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Estimation of the Effects of Vegetation on Local Climate Using GIS and Remote Sensing Data

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Estimation of the Effects of Vegetation on Local Climate Using GIS and Remote Sensing Data

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By

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ABSTRACT

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As one of the effective methods to control urban temperatures, the effects of trees and other vegetation have come into focus. Geographic Information System (GIS) and remote sensing data, Digital Orthophoto Quarter-Quadrangle (DOQQ) and Landsat Thematic Mapper (Landsat TM), have been applied in this study to analyze the UHI. The effect of road-side trees on local micro-climate was examined with in-situ temperature measurement and simulated shade. Regression analyses revealed significant negative slopes for all time periods. This trend continued throughout the entire night until sunrise the next morning. The relationship between thermal patterns and vegetation distributions was investigated using the Landsat TM images. The result of regression analyses showed that vegetation affects surface temperature across study sites. Where the higher the Normalized Difference Vegetation Index (NDVI), the surface temperature was lower. It was observed in most seasons except winter. This relationship became stronger into summer, and then weaker into autumn.

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CHAPTER I

Introduction

Rapid urbanization and industrialization have induced numerous environmental problems. Especially, urbanization has produced significant changes in the surface and atmospheric properties that can cause climate changes in most cities (Kim *et al*. 2002). A well known phenomenon is the urban heat island (UHI), which can be caused by various factors such as increased anthropogenic heat, reduced water evaporation, and increased flux in short wave absorption by the urban canopy, which is the assemblage of buildings, trees, and other objects composing a town or city and the spaces between them. Configurations of the urban canopy are characterized by building coverage, canopy height, orientation of roads, and building height distribution (Kondo *et al*. 2001). The urban heat island refers to the phenomenon where the temperatures of the urbanized areas are higher than those in the surrounding suburban and rural areas (Streutker 2002 and Kim *et al*. 2004). It also causes "warmer nighttime temperatures in the core of the built environment when compared with the surrounding rural environment" (Hawkins *et al*. 2004).

Since the UHI phenomenon was first observed in large urban areas, it has been studied in various aspects by many researchers for the past forty years. As one element of regional climate phenomena, UHI studies have been conducted worldwide. For example, UHI studies using remote sensing data (Table 1) have been conducted in St. Louis, Missouri (Vukovich, 1997), Seoul, Korea (Lee, 1993), thirty seven cities in the United States (Johnson *et al*. 1994), Huntsville, Alabama (Lot *et al*. 1997), Vancouver, British Columbia, Canada (Owen *et al*. 1998 and Voogt and Grimmond 2000), Houston, Texas (Streuker 2002), the Tokyo metropolitan area in Japan (Hirano et al. 2004), and Indianapolis City, Indiana (Weng *et al*. 2004).

Recent researches into urban climates were summarized by Arnfield (2003) and McKendry (2003). Arnfield classified UHI studies into three categories: observational

Table 1 UHI studies using remote sensing data

Author	RS Data	Time	Resolution	Study Area
Carlson and Arthur (2002)	AVHRR[1]	1986 to 1987	1.1Km	Philadelphia, Pennsylvania
Gallo and Tarpley (1996)	AVHRR	June to August 1991	1.1Km	28 cities in the US
Hafner and Kidder (1999)	AVHRR	February	1.1km	Georgia
Hirano *et al*. (2004)	JERS-1[2]	July 1997	100m	Tokyo metropolitan area
Johnson *et al*. (1994)	AVHRR	July 1989	1.1km	37 cities in the US
Lee (1993)	AVHRR	-	1.1km	Seoul, Korea
Lo *et al.* (1997)	ATLAS	September 1994	5m	Huntsville, Alabama
Owen *et al*. (1998)	AVHRR	1985 to 1994	1.1km	State College, Pennsylvania
Rosenzweig *et al*. (2006)	Landsat ETM+	August 2002	30m	New York, New York
Streutker (2002)	AVHRR	April 1998 to January 2000	1.1km	Houston, Texas
Vukovich (1983)	HCMM[3]	June 1978, February 1979, and September 1979	500m	St. Louis, Missouri
Weng (2001)	Landsat TM	1989 to 1997	120m	Zhujiang Delta, China
Weng (2003)	Landsat TM	December 1989, March 1996, and August 1997	120m	Guangzhou, China
Weng *et al.* (2004)	Landsat ETM+[3]	June 2000	30m	Indianapolis City Indiana

[1] AVHRR: Advanced Very High Resolution Radiometer
[2] JERS-1: Japanese Earth Resources Satellite-1
[3] HCMM: Heat Capacity Mapping Mission
[4] Landsat ETM+: Landsat Enhanced Thematic Mapper Plus

studies, determinants of UHI, and large-scale UHI studies (Table 2). Observational studies focus on the UHI by observing the existing situation or condition of the UHI. The studies, which focus on the empirical generalization of the UHI, belong to the second category: determinants of the UHI. Large-scale studies generalize the UHI model at large scales.

Most UHI studies are observational studies. For example of the observational studies, the UHI phenomenon of the metropolitan area of Washington, District of Columbia has been analyzed by Kim (1992). Kim focused on the changes and causes of urban heating and discovered that urban heating was influenced by the rapid heating of urban surface such as buildings, asphalt, bare-soil, and short grass.

The existing states of intensity, spatial and temporal structures, and determinants of the UHI in Seoul, Korea were investigated by Kim and Baik (2002, 2004, and 2005). They found that the previous-day maximum UHI intensity, among the four predictors (the previous day, wind speed, cloudiness, and relative humidity), was the most correlated with the maximum UHI intensity (2002). They studied the trend of average

Table 2 UHI study trends by Arnfield and vegetation related studies

Trends	**References**
Observational Studies	Kim (1992), Kim and Baik (2002, 2004, and 2005), Gedzelman *et al*. (2003), and Li *et al*. (2004)
Determinants of the UHI	Weng (2001), Morris *et al.* (2001), Streutker (2002), Hawkins *et al*. (2004), Grimmond and Oke (1999), Owen *et al*. (1998), and Hirano *et al*. (2004)
Large-scale UHI studies	Atkinson (2003), Hafner and Kidder (1999)
Vegetation related studies	Carlson and Arthur (2000), Heisler (1986), Owen *et al*. (1998), Scott *et al*. (1999), Spronken-Smith and Oke (1998), Rosenzweig *et al*. (2006), Nowak *et al*. (2002 and 2006), and Weng *et al*. (2004)

annual maximum UHI intensities, which was smaller in coastal cities than in inland cities (2004) and the UHI in Seoul, which was stronger in the nighttime and on weekdays than in the daytime and on weekends (2005).

The trend of the UHI in New York City (NYC) was analyzed by using a meso-scale analysis, which ranges from a few to several hundred kilometers (Gedzelman *et al*. 2003). They found that the UHI in NYC increased in the afternoon, continued during the night, and decreased rapidly after dawn in all seasons. Li *et al*. (2004) studied the correlation between the UHI and annual temperature in China. They discovered that the UHI effect in cities, which have a population over ten thousand, affected the annual mean temperatures, such as increase of the average values, decrease of variances and change of climatic trends, depending on regions.

While observational studies have shown the general phenomena of the UHI, other researchers have studied the specific determinants of the UHI. The relationship between urban growth and surface temperature in China has been studied by Weng (2001).

By using remote sensing and GIS, Weng found that urban growth patterns in the Zhujiang Delta, China caused surface radiant temperatures to increase. With wind and cloud data over twenty years, the development of the UHI in temperatures to Melbourne, Australia was limited to increasing wind speed, turbulent transport and the features on urban environments that affect urban air temperature in clear sky and calm wind condition (Morris *et al*. 2001).

The changes of the difference between urban and rural temperatures have been studied as one of the determinants of the UHI (Streutker 2002 and Hawkins *et al*. 2004). Streuker found that the UHI magnitude, the difference in temperature between urban and rural areas, was correlated inversely with rural temperature (Streutker 2002). Depending on the land coverage classes in rural areas, the average UHI effect was distributed form 9°C to 12°C and the maximum UHI effect ranged from 10.7°C to 14.6°C (Hawkins *et al*. 2004).

Some researchers have focused on heat flux, a significant component of urban areas. Grimmond and Oke (1999) have found that the storage heat flux, an important component of the energy balance in urban areas, is the greatest in more urbanized sites, such as downtown and industrial areas. The impacts of surface condition or land coverage parameters on the UHI have been studied by Owen *et al*. (1998) and Hirano *et al*. (2004). Owen *et al.* (1998) studied the relationship between land coverage changes and climate effect. They found that the change of the urban land coverage was significantly correlated to the decrease of fractional vegetation coverage and the increase of surface radiant temperatures. Hirano *et al.* (2004) focused on the relationship between vegetation coverage distribution and urban climate. Their study revealed that the difference of air temperature between vegetation and non-vegetation land cover condition was up to 1.5°C. Areas with decreased vegetation abundance and increased residence were warmer than areas with low-rise residential areas in Tokyo, Japan.

Generalizing or modeling UHI phenomena belong to the large-scale UHI studies. It adopts surface parameters or remotely sensed data to observe the large-scale land use zones. For example, Atkinson (2003) has established numerical modeling of the UHI intensity and showed the difference between the daytime UHI and the nighttime UHI. The individual effects, which are caused by Albedo, anthropogenic heat, emissivity, sky-view factor, and thermal inertia, ranged from 0.2°C to 0.8°C in the daytime and from 0.3°C to 0.75°C at night. A hydrostatic three-dimensional meso-scale model was performed to investigate the effect of the surface parameters using Advanced Very High Resolution Radiometer (AVHRR) satellite data by Hafner and Kidder (1999).

A variety of studies focused on the effect of trees and other vegetation on the urban environment (Table 2). Scott et al. (1999) focused on the effect of tree cover on parking lots. Trees created shade, and it keeps the surface and air temperature cool. They observed temperature differences between shaded and exposed site by collecting surface and air temperature data. The shaded sites were cooler than exposed sites and the maximum difference of surface temperature was 39°C during the warm period, August 5 to 7 in 1995. The differences of air temperature between shaded and exposed sites were observed. The difference was 1.3°C during the warm period. However, the difference of air temperatures was smaller than that of the surface temperatures. Also, they found that the tree shade affected fuel-tank temperatures of parked cars. The highest temperature of the fuel-tank interior parked at exposed area was recorded 38.6°C. These temperature differences had influence on emission of oxides of nitrogen (NOx) and hydrocarbons in the form of reactive organic gases (ROGs). Due to reducing the temperature of fuel-tank for shaded vehicles, lower level of gases emitted from the fuel-tank. For example, the amount of ROG emission at 50% canopy coverage site was 0.85 tons per day (tpd) less than 8% canopy coverage site. NOx emission was reduced 0.1tpd at the 50% canopy coverage sites.

