive observation sites in Shanghai urban region is about 4 km. Among them 10 stations locate in 10 suburban counties, respectively. Longhua station (hereafter call LH station for short, as the same, all station and site names are abbreviated with two or tree capital letters) locates at the edge of Shanghai proper. The temperature in an hour and the maximum temperature were read each day.

Totally 30 day's data in TIO'9798 were collected when the maximum temperatures at LH station exceeded 33.0? . Fortunately the third hottest weather since 1873 happened in Shanghai region in the summer of 1998, the maximum temperatures of the collected 30 days range from 33.3? to 39.4? , almost covering the possible maximum temperatures in midsummer at LH station. Meanwhile there exist certain days in each interval of 1? . It indicates the 30 day's data are rather representative.

The remote sensing data of NOAA-14 was collected during TIO’9798. Because the time for the satellite to pass over Shanghai is required to be close to the time when the local maximum temperature occurs and the local sky is required to be clear, only 5 day’s satellite images were collected during TIO’9798. The brightness temperatures of the 5 day’s satellite images were averaged and got a composed image in order to smooth the variations of days.

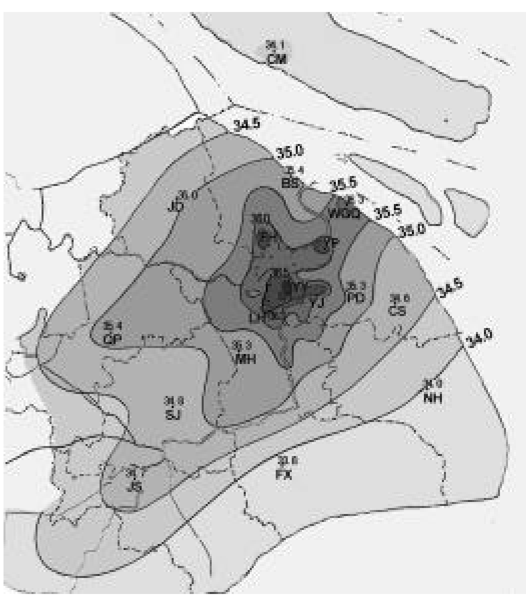
2. The analyses of high temperature field and heat island in Shanghai region

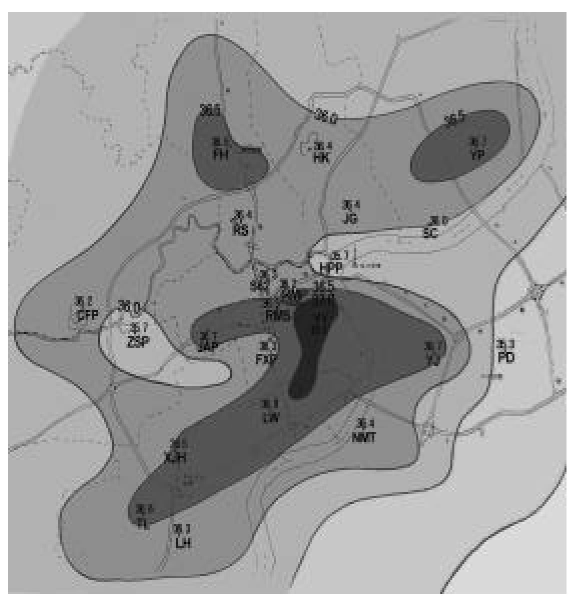
Fig 1 shows the distribution of the mean maximum temperature averaging the 30 day's data. It demonstrates a distinct high temperature area enclosed by 35.5 ? isotherm. This area fits roughly the Shanghai urban scope. The high temperature increases toward the Shanghai downtown. The hot area enclosed by 36.0 ? isotherm roughly coinciding with the Shanghai proper scope. There are three blazing hot areas surrounded by 36.5 ? isotherm, two in north correspond to the district gathering steel-making factories and textile factories, one in south does to the commercial center. The area over 37.0 ? is called as hot core, it happens to correspond to the densest residential district in Shanghai, the population density there reaches 110 thousand persons per square kilometer. Besides there are two cooler areas with the temperature less than 36.0 ? , one in east locates around the joint point of Huangpu river and Suzhou creek. The lower temperature is due to cooling of the broad water surface. The western one locates in the most greening district in Shanghai.

