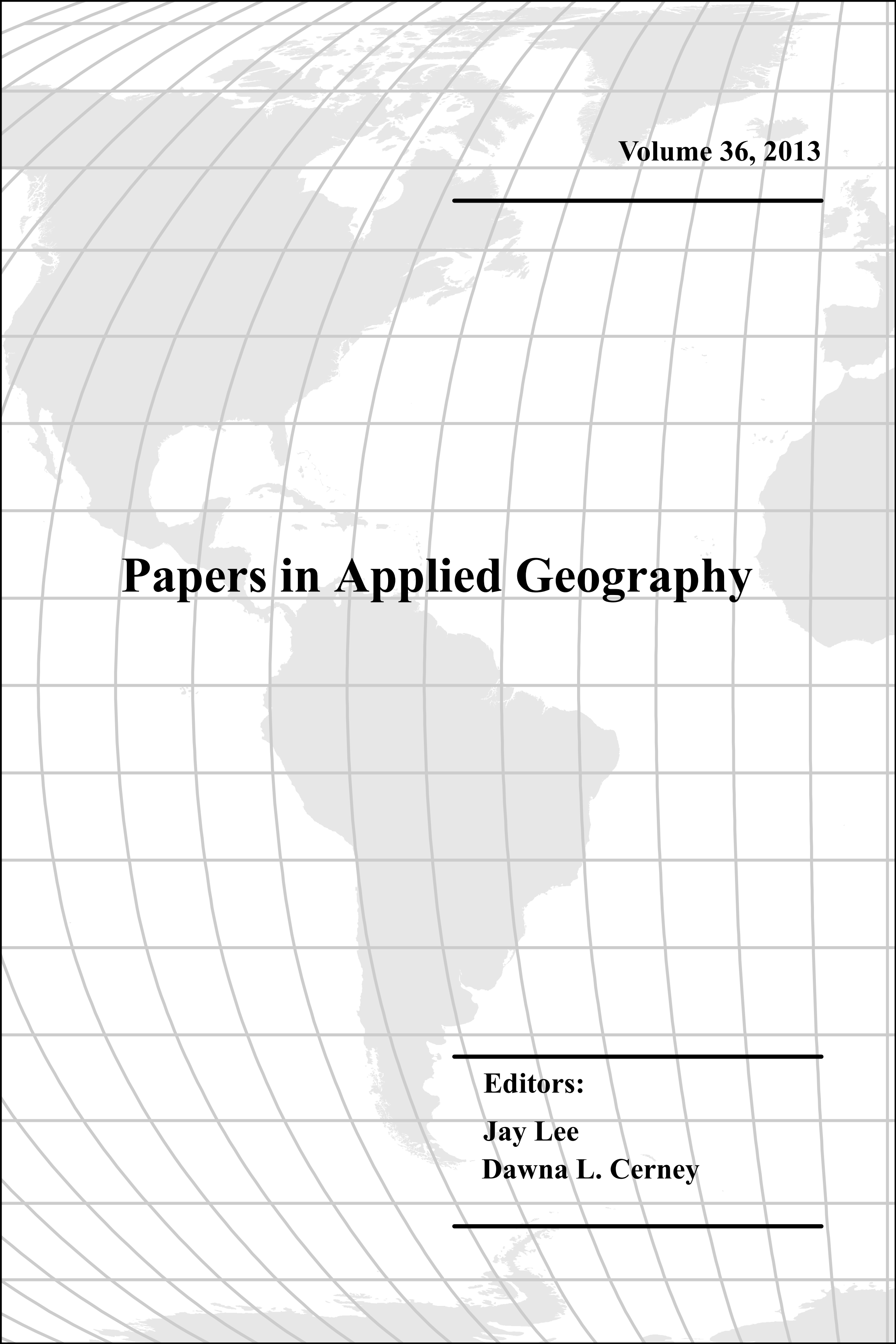

Volume 36, 2013

Papers in Applied Geography

Editors:

Jay Lee
Dawna L. Cerney

PAPERS IN APPLIED GEOGRAPHY

VOLUME 36, 2013

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THE RELATIONSHIP BETWEEN LAND COVER AND TEMPERATURE IN THE AUBURN—OPELIKA, ALABAMA URBAN AREA

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1. INTRODUCTION

Land use and land cover changes are among the most profound influence of urbanization in the form of conversion of pervious surfaces to impervious surfaces (Tang, 2005). An effect of covering pervious surfaces with impervious surfaces, such as buildings, asphalt, and concrete, is an increased amount of solar radiation absorbed, producing a greater thermal capacity and conductivity, thereby storing more heat Impervious surfaces can be used as a measure of urbanization and are defined as any material that prevents infiltration of water into the soil. Roads and rooftops are the most common types; however other examples include patios, bedrock outcrops, sidewalks, parking lots, and compacted soils (Arnold, 2007).

Consequences of this process include increased surface runoff, meaning more local flooding (because there is less soil surface, less water infiltrates the ground, which in turn, produces more drainage), fewer residential and municipal water supplies, increased lake and wetland levels (level becomes more dependent upon individual rainfall events) (Mills, 2007), less groundwater for water recharge, decreased evaporation (Tang, 2005) and reduced evapotranspiration (Cui, 2012). Moreover, impervious surfaces collect hazardous materials that are either dissolved in runoff or associated with sediment such as heavy metals, pesticides, grease, oil, and fecal coliform bacteria, which are then washed off and distributed by storm water (Tang, 2005).

Another result of covering pervious surfaces with impervious surfaces, such as buildings, asphalt, and concrete, is an increased amount of solar radiation absorbed, producing a greater thermal capacity and conductivity, thereby storing more heat. Land cover modification in urban environments has shown to cause both local surface temperatures and local air temperatures to rise several degrees over surrounding vegetative areas (Xiao, 2006), producing an urban heat island (UHI). UHIs are defined as the difference in temperature between urban areas and surrounding rural locations (Sullivan, 2009). Reasons for the variance in urban and rural temperatures include changes in the albedo, heat conductivity, and thermal capacity of the surface, attributed to

2. the replacement of vegetative surfaces with impervious, urban surfaces
3. a reduction in evapotranspiration due to decreased availability of vegetation as well as surface moisture
4. changes in the near surface air flow due to street and building geometry, and
5. heat emissions from anthropogenic sources (Xiao, 2006).

However, according to Streutker (2002), impervious surfaces in an urban environment are the main cause of variances in land surface temperatures. Numerous studies have analyzed the relationship between land cover and temperature, such as Dousset and Gourmelon (2003), which investigated the effects of downtown surface physical properties, especially in business and industrial districts that display heat island effects larger than 12.6 degrees Fahrenheit, and

Weng (2001), which explored the relationship of land cover and land surface temperature in the Zhujiang Delta, China. In addition, Yang (2003) showed that urban surfaces alter the sensible and latent heat fluxes, existing between the urban surface and boundary layers, which in turn affects urban surface temperatures.

Increased urban surface temperatures can also be of public policy concern and pose health risks because of their potential coincidence with heat waves, which exacerbate the effects of the UHI. This issue is associated with Chicago from the 1995 heat wave that killed 700 people, and the extended heat wave that hit Western Europe in 2003. France suffered the most deaths at 18,400, and 475 of those deaths occurred in Paris (Solecki, 2005).

A number of programs at the state, federal, and local levels were developed in the 1990s to help mitigate or ameliorate the effects of UHIs. The Heat Island Reduction Initiative (HIRI) was instituted, and it included members from the U.S. Department of Energy, the Environmental Protection Agency, and National Aeronautics and Space Administration. HIRI suggested the use of light colored, reflective roofing materials and pavements, and the planting of trees and vegetation to help ameliorate the effects of UHIs (Solecki, 2005). Given that the mineral-based, impervious surfaces commonly used in urban environments have a low albedo and store heat, preserving and planting trees can also provide a major benefit. Trees shade the ground, which reduces incoming radiation and also promotes evapotranspiration. Another helpful factor would be to reduce the amount of waste heat by reducing vehicle emissions (Stone 2005). This study is the first part of an ongoing, more expansive and detailed study that will explore and contribute further to the UHI behavior, mitigation, and human health risks.