The influences of urban parks were studied by Spronken-Smith and Oke (0998) and Rosenzweig *et al*. (2006), while Scott *et al*. studied the effect of trees on the local micro-climate. Spronken-Smith and Oke discovered that vegetated urban parks affected surface and air temperatures in Vancouver, BC and Sacramento, CA. Based on the surface and air temperature, parks create cool islands (cool island effect; PCI). This study showed that park's temperature in Vancouver, BC could be 5°C cooler and temperature in Sacramento, CA could be 5-7°C cooler than the park's surroundings, if parks are in the best conditions. However, the type of parks is an important factor in PCI effect. In the PIC effect, trees had a significant role through shade by tree canopy and evaporative cooling. If park's surface is dry grass, it might be warmer than park's surrounding, due to rapid heating and cooling.

Rosenweig *et al*. (2006) focused on mitigating elements of the UHI in New York City, such as urban forestry, living roofs, and light surfaces. In this study, they used a regional climate model (MM5) and geographic information system (GIS) to decide the characteristics of the NYC's UHI. Based on the result of this study, vegetation reduced temperature effectively more than other elements. However, light surfaces were the most effective element on dropping temperature in NYC, due to the large proportion of developed areas.

The relationship between surface temperature and vegetation was study by Weng *et al*. (2004), Carlson and Arthur (2000), and Owen *et al*. (1998). Weng *et al*. (2004) focused on vegetation fraction as an indicator of vegetation abundance instead of the NDVI. Vegetation abundance was one of important factors to determine the surface temperature. Result shows that unmixed vegetation fraction was negatively correlated with the surface temperature stronger than NDVI for all land cover types.

On the other hand, Carlson and Arthur (2000) and Owen *et al*. (1998) studied the effect of land coverage changes on surface temperature. Through developing and analyzing land coverage parameters using remote sensed data, Carlson and Arthur found that temperature became higher, as vegetation grew smaller due to the urbanization. Owen *et al*. (1998) focused on the effect of urbanization on urban climate using two land cover parameters, fractional vegetation cover and surface moisture availability. Land cover changes in urban area affected on the fractional vegetation cover and surface temperature. As a result of this study, decreased vegetation coverage, which was influenced by urbanization, was correlated with increasing surface temperature.

Another benefit of tree is energy savings. Trees had influence on the energy use in buildings through blocking solar radiation and wind (Heisler, 1986). Although the amount of energy saving differ with climate, depending on the spacious and locations, up to twenty five percent of annual space conditioning energy could be saved in the best condition with trees in an optimum arrangement, compared to the same house in an open field.

Nowak *et al*. (2002 and 2006) focused on the trees' effect on carbon storage and sequestration and air pollutant removal by urban trees. They observed that urban trees in the U.S. stored 700 million tons of carbon, while trees annually eliminated 22.8 million tons of carbon (Nowak *et al.* 2002). The level of atmospheric carbon dioxide was affected by the amount of tree canopy and proportions of large trees. Also, trees had a significant role in the removal of air pollutants, such as carbon monoxide (CO), hydrocarbon, nitro dioxide (NO_2), surfer dioxide (SO_2), and ozone (O_3) (2006). Approximately, 0.7 million metric tons of total annual air pollution were removed by urban trees. The amount of pollution removal was affected by several factors, such as the amount of tree cover, length of in-leaf season, and meteorological variables which had influenced on urban trees.

Objectives

The purpose of this study is twofold: 1) to investigate the effect of road-side trees on the local micro-climate in residential areas in a day and 2) to examine the relationship between vegetation distributions and thermal patterns across the year through the use of remotely sensed data.

CHAPTER II

Study Area

The study site, the City of Huntington, is located in the Southwest part of the State of the West Virginia along the Ohio River. Huntington is the largest City in the Huntington – Ashland, West Virginia (WV) – Kentucky (KY) – Ohio (OH) Metropolitan Statistical Area (MSA) and the second largest city in West Virginia, following Charleston, the Capital (Figure 1).

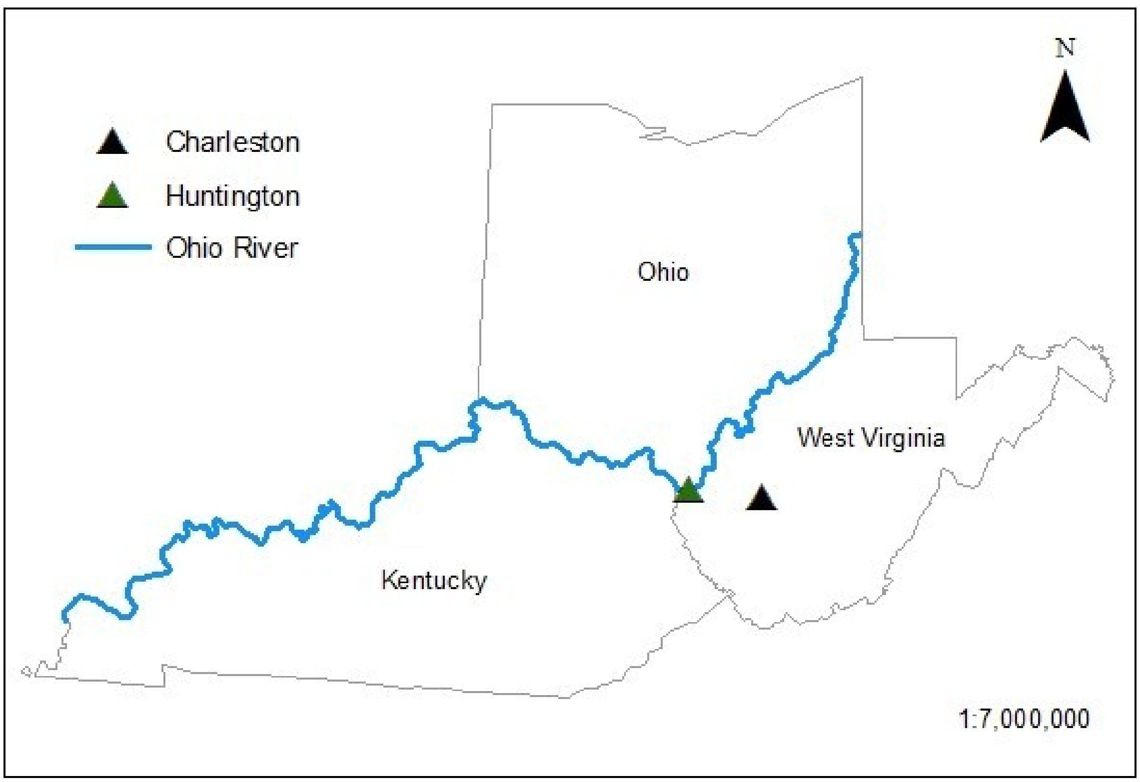

Figure 1 The Huntington - Ashland, WV-KY-OH Metropolitan Statistical Area

Figure 2 shows the central part of Huntington which displays a gradient of increasing urbanization from south to north. The south part of Huntington is covered by forest hills with scattered residences. Residential areas, commercial areas, and the downtown business district follow the forest area from south to north. The State of Ohio is located across the Ohio River.

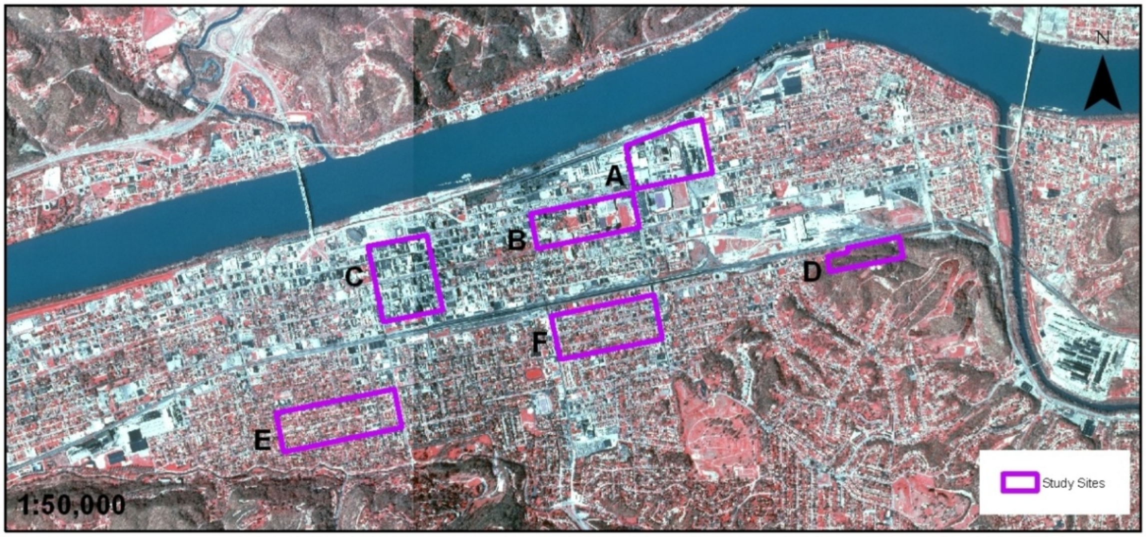

Figure 2 Study area in the City of Huntington, WV (Study sites, A: industrial area, B: Marshall University's Campus, C: Downtown, D: Forest, E: Residential area 1, and F: Residential area 2) Image source: DOQQ images created on April 3, 1997

Residential areas in southern Huntington have large and mature trees along the street. Commercial areas have lower buildings and larger proportions of selected surfaces than residential areas. Along the Ohio River, the downtown and industrial areas are located.

Materials

Two kinds of remotely sensed images were used in this study: Digital Orthophoto Quarter-Quadrangle (DOQQ) images and Landsat Thematic Mapper (Landsat TM) images (Table 3).

DOQQ images (1m resolution, east and west side of Huntington, WV) were used for digitizing the study sites and as a reference image. DOQQ images in this study were created on April 3, 1997.

Twelve Landsat TM images (30m resolution, Path 33 or 34 and Row 33), spread across the year, with low cloud cover were acquired. These images were used to calculate the Normalized Difference Vegetation Index (NDVI) from the Red and Near Infrared (NIR) channels and to examine the relationship between vegetation distributions and surface temperatures as derived from thermal infrared red channel (Band 6, NIR). One of the Landsat TM images, acquired on July 25, 2005, coincided with the time of the study of the effect of road-side trees on the local micro-climate. Landsat TM images in this study were downloaded from the Ohio View website (http://www.ohioview.org).

Both images, DOQQ and Landsat TM, in this study were referenced to the projection, Universal Transverse Mercator (UTM) Zone 17N, with the datum of the World Geodetic System (WGS) 1984.

