URBAN HEAT ISLAND STUDY BASED ON LANDSAT REMOTE SENSING IMAGES: A CASE STUDY OF HANGZHOU

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Abstract— Urban is the center of the region society, economy, politics and culture. And urban is a symbol of human civilization and development. Urbanization is a common trend in many countries. In developing countries, this situation is particularly evident. With rapid urbanization, there are lots of environment problems. Among these environmental problems, the urban heat island effect is the most important. UHI has deep impacts on material cycles and energy transfers within urban ecosystems and has become an important issue in urban climate and environmental research. Hangzhou is an important city in the urban circle of the Yangtze River delta as the capital of Zhejiang Province in China. And nowadays, Hangzhou is in a period of rapid development. With the development of urban, the environmental problems become more and more important, especially the urban heat island effect. This paper, based on the Multi-time-phase TM /ETM+ Remote Sensing images, takes Hangzhou as an example to contrast four time inversions results and study the evolution rule and the characteristic of the heat island effect with Single-Channel Algorithm. Through this study, we can find the evolution law of urban heat island in Hangzhou. And then for the future development of cities and solutions to the urban heat island effects, it can provide a more effective way of train of thought and methods

Index Terms— GIS; Remote Sensing; Urban Heat Island; Land Surface Temperature; Single-Channel Algorithm

I. INTRODUCTION

With rapid urbanization, there has been a tremendous growth in population and buildings in cities. The high concentration of hard surfaces actually triggered many environmental issues. In these issues, urban heat island (UHI) effect is one of the most typical problems and what we most need to pay attention to.

The urban heat island is a phenomenon that urban air-temperature is at least two degrees higher than suburbs. On the spatial distribution of temperature, the urban is like an island. So, we call it the urban heat island effect. (Shown in Fig.1)

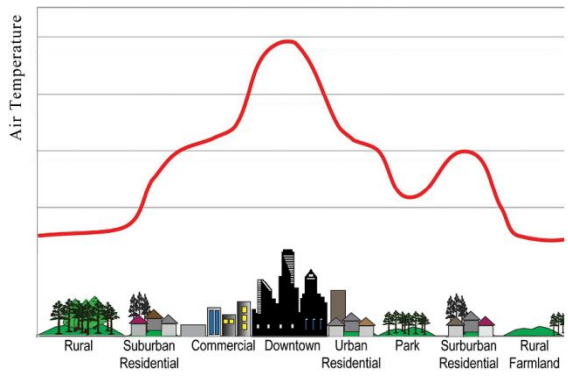


Fig1. A Diagram of Urban Heat Island

The causes for the urban heat island are multiple. For one thing, it's caused by nature, such as some special landform condition and climatic condition. For another, the more important is the development of human society. Entering 21st century, the temperature in urban is higher and higher because of urban extension, population concentration, developed industry, traffic jams, air pollution and most of buildings in urban made of concrete with low heat capacity and high heat conductivity. At the same time, the high-rise buildings will weaken the wind, then the temperature will rise. Conversely, in sub-urban, the environment is closer to nature and in stark contrast to that in urban. It leads to the urban heat island effect highlighting.

There are a lot of several problems caused by urban heat island effect. With the air temperature increasing, there will be a low-pressure vortex at the urban center. The pollutants, such as sulfur oxides, nitrogen oxides, carbon oxides, hydrocarbon, etc. produced by daily life, vehicles and factory will be gathered in the urban and damage people's health. And then, the air temperature will rise further because of air pollution. Finally, it will be a vicious circle, and generate even more serious social problems.

II. RESEARCH REGION

Hangzhou is the capital of Zhejiang Province, located in the southeast of China, the north central of Zhejiang Province, the southern part of the Yangtze River Delta, the west end of Hangzhou Bay, the downstream of Qian Tang River and the southern tip of The Beijing-Hangzhou Grand Canal. And it is the important central cities of the Yangtze River Delta and the transportation hub of Southeast China. (Shown in Fig.2)

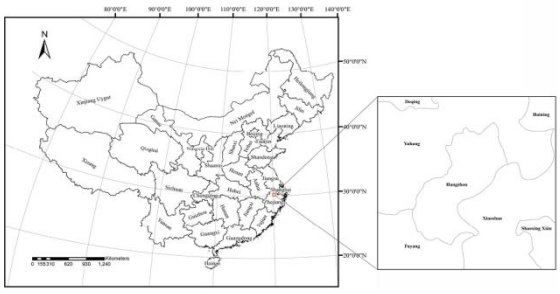


Fig.2 Research Region

Geomorphic categories are diverse. The terrain is high in the West and low in the East. The west, center and south are hill, and the northeast is Northern Zhejiang Plain. The hill takes up 65.6% of area, the plain is 26.4% and the river, lake and reservoir are 8%. Hangzhou is a typical "The south of the lower reaches of the Yangtze River" with a network of rivers, lakes, ponds and other water dotted.