In order to define the area and intensity of urban heat island, it is necessary to choose a reasonable background influenced least by heat island. 9 meteorological stations in outskirts of Shanghai can be considered fitting the condition and are classified. Table 1 lists the differences between the mean maximum temperatures in the 9 stations. If the stations with the temperature difference less than 0.2 ? could be merged into a group of the resemble geographical feature, there exist three parallel isothermal zones, as marked by shade in table 1. The northwest isothermal zone consists of BS station and QP station and the mean maximum temperature of the zone is 35.3 ? . The middle isothermal zone consists of CS station, SJ station and JS station and the mean temperature is 34.7 ? . The southeast isothermal zone locates along NH station and FX station with the mean temperature of 33.9 ? . Obviously there exist a temperature gradient with the direction from northwest to southeast. It is due to the peninsula geographic feature of Shanghai.

Table 1. The differences between the mean maximum temperatures in the stations each other in Shanghai outskirts during TIO'9798. (unit is ?)

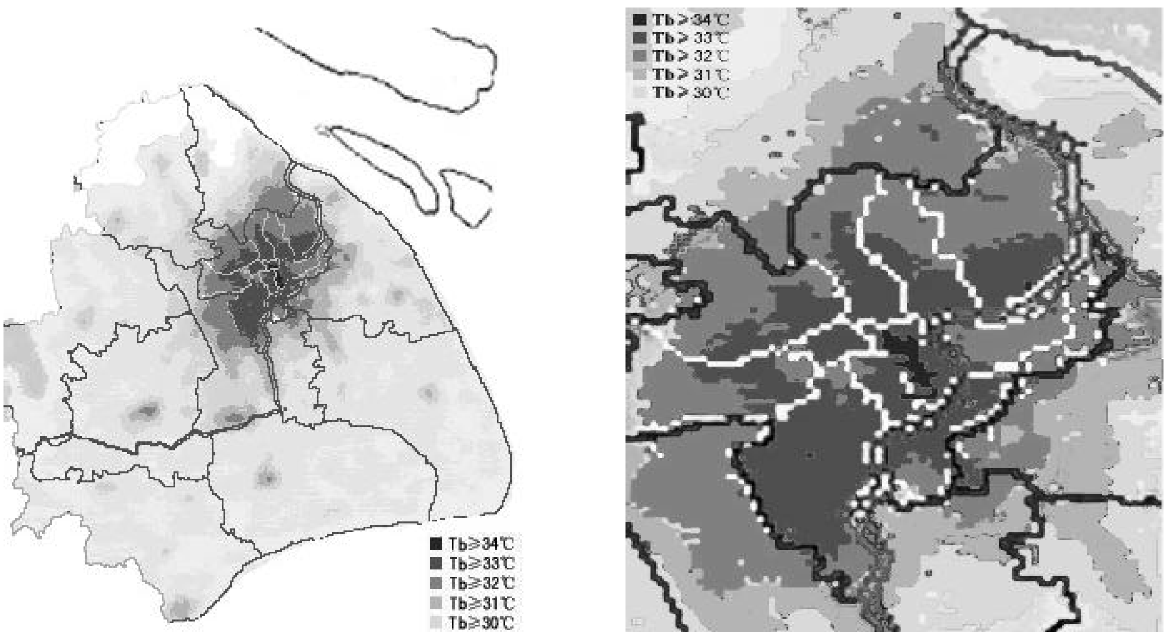
station		CM	BS	QP	JD	SJ	JS	CS	NH	FX
temperature		34.1	35.4	35.4	35.0	34.8	34.7	34.6	34.0	33.8
CM	34.1	0.0	1.3	1.3	0.9	0.7	0.6	0.5	- 0.1	-0.3
BS	35.4	-1.3	0.0	0.0	0.4	0.6	0.7	0.8	1.4	1.6
QP	35.4	-1.3	0.0	0.0	0.4	0.6	0.7	0.8	1.4	1.6
JD	35.0	- 0.9	-0.4	- 0.4	0.0	0.2	0.3	0.4	1.0	1.2
SJ	34.8	-0.7	-0.6	- 0.6	-0.2	0.0	0.1	0.2	0.8	1.0
JS	34.7	-0.6	-0.7	- 0.7	-0.3	- 0.1	0.0	0.1	0.7	0.9
CS	34.6	- 0.5	-0.8	- 0.8	-0.4	- 0.2	-0.1	0.0	0.6	0.8
NH	34.0	0.1	-1.4	-1.4	-1.0	- 0.8	-0.7	-0.6	0.0	0.2
FX	33.8	0.3	- 1.6	-1.6	-1.2	- 1.0	-0.9	-0.8	-0.2	0.0





