

CORRELATION BETWEEN URBAN HEAT ISLAND EFFECT AND THE THERMAL INERTIA USING ASTER DATA IN BEIJING, CHINA

Yurong CHEN^{a,*}, Mingyi DU^a, Rentao DONG^b

^a School of Geomatics and Urban Information, Beijing University of Civil Engineering and Architecture, 1# Zhanlanguan Road, Beijing 100044, China

^b The 3rd Engineering Ltd. of the 18th Chinese Railway Bureau, Zhuozhou Hebei 072750, China

SS-7

KEY WORDS: Urban, Land Surface Temperature, Thermal Environment, City, Correlation, Data

ABSTRACT:

This paper focuses on the analysis of the relationship between the urban heat island effect and the thermal inertia using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data. To analyze the relationship between the thermal inertia and the urban heat island, the image classification was performed in the second ring using the decision tree and supervised maximum likelihood method as water, forest, grassland, road and building. Correlation coefficients were calculated by performing simple linear regression analysis between the urban heat island intensity and the thermal inertia. They are in a strong inverse correlation. The linear regression models between the thermal inertia and heat island intensity of the five subsurface land cover types were established by a linear regression analysis. It was considered that the linear regression relation of the models were significant from the significance tests.

1. INTRODUCTION

The urban heat island (UHI) effect refers to the temperature rise of any man-made area, which can make it distinctively protrude as a 'warm island' among the 'cool sea' that the lower temperature of their natural landscape represents. This effect is due primarily to the concentration of human activities and artificial built surfaces which are mainly composed by construction materials that efficiently absorb and store solar energy, releasing heat slowly, and mainly during the night (Zhang, 2007). And thermal inertia is one of the typical parameters for describing the thermal characteristics of subsurface materials. The thermal characteristic of urban subsurface is one of the main impacting factors on urban heat island effect. So this paper focuses on the analysis of the relationship between the urban heat island effect and the thermal inertia using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data.

2. STUDY AREA AND METHODOLOGY

2.1 Study area and data description

Beijing is capital city and is one of the largest cities situated in north of China whose central geographical location is 39°56'N, 116°20'E. Our main study area is the old city of Beijing which is enclosed by the range of second ring road. The old city of Beijing is not only the main protective region of archaic architecture and archaic inhabitation, but also representing the historic and cultural city of Beijing. Several studies have shown that the heat island effect in Beijing was reinforced year after year, especially in the second ring road (Zhang, 2007; Song, 2003).

We have taken the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data as the main data source. ASTER data have three visible and near infrared (VNIR) channels at 15m spatial resolution and five thermal infrared (TIR) channels at 90m spatial resolution. The VNIR data can be used to classification and the TIR data can be used to obtain the surface temperature. Because there was no available ASTER data at night we have in Beijing, the MODIS (Moderate Resolution Imaging Spectroradiometer) data at night was used for the following land surface temperature difference computation. MODIS data have five thermal infrared bands at 1000m spatial resolution. The data we used were obtained on January 27, 2004 and August 31, 2004.

2.2 Methodology

Because it is usually believed that radiant temperatures of the land surface layer correspond closely to atmospheric temperatures of the layer situated immediately above this one, due to the transference of energy emitted from the former to the latter. So in this paper, the urban heat island effect was assessed by the land surface temperature difference between the urban area and the country side. The land surface temperature was determined using an iterative self-consistent approach (Y. Xue et al., 2005) which is based on the split-window method and the fact that the actual land surface temperatures are the same for all the ASTER thermal infrared bands and for MODIS thermal infrared bands. Then the heat island intensity was calculated by relative surface temperature. The urban heat island intensity was assessed by the relative land surface temperature which is defined as $\Delta T/T_a$, where ΔT represents the difference between the land surface temperature of urban area and the averaged surface temperature of country side, T_a is the averaged surface temperature of country side (Sun et al., 2002).

* Corresponding author: cyr6666@163.com.

To analyze the relationship in detail between the thermal inertia and the urban heat island, the image classification was performed in the second ring using the decision tree and supervised maximum likelihood method as water, forest, grassland, road and building. Firstly, based on the NDVI vegetation index and threshold methods, the original image (ASTER VNIR data, Figure 1) was decomposed using the decision tree classification module of the ENVI software. Secondly, the composed images were used to pick up the subsurface land cover types by the supervised maximum likelihood method further. Finally, every decomposed image was composed to a whole image. The last image was the final classification image (Figure 2).