Hangzhou is the subtropical monsoon climate. The average temperature is about 16.2 degrees centigrade, in summer it is about 28.6 degrees centigrade, in winter is about 3.8 degrees centigrade. The average annual precipitation is about 1100 to 1600 millimeters, mainly in spring rain, plum rains and typhoon rains. The average annual total solar radiation is between 100-110 kcl/cm^2 and the sunshine hours are 1800-2000 hours.

There are many rivers in Hangzhou. The rivers mainly belong to two basins: one is the Qian Tang River Basin and the other is the Taihu Basin. There are 286 large and small rivers with a total length of 846.92 kilometers and many reservoirs in the west of Hangzhou, forming a unique wetland zone.

Hangzhou is the capital and most populous city of Zhejiang Province in east China. And it is one of the sub-provincial cities, the political, economic, cultural and financial centers of Zhejiang Province, China's important e-commerce center and internationally renowned tourist city. Hangzhou has a total area of 16596 km^2, with an urban area of 3068 km^2. And it has 9 districts, 2 county-level cities and 2 counties.

Hangzhou's GDP is 10.050 billion yuan in 2015. The economic growth has remained strong for the several consecutive years. At the end of 2015, the population is about 7.24 million.

Considering the characteristics of remote sensing image processing software and corresponding data collection, in this study, we take the West Lake as the center, and choose a rectangular area with a length and width of 50 kilometers in Hangzhou. In the WGS-1984 coordinate system, the upper left coordinate is (777563m, 3274744m), and the lower right coordinate is (827563m, 3324743.7). The total area of research region is 2500 square kilometers, including Deqing county, Haining county, Yuhang District, Gongshu District, Shangcheng District, Xiacheng District, Xihu District, Jianggan District, Binjiang District, Xiaoshan District, Fuyang District and Shaoxing County. The research region includes Hangzhou center, also contains most of the suburbs. And it contains various landforms, can typically reflect the urban area of Hangzhou.

III. RESEARCH DATA

The remote sensing data used in this paper is LANDSAT-5 TM of Hangzhou from 2000 to 2010 (Shown in Table 1), and the orbital number is 119/39. The LANDSAT Thematic Mapper (TM) sensor was carried onboard LANDSAT 4 and 5 from July 1982 to May 2012 with a 16-day repeat cycle.

Table 1 Imaged used in this study

Sensor	Data
LANDSAT-5 TM	2000-11-04
LANDSAT-5 TM	2003-10-28
LANDSAT-5 TM	2005-11-02
LANDSAT-5 TM	2010-10-31

The weather of data that we selected was sunny. The visibility in the study area is high. And the imaging quality chosen is good. And the software used for the study is ArcGIS 10.3.

IV. RESEARCH METHOD

Land Surface Temperature is an important parameter for many research applications. And I used Single-Channel Algorithm for automatic retrieval of brightness temperature, land surface emissivity and Land Surface Temperature from LANDSAT data to estimate land surface temperature.

This method can be used in order to process both LANDSAT TM and ETM+ data. It consists of 3 separate steps, namely, NDVI Thresholds, Thermal Band to Brightness Temperature and Retrieve LST (Land Surface Temperature).

A. NDVI Thresholds

This step estimates land surface emissivity employing Normalized Difference Vegetation Index Thresholds Method ($NDVI^{THM}$) to distinguish between soil pixels ($NDVI < NDVI_S$), full vegetation pixels ($NDVI > NDVI_V$) and mixed pixels ($NDVI_S \leq NDVI \leq NDVI_V$). And the threshold values of $NDVI_S = 0.2$ and $NDVI_V = 0.5$ make the method applicable for global conditions. The NDVI can be calculated from LANDSAT 4, 5 and 7 by equation 1 and LANDSAT 8 by equation 2. And then Normalized Difference Vegetation Index (NDVI) are converted to Land Surface Emissivity (LSE) using modified $NDVI^{THM}$.