Table 3 Landsat Thematic Mapper images used in this study

Path	Row	Date of Acquisition	Unique Identification	Landsat	Sensor	Cloud cover (%)
18	33	11/27/2004	0800411270127_0001	5	TM	0
19	33	1/21/2005	0800501220185_00003	5	TM	0
18	33	2/15/2005	0800502150140_00004	5	TM	30
18	33	4/4/2005	0110504070012_00003	5	TM	0
18	33	5/6/2005	0800505070054_00003	5	TM	0
19	33	5/29/2005	0800505290025_00003	5	TM	0
18	33	6/23/2005	0800506240091_00003	5	TM	0
18	33	7/9/2005	0800507090108_00003	5	TM	0
18	33	7/25/2005	0800507260120_00001	5	TM	20
18	33	9/11/2005	08005090110029_00003	5	TM	0
18	33	10/29/2005	08005010290072_00002	5	TM	0
18	33	8/13/2006	0800608130011_00003	5	TM	
18	33	12/3/2006	0110701250035_00007	5	TM	

Methodologies

The Effect of Road-side Trees on Local Micro-Climate

To examine the effect of road-side trees on local micro-climate, residential area 1 (E in Figure 2: second to eighth street and eleventh and twelfth Avenue in Huntington, WV) was used. Along the twelve block of the study site, all trees, which are growing between side-walk and street, were mapped by digitizing and address matching. The trees' canopy width were measured and recorded into the street. The roads were digitized from the DOQQ reference images (1m cell size).

Temperature sites were selected and mapped in locations of various levels of shade, based on a visual evaluation of shading level, such as exposed (Sun, 0), morning shade (1), evening shade (2), afternoon shade and evening sun (3), and shade (4). Temperatures of selected temperature sites had been measured three times a day (afternoon, evening, and next morning before sunrise) during a summer heat wave in 2005 that coincide with satellite over-passes, using hand-held thermal infrared thermometers. Tree heights had been calculated by comparing tree height with the width of the street on photographs.

Because the initial evaluation of shade was assessed only qualitatively, a more quantitative measure of shading level was needed. In order to make a three-dimensional canopy for shading analysis, a slope with a flattop was simulated for the trees (Figure 3). For this purpose, trees along the streets were classified into six groups by height (short: 0-10m, medium: 10-20m, and tall: 20-30m) and direction (south and north in each Avenue). Three extents of canopy widths were digitized for each tree using buffer analysis in ESRI ArcMap: half width for the top quarter for the tree, three quarter width for the second quarter of the height, and full width from the middle down to the ground. However, the raised crown and trunk under the canopy were not simulated.

A three-dimensional surface of the canopy height was created through overlaying all canopy widths with their associated heights into a raster (Figure 4).

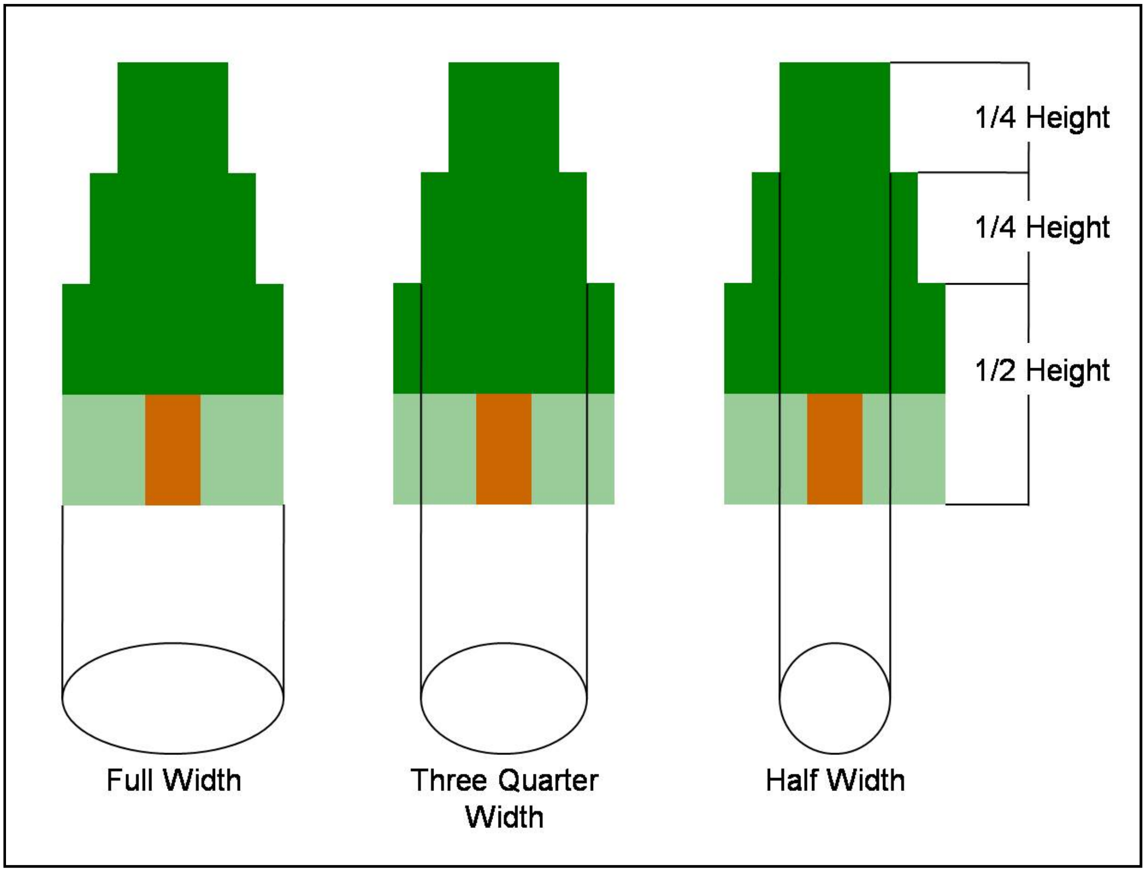

Figure 3 Simulated canopy shape

Figure 4 Canopy height estimations of road-side trees

Shading of this canopy elevation raster was simulated in one hour intervals for a day during a heat wave for which ground temperatures were collected on July 24, 2005 using sun altitude and azimuth data acquired from the U.S. Naval Observatory (aa.usno.navy.mil) by Hillshade analysis in ESRI ArcMap (Figure 5).

Figure 5 Shade simulations for 10:00 A.M. on July 24, 2005

Each simulated shade image was reclassified into shade (1) and exposed (0). Every reclassified image was combined to estimate the frequency of the pixels which were exposed to sun over the day (Figure 6).

Shade levels (independent variable) were regressed against surface temperatures (dependent variable) for each measured daytime: in the afternoon, evening after sunset, and the next morning before sunrise.

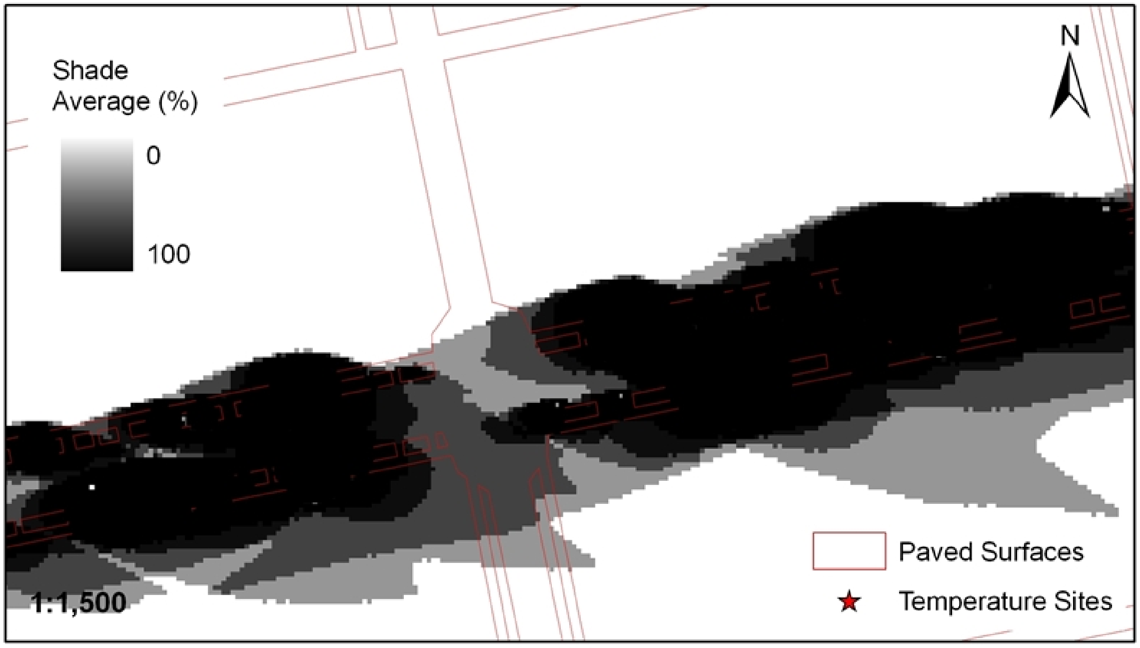

Figure 6 Combined shade simulations for daylight with 1 hour intervals on July 24, 2005

The relationship between vegetation and surface temperature detected from the satellite images

Six study site of eight to twelve blocks each in Huntington, WV were selected: two residential areas, the downtown business district, Marshall University's campus, an industrial area, and one forest (Figure 1). Each study site has its own characteristics. Four of the study sites were selected as representative for typical city-rural land use gradient with varying vegetation cover: forest (fully vegetated), two residential areas (well vegetated), and downtown (little vegetated). Six study sites were digitized from the reference images, DOQQ.

The Normalized Difference Vegetation Index (NDVI) was calculated from every Landsat TM image using the following NDVI formula (Figure 7):

$$NDVI = \frac{Band4 - Band3}{Band4 + Band3}$$

Where:

Band 3: Red

Band 4: Near Infrared (NIR)

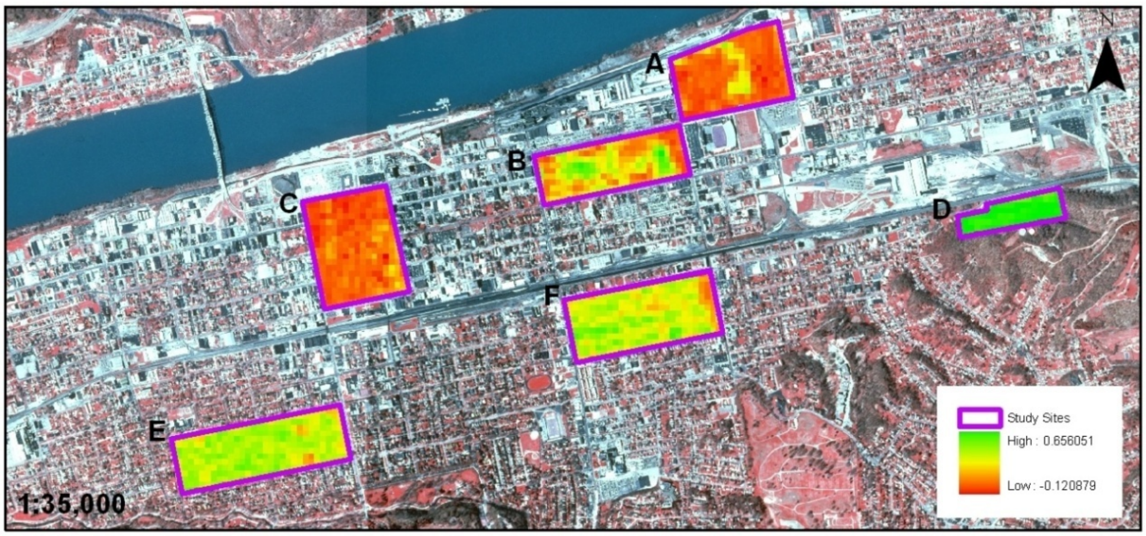

Figure 7 NDVI patterns on July 9, 2005 (study sites, A: industrial area, B: Marshall University, C: downtown, D: forest, E: residential area 1, and F: residential area 2)