a. Shanghai region b. Shanghai proper

Figure 1. The distribution of the mean maximum temperature (?) in Shanghai during TIO'9798. The dotted line is the boundary of the counties and urban area. The thin double lines indicate the high ways and the thick double line means the Wangpu River. All station and site names in the fig are abbreviated by two or three capital letters.



a. Shanghai region b. Shanghai proper

Figure 2. The composite image of the satellite remote sensing brightness temperature of NOAA-14 in Shanghai during TIO'9798. The brown line means the boundary of counties and urban area. The white line indicates the urban districts. The double brown line means the Wangpu River.

Because the urban region locate in the middle isothermal zone, the area of the urban heat island in Shanghai can be defined by the region where the mean maximum temperatures are 0.8 ? higher than that in the middle zone. The intensity of heat island in a location can be defined by temperature difference between in this location and in the middle zone. Thus The scope of the heat island in Shanghai in 1997~1998 happens to be outlined by the 35.5 ? isothermal line, the area of the heat island is about 850 km^2. The intensity of the heat island ranges from 0.8 ? in the edge of the heat island to 2.4 ? in YYP site. It should be noted that because of the rapid extension of the built-up urban area in Shanghai in the recent 20 years, many places in outskirts have been influenced more or less by heat island, the actual intensity of heat island should be higher than what the above says.

Figure 2 clearly displays the area and intensity of the heat island, too. The brightness temperatures (Tb) in Shanghai region vary in 28 ? ~34 ? . The boundary of Tb=31 ? coincides well with the 35.5 ? isotherms in fig 1, outlining the scope of the heat island. The area of Tb=33 ? coincide with the hot area with mean maximum temperature over 36.0 ? in fig 1. Especially the area of Tb=34 ? fits to the hot core with mean maximum temperature over 37.0 ? in fig 1. It proves that both of the kinds of the data have high reliability in analysis of heat island.

3. The discussion on the relationship between the urban factors and the heat island.

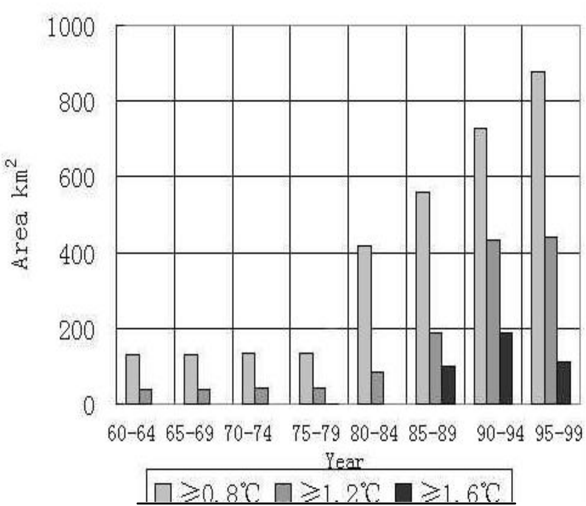
3.1 The relationship between the built-up urban area and the heat island.