$$NDVI = \frac{Band4 - Band3}{Band4 + Band3} \quad (1)$$

$$NDVI = \frac{Band4 - Band5}{Band4 + Band5} \quad (2)$$

In the conversion, the emissivity (ε) of soil and full vegetation pixels should be used. And the emissivity can be defined by user. In general, the default emissivity values are:

soil pixels:

$\varepsilon = \varepsilon_{S\lambda} = 0.96$

full vegetation pixels:

$\varepsilon = \varepsilon_{V\lambda} + C_\lambda = 0.985 + 0.05 = 0.99$

The emissivity of mixed pixels is calculated by

equation 3. Each pixel (P_V) is calculated by equation 4 considering the proportion of vegetation. And the cavity effect (C_λ) that due to surface roughness is calculated by equation 5. In this equation, the geometrical factor (F') is the mean value 0.55.

$$E = E_{V\lambda} \cdot P_V + E_{S\lambda} \cdot (1 - P_V) + C_\lambda \quad (3)$$

$$P_V = \left(\frac{NDVI - NDVI_S}{NDVI_V - NDVI_S}\right)^2 \quad (4)$$

$$C_\lambda = (1 - E_{S\lambda}) \cdot \varepsilon_{V\lambda} \cdot F' \cdot (1 - P_V) \quad (5)$$

Additionally, this step allows the user to define the emissivity for the surface water. Normally, the default emissivity is 0.99. Before then, water bodies mask and the subset area (polygon feature layer) must be defined.

B. Thermal Band DN to Brightness Temperature

The next step is using appropriate conversion coefficients (gain and bias) to convert pixel values of LANDSAT thermal band (band 6) to at-sensor spectral radiance in $W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$ according to equation 6 and then transforming L_s to at-sensor brightness temperature (T_s) applying inverted Planck's Law and specific calibration constants (K_1 and K_2) as in the equation 7. And this step can only work with LPGS (Level-1 Product Generation System) data.

$$L_s = gain \cdot DN + bias \quad (6)$$

$$T_s = \frac{K_2}{\ln\left(\frac{K_1}{L_s} + 1\right)} \quad (7)$$

C. Retrieve LST

This step estimates LST (Land Surface Temperature) with S-C (Single-Channel) Algorithm according to equation 8a, 8b and 8c.

$$LST = \gamma\left[\frac{1}{\varepsilon}(\psi_1 L_s + \psi_2) + \psi_3\right] + \delta \quad (8a)$$

$$\gamma = \left[\frac{c_2 L_s}{T_s^2}\left(\frac{\lambda^4 L_s}{c_1} + \frac{1}{\lambda}\right)\right]^{-1} \quad (8b)$$

$$\delta = -\gamma \cdot L_s + T_s \quad (8c)$$

In these equations, the necessary data are: the calculated brightness temperature (T_s) and the land surface emissivity (ε) datasets as well as some specific atmospheric functions (AF). The AF's (ψ_1, ψ_2 and ψ_3) are used for correction of the atmosphere influence which is very important part of the LST retrieval algorithm. The AF's are computed from atmospheric parameter with equation 9a, 9b and 9c.

$$\psi_1 = \frac{1}{\tau} \quad (9a)$$

$$\psi_2 = -L^{\downarrow} - \frac{L^{\uparrow}}{\tau} \quad (9b)$$

$$\psi_3 = L^{\downarrow} \quad (9c)$$

In these equations, τ is atmospheric transmissivity, $L^{\uparrow}$ is up-welling atmospheric radiance, and $L^{\downarrow}$ is down-welling atmospheric radiance. The site specific atmospheric parameters can be calculated by means of an atmospheric radiative transfer model, such as ACPC (Atmospheric Correction Parameter Calculator that is a freely accessible web based on MODTRAN interface). The S-C Algorithm uses also Planck's radiation constants ($c_1 = 1.19104 \cdot 10^8 W \cdot \mu m^4 \cdot m^{-2} \cdot sr^{-1}; c_2 = 1.43877 \cdot 10^4 \mu m \cdot K$) and the effective wavelength of LANDSAT TM/ETM+ band 6.

These three steps are the whole procedure of Land Surface Temperature retrieval from LANDSAT data. Using this method, we can invert the land surface temperature. And then, through ArcGIS, the air temperature pattern of Hangzhou can be gotten. The urban heat island effect is obvious in air temperature pattern. And we can find the evolution rule of urban heat island effect in Hangzhou in the past several years.