NDVI and thermal infrared (Band 6, TIR) were extracted from the Landsat TM images for each pixel within the study area. Digital Numbers (DN) of the TIR channel were converted to degree Celsius through the following formula from the website, Center for Earth Observation at Yale University (http://www.yale.edu/ceo) (Figure 8):

$$CV_R = G\ (CV_{DN}) + B$$

Where:

CV_R: the cell value as radiance

CV_{DN}: the cell value digital number

G: the gain values from the header file of Landsat TM image

B: the bias (or offset) from the header file of Landsat TM image

$$T = \frac{K_1}{\ln(\frac{K_2}{CV_R} + 1)}$$

Where:

T: degrees, Kelvin

K_1: 607.76 for TM

K_2: 1260.56 for TM

$$T\ (°C) = T\ (K) - 273$$

Where:

T (°C): surface temperature

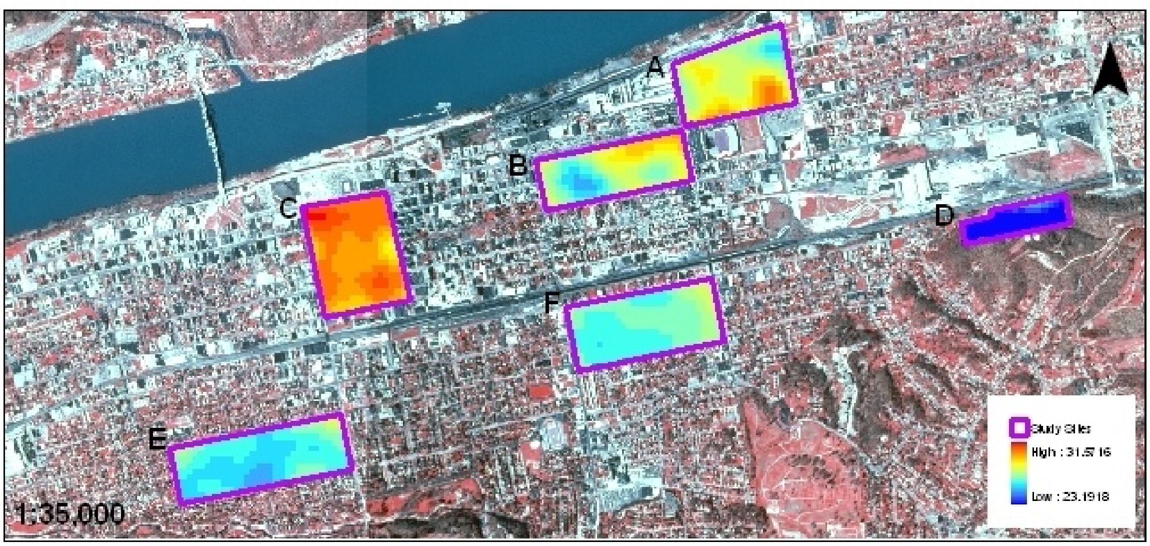

Figure 8 Celsius patterns on July 9, 2005 (study sites, A: industrial area, B: Marshall University, C: downtown, D: forest, E: residential area 1, and F: residential area 2)

Linear regressions were performed with surface temperatures as the dependent variable and the NDVI as the independent variable by study sites and monthly period. Regression analysis was repeated monthly for the call combined study sites, and individual study sites. In addition to the four study sites (forest, residential area 1 and 2, and downtown), which represent a typical vegetation gradient from rural areas into cities, were combined and analyzed by regression analysis to examine changes in the relationship between NDVI and surface temperature for a wide range of vegetation cover across the year. The slope was extracted and plotted against the month for all combined study sites, each study site separately and the four combined study sites.

CHAPTER III

Results and Discussion

The Effect of Road-side Trees on Local Micro-Climate

The road surface of residential area 1 consists of pavement and cobblestone. Based on the data, surface temperatures on July 24, 2005 ranged from 28.5°C to 56.7°C in the afternoon, from 27.5°C to 38.1°C in the evening, and from 23.2°C to 29.1°C the next morning.

While the lowest temperature were recorded at shaded site (4: shade), the highest temperatures were in exposed site (0: sun or 2: evening sun). As the night passed, the difference between the highest and the lowest temperature became smaller. The biggest range was 28.2°C in the afternoon, while the smallest range was 5.9°C the next morning.

Regression analysis revealed significant trends of surface temperatures as a function of shade proportion for all three time periods (afternoon slope = -0.285, $p \leq 0.0001$, evening slope = -0.095, $p \leq 0.0001$, and morning slope = -0.027, $p \leq 0.0021$: Figure 9). The less sun areas received during the day, the cooler the surface remained throughout the day. This effect was still significant after a full night of cooling.

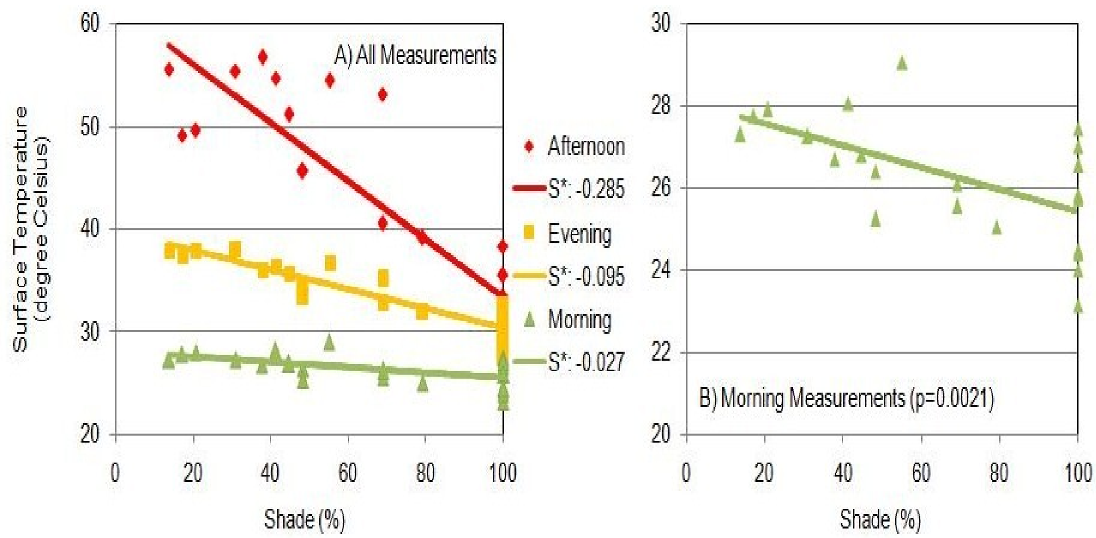

Figure 9 Results of regression analysis (S*: slope value)

The relationship between vegetation and surface temperature detected from the satellite images

Trends of NDVI and surface temperature across the year

The NDVI as a numerical indicator of vegetation and surface temperature was extracted from the satellite images. Across a year, the NDVI ranged from -0.3103 to 0.7527 and the surface temperature was distributed from -14.6°C to 39.1°C across all study sites. As expected, the highest NDVI was recorded in forest in June and the highest surface temperature was in downtown area in June. However, contrary to the expectation, both the lowest NDVI and the lowest surface temperature were observed in forest. The lowest NDVI was observed in January and the lowest surface temperature was in December. Throughout the spring, both mean NDVI and mean surface temperature increased, and recorded peaks in summer. After that, NDVI and surface temperature became smaller.

The trends of NDVI and surface temperature in the six study sites (forest, residential area 1 and 2, downtown, Marshall University's campus, and industrial area) were examined individually. Across a year, the NDVI ranged from -0.0390 to 0.7527 in forest, -0.1367 to .6400 in residential areas, -0.2683 to 0.3333 in downtown, -0.2239 to

0.6301 in Marshall University's campus, and -0.1927 to 0.4656 in the industrial area. The maximum ranges between the highest and the lowest NDVI in a single month were 0.6000 in October (forest), 0.6713 in June (residential areas), 0.5264 in October (downtown), 0.7010 in June (Marshall University's campus), and 0.5746 in June (industrial area). Surface temperatures distributed from -14.6°C to 30.8°C in forest, -14.0°C to 35.2°C in residential areas, -13.4°C to 34.8°C in downtown, -12.8°C to 37.9°C in Marshall University's campus, and -14.0°C to 38.3°C in industrial area. The largest ranges of the surface temperatures in a single month were 7.1°C in June (forest), 6.7°C on May 29 (residential areas), 6.0°C in April (downtown), and 9.0°C in November (Marshall University's campus).

Figure 10 shows the annual trends of mean NDVI and surface temperature by individual study sites. Across a year, mean NDVI in residential areas and Marshall University's campus grew larger into summer and then smaller into winter. Trend of mean NDVI in forest was similar to that of other areas above. However, mean NDVI in forest was larger in the growing season than in the other areas above, while forest NDVI was smaller in the winter season. The trends of mean NDVI downtown and in the industrial area showed little variation across the year. The difference between the highest mean NDVI (growing seasons) and the lowest mean NDVI (winter season) were small in these sites, even though mean NDVI during the growing season was larger than in winter.

While mean NDVI showed different trends depending on study sites, the mean surface temperatures showed similar trends across all study sites, rising mean surface temperature into summer, cooling thereafter. The forest temperature curve was consistently below the others throughout the year. The highest mean surface temperatures were observed in downtown except for winter seasons (December, January, and February).