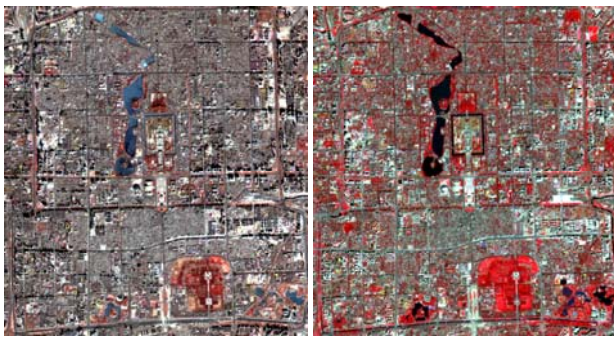


Figure 1 ASTER VNIR data in the second ring on Jan.27 and Aug.31, 2004

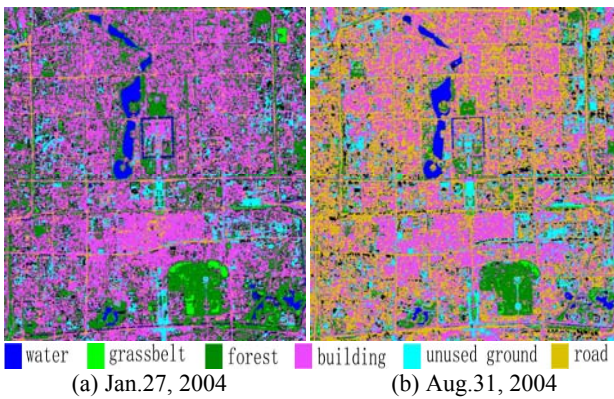


Figure 2 Classification image in the second ring on Jan.27 and Aug.31, 2004

And thermal inertia is one of the typical parameters for describing the thermal characteristics of a material, it is a physical parameter representing the ability of a material to conduct and store heat, and in the context of planetary science, it is a measure of the subsurface's ability to store heat during the day and reradiate it during the night. It is defined as

$P = \sqrt{k\rho c}$, where P [$Jm^{-2}S^{-1/2}$] represents thermal inertia, k [$Wm^{-2}K^{-1}$] is thermal conductivity, ρ [kgm^{-3}] is bulk density, and c [$Jkg^{-1}K^{-1}$] is specific heat capacity. Thermal inertia can be obtained by remote sensing information model. The parameter of expressing the relative surface thermal inertia value is an apparent thermal inertia which can be used for the contrast of the thermal characteristic of subsurface and be obtained from satellite images easily.

The apparent thermal inertia was obtained by combining the day time ASTER data and night time MODIS data using a real thermal inertia model which requires surface albedo and surface temperature difference during the satellite overpass time at day and night respectively. It is defined as $(1-A)/\Delta T$, where A is the surface albedo, ΔT is the diurnal land surface temperature difference. Surface temperature difference can be obtained by the determination of the land surface temperature mentioned above. Because there was no available ASTER data at night corresponding to the day time ASTER data we have in Beijing, and the surface temperature at night would be almost the same at an area of $1 km^2$ or so, so after pre-processing the images such as geo-rectification, image matching, and after resampling the night time surface temperature into a spatial resolution of 90m using a nearest neighbor method, the difference between the day time land surface temperature derived from ASTER and the night time land surface temperature retrieved from MODIS data can be our required land surface temperature difference. The surface albedo can be obtained through weighting the spectral reflectance. The weight index is the simulated values using 6S model. The spectral reflectance can be calculated after getting the aerosol optical depth which can be derived by the synergy of the two directions of the band 3B and 3N in ASTER data. Figure 3 is the obtained image of apparent thermal inertia.