V. RESULTS AND ANALYSIS

According to the above research method, LANDSAT-5 TM images are converted into the distribution maps of Hangzhou Land Surface Temperature in November 4th 2000, October 28th 2003, November 2nd 2005 and October 31st 2010 (following show with 2000, 2003, 2005 and 2010). In the distribution maps, the red area is the high-temperature zone, namely urban heat island area, and the blue area is the low-temperature zone. The more different in color between two regions, the more different in temperature between these regions.

D. Land Surface Temperature and Urban Heat Island Effect Analysis in 2000

1) Land Surface Temperature in 2000

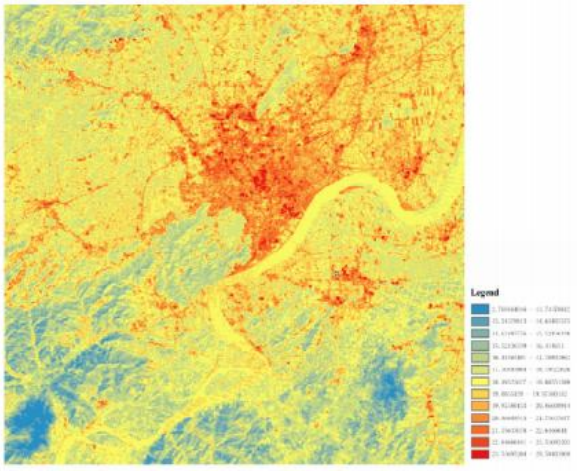


Fig.3 The distribution of LST (2000-11-04)

The mean of Land Surface Temperature in 2000 is 18.64 degrees Celsius. The maximum is 20.88 degrees Celsius. the minimum is 16.42 degrees Celsius. And maximum temperature difference is 4.46 degrees Celsius.

2) Urban Heat Island Effect Analysis in 2000

Through Fig.3, in 2000, the urban heat island effect is serious in Hangzhou. At the western and the north-eastern corner of the diagram, there is a large blue area below 10 degrees Celsius, and the temperature is the lowest in this diagram, because in these areas are hills and mountains covered with a large area of forest. And at the center of the diagram, there is a little orange zone with about 19 degrees Celsius. It is West Lake as a transition between the city and hills. At the north-east

of West Lake, there is a large red area with the air temperature ranges from 20 to 25 degrees Celsius. It is the high-temperature zone, namely urban heat island area, because it is the downtown areas of Hangzhou including Gongshu District, Shangcheng District, Xiacheng District, Xihu District and the western part of Jianggan District. And at the south-east of urban heat island area, there is a less urban heat island area, is Xiaoshan District. There is a yellow belt area with about 18 degrees between two urban heat island areas, is Qiantang River. And other areas are the low-temperature areas belong to suburb.

E. Land Surface Temperature and Urban Heat Island Effect Analysis in 2003

1) Land Surface Temperature in 2003

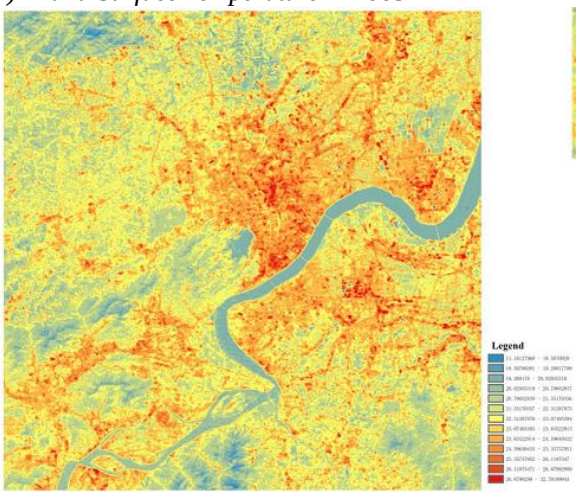


Fig.4 The distribution of LST (2003-10-28)

The mean of Land Surface Temperature in 2003 is 22.69 degrees Celsius. The maximum is 25.43 degrees Celsius. the minimum is 20.54 degrees Celsius. And maximum temperature difference is 4.89 degrees Celsius.

2) Urban Heat Island Effect Analysis in 2003

Through Fig.4, we can find that the red areas in 2003 is more than that in 2000. That means that the urban heat island area is bigger, especially, the south-western parts of the research region, the eastern part of Jianggan District and the Xiaoshan District. And the blue areas, namely the low-temperature areas are decreasing, the south-western parts of the region are the most obvious. At the same time, the Land Surface Temperature is showing an upward trend. Compared to the same period in 2000, the maximum temperature difference rises slightly.