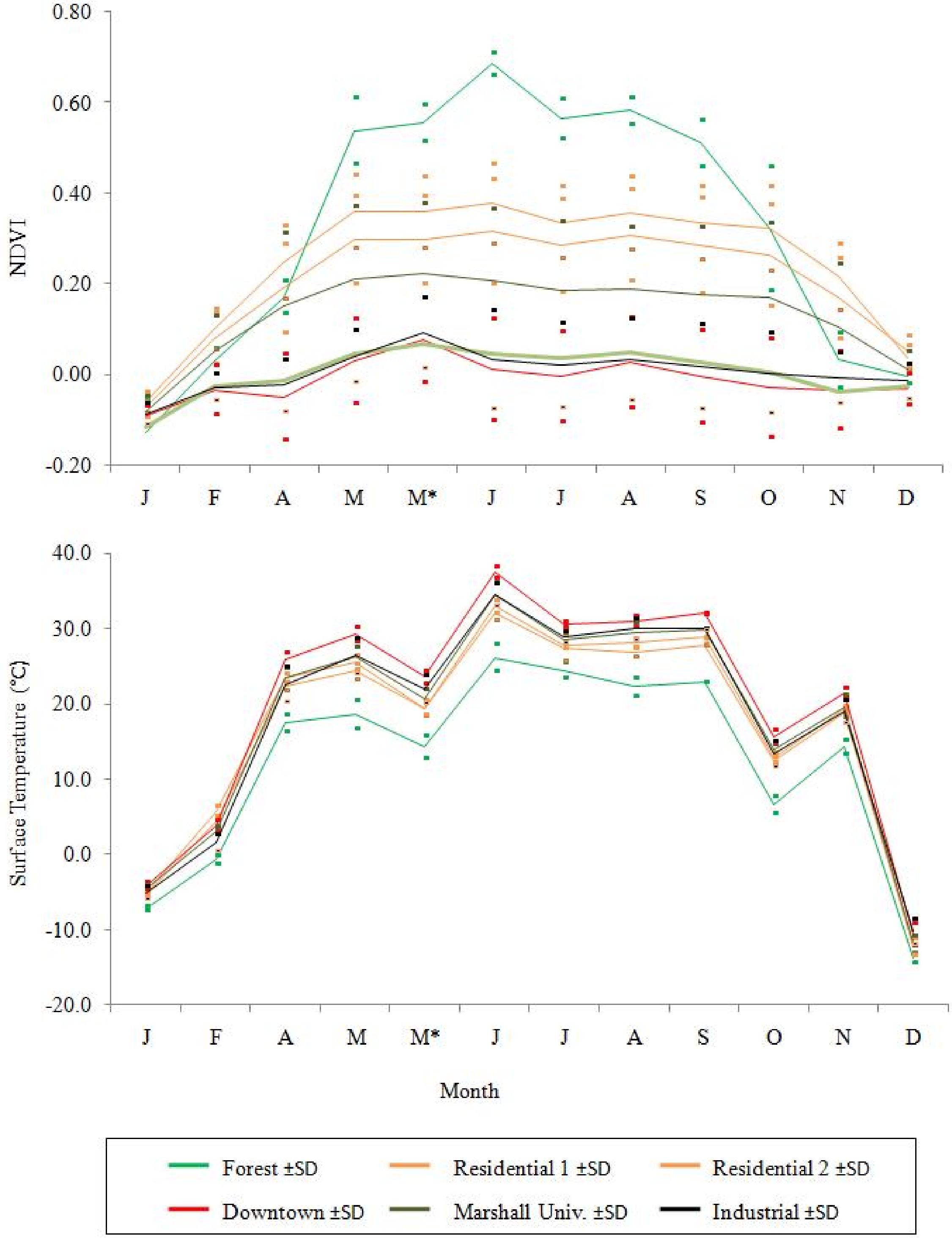

Figure 10 Trends of mean NDVI by individual study sites (M*: May 29)

The relationship between vegetation and surface temperature

Regression analyses were performed with NDVI and surface temperatures. Results revealed that vegetation affected surface temperatures across all study sites combined. Temperatures in vegetated areas were lower than those in other areas in most seasons except for winter. This effect can be seen by a negative slope between temperature and NDVI values. As time passed from spring to the summer, this relationship got stronger and then weaker into autumn (Figure 11). It was the strongest in July (slope* = -0.098: Figure 12). The results of the regression analyses of the six individual study sites are shown in Figure 13 and Table 4.

As the most vegetated area, **forest** was expected to have the strongest negative relationship between vegetation and surface temperature. However, as a result of regression analysis, this relationship was discovered in only four months: May 6 (slope = -0.012), May 29 (slope = -0.034), July (slope = -0.024), and September (slope = -0.010).

The lack of a strong negative slope is caused by the uniform surface which is covered in trees. If the surface is covered by full vegetation, there are no pixels of low vegetation coverage and all pixels are cool. Consequently, no significant slope can be observed. On the other hand, different plant species leaf out or drop leaves at different times in spring (May) or fall (September). These species create temporary heterogeneity in the forest at that time, and a significant slope can be observed temporarily. Accordingly, the greatest negative significant slope was discovered not in July but in May in this study.

The **residential areas** are located in the Southside of Huntington, WV (area 1) and southeast of downtown Huntington along the railroad (area 2). Based on the result of regression analysis in residential areas, it was found that vegetation affected surface temperature in most months. While it was not observed in January and February in residential area 1, it was not discovered in November in residential 2. It was the greatest in July in residential area 1 (slope = -0.082) and residential area 2 (slope = -0.0143).

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* slope: a measure of the "steepness" of the line. A positive slope indicate that a line goes up from left to right along the X axis, while a negative slope indicates a line goes down (from a website of Stat Trak).

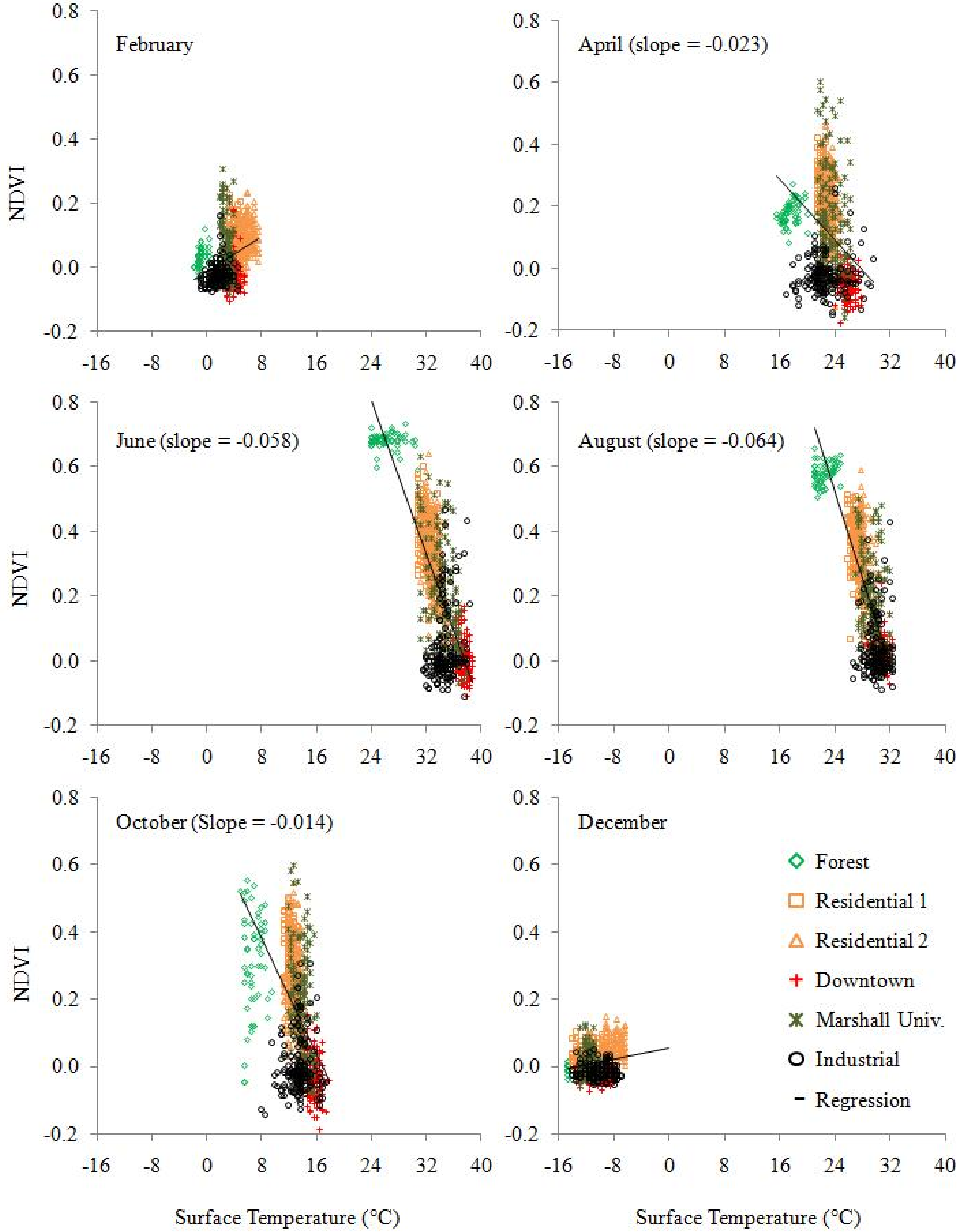
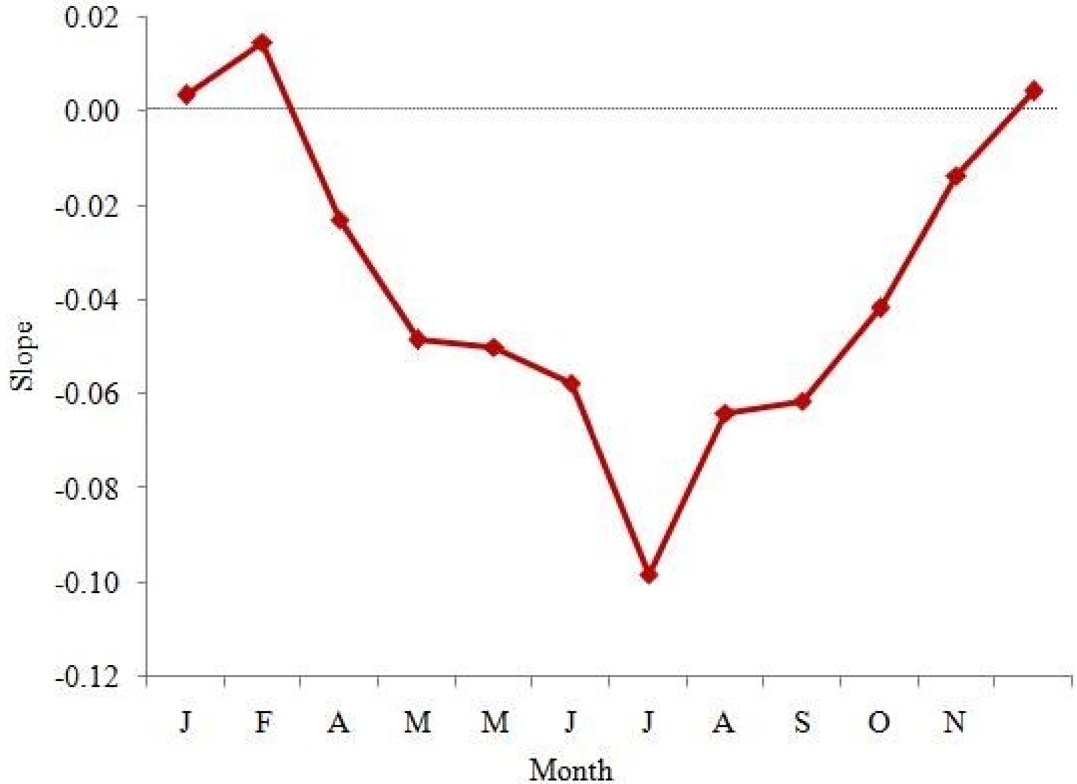