As involving in the relationship between the built-up urban area and the heat island, the city size is often measured by the population count in the city rather than by the built-up urban area, such as in the papers of Zhou Shuzheng , Kusaka and others. The evolution of heat island of Shanghai in recent 40 years presents that the area and intensity relate better to the built-up urban area.

In order to analyze more exactly the evolution of the heat island in Shanghai, CM station in Chongming island is selected to be the background for comparing the temperatures because the urban construction in Chongming island developed least in Shanghai region. The mean temperatures in July~August every year during 1960~1999 are employed in this section. For more stable statistical results the mean temperatures in every station are averaged in every 5 years. During 1960~1974 the differences between the mean temperatures in all stations limited within -0.2 ? ~ +0.2 ? . It indicates that before 1975 the influence of the urban heat island effect did not reach the stations. But from 1980's the differences of the mean temperatures of all stations minus that of CM station increase gradually, indicating the heat island in Shanghai region is enlarging.

Consulting the definition of heat island in section 2, the coverage of the difference of the mean temperatures over 0.8 ? is defined as the area of the heat island, the area of the mean temperature differences over 1.2 ? and 1.6 ? can be defined as the intensity of heat island. Fig 3 illustrates the evolution of the area and intensity of the heat island since 1960. The area of heat island during 1960~1979 was limiting within 100 km^2 , but it goes up straightly over 400 km^2 since 1980 and increase continuously to be about 850 km^2 in 1995~1999, almost enlarging 7 times in the recent 20 years. In the early 20 years the area of the mean temperature differences over 1.2 ? limited within 50 km^2 , showing the intensity of heat island kept weak. While in 1985~1989 the area of mean temperature differences of over 1.2 ? reached near 200 km^2 , the mean temperature differences of over 1.6 ? appeared and its area is about as large as the area of the mean temperature differences of over 0.8 ? in 1960~1979, it means the intensity of heat island enhanced one time. Furthermore in 1990~1994 the area of the mean temperature differences of over 1.2 ? and of over 1.6 ? enlarged to be 400 km^2 more and 200 km^2, respectively, implying the intensity enhanced 4 times at least in the recent 20 years. But it worthy to notice that during 1995~1999 the area of the difference of over 1.2 ? stops the increasing and the area of the difference of over 1.6 ? reduced , this indicates the heat island intensity mitigates in the recent 5 years. It should be owed to the greening plan undergoing in Shanghai proper in the recent years.

The evolution of the area and intensity of heat island relates well with the development of the urban construction. Fig 4 shows the built-up urban area expanded very small from 1964 to 1984, but expanded much larger from 1984 to 1996. It basically synchronized with the increasing of the area and intensity of heat island. Besides fig 4 illustrates that the expansion of the built-up urban area in north west is more than that in east, the increasing of the scope of heat island exhibits the same shape (the fig is omitted). It proves the area and intensity of heat island relate well with the built-up urban area. It has been noted that the area of heat island is much larger than the area of the built-up urban area, this results from the heat advection driven by wind. It doesn't discussed more here..



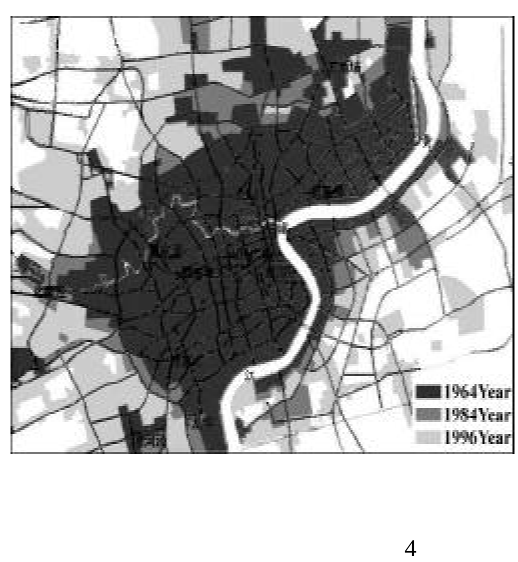


Fig 3. The evolution of the area and intensity of heat island in Shanghai. The abscissa indicates years. The numbers in ordinate mean area in unit of km^2 .