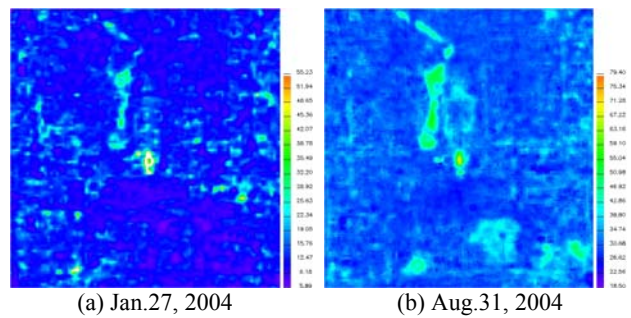


Figure 3 Apparent thermal inertia in the second ring on Jan.27 and Aug.31, 2004

3. CORRELATION ANALYSIS AND DISCUSSION

The relationship between the thermal inertia and heat island intensity was studied by Pearson's correlation coefficient. The formula is (Xinquan, 2006):

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}} \quad (1)$$

where \bar{x} , \bar{y} = the average values of variable x , y
 x_i , y_i = the observations of variable x , y

The significance of each correlation coefficient was determined using a one-tailed Student's t-test.

$$t = r \sqrt{\frac{n-2}{1-r^2}} \quad (2)$$

where r = correlation coefficient
 n = the number of sample observation
 n-2 = the degree of freedom

The article calculated the correlation coefficients between the thermal inertia and the urban heat island intensity of five subsurface types (Table 1). The correlation coefficients are negative which means that the urban heat island intensity and the thermal inertia has an inverse relationship. Which means that the surface temperature of a material with a small thermal inertia such as water can be rise rapidly, on the contrary, the surface temperature of a material with a higher thermal inertia such as building can be rise slowly. The correlation degree is different at the different times and subsurface types. In Jan.27, 2004, the highest negative correlation was found in forest (-0.3970), followed by road (-0.3549) and water (-0.3140), and with a decrease for building (-0.2941). the lowest correlation was observed in grassland (-0.2883); However, the strongest, negative correlation, in Aug.31, 2004, existed in water (-0.5683). The correlation coefficient values dropped slightly for forest (-0.4882) and grassland (-0.4697), with a sharp decrease for building (-0.1811). The least correlation was found in road (-0.1403). All correlation was significant at the 0.01 level.

subsurface type	Jan.27, 2004	Aug.31, 2004
water	-0.3140	-0.5683
forest	-0.3970	-0.4882
grassland	-0.2883	-0.4697
road	-0.3549	-0.1403
building	-0.2941	-0.1811

Table 1 Correlation coefficient between thermal inertia and heat island intensity

The linear regression models between the thermal inertia and heat island intensity of various subsurface types were established by a linear regression analysis. The modelling results for water are displayed in Table 2. The linear regression models are significant at 0.05 level. Whether on Jan.27 or on Aug.31, the values of the Significance F are less than 0.05. So we can conclude that the linear regression relation are significant between the ATI and heat island intensity. The coefficient of determination, R², is 0.0986 on Jan.27, indicating that the predictor (ATI) account for 9.86% of variance in the heat island intensity distribution. However, R² is 0.3230 on Aug.31. The results suggest that the linear regression relation for water on Jan.27 is more significant than the relation on Aug.31. Similarly, the linear regression models for forest, grassland, road and building were obtained (Table 3 to Table 6). From the tables, it can be concluded that the linear regression relation of the models are all significant.

4. CONCLUSIONS

In this study we have researched the relationship between the urban heat island effect and the thermal inertia using ASTER data in the old city of Beijing. The correlation coefficients are negative which means that the urban heat island intensity and the thermal inertia has a relationship of strong inverse correlation. The correlation degree is different at the different times and subsurface types. The linear regression models were retrieved by performing simple linear regression analysis between the urban heat island intensity and the thermal inertia. It was considered that the linear regression relation of the models were significant from the significance tests. This result provides helpful information for the city designers and the local government to choose some construction materials with a small thermal inertia that is benefit for mitigating the urban heat island effect and making a favorable living environment for the citizens when they performing a city planning.