Figure 11 Results of regression analyses of all study sites



Month	All study sites	
	Slope±SE	P
Jan. 1 2005	0.003±0.001	**
Feb. 15 2005	0.015±0.001	****
Apr. 4 2005	-0.023±0.002	****
May 6 2005	-0.049±0.001	****
May 29 2005	-0.050±0.001	****
Jun. 23 2005	-0.058±0.001	****
Jul. 9 2005	-0.098±0.002	****
Aug. 13 2006	-0.064±0.001	****
Sep. 11 2005	-0.062±0.001	****
Oct. 29 2005	0.042±0.002	****
Nov. 27 2004	-0.014±0.002	****
Dec. 3 2006	0.004±0.001	****

Figure 12 Slope of linear regression analyses of NDVI (X) versus surface temperature (Y) and significance level of P (* ≤ 0.05, ** ≤ 0.01, *** ≤ 0.001, and **** ≤ 0.0001)

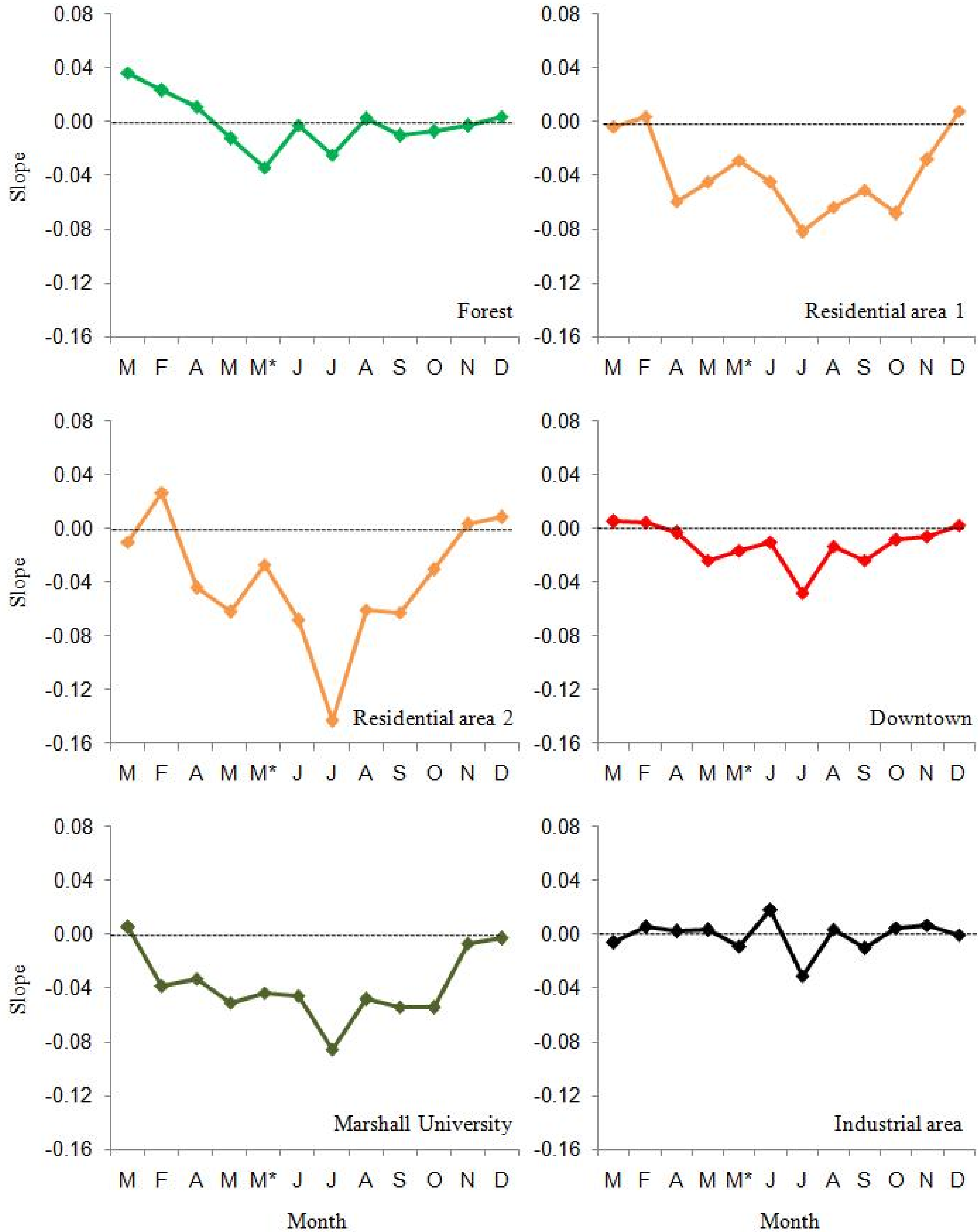


Figure 13 Results of regression analyses by individual study sites (M*: May 29)

Table 4 Results of regression analyses by individual study sites

Date	Forest		Residential Area 1		Residential Area 2		Downtown		MU Campus		Industrial	
	Slope±SE	P	Slope±SE	P	Slope±SE	P	Slope±SE	P	Slope±SE	P	Slope±SE	P
Jan. 1 2005	0.036±0.027	-	-0.004±0.004	-	-0.010±0.004	*	0.005±0.005	-	0.006±0.004	-	-0.006±0.002	**
Feb. 15 2005	0.023±0.004	****	0.004±0.004	-	0.026±0.003	****	0.004±0.003	-	-0.038±0.009	****	0.005±0.002	**
Apr. 4 2005	0.011±0.003	**	-0.059±0.008	****	-0.044±0.011	****	-0.003±0.002	-	-0.033±0.008	****	0.002±0.002	-
May 6 2005	-0.012±0.003	****	-0.044±0.004	****	-0.062±0.006	****	-0.024±0.004	****	-0.051±0.007	****	0.003±0.003	-
May 29 2005	-0.034±0.004	****	-0.029±0.003	****	-0.027±0.010	**	-0.017±0.003	****	-0.043±0.006	****	-0.009±0.003	**
Jun. 23 2005	-0.003±0.001	-	-0.044±0.005	****	-0.069±0.007	****	-0.010±0.005	*	-0.045±0.005	****	0.018±0.005	****
Jul. 9 2005	-0.024±0.004	****	-0.082±0.009	****	-0.143±0.014	****	-0.048±0.008	****	-0.086±0.010	****	-0.030±0.007	*****
Aug. 13 2006	0.002±0.002	-	-0.063±0.007	****	-0.061±0.010	****	-0.013±0.004	***	-0.048±0.007	****	0.004±0.004	-
Sep. 11 2005	-0.010±0.005	*	-0.051±0.006	****	-0.062±0.007	****	-0.024±0.006	****	-0.054±0.006	****	-0.010±0.005	*
Oct. 29 2005	-0.007±0.013	-	-0.068±0.008	****	-0.031±0.009	**	-0.008±0.004	-	-0.054±0.010	****	0.005±0.003	-
Nov. 27 2004	-0.003±0.007	-	-0.028±0.008	***	-0.003±0.010	-	-0.006±0.003	-	-0.007±0.006	-	0.007±0.002	**
Dec. 3 2006	0.004±0.002	-	0.008±0.001	****	0.008±0.002	****	0.002±0.001	***	-0.003±0.003	-	0.000±0.000	-

- Significance levels of P-values: * ≤ 0.05, ** ≤ 0.01, *** ≤ 0.001, **** ≤ 0.0001, and – = non-significant

Downtown is the least vegetated area among the study sites. It was expected that the relationship between vegetation and surface temperature was weak. The negative relationship was significant May through September. It was the greatest in July (slope = -0.048).

Due to the uniform coverage in the downtown area, the result was similar to that of forest. There is not enough vegetation coverage downtown. It is composed mostly of paved surfaces and large buildings. Dense urbanized coverage causes that there are no pixels of pure vegetation and all pixels are hot. Consequently, no significant slope can be investigated and the relationships downtown were weaker than in other study sites.

In **Marshall University's campus**, which includes large buildings, lawns, and a field, significant negative regression slopes were observed across the year except for November, December, and January. The relationship was the greatest in July (slope = -0.086). Due to similar vegetation proportions, the results of the regression analyses in this site were analogous to that of the two residential areas. All these area are heterogeneous and include buildings, trees, and lawns, even though the sizes of buildings are different.

Because the **industrial area** includes huge complexes and paved surfaces, it was expected that the relationship was weak. A significant negative regression slope in this area was observed only four months: January (slope = -0.006), May (slope = -0.009), July (slope = -0.030), and September (slope = -0.010). Because vegetation in this area is composed of large lawns rather than woody plants, this area exhibits a lack of heterogeneity and the effect of vegetation on surface temperature is weak. Consequently, the relationship in this area was weaker than that in other sites. This area was also the only study site with a significant positive slope during the growing season (June).

For developing the UHI model, four study sites were selected: the downtown, two residential areas, and the forest. These predominated cover types represent a typical urban gradient from least vegetation (downtown), through well vegetated (residential areas), and to entirely vegetated (forest). On the other hand, the industrial area and Marshall University's campus are complex. These excluded areas contain not only large unvegetated cover that is displayed by the selected four study sites. This can be seen in

July where the industrial area fell below and Marshall University's campus above the regression line (Figure 14).

The result of the regression analyses of the selected study sites were similar to that of all study sites combined (Figure 15). However, the proportion of variability (r^2) [*]of the relationships in the selected study sites was larger than that in all study sites. For example, it was 0.84 in July for the selected study sites, while it was 0.68 for all study sites. In the selected study sites, the relationships between vegetation and surface temperature were observed in most months except for the winter months (December, January, and February). The relationship grew stronger into summer, and peaking in July (slope = -0.962). After that, it became weaker into autumn.