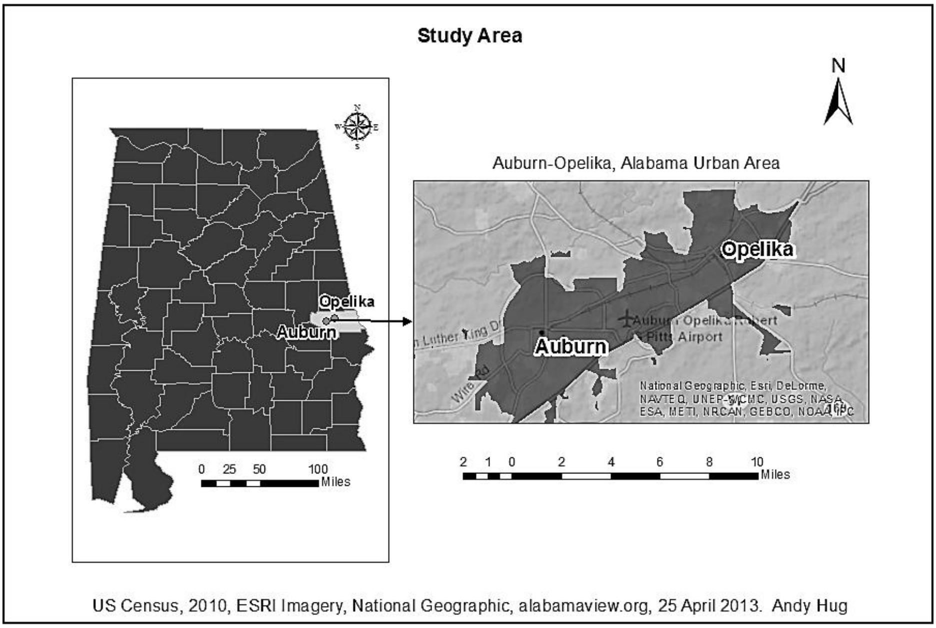
To help further alleviate these concerns, it is important to conduct more UHI related research, and perhaps not exclusively in large cities. Many UHI studies are conducted in large cities such as New York (Bornstein, 1968) and Mexico City (Cui, 2012); however, very few studies exist on midsize cities such as Auburn-Opelika. The objective of this study was to assess land cover's effect on temperature. Slope and aspect were also considered in order to observe their potential effects on temperature in Auburn-Opelika, Alabama as well. Temperatures were expected to be highest on south facing slopes covered with impervious surfaces.

2. STUDY AREA

The area of interest for this study is the Auburn-Opelika, urban area, located in Lee County, Alabama, shown below in Figure 1. Many UHI studies have been done for large cities, such as Singapore (Chow, 2006), Mexico City (Cui, 2012), and New York City (Bornstein, 1968). Very few studies have been done on small to mid-size cities such as Auburn-Opelika. The Auburn-Opelika area was chosen as the study area after considering its size and the lack of literature on UHIs in small to mid-size cities. The area of interest is 121.89 square miles and has an average annual temperature of 62.4 degrees Fahrenheit. July and August are the warmest months on average, with mean maximum temperatures of 90 degrees Fahrenheit and 89 degrees Fahrenheit respectively.

The record maximum is 103 degrees Fahrenheit and was recorded twice; once in July of 1980, and again in August of 2007 as part of a heat wave in which 12 people died in Alabama alone (NOAA, 2013). May is the driest month on average with a mean precipitation amount of 3.38 inches. March is the wettest month and has an average precipitation amount of 6.23 inches (NOAA, 2013).