Fig 4. The expansion of the built-up urban area in Shanghai.

3.2 The contribution of different land use categories to heat island.

Because of the different capability of absorbing and reflecting the sun heat and leaking water, the different land use categories share different proportions of the contribution to form heat island. Usually the area ratio of a land use category to the heat island area is taken to measure the contribution for the land use category to form heat island.

Park analyzed the observation data in Seoul during June~August in 1982 and concluded that the factory and shopping use land take the biggest proportion of the contribution to form heat island , the second biggest one belongs to the residence area. The situation in Shanghai appears different with that in Seuol. Table 2 lists the area ratio of some main land use categories in each intensity level of heat island measured by the brightness temperature (Tb) in fig 2.

Table 2 the area ratio of the main land use categories to the area of each intensity level of heat island in Shanghai. (ratio unit is %, brightness temperature (Tb) in fig 2 presents the intensity level of heat island)

Intensity of heat island Land use category	Tb = 31 ?	Tb = 32 ?	Tb = 33 ?	Tb = 34 ?
farmland	42.5	18.8	5.4	0.0
unused land	5.0	5.2	3.5	0.9
public facilities	2.1	4.4	5.7	0.9
industry use land	14.2	16.1	17.5	15.5
road and square	6.2	12.1	17.2	23.6
resident use land	16.2	29.6	38.7	54.5

As the intensity level of heat island going up, the contribution ratios of the resident use land and road and square to heat island increase gradually, while the ratio of the industry use land keeps about 16%. Especially for the hot area (Tb= 33 ?) and the hot core area (Tb = 34 ?), The resident use land offers the biggest contribution, it takes more than 35% proportion of the total heat contribution. The second biggest contribution belongs to the road and square land, taking about 20% proportion. The contribution of the industry use land falls into the third one.

The heat contribution of resident use land to heat island relates with the building density. According to the statistical data of the building density in Shanghai proper in 1997, the building density of many places in the hot area exceeds 60%. Especially in the hot core area, the building density of 4/5 area exceeds 60% and the building density of 2/5 area exceeds 80%. The road and square land can absorb sun heat best, while the open place leads the heat disperse easy, so the road and square use land belongs to the second biggest contribution to form heat island. The contribution of the factory use land results from the fuel burning. These factories release a large amount of heat, but they separate each other more widely, the released heat is difficult to concentrate, resulting the industry use land into the third one.

The above conclusion suggests that reducing the building density in resident area may be the effective measure to mitigate the intensity of heat island. Meanwhile greening the road and square is important to relax the heat island .

3.3 The relationship between the population density and the intensity of heat island.

Mitchel etc. explained that the most intensity of heat island in a city has positive correlation to the square root of the population count of a city according to the statistical results of 77 cities in the United States. Oke analyzed the data of 29 cities in The North America and Europe and demonstrated a linear correlation relationship between the most intensity of heat island and the logarithm of the population count in a city. Based on the data in Japan cities in 1983, Fukuoka points out the nonlinear relationship between the most intensity of heat island and the logarithm of the population count in a city. It should point out that all the above conclusions neglect the geographic and climatic distinctions which can cause differences between the intensities of heat island of the different cities.