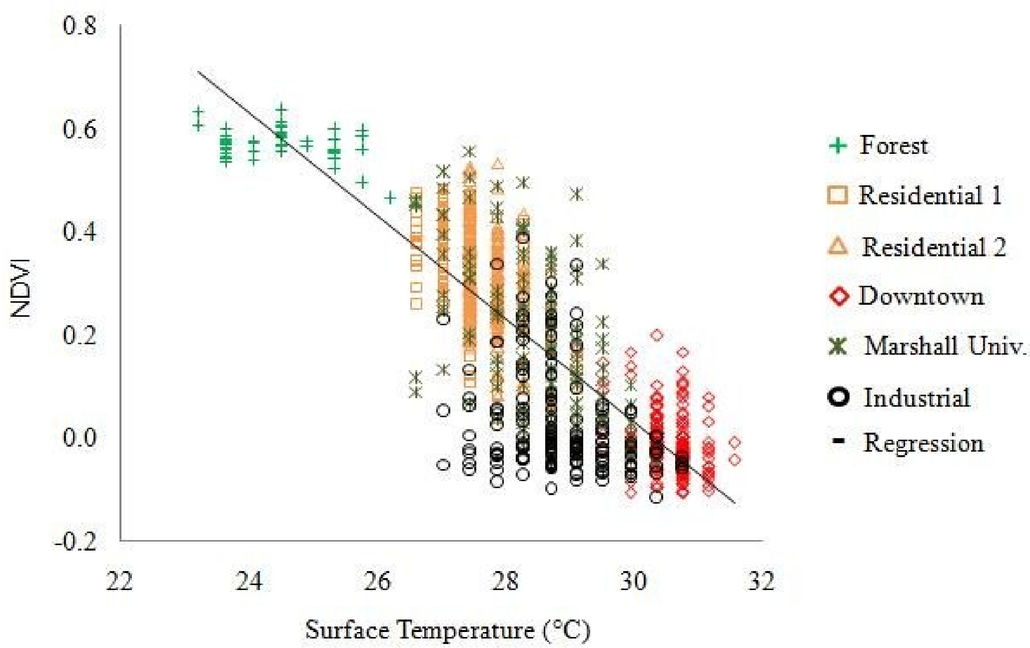
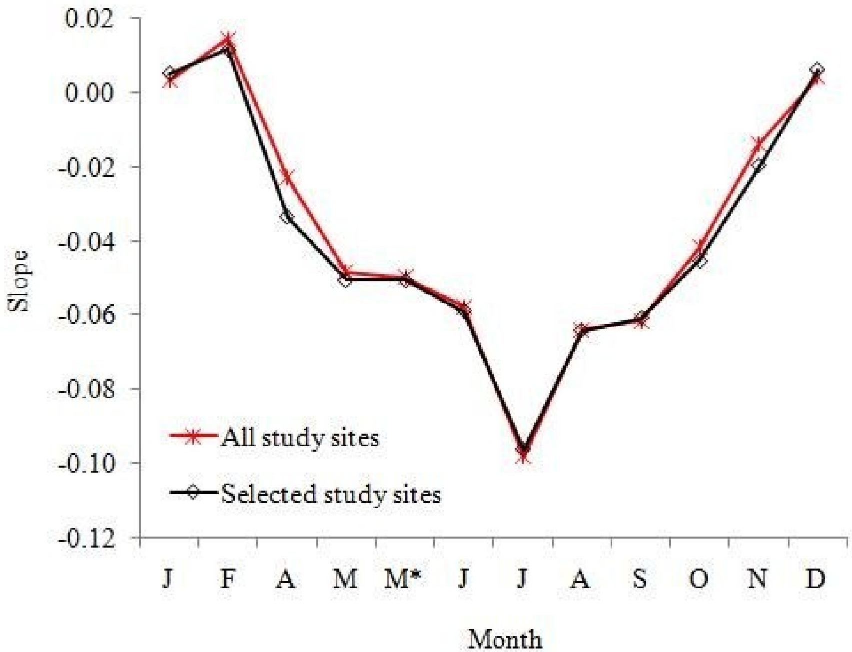


Figure 14 Result of regression analysis in July

[*] r^2 (R-square, the coefficient of determination): the relative strength index for regression. r^2 = indicates that the model can explain all variability, while r^2=0 means no linear relationship between factors. If r^2 = 0.7, it means that approximately seventy percent of the variation can be explained by the explanatory variable (McGrew and Monroe, 2000 and Website of Stat trek: http://stattrek.com).

Regression analysis was not the best method to describe the relationship outside the growing season. The results of regression analyses showed that significant negative regression slopes were observed not in the winter seasons but in the growing seasons.

The UHI, where temperatures in an urbanized area are higher than those in surrounding suburban and rural areas, can clearly be observed throughout the year (Figure 16). Based on the temperature data, the surface temperatures were always lower in forest and became higher in residential areas and downtown. It was not related to the value of NDVI in the forest. The forest NDVI grew higher during the growing season, and then spread out in autumn. After that, it was the lowest in winter. Due to the amount of lawns in each site, the NDVI in residential areas (more lawns) was higher than that in forest (fewer lawns). However, the surface temperatures in the forest were still lower than residential areas in December.



Month	All study sites			Selected study sites		
	r^2	Slope+SE	P	r^2	Slope+SE	P
Jan. 1 2005	0.01	0.003±0.006	**	0.01	0.005±0.001	**
Feb. 15 2005	0.14	0.015±0.001	****	0.09	0.012±0.001	****
Apr. 4 2005	0.13	-0.023±0.002	****	0.32	-0.033±0.002	****
May 6 2005	0.55	-0.049±0.001	****	0.79	-0.050±0.001	****
May 29 2005	0.62	-0.050±0.001	****	0.76	-0.050±0.001	****
Jun. 23 2005	0.63	-0.058±0.001	****	0.83	-0.059±0.001	****
Jul. 9 2005	0.68	-0.098±0.002	****	0.84	-0.096±0.001	****
Aug. 13 2006	0.65	-0.064±0.001	****	0.78	-0.064±0.001	****
Sep. 11 2005	0.59	-0.042±0.002	****	0.75	-0.061±0.001	****
Oct. 29 2005	0.27	-0.014±0.002	****	0.40	-0.045±0.002	****
Nov. 27 2004	0.04	-0.042±0.002	****	0.10	-0.020±0.002	****
Dec. 3 2006	0.04	0.004±0.001	****	0.09	0.006±0.001	****

Figure 15 Slopes of linear regression analyses of NDVI (X) versus surface temperature (Y) (Significance levels of P: * ≤ 0.05, ** ≤ 0.01, *** ≤ 0.001, and **** ≤ 0.0001)

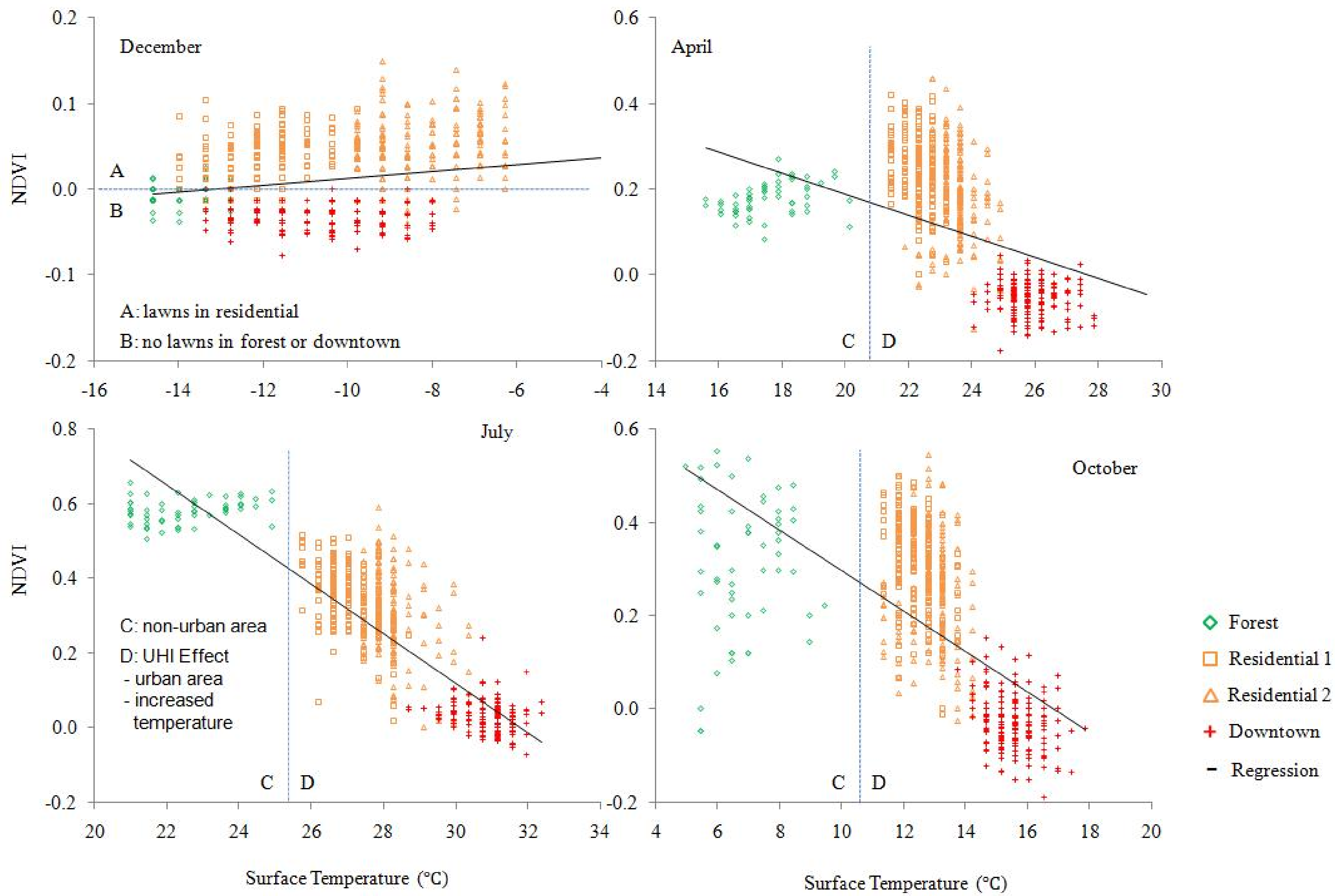


Figure 16 The UHI in the selected study sites

CHAPTER IV

Summary and Conclusion

The UHI has become one of the most significant environmental problems since it was first observed in large urban areas. Studies into the UHI have been conducted in three categories: observational studies, determinants of UHI, and large-scale UHI studies.

The factors which cause the UHI are various such as the urban growth pattern (Weng 2001), wind conditions (Morris *et al*. 2001), the difference between urban and rural temperatures (Streutker 2002 and Hawkins *et al*. 2004), the storage heat flux (Grimmond and Oke 1999), and surface conditions or land coverage parameters (Owen *et al*. 1998 and Hirano *et al*. 2004). Among the determinants of the UHI, vegetation is one of the most effective ways to control urban temperatures. The effects of trees and other vegetation on urban environments have recently come into focus. New tools, such as GIS and remote sensing techniques, have been applied to analyze the UHI more effectively. The primary objectives of this study were to investigate the vegetation effects on local climate using in-situ measurements, GIS and remotely sensed data.

This study was performed by two parts: local micro-climate and satellite study to make up for disadvantages in each part. The local micro-climate study can control small uniform areas and measure temperatures at each point, especially, under the trees. However, surface temperatures cannot be extrapolated through the point measurement. On the other side, satellite study can cover large areas across all cover types, such as forest, residential and downtown. Due to the resolution of satellite image, each pixel covers all mixed areas. For example, exposed and shaded areas can be covered in a single pixel. Moreover, it cannot observe exact ground condition. In case of forest temperatures extracted from satellite images, the temperatures recorded were not on the ground, but on the trees.

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The influence of road-side trees on the local micro-climate in a specific residential area in a day was examined. The study was performed using surface temperature data which was measured by handheld TIR sensors. Instead of Landsat TM images, in situ measurement and simulated shades were used. Shaded areas were simulated after mapping the canopy using the Hillshade analysis.

As expected, the surface temperatures were lower at shaded sites, while higher at exposed sites. The differences between the highest and the lowest temperatures became smaller after sundown through the next morning. The result of regression analysis of shade level versus surface temperature showed significant negative slopes. This trend lasted, even after the surface cooled for a full night.