Auburn is committed to being an attractive, environmentally conscious community that is progressive, responsible, and hospitable, according to the City of Auburn's vision statement. It has a population of 54,566 and is home to Auburn University (City of Auburn, 2013). Auburn is located in the southwestern part of Lee County at 32.6097° N, 85.4808° W. Opelika, with a population of just over 27,000, affirms to be a progressive city of the South and claims to be "rich in heritage with a vision for the future." It is located in the north central part of Lee County at 32.6453° N, 85.3783° W, and holds the county seat (City of Opelika, 2013).



US Census, 2010, ESRI Imagery, National Geographic, alabamaview.org, 25 April 2013. Andy Hug

FIGURE 1
STUDY AREA

3. METHODS

Land cover and temperature were assessed through the analysis of satellite imagery. A Level-1 processed Landsat 5 thematic mapper geotiff image dating 9 August 2008 row 19, path 37 was downloaded from www. glovis.usgs.gov, and the ten meter DEM (digital elevation model) of Lee County produced by the USGS was downloaded from www. alabamaview.org,a consortium of institutions sharing geospatial data in the state of Alabama All seven bands of the Landsat image were loaded into ERDAS Imagine Classic Interface, where they were subset to the extent of the Auburn-Opelika area. The thermal band (band 6) was also subset to the same extent as an additional image. Next, the seven band image was classified using an unsupervised classification into 20 initial classes, which were then recoded into four classes: 1.) water, 2.) vegetation, 3.) urban (*i.e.,* impervious), and 4.) barren land. An accuracy assessment was performed to assess the correctness of the classification by randomly selecting 100 pixels to verify the correctness using a combination of high resolution ortho imagery and the 4-3-2 false color composite of the Landsat scene. The results showed the classification to be 91 percent correct.

The ten meter DEM for Lee County was subset to the same extent as the Landsat image. Both slope and aspect topographic analyses were generated from the 10 meter DEM using the ERDAS topographic analysis tools. The National Park Service's Alaska Pak was used in Arc Map 10.1 to generate 1,000 random points over the study area for each layer (including a slope layer, aspect layer, thermal layer, and classified layer). Values were extracted for each of the four raster layers for all of the 1,000 randomly selected points. For example, each of the points on the classified raster layer was given a value of 1, 2, 3, or 4 depending on the location of the random point. If it was located in a vegetative area, it received a value of 2. Likewise, if it was located on an impervious surface, it received a value of 3. The same procedure was used on the remaining layers (slope, aspect, and thermal emmittance). The attribute tables from the newly created point layers (point layers created by the extract values to points function) were exported and loaded into Microsoft Excel 2010 for statistical analysis.