F. Land Surface Temperature and Urban Heat Island Effect Analysis in 2005

1) Land Surface Temperature Analysis in 2005

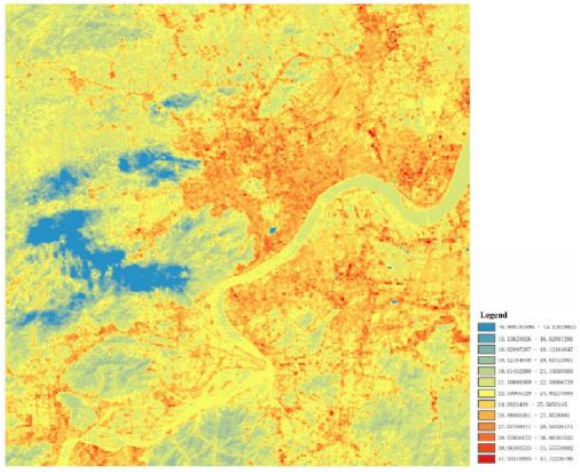


Fig.4 The distribution of LST (2005-11-02)

The mean of Land Surface Temperature in 2005 is 23.35 degrees Celsius. The maximum is 26.71 degrees Celsius. the minimum is 20.63 degrees Celsius. And maximum temperature difference is 6.08 degrees Celsius.

2) Urban Heat Island Effect Analysis in 2005

Through Fig.5, we can find that there are some large blue areas, namely low-temperature areas, in the south-west of Hangzhou. And the temperature is very low. But in the urban, the red areas are bigger comparing to 2003. It means that the urban heat island area is expanding. And in 2010, the maximum temperature difference reaches a maximum value, is 6.08 degrees Celsius. And this suggest that urban heat island effect in Hangzhou has become more serious.

G. Land Surface Temperature and Urban Heat Island Effect Analysis in 2010

1) Land Surface Temperature Analysis in 2010

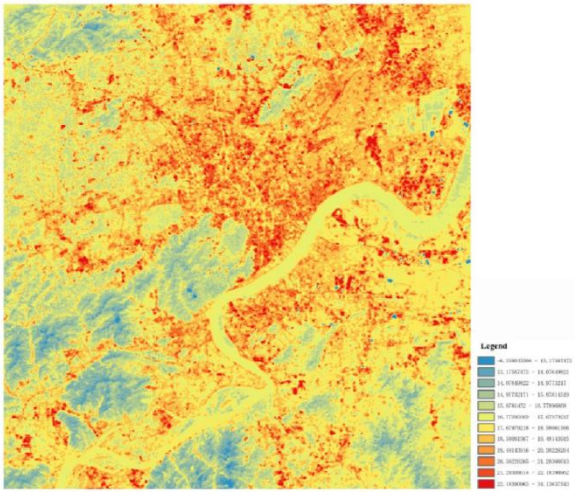


Fig.6 The distribution of LST (2010-10-31)

The mean of Land Surface Temperature in 2003 is 18.13 degrees Celsius. The maximum is 20.29 degrees Celsius. the minimum is 15.86 degrees Celsius. And maximum temperature difference is 4.43 degrees Celsius.

2) Urban Heat Island Effect Analysis in 2010

Through Fig.6, we can find the urban heat island areas are still expending, especially the north and north-east. And there are lots of new urban heat island appearing on the coast of Qian Tang River. But, meanwhile, the average temperature is decreasing and the maximum temperature difference is also decreasing.

CONCLUSION

According to the distribution of Land Surface Temperature in Hangzhou at the end of October and the beginning of November in 2000, 2003, 2005 and 2010, inverted by LANDSAT-5 TM with Single-Channel Algorithm, the urban heat island areas are expending year by year since 2000. The most obvious extension areas are the north-east of the urban, the coast of Qian Yang River, Binjiang District and Xiaoshan District.

Combined with the economic development and urban expansion of Hangzhou in these 10 years and the location of Hangzhou, we can find the inevitable link between the deterioration of urban heat island and the development of urban in Hangzhou. In these 10 years, the Hangzhou GDP expanded an average of about 14.28% a year. With the development of economy, urban has to expand rapidly to meet the needs of economic development and restricted to the hills in south and west, the urban can only expand west, especially north-west.

Because of human social activities in urban, the maximum temperature difference reaches the highest value in 2005. But since 2005, the difference has the reduction tendency, because the government has attached more important to environmental problems and has implemented a series of measures to mitigate the urban heat island effects.

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