Landsat TM images were used for the second part of the study, to examine the relationship between vegetation and surface temperatures during a year. The NDVI and surface temperature in each study site were extracted from the satellite images (Landsat TM). Regression analysis was performed, using surface temperatures and NDVI, by study sites and monthly period.

The trends of surface temperatures were similar across all study sites, rising into summer, and then cooling thereafter through the year. Forest temperature was consistently cooler than the others study sites, while downtown was warmer. Conversely, the trends of the NDVI were different depending on the study sites. The NDVI curves in the residential areas and Marshall University's campus were similar, rising during the growing season and dropping in winter. The forest NDVI curve was lower than others in winter and higher during the growing season. However, the NDVI curves of downtown and the industrial area behaved differently. They didn't show the significant changes during the year.

The results of the regression analysis revealed that surface temperatures were influenced by vegetation across all study sites combined. Significant negative slopes were observed in most seasons except for winter. The more vegetation presents in an area, the lower the surface temperature. As time passed, this relationship became stronger into summer, and then weaker into autumn.

The results of regression analyses at each individual study site were different depending on the characteristics of study sites. Contrary to the expectation, this relationship in the forest was observed in only four months and was weaker than other study sites, due to the uniform surface (covered in trees). As expected, the relationship was weak downtown, where vegetation was insufficient, even though it was significant in May through September. In the industrial area, the weak relationship was observed during four months. A lack of heterogeneity affected the relationship in this area. The relationship in residential areas and Marshall University's campus are analogous, due to the similar proportion of vegetation. The relationship grew stronger into summer, then weaker thereafter.

Significant negative slopes were observed only during the growing seasons. Regression analysis was not the best way to describe the relationship outside the growing season. The UHI was observed throughout the year. Based on the temperature data, the surface temperatures in the rural area (forest) were always lower than those in the urban area (residential and downtown). Due to the lawns, the NDVI in residential areas was higher than the forest area in winter. However, the surface temperatures were still lower in the forest.

The results of this study can be used as a reference for urban planners to establish urban planning in an environmentally friendly manner. Due to the difficulty with management and for safety reasons, the City of Huntington encourages the planting of small trees instead of large-growing varieties. Contrarily, many planners and researchers have focused on urban vegetation, such as road-side trees, urban parks, and urban forests, as an effective method to control the urban temperatures and air quality, since the UHI became one of the environmental problems. For example, Taegu, Korea succeeded in controlling urban temperatures through tree-planting and developing urban parks (Kim, 2002). Compared to earlier temperature data, in 30 years temperatures in Taegu were reduced 1.2°C, while temperature in other cities were increased 1~2°C.

Following studies may have three objectives. First, differences of NDVI vegetation mapping results between using high resolution image (IKONOS: 4m resolution) and using low resolution (Landsat TM: 30m resolution) will be investigated. Using higher resolution images should result in more accurate results. Second, the difference between trees and lawns on surface temperatures will be examined. Third, the effects of small parks in urban areas on the temperatures in its surrounding areas will be examined.

BIBLIOGRAPHY

Reference

Arnfield, A. J., 2003, Two Decades of Urban Climate Research: A Review of Turbulence, Exchanges of Energy and Water, and the Urban Heat Island, *International Journal of Climatology*, **23**, 1~26

Atkinson, B. W., 2003, Numerical Modeling of Urban Heat-Island Intensity, *Boundary-Layer Meteorology*, **109**, 285~310

Carlson, T. N. and Arthur, S. T, The Impact of Land Use – Land Cover Changes due to Urbanization on Surface Microclimate and Hydrology: a Satellite Perspective, *Global and Planetary Change*, 25(2000), 49~65

Gallo, K. P. and Tarpley, J. D., 1996, The Comparison of Vegetation Index and Surface Temperature Composites for Urban Heat-island Analysis, *International Journal of Remote Sensing*, **17 (15)**, 3071~3076

Gedzelman, S. D., Austin, S., Cermak, R., Stefano, N., Partridge, S., Quesenberry, S., and Robinson, D. A., 2003, Mesoscale Aspects of the Urban Heat Island around New York City, *Theoretical and Applied Climatology*, **75**, 29~42

Grimmond, C. S. B. and Oke, T. R., 1999, Heat Storage in Urban Areas: Local-Scale Observations and Evaluation of a Simple Model, *Journal of Applied Meteorology*, **38**, 922~940

Hafner, J. and Kidder, S. Q., 1999, Urban Heat Island Modeling in Conjunction with Satellite-Derived Surface/Soil Parameters, *Journal of Applied Meteorology*, **38**, 448~465

Hawkins, T. W., Brazel, A. J., Stefanov, W. L., Bigler, W., and Saffell, E. M., 2004, The

Role of Rural Variability in Urban Heat Island Determination for Phoenix, Arizona, *Journal of Applied Meteorology*, **43**, 476~486

Heisler, G. M., 1986, Energy Saving with Trees, *Journal of Arboriculture*, **12 (5)**, 113~125

Hirano, Y., Yasuoka, Y., and Ichinose, T., 2004, Urban Climate Simulation by Incorporating Satellite-derived Vegetation Cover Distribution into a Mesoscale Meteorological Model, *Theoretical and Applied Climatology*, **79**, 175~184

Johnson, G. L., Davis, J. M., Karl, T. R., McNab, A. L., Gallo, K. P., Tarpley, J. D., and Bloomfield, P., 1994, Estimating Urban Temperature Bias Using Polar-Orbiting Satellite Data, *Journal of Applied Meteorology*, **33**, 358~369

Kim, H. H., 1992, Urban Heat Island, *International Journal of Remote Sensing*, **13 (12)**, 2319~2336

Kim, S. B., 2002, Research into the network system in urban ecological environmental for developing wind pathway in Taegu area, Taegu Regional Environmental Technology Development Center (translated from research paper written by Korean)

Kim, Y. H. and Baik, J. J., 2002, Maximum Urban Heat Island Intensity in Seoul, *Journal of Applied Meteorology*, **41**, 651~659

Kim, Y. H. and Baik, J. I., 2004, Daily Maximum Urban Heat Island Intensity in Large Cities of Korea, *Theoretical and Applied Climatology*, **79**, 151~164

Kim, Y. H. and Baik, J. J., 2005, Spatial and Temporal Structure of the Urban Heat Island in Seoul, *Journal of Applied Meteorology*, **44**, 591~605

Kondo, A., Ueno, M., Kaga, A., and Yamaguchi, K., 2001, The Influence of Urban Canopy Configuration Urban Albedo, *Boundary-Layer Meteorology*, **100**, 225~242

Lee, H. Y., 1993, An Application of NOAA AVHRR Thermal Data to the Study of Urban Heat Island, *Atmospheric Environment*, **27B (1)**, 1~13

Li, Q., Zhang, H., Liu, X., and Huang, J., 2004, Urban Heat Island Effect on Annual Mean Temperature during the Last 50 Years in China, *Theoretical and Applied Climatology*, **79**, 165~174

Lo, C. P., Quattrochi, D. A., and Luvall, J. C., 1997, Application of High-resolution Thermal Infrared Remote Sensing GIS to Assess the Urban Heat Island Effect, *International Journal of Remote Sensing*, **18 (2)**, 287~304

McKendry, I. G., 2003, Applied Climatology, *Progress in Physical Geography*, **27 (4)**, 597~606

McGrew, J. C. and Monroe, C. B., 2000, An Introduction to Statistical Problem Solving in Geography, Second Edition, Boston, MA: McGraw-Hill

Morris, C. J. G., Simmonds, I., and Plummer, N., 2001, Quantification of the Influences of Wind and Cloud on the Nocturnal Urban Heat Island of a Large City, *Journal of Applied Meteorology*, **40**, 169~182

Nowak, D. J and Crane, D. E., 2002, Carbon Storage and Sequestration by Urban Trees in the USA, *Environmental Pollution*, **116 (2002**), 381~389

Nowak, D. J., Crane, D. E., and Stevens, J. C., 2006, Air Pollution Removal by Urban Trees and Shrubs in the United States, *Urban Forestry & Urban Greening*, **4 (2006)**, 115~123

Owen, T. W., Carlson, T. N., and Gillies, R. R., 1998, An Assessment of Satellite Remote-sensed Land Cover Parameters in Quantitatively Describing the Climatic Effect of Urbanization, *International Journal of Remote Sensing*, **19 (9)**, 1663~1681

Rosenzweig, C., Solecki, W., Parshall, L., Graffin, S., Lynn, B., Goldberg, R., Cox, J., and Hodges, S., Mitigating New York City's Heat Island with Urban Forestry, Living Roofs, and Light Surfaces, the 86th Annual Meeting of American Meteorological Society on January 2006

Scott, K. I., Simpson, J. R., and McPherson, E. G., 1999, Effects of Tree Cover on Parking Lot Microcliamte and Vehicle Emissions, *Journal of Arboriculture*, **25 (3)**, 129~142

Spronken-Smith, R. A. and Oke, T., R., 1998, The Thermal Regime of Urban Parks in Two Cities with Different Summer Climates, *International Journal of Remote Sensing*, **19**, 2085~2104

Streutker, D. R., 2002, A Remote Sensing Study of the Urban Heat Island of Houston, Texas, *International Journal of Remote Sensing*, **23**, 2595~2608

Voogt, J. A. and Oke, T. R., 1997, Complete Urban Surface Temperatures, *Journal of Applied Meteorology*, **36**, 1117~1132

Voogt, J. A. and Grimmond, C. S. B., 2000, Modeling Surface Sensible Heat Flux Using Surface Radiative Temperatures in a Simple Urban Area, Journal of Applied Meteorology, 39, 1679~1699

Vukovich, F. M., 1983, An Analysis of the Ground Temperature and Reflectivity Pattern about St. Louis, Missouri, Using HCMM Satellite Data, *Journal of Climate and*

Applied Meteorology, **22**, 560~571

Weng, Q., 2001, A Remote Sensing-GIS Evaluation of Urban Expansion and Its Impact on Surface Temperature in the Zhujiang Delta, China, *International Journal of Remote Sensing*, **22 (10)**, 1999~2014

Weng, Q., 2003, Fractal Analysis of Satellite-Detected Urban Heat Island Effect, *Photogrammetric Engineering & Remote Sensing*, **69 (5)**, 555~566

Wend, Q., Lu, D., and Schubring, J., 2004, Estimation of Land Surface Temperature-Vegetation Abundance Relationship for Urban Heat Island Studies, *Remote Sensing of Environment*, **89 (2004)**, 467~483

Internet Sites

Glossary of Meteorology: http://amsglossary.allenpress.com/glossary
The Ohio View: http://www.ohioview.org
U.S. Naval Observatory: http://aa.usno.navy.mil
Center for Earth Observation at Yale University: http://www.yale.edu.ceo
Stat Trek (Statistics and Probability): http://stattreck.com

Software Utilized

ESRI ArcGIS 9.1
Microsoft Excel
Microsoft Word