A Thesis
Detection of Urban Heat Islands in the Great Lakes Region with GLOBE Student Surface Temperature Measurements

by

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Modern urbanization changes the albedo, temperature and hydrography of the natural landscape resulting in an increase in surface temperature of urban areas compared to the surrounding rural areas. This urban-rural temperature difference is called Urban Heat Island (UHI). This research utilizes GLOBE student surface temperature data in the study of UHIs and provides a critical analysis of the viability of GLOBE data. The GLOBE Program is a worldwide program that engages students in scientific observation by providing protocols for the collection and reporting of environmental observations to a public database. The first objective of this research was to establish focus areas using climate and physiographic regions, for study of UHI using available GLOBE data in the Great Lakes region. The second objective compared GLOBE surface temperature data to Landsat thermal imagery in order to determine validity of GLOBE measurements and ability to detect UHI. Previous research has established an expected temperature difference between Landsat Thermal Imagery and in-situ ground measurements to be within 2.7°C (Goetz, 1997). Inherent to the student data is the potential for errors such as temperature reported in Fahrenheit rather than Celsius, local time instead of UTC time, inaccurate GPS coordinates of study site, and accuracy of surface temperature measured
by the student. It is also difficult to find GLOBE data that was collected at the exact same
time as the Landsat overpass time. Within these limitations, GLOBE data is most
comparable to Landsat on vegetated surface cover within 1 hour of overpass time.
Generally where Landsat detects UHI, GLOBE schools detect a UHI with the same
magnitude. Finally, this research utilized GLOBE data in a comparison of surface
temperature by cover type. This research found that impervious surface and urban
location had the greatest warming influence on surface temperature. Urban areas tended
to have a warming effect and when coupled with impervious surface cover; there was a
strong warming effect.

**Key Words:** Urban heat island, GLOBE Program, Remote sensing, surface temperature,
Geographic Information System, Landsat-5
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Chapter 1

Introduction

In 1833, in his review of the climate of London, Luke Howard examined meteorological measurements collected in the city and surrounding countryside and discovered that urban areas are 1.58°C warmer than rural areas. Luke Howard is cited as the first to record a measurable urban-rural temperature difference (Howard, 1833). Luke Howard was not a climatologist, he was a pharmacist with an interest in meteorology. However, he was able to make significant contributions to the study of climatology including the classification scheme for cloud names (RMetS, 2014). The very same cloud classifications proposed by Howard are used by GLOBE students when making cloud observations to submit with their surface temperature recordings. Like Howard, GLOBE students are not professional climatologists, however they have a desire to contribute to the understanding of global climate.

At the turn of the 20th century just 15 percent of the world’s human population was living in cities or areas considered “urban”. Over the next 100 years the number of people living in urban areas increased drastically. By 2008 more than half of the world’s population, or 3.3 billion people, were living in urban areas (Obaid, 2007). The world’s
landscape has transformed from small, isolated population centers to expansive, interconnected physical features of the landscape (Xian and Crane, 2005). The physical infrastructure of cities have replaced native soil and vegetation with concrete, asphalt and buildings which alter the albedo and runoff characteristics of the land surface. Surface and atmospheric modifications resulting from urbanization have led to a localized thermal climate that is warmer than surrounding non-urbanized areas called an Urban Heat Island (UHI) (Voogt and Oke, 2003). Studies have shown the average temperature of large metropolitan areas such as Los Angeles has increased by 2.8 °C (Semarau, 1992). This research paper seeks to study urban heat islands in the Great Lakes region using a student generated ground observations collected as part of the GLOBE program.

Climatologists have been using remote sensing and ground surface temperature measurements for decades in the context of climate change studies. The first surface urban heat island observations from satellite based sensors were reported by Rao (1972). Since the early days, a variety of platforms such as satellite, aircraft, and ground-based measurements have been affixed with thermal sensors to report surface temperature at varying temporal and spatial resolutions. Such studies have used thermal remote sensing to examine the spatial distribution of UHI and its relationship to land cover (Voogt and Oke, 2003, Aniello, 1995, Lino and Hoyan, 1996). Multispectral imagery such as Landsat-5 TM or Landsat 7 ETM+ satellites record imagery utilizing multiple sensors such as near-infrared, true color as well as thermal imagery at the same time and location. This is particularly useful for studies in which surface temperature is studied in the context of the underlying ground surface characteristics and vegetation (Quattrochi and Luvall), 1999). Landsat imagery are particularly useful for mapping urban-rural
temperature variations due to their high resolution imagery, extensive image archive and regular pass interval. Often studies use ground measurements to verify or validate satellite derived thermal imagery (Lino and Hoyan, 1996, and Aniello, 1995). Climatologists are not the only scientists interested in urban heat islands and their implication for the environment. Research focused on human health and illness have taken an interest in the detection of urban heat islands and their effect on the human population that come in contact with them.