To avoid the above shortcoming, here the data comes from the Shanghai region only. 14 site's data are collected along the line across Shanghai urban area.. The YY district has the highest population density of 110 thousand persons per square kilometers, it happens to be the most intensive heat island in fig 1.The second highest population density falls in LW district with 90 thousand persons per square kilometers, the intensity of heat island in this place reaches 2.2 ? , it is the second most intensive heat island in Shanghai. Few cities in the world have such dense population. Contrary, the Lujiazhuei district in east bank in Pudong area has low population density of 38 thousand persons per square kilometers, the heat island intensity falls to 0.9 ? . The population density in the west edge of the Shanghai urban region is 2 thousand persons per square kilometers, the heat island intensity is 0.3 ? only. Based on the data of the selected 14 points, the nonlinear relationship between the heat island intensity and the logarithm of the population density is simulated as a parabola approximately, showing as fig 5. The regression equation expresses as below

? T=0.657+0.130* logP+0.428*(logP)2 (1)

here ? T means the heat island intensity with the unit of ? , P means the population density with the unit of ten thousands persons per square kilometer, log is common logarithm.

It can divide into three kinds of circumstances: When P<0.5, the heat island intensity keeps low level, ? T ˜ 0.4 ? ; when 0.5< P<7 , ? T vary with logP in linear correlation; while P>7 , ? T may increase with the square of logP. This result advises that trying to reduce high population density in some districts is a key measure to mitigate the heat island intensity.

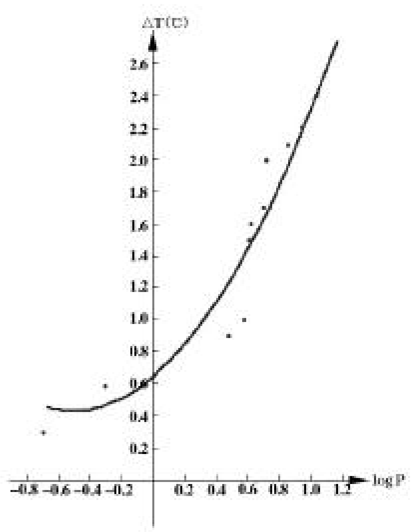


Figure 5. The relationship between the heat island intensity and the population density. ? T means the heat island intensity, P means the population density with the unit of ten thousands persons per square kilometer, log is common logarithm.

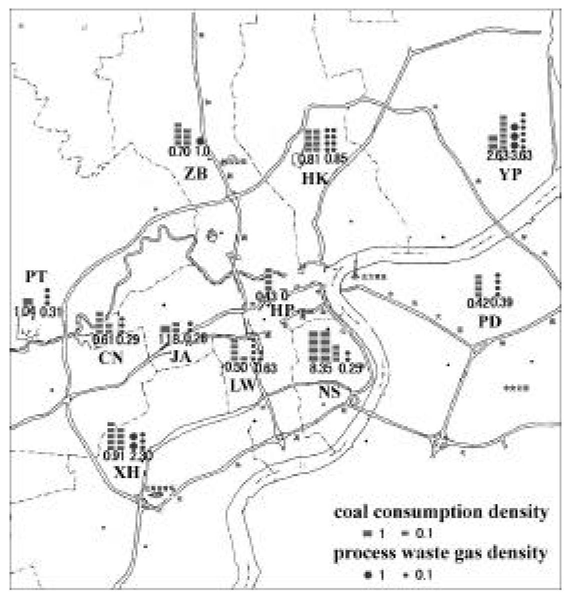


Figure 6. The distribution of the of coal consumption density (Rm) and the industrial processed waste gas density (Gm). The Rm unit is 10^4 t/(a*km^2). The Gm unit is 10^8 nm^3/(a* km^2). t, a, nm^3 mean ton, year and the cubic meter air under a standard air pressure, respectively.