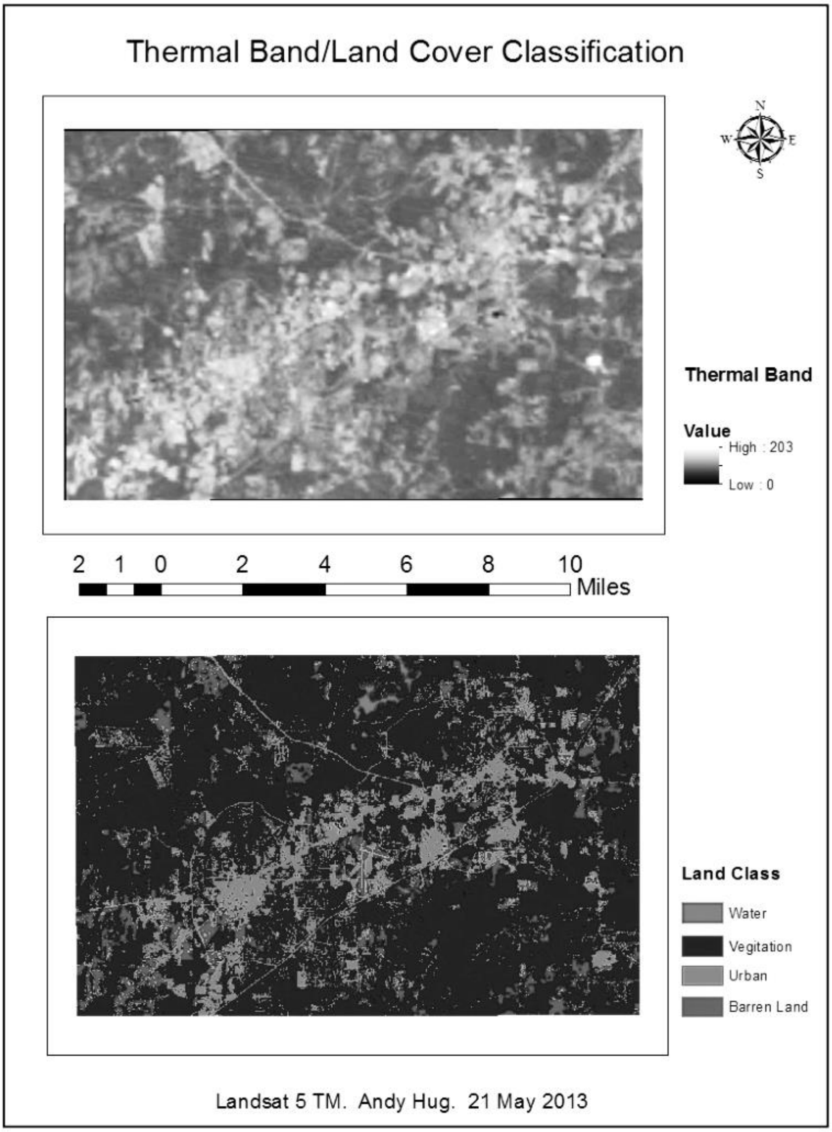
The thermal band ranges were categorized according to land cover class. Landsat TM has a thermal band resolution of 120 meters, and it stores thermal data acquired through the thermal band as digital numbers (DNs) between 0 and 255 (Weng, 2001). Water (class1) had a DN range of 141-201 and an average of 157. All except one water point value was less than 160. The only water point value which was above 160 had a value of 201, and it was located in a small water body in downtown Opelika surrounded by asphalt and concrete. Vegetation (class 2) had a DN range of 139-163 and an average of 145, urban (class 3) had a DN range of 143-174, and an average DN value of 157, and barren land (class 4) had a DN range of 143-174 with an average DN value of 154. As expected, the urban temperature was the warmest on average, with a DN value of 157. An illustration of the thermal band and the classified image of the study area is shown in Figure 2 on the following page.

A multiple linear regression was used to test the effects of land cover, slope, and aspect on temperature. Temperature was the dependent variable (Y), and land cover, slope, and aspect were the independent variables (X). Multiple scenarios were modeled, but all results indicated that slope and aspect had a negligible impact on temperature. Reasons for these results may include that the Auburn-Opelika area is relatively flat, the Landsat 5 satellite passes over in the early daylight hours, and the pixel size for the thermal band (120 meters) may be too large to explain the effects of slope and aspect on temperature for this study area. Following these results, the thermal raster values (DNs) were joined with the recode raster values (land cover value 1, 2, 3, 4). Next a vector layer was created for the land cover raster layer in order to stratify the sampling points according to urban and vegetation classes, urban and water classes, and urban and barren land cover classes. The select by attribute function in Arc Map was used for this process by using the formula, recode raster value =2, or recode raster value =3 for the urban and vegetation class stratification. The same procedure was used for the other stratifications. New layers were created from selected features, and the tables from the newly created layers were exported and statistically analyzed. There were total of 852 observations between the vegetation and urban land classes.

A linear regression was run using thermal DNs as the dependent variable (Y), and vegetation and urban land classes as the independent variables (X) (aspect and slope were not included in this regression considering the minimal effects they had on temperature in the previous scenarios mentioned earlier). Two additional regressions were run using DNs as the dependent variable and land class as the independent variable to compare the urban land class and temperatures with the remaining land classes and temperatures (*i.e.* urban and water, urban and barren land) in the same way that urban and vegetation land classes and temperatures were compared. Three regression models were run between the urban land class and the remaining three land classes.