Epidemiologists are now using remote sensing, ground observations and advanced spatial modeling to study UHI in the context of public health and wellness. A recent study by Jalonne White-Newsome, in 2013, investigated surface temperature of urban and rural areas to assess the relationship between land surface temperature and land cover in the context of predicting excessive heat exposure to residents. The study sought to establish a methodology for public health researchers to identify hot spots, based on surface characteristics within a city as an indicator of potential public exposure to elevated temperatures. The study cited a major limitation to public and private research is the poor accessibility to remote sensing data and spatial modeling to be applied to public health problem. A second limitation the study cited was the lack of available in-situ ground surface temperature measurements and land cover observations to accompany and verify remotely sensed data (White-Newsome, 2013).

One such dataset that provides ground surface temperature measurements and land cover observations is the GLOBE program. GLOBE stands for the Global Learning and Observations to Benefit the Environment, a worldwide program that involves
students in scientific reporting by providing avenues for the collection and submittal of viable environmental measurements to a publicly accessible database (Semple, 2011). The GLOBE database provides a wide variety environmental datasets such as budburst timing, soil and air temperature monitoring, land cover classification, stream monitoring, and surface temperature measurements. Each GLOBE dataset has a precise methodology designed by scientists and subject matter experts on a proper protocol for making concise, repeatable and scientifically viable observations. Of particular interest to this study is the surface temperature protocol designed to direct students in the collection of surface temperature, surface cover, sky conditions, cloud type and percent cover, and snow depth observations (Czajkowski, 2014).

The GLOBE database provides a meaningful environmental database of high quality measurements that can be applied to research within the academic scientific community. GLOBE provides a global network of observations that are publicly available at no charge to the researcher. Established in 1994, many datasets have more than a decade’s worth of observations from schools distributed both nationally and internationally (Creilson et al, 2008). From the GLOBE.gov website, researchers can query and visualize the data by type of measurement, location, timeframe and individual contributing school. Several remote sensing studies have applied GLOBE databases directly to the research and/or indirectly in the validation of satellite remote sensing products. One study successfully applied GLOBE snow and cloud observations to validate the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite’s snow product in the Lower Great Lakes region. Another study in the Netherlands used GLOBE student observations to validate MODIS aerosol optical thickness measurements. This
same study also compared GLOBE measurements to professional Sun photometer measurements and determined that GLOBE measurements live up to a professional standard (Ault et al, 2006). This research seeks to establish a methodology to utilize GLOBE surface temperature measurements in the study of UHI with the purpose of expanding and encouraging the application of student data to research in climatology, environmental science and public health research.

1.1 Objectives

The purpose of this thesis is to analyze GLOBE surface temperature dataset and its application to the study of UHI in the Great Lakes region. Specifically this study will establish a workflow for utilizing the GLOBE surface temperature dataset for studying UHI from and urban and rural perspective. A GIS will be used to compile, correct, and analyze the spatial distribution of GLOBE surface temperature measurements and explore the UHI in urban and rural settings. Landsat thermal imagery will be used to test the viability of GLOBE surface temperature measurements as viable observations to study UHI. Finally this research will use GLOBE surface cover observations to analyze the effects of surface cover on surface temperature.

Specifically this research seeks to fulfill the following three objectives:

1. Determine focus areas for the study of UHI using GLOBE student data
2. Determine viability of GLOBE student surface temperature data in the study of UHI
3: Analyze the effects of surface cover on surface temperature in both urban and rural settings using GLOBE student data

The stated objectives outline the approach for this research. These objectives will utilize GLOBE surface temperature measurements, Landsat multispectral imagery, and published calibration procedures for deriving surface temperature from Landsat imagery, published climate, land use and physiographic mapping, in a Geographic Information System (GIS). The ultimate goal of the objectives is to assess GLOBE surface temperature measurements as a viable data source for studying UHI and then apply it to the study of UHI in the context of surface cover type and urban and rural temperature gradients. The next section is literature review of current research related to the analysis of UHI.
Chapter 2

Literature Review

2.1 Introduction to the Urban Heat Island

Urban environments completely change the original physical characteristics of a natural landscape by introducing anthropogenic structures. These buildings, roads, parking lots, and paved surfaces replace vegetation cover and increase impervious surface area and heat storage capacities (Xian and Crane, 2005). These alterations impact surface albedo, or the ratio of incoming electromagnetic radiation to reflected radiation (Lo and Quattrochi, 2003). Land surface temperature (LST) is important in controlling energy and water balance between the atmosphere and land surface (Pinho & Orgaz, 2000). This temperature difference between urban and rural areas is referred to as the Urban Heat Island (UHI). The following figure, Figure 2.1 shows the profile of temperature change by land cover type.
Figure 2.1: Typical Urban Heat Island Temperature Profile by Land Cover (EPA, 2009)

Generally speaking Urban Heat Island refers to the increase in temperature of urban areas as compared to surrounding non-urbanized areas. However, UHI’s are typically more specifically defined by the layer of the urban atmosphere to which they are located. The urban canopy layer (UCL) is the layer of urban atmosphere that extends upward from the surface to approximately mean building height. The urban boundary layer (UBL) sits just above the UCL and extends just to the top of the buildings. Finally there is the surface urban heat island (SUHI) which refers to the temperature difference detected at the surface of urban areas. SUHIs are detectable at all times of the day, however are most intense during the day in the summer months. The highest surface
temperatures are normally recorded by day, when impervious surfaces are receiving the most incoming radiation. SUHI experience the most spatial and temporal variation during the day and are slightly more stable at night. SUHI are measured directly via stationary meteorological stations, *in-situ* ground measurements and also indirectly via thermal remote sensors from aircraft or satellites. Night-time UHIs are observable in the air column as heat energy is slowly released from impervious surfaces and heat pollution from nearby buildings.

Previous studies have shown that around the world, cities with populations greater than 100,000 have heat islands 1-4.5 °C warmer than rural areas (Semrau, 1992). Elevated temperatures from urbanization have environmental, human health and atmospheric impacts. Surface temperature is important to urban climates because it regulates the air temperature of the lowest layers of the atmosphere most effecting city dwellers (Voogt & Oke, 2002). Cities experiencing a significant UHI effect experience increased daytime surface temperatures, reduced night time cooling, greater air pollution leading to general discomfort, respiratory problems and heat related illness including heat stroke, exhaustion and death. Sensitive populations such as children and elderly are particularly susceptible to extreme heating conditions (EPA, 2010). Particularly severe heat waves, such as one that occurred over Chicago, Illinois in July, 1995 where 525 people died of heat related illness, have been blamed on UHI effects (Quattrochi & Lo, 2003). Urban climatology is an important realm of study because it directly impacts more than half the world’s population (Small, 2005).
Increased surface temperature from UHI effects impacts on air quality and environmental conditions. Higher temperatures increase ozone production at ground level from volatile organic compounds emitted from the combustion of fossil fuels. Ground level ozone and elevated temperatures are hazardous to public health because it can cause respiratory and cardiovascular problems (Quattrochi & Lo, 2003). The elevated temperatures within urban environment also have biological and economic impacts. Warmer temperatures in urban areas result in earlier green-up of flowers and trees in the city, a longer growing season and the attraction of birds to warmer habitats. Economically, heat islands insulate nearby buildings and decrease the need for winter heating, but increase cost of cooling in summer (Aniello, 1994).

2.2 Remote Sensing of UHI

UHIs are commonly studied using thermal remote sensors mounted on aircraft or satellites. Remote sensing is particularly applicable to observing UHIs because the spatial patterns of the UHI can be observed easily from space (EPA, 2009). Satellites affixed with a thermal remote sensor provide a wide range of spatial and temporal resolutions for studying UHI. The first detection of the phenomenon via satellite was by Rao in 1972 where he described the spatial distribution of UHI. Later, surface temperature measurements were taken from aircraft which substantially improved spatial and temporal resolution of the imagery (Quattrochi, 2003).

Satellites are technically constrained to either high temporal resolution or spatial resolution but not both. For example, a satellite with a high resolution sensor will have a small swath and will have a less frequent pass rate resulting in high resolution imagery
collected less frequently. Conversely a low resolution sensor has a large swath and will have more frequent passes, in some cases multiple times per day, resulting in lower resolution imagery collected more frequently. Commonly used satellites with high resolution thermal imagery include Landsat-5 TM and 7ETM+ and the satellite Advanced Spaceborn Thermal Emission and Reflection Radiometer (TERRA ASTER) providing LST at a high spatial resolution of \( \leq 120\) m and a relatively frequent 16 day pass cycle. Satellites with lower resolution ~1km thermal bands include Moderate-Resolution Imaging Spectroradiometer (MODIS) and Advanced Very High Resolution Radiometer (AVHRR) are chosen for their high temporal resolution providing twice daily Land Surface Temperature (LST) imagery (Stathopoulou, 2009).

This research will utilize thermal imagery derived from the Landsat-5 Thematic Mapper satellite. The Landsat satellite project, a joint initiative of the U.S. Geological Survey (USGS) and National Aeronautics and Space Administration (NASA), is dedicated to gathering Earth data from space. NASA is responsible for developing, building and launching the satellites and the USGS handles the operation, maintenance, data reception, processing and distribution. Landsat represents the world’s longest continuously acquired satellite remote sensing data set (USGS, 2012). Landsat satellite imagery is particularly useful for UHI studies because one of the data products Landsat provides is Thermal-Infrared (TIR) data. In the late 1970’s Landsat began collecting (TIR) data with the launch of the Landsat 3 platform. This new sensor allowed for thermal imagery to be capture of the earth’s surface at a resolution of 120 meters. (USGS, 2010). Landsat-5 TM has a repeat cycle of 16 days and when coupled with the data from Landsat-7 ETM+ the pair of satellites produce imagery every 8 days. Footprints of
Landsat-5 imagery are mapped using a global grid designating path/row reference numbers for the location of each image. Landsat-5 is equipped with a 30m resolution visible band, 120m resolution thermal band (USGS, 2012). This research will utilize the calibrated and corrected 120m thermal imagery from Landsat-5TM converted to surface temperature in degrees Celsius.

Many thermal remote sensing studies utilize in-situ, or ground measurements in order to improve image spatial resolution, temporal resolution or gather additional information about the air column above the surface or surface cover conditions. Measurements are often taken from weather stations with infrared thermometers (IRT) aimed at the earth’s surface, or mounted air temperature sensors on towers or buildings (USCRN, 2010). In situ measurements have a temporal advantage over satellite imagery as they can be collected on a continuous basis. Ground measurements can also collect data from unique perspectives such as below canopy or from views otherwise obstructed from satellite platforms. In-situ measurements are often used to validate and/or calibrate thermal satellite imagery, determine surface temperature on cloudy days when satellite imagery would be obscured and correct imagery with atmospheric interference (Rigo, 2006). There are several campaigns working to provide regular surface temperature measurements of the earth’s surface. One of the most extensive surface temperature measuring efforts is FLUXNET. FLUXNET is an international network of over 400 flux tower sites that continually measure CO2, water vapor, energy flux and surface temperature. AmeriFlux is a smaller network of tower sites throughout the U.S. that also measures meteorological and surface conditions (DAAC, 2010). There are also smaller, short term projects such as BUBBLE, the Basel Urban Boundary Layer Experiment,
which is a European research project that installed several flux towers in Switzerland. These datasets are often used to validate satellite data.

2.3 GLOBE Surface Temperature Measurements

This research will use surface temperature data collected by students participating in the GLOBE program. GLOBE stands for (Global Learning and Observations to Benefit the Environment) and is an international science education program with over 24,000 schools where teachers, students and scientists work together to study and understand the global environment (The GLOBE Program, 2014). The program was started in 1993 in cooperation with Colorado State University and University of Atmospheric Research (UCAR) and funded by the National Aeronautics and Space Program (NASA) and the National Science Foundation (NSF). Scientists develop rigorous scientific protocols that establish precise procedures for collecting and submitting earth science measurements onto the GLOBE website. As part of their science curricula, students all over the world make scientifically valid measurements near their school and report their data via the GLOBE data archive. The purpose of the website is to organize the data and share it with scientists and students around the world (Becker Et. Al. 1998).

This research will utilize GLOBE data from the Atmosphere Group, specifically the Surface Temperature Protocol. The Surface Temperature Protocol is an established methodology designed by scientists and subject matter experts on the precise procedure for making surface temperature observations (Czajkowski, 2014). Using this protocol students follow a detailed, step by step methodology for collecting consistent,
scientifically viable, surface observations. Students are instructed to establish a study site that is a large, open, homogenous location. The site can be any size but students are encouraged to observe large areas, greater than 90 meters by 90 meters. If the area is smaller than 90 by 90 m², and larger than 30 meters by 30 meters, they report that and then if it is smaller than 30 by 30 m², then they report the size of the site. Students are instructed to take daily surface temperature measurements, on sunny days with few clouds with the intention to compare to satellite observations. Students measured ground temperature with a hand-held infrared thermometer (IRT) wrapped in a thermal glove (Figure 2.3). The thermal glove prevents temporary inaccurate temperature readings due to thermal shock from moving the instrument quickly from the indoors to outdoor temperatures. For each daily observation students record a total of 9 individual surface temperature measurements that later will be combined and the mean surface temperature will be derived as the final surface temperature measurement. Students also make note of the surface cover conditions, cloud cover, visibility of contrail, and precise date and time. The thermal glove prevents temporary inaccurate temperature readings due to thermal shock from moving the instrument quickly from the indoors to outdoor temperatures. All students are taught to use a hand-held infrared thermometer (IRT) by a certified GLOBE teacher. Figure 2.2 demonstrates correct use of IRT with and without a thermal glove.

Once student data has been fully submitted, students from other schools and scientists can go to the GLOBE.gov website and query for datasets. The GLOBE.gov website allows researchers to search, visualize and retrieve GLOBE data.
Figure 2.2: Demonstration of Correct Use of IRT without and with Thermal Glove (Czajkowski, 2014).

Figure 2.3: Hand-held Infrared Thermometer (IRT). This Fluke IRT is the recommended instrument used as part of the GLOBE Surface Temperature Campaign (Czajkowski, 2014).
Inherent to GLOBE data are several potential limitations to the accuracy of the data. There are opportunities for error introduced to the student measurements as the time students collect surface temperature measurements, make weather observations, record date, time, and location information. Human error is introduced with each measurement in the form of misreading surface temperature measurement, improper reporting in Fahrenheit instead of Celsius and potential that measurements could be taken outside of designated study site. Each hand held IRT introduces its own potential for bias in the calibration of the unit. Furthermore, students are required to convert local time to UTC time, which introduces another potential for error. The potential for incorrect reporting of time of measurement is a significant problem particularly when comparing GLOBE measurements to satellite imagery. Another limitation with GLOBE data is that student participation is inconsistent. A particular school might participate for a number of years and then fail to continue monitoring. Students are often limited to taking measurements during the school year and only on days when school is in session. Finally, the location of each site is reported by students and the accuracy of the location depends on the accuracy of the GPS unit used. These limitations of the GLOBE dataset must be considered when utilizing this database.

2.4 Surface temperature and land cover

In addition to urban-rural temperature differences, studies have found a variance between surface cover types as well. For example, industrial and urban areas produce a warming influence whereas vegetated areas such as farmland and forest produce a cooling effect (Roth, Oke and Emery, 1989). Specifically, paved surfaces such as asphalt were found to heat to a higher extent and contribute the most to the magnitude of UHI.
Black top and concrete pavement store the most heat during the day and releases heat into the atmosphere at night contributing to nighttime UHI (Asaeda, 1993). The greatest influence of UHI results from the physical infrastructure of urban environments that replace vegetation and soil with concrete, asphalt and buildings that alter albedo and energy exchange of the landscape creating a heating effect (Voogt & Oke, 2002). The National Land Cover Dataset (NLCD) is a common land cover database used in studies concerning remote sensing of urban heat islands (Imhoff, Ping, Wolf, and Bounoua, 2010). As part of the GLOBE surface temperature protocol students make observations about surface cover and surface temperature. This research will utilize GLOBE surface temperature measurements to determine how surface cover effects surface temperature in urban and rural settings.

2.5 Geographic Information Systems and Modeling

Geographic information systems are often used in UHI studies to synergize several data sources into one viewing area, perform analysis, model and predict UHI conditions. Satellite, aerial and ground data can be combined with land use/land cover maps and analyzed using a combination of GIS or image processing software (Jensen, 2005; Voogt & Oke 2003). A 1994 study on Micro-Urban Heat Islands using Landsat TM and GIS, merged tree cover data with thermal imagery to locate “hot spots” in the urban area of Dallas, Texas (Aniello et al. 1994). Other studies use land cover data layers in conjunction with thermal satellite imagery to predict UHI intensity (Friedl, 2002). This research will utilize a GIS, spatial analysis tools, and image processing software to organize geographic datasets, calculate relationships between the location of GLOBE
surface temperature measurements in relation to thermal imagery, climate, physiographic region and land use mapping.
Chapter 3

Methodology

This chapter will address the methodology implemented for this research paper. The chapter is divided into sections that will address the development of the study area, five focus areas, classification of GLOBE schools, image calibration and processing, viability of GLOBE data and surface cover effect on surface temperature.

3.1 Study Area, Great Lakes region, USA

The study area for this thesis research focuses on the available GLOBE data within the Great Lakes region, primarily in Ohio, Kentucky, Michigan, Pennsylvania and West Virginia. Participating schools are located in both urban and rural settings. Major cities within the study area include Detroit, Michigan, Cleveland, Ohio, Columbus, Ohio, Ohio, Akron, Ohio and Pittsburg, Pennsylvania. The study area has several key landforms including Lake Erie, Lake Michigan and the Appalachian Mountains. Figure 3.1 depicts the study area, the Great Lakes region, and the available 177 GLOBE schools with surface temperature observations considered in this paper.
Figure 3.1: 177 Participating GLOBE Schools located in Ohio, Michigan, Kentucky, West Virginia and Pennsylvania are considered in this research.

3.2 Focus Area Development

Objective 1. Determine focus areas for the study of UHI using GLOBE student data

Crucial to the study of UHI utilizing student data is grouping schools that are located in areas that have similar climate and physiographic characteristics. Objective 2 seeks to establish focus areas in order to compare GLOBE data from schools that have a similar climate and regional influence. This study considered all GLOBE surface
temperature data located within the Great Lakes region. Participating schools were distributed across major cities, suburban areas and in rural villages. Major cities with contributing schools included Detroit, Michigan, Cleveland Ohio, Pittsburg, Pennsylvania, Columbus, Ohio, Cincinnati, Ohio and Toledo, Ohio. Within the relatively small geographic region of the Great Lakes there is variance of topography, land cover, climate and microclimate. Schools located in Western Michigan along Lake Michigan have vastly different physiographic and climate influences from schools located in Western Pennsylvania at the foothills of the Appalachian Mountains. Therefore, focus areas were developed using published mapping of physiographic regions, zones of mean annual average temperature and proximity to major physiographic features, to minimize the variance between groups of schools.

In order to divide schools into areas of similar topography, bedrock geology and geomorphic history the schools were mapped against the *Physiographic Divisions of the Conterminous U.S.* (Fenneman, 1946). This mapping divides the conterminous United States into 25 provinces representing distinctive areas of common topography, rock types, geologic structure and geologic history. Figure 3.3 shows the mapped GLOBE schools with nearly half of the schools located within the Central Lowland province and the remaining schools are located in the Appalachian Plateaus province with a couple schools in the Central Lowland. Schools located across this study area experience a divide in physiographic province from west to east. The Appalachian Plateau is characterized by dendritic streams progressed to the mature stage with most having well-developed floodplains and meanders. The topography of the Appalachian Plateau is sloping by only a few hundred feet with the hills between major streams exhibiting
shallow slopes and rounded summits. The Central Low Plateau is characterized by a low-relief surface formed by glacial till, outwash plains and glacial lake plains. Long low arcuate ridges formed by recessional moraines are common (Fenneman, 1946).

Generally, based on physiographic divisions, schools were divided utilizing this west-east division of physiography.

![GLOBE Schools plotted in the Physiographic Provinces of the USA](image)

> Figure 3.2: GLOBE Schools plotted in the Physiographic Provinces of the USA. Schools are generally divided by the Central Lowland region in the west and the Appalachian Plateau in the east. Schools are generally divided north to south by temperature banding.
Across the study area is a variation in climate from north to south, along the Great Lakes and near the Appalachian Mountains to the east. In order to further divide schools into groups with similar climate and average temperature, schools were divided using the Mean Annual Average Temperature maps for the USA (NCDC, 2005). This mapping represents the temperature gradient across the conterminous United States averaged across the year. Generally, northern schools in Western Michigan experience the coldest average temperatures, schools around the Great Lakes experience slightly milder temperatures and schools located in Southern Ohio, Kentucky and West Virginia experience the warmest average temperatures in the study area. Figure 3.3 shows the GLOBE schools mapped against the Mean Annual Average Temperature map from the National Climatic Data Center (NCDC). Schools were grouped in consideration of temperature gradient that exists generally north to south, within proximity to the Great Lakes and Appalachian Mountain range.
Figure 3.3: GLOBE Schools plotted across the Mean Annual Daily Average Temperature mapping in order to group schools into groups of schools that receive similar climate influences.

Five focus areas were established utilizing existing mapping of physiographic and climate regions. Figure 3.4 shows the mapped GLOBE schools and the resulting 5 focus areas as divided by physiographic regions and climate zones. Schools were generally divided north-south based on average temperature mapping by the NCDC. Furthermore, schools were divided east to west based on established physiographic regions and
proximity to the Great Lakes and Appalachian Mountains. Schools located in Western Michigan were placed in a group because they are solidly located within the Central Lowland physiographic province, and are within close proximity to Lake Michigan and experience 40.2-45.0 °F mean annual average temperature. Schools located approximately within 100-km of Toledo, Ohio were grouped based on their placement within the Central Lowland physiographic province, close proximity to Lake Erie and mean annual average temperature. Schools roughly within 100-km of Cleveland, Ohio were grouped based on their placement within the Appalachian Plateaus, proximity to Lake Erie and also similar annual average temperature.
Figure 3.4: Schools were grouped into five Focus Areas such that schools within each group receive similar climate and physiographic regional influence.

Schools located in Western Pennsylvania and Western West Virginia were grouped based on their placement within the Appalachian Plateaus province, proximity to the Appalachian Mountains and similar annual average temperature. Finally schools located in Southern Ohio and Northern Kentucky were grouped based on their average temperature and proximity to the transition between the Central Lowland and Appalachian Plateaus. Table 3.1 describes the resulting number of schools across focus areas. Focus areas with a large number of schools will be particularly helpful in establishing spatial distribution of surface temperature measurements.
Table 3.1: Number of GLOBE Schools by Focus Area as divided by physiographic region and climate mapping.

<table>
<thead>
<tr>
<th>Focus Area</th>
<th>Total Schools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Mountains</td>
<td>15</td>
</tr>
<tr>
<td>Cleveland, Ohio</td>
<td>69</td>
</tr>
<tr>
<td>Lake Michigan</td>
<td>11</td>
</tr>
<tr>
<td>Toledo, Ohio</td>
<td>52</td>
</tr>
<tr>
<td>Southern Ohio</td>
<td>30</td>
</tr>
</tbody>
</table>

### 3.3 Classification of GLOBE Schools as Urban or Rural

This research seeks to utilize GLOBE student data to compare surface temperature measurements from urban and rural areas in the study of UHI. The GLOBE dataset does not provide a designation for schools describing whether they are located in an urban or rural area. In order to utilize GLOBE student data to study an urban/rural surface temperature relationship schools were classified as ‘urban’ or ‘rural’ based on predominate surrounding land cover. As outlined in the literature review, previous research suggest that impervious surface associated with urban areas can have up to a 10-km land cover influence on air temperature. There wasn’t specific guidance in the literature about the process for designating a particular location as urban or rural based on land cover. Since the literature mentions that UHI can have 10-km reach, this research chose a more conservative approach and considered the land use within 3-km of each school. The classification of schools as ‘urban’ or ‘rural’ was based on a 3-km buffer search of land cover within range of the school. A school was classified as urban if the land cover within 3-km of the school was more than 50% urban. This 3-km buffer distance was not based on published methodology for classifying a location as urban or rural. The literature references that UHI can have up to a 10-km reaching effect on the
surrounding landscape. This research chose to use a 3-km buffer because it was a number that was slightly more conservative and resulted in a distribution of schools that visually made sense. The choice to make the division of urban and rural at 50% cover was also not based on published methodology, rather as a generalized approach for dividing schools. A possible alternative approach would consider population density around the school location either to categorize schools as urban or rural.

Therefore, schools surrounded by predominately developed, impervious, urban land cover surrounding them were classified as ‘urban’ schools and schools surrounded by undeveloped, forested, or farm land were classified as ‘rural’. In order to classify schools within the study area as urban or rural the land cover near the school was mapped and quantified within 3-km of each school location. The land cover mapping used for this study is the National Land Cover Database (NLCD), a nationwide land cover dataset