3.4 The relationship between the fuel burned heat and the heat island intensity.

The city fuel burned heat primarily comes from living and industrial consumption fuels. In this text the mean consumption coal density in a year (Rm) expresses the total fuel burned heat, the Rm unit is

10^4 t/(a*km^2). The mean industrial process waste gas density (Gm) indicates the factory burned heat, the Gm unit is 10^8 nm^3/(a* km^2). Here t, a, nm^3 mean the ton, year and the cubic meter air under a standard air pressure, respectively. Statistic al result express that the Rm and Gm in the urban region is 7.26 times and 5.50 times as many as that in the suburban area in Shanghai, respectively. This elucidates that the city fuel burned heat is an important factor to form the heat island. Fig 6 shows the distribution of Rm and Gm in Shanghai proper. Comparing to fig 1b, Rm and Gm have positive correlation in qualitatively to the heat island intensity. The three places where Rm exceeds 1.10 correspond the mean maximum temperature of above 36.7 ? . The Rm in YY district reaches 8.35, being the highest Rm in Shanghai, it happens to correspond to the hot core. It worth noting that the Gm in YY district is 0.25 only, being the second least one in Shanghai proper, this indicates that the fuel burned heat comes mainly from living consumption fuel. Besides the population density in YP district is about 40 thousand persons per square kilometer, being the least population density in Shanghai proper. According the equation (1), the heat island intensity should be 1.48 ? and the mean maximum temperature should become 36.2 ? . But Fig 1b shows the mean maximum temperature actually is 36.7 ? . The reason is that the Rm in YP district reaches as much as 2.63, being the second most one in Shanghai proper, andt the Gm takes the most one in Shanghai proper for 3.63. The factorial fuel burned heat produce a heat center. So trying to remove the factories with burning huge amount of fuel out away the city proper is one of important measures to mitigate heat island intensity.

4. Conclusions

(1) Definition of heat island is an argumentative problem. The key is to choose a reasonable background influenced at least by heat island. During TIO'9798 the area of heat island in Shanghai is defined by the region scope where the mean maximum temperatures are 0.8 ? higher than that in the middle zone. The intensity of heat island in a location is defined by the temperature difference between in this location and in the middle zone. The area of the heat island is about 850 km^2. The intensity of the heat island ranges from 0.8 ? in the edge of the heat island to 2.4 ? in Shanghai proper.

(2) The evolution of heat island in the last 40 years reveals that the heat island in Shanghai enlarged and enhanced rapidly just since 1980's. The area of heat island during 1960~1979 was limiting within 100 km^2 , but it goes up straightly over 400 km^2 since 1980 and increase continuously to be about 850 km^2 in 1995~1999, almost enlarging 7 times in the recent 20 years. The intensity enhanced 4 times at least in the recent 20 years. Fortunately the heat island intensity appears mitigating in the recent 5 years. It should be owed to the greening plan undergoing in recent years. The evolution of the area and intensity of heat island relate well with the built-up urban area.

(3) The different land use categories share different proportions of the contribution to form heat island. For the first and the second top intensity of heat island, The resident use land offers the biggest contribution, it takes more than 35% proportion of the total heat contribution. The second biggest contribution belongs to the road and square use land, taking about 20% proportion. The contribution of the industry use land falls into the third one with the proportion of about 16%. It suggests that reducing the building density in resident area may be the key measure to mitigate the intensity of heat island.

(4) There exists a nonlinear relationship between the heat island intensity and the logarithm of the population density. It can illustrate as a parabola approximately. The regression equation expresses as

$$? T=0.657+0.130* \log P+0.428*(\log P)2$$

It can divide into three kinds of circumstances: When P<0.5, the heat island intensity (? T) keeps low level, ? T ~ 0.4 ? ; when 0.5< P<7 , ? T vary with logP in linear correlation; while P>7 , ? T may increase with the square of logP. This result advises that trying to reduce high population density in some districts is a key effective measure to mitigate the heat island intensity.

(5) The city fuel burned heat is an important factor to form the heat island. The distribution of the mean consumption coal density (Rm) have positive correlation in qualitatively to the heat island intensity. Trying to remove the factories with burning huge amount of fuel out away the city proper is one of the important measures to mitigate heat island intensity.

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