4. RESULTS

All independent variables were significant at the 95 percent confidence level. Models 1 and 2 had positive coefficients, indicating that land class has a positive relationship on the change in temperature. For example, as urban and vegetation land covers increase, the difference in temperature between the two land covers increases. The temperature between the urban and vegetation land covers varies more than the temperature between the urban and water classes, as communicated through both the coefficients and the R-square values. However, model number 3 had a negative coefficient, showing that urban and barren land classes have a negative relationship on change in temperature between the two land covers. As urban and barren land cover increases, the difference in temperature decreases between the urban and barren land classes. Model 3 also had the lowest R-square value which stands to reason considering the urban and barren land class temperature ranges and averages. Barren land surfaces are pervious, but have little to no vegetation. Moisture content and cooling processes such as evapotranspiration are minimal to non-existent, which help to explain the similar temperatures between barren land and urban surfaces. Considering these factors, covering or replacing barren land surfaces with green vegetation could substantially contribute to reduced urban temperatures. The regression results are shown below in Table 1.


Thermal Band/Land Cover Classification

Landsat 5 TM. Andy Hug. 21 May 2013

FIGURE 2
THERMAL BAND AND LAND CLASSIFICATION OF STUDY AREA

The results from model 2 display a larger R-square value than model 3 does. This indicates a larger difference in temperature between the urban and water classes than between urban and barren land. It also stipulates that more of the difference in temperature is being explained by the different land covers. The most significant results were the urban and vegetation land classes, displaying an R squared value of 0.47 and a significance F value of 6.3 E-120, as seen in Table 2. The significance F value was well below the 0.05 threshold, indicating the regression model is valid. According to these results, the land cover is explaining 47 percent of the difference in temperature between the urban and vegetative land cover in the warmest part of the year.

TABLE 1
REGRESSION RESULTS

Model Number:	1	2	3
Land Class	Urban/Vegetation	Urban/Water	Urban/Barren Land
Number of Observations	852	186	297
R Square	0.471	0.112	0.037
Adjusted R Square	0.471	0.107	0.034
P-Value (X)	6.30E-120	3.06E-06	0.00
Coefficients	11.218	4.588	-2.550

5. SUMMARY AND CONCLUSION

Much more literature exists on the UHI's effect in large cities than in small or mid-sized cities. The results from this study show that UHIs exist in smaller urban areas to an extent that may be comparable to those of previous studies conducted in larger cites. This study used Landsat imagery and an unsupervised classification to assess the impact of urban landscape on temperature in the mid-sized city of Auburn-Opelika. Slope and aspect were included in the initial analysis, but were found to impact temperature negligibly and were left out for the final analysis. The linear regressions assessed the change in temperature between the land classes in one of the hottest months of the summer. The results of this study showed that land cover had the most significant impact on temperature between the vegetation and urban land surfaces. This can be attributed to factors such as reduced amount of evapotranspiration in urban areas due to lack of vegetation, impervious qualities of urban surfaces, lower albedo of impervious surfaces, and increased absorption of solar energy.

6. FUTURE DIRECTIONS

This research was a preliminary part of a more extensive study used to check for the existence of a UHI in the Auburn-Opelika urban area. In the future, the thermal DNs will be converted to temperature values to further analyze the differences in temperatures spatially among land cover and to allow for comparisons through time. Small temperature logging instruments called ibuttons purchased from www.embeddeddatasystems.com will be placed around the downtown areas of Auburn and Opelika as well as surrounding rural areas for at least one year to analyze the behavior of the UHI spatially and seasonally. Ibuttons will also be placed around the city of Birmingham to compare the UHI of a larger city to the UHI of a more mid-sized city. This future study will contribute to the limited amount of literature on UHIs in mid-sized cities, and in Alabama in addition to mitigation techniques. This research and other UHI research is especially significant considering the findings of the IPCC Fourth Assessment Report (AR4) report, which provides strong evidence that the global surface temperature has warmed 0.74°C (1.35°F) over the past 100 years (1906-2005). Over the past 57 years, the warming trend has averaged 0.13°C (0.234°F) per decade, and the years between 1995 and 2006 rank among the warmest years since 1850 (IPCC 2007).

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