REFERENCES

- Song Y L, Zhang S Y., 2003. The study on heat island effect in Beijing during last 40 years. *Chinese Journal of Eco-Agriculture*, 11(4), pp.126-129.
- SUN Sa-mei, LU Chang-yi, 2002. Study on Monitoring Intensity of Urban Heat Island and Taking it as an Indicator for Urban Ecosystem by Remote Sensing. *Journal of Xia men University (Natural Science)*, 41(1), pp. 66-70.
- Weng, Q., Lu, D., & Schubring, J., 2004. Estimation of land surface temperature-vegetation abundance relationship for urban heat island studies. *Remote Sensing of Environment*, 89, pp. 467-483.
- Xiao, S., Liao, F., Ni, Z., et al., 2002. The relationship between hot island effect and vegetation of Xiamen city by remote sensing. *Journal of Northeast Forestry University*, 30(3), pp. 141-143.
- Xinquan Ge, Bin Wang, 2006. *Applied statistics*. Social sciences academic press(china), pp.107-122.
- Y. Xue, Guoyin Cai, et al., 2005. Iterative self-consistent approach for Earth surface temperature determination, *International Journal of Remote Sensing*, 26(1), pp. 185-192.
- ZHANG Zhao-ming, HE Guo-jin, et al., 2007. Study of Urban Heat Island of Beijing City Based on RS and GIS. *Journal of Earth Sciences and Environment*, 29(1), pp. 107-110.

Time	Model	Coefficient of determination, R ²	Adjusted R ²	Significance level	
Jan.27, 2004	y=-40.45x+0.122	0.0986	0.0985	0.05	
Aug.31, 2004	y=-35.771x+0.116	0.3230	0.3229	0.05	
Jan.27	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	0.021	0.021	731.644	5.278E-153
Residual	6687	0.192	2.867E-05		
Total	6688	0.213			
Aug.31	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	0.112	0.112	3616.215	0
Residual	7581	0.235	3.098E-05		
Total	7582	0.347			

Table 2 Linear regression models of water for predicting heat island intensity of the ATI

Time	Model	Coefficient of determination, R ²	Adjusted R ²	Significance level	
Jan.27, 2004	y=-38.234x+0.124	0.1576	0.1576	0.05	
Aug.31, 2004	y=-27.903x+0.095	0.2383	0.2383	0.05	
Jan.27	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	0.095	0.095	4175.154	0
Residual	22312	0.506	2.266E-05		
Total	22313	0.600			
Aug.31	df	SS	Mean Square	F	Significance F
Regression	1	Sum of Squares	0.430	18462.23	0
Residual	59000	1.374	2.329E-05		
Total	59001	1.804			

Table 3 Linear regression models of forest for predicting heat island intensity of the ATI

Time	Model	Coefficient of determination, R ²	Adjusted R ²	Significance level	
Jan.27, 2004	y=-31.87x+0.105	0.0831	0.0829	0.05	
Aug.31, 2004	y=-24.66x+0.082	0.2206	0.2204	0.05	
Jan.27	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	0.013	0.013	317.120	5.658E-68
Residual	3497	0.140	3.998E-05		
Total	3498	0.152			
Aug.31	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	0.030	0.030	1247.728	6.784E-241
Residual	4408	0.106	2.409E-05		
Total	4409	0.136			

Table 4 Linear regression models of grassland for predicting heat island intensity of the ATI

Time	Model	Coefficient of determination, R ²	Adjusted R ²	Significance level	
Jan.27, 2004	$y=-34.679x+0.113$	0.1260	0.1259	0.05	
Aug.31, 2004	$y=-6.904x+0.030$	0.0197	0.0196	0.05	
Jan.27	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	0.268	0.268	11883.982	0
Residual	82468	1.859	2.255E-005		
Total	82469	2.127			
Aug.31	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	0.006	0.006	283.719	4.783E-63
Residual	14134	0.279	1.971E-05		
Total	14135	0.284			

Table 5 Linear regression models of road for predicting heat island intensity of the ATI

Time	Model	Coefficient of determination, R ²	Adjusted R ²	Significance level	
Jan.27, 2004	$y=-31.370x+0.103$	0.0865	0.0865	0.05	
Aug.31, 2004	$y=-8.779x+0.036$	0.0328	0.0328	0.05	
Jan.27	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	0.233	0.233	10375.424	0
Residual	109542	2.456	2.242E-005		
Total	109543	2.688			
Aug.31	df	Sum of Squares	Mean Square	F	Significance F
Regression	1	0.081	0.081	4841.176	0
Residual	142694	2.385	1.671E-005		
Total	142695	2.465			

Table 6 Linear regression models of building for predicting heat island intensity of the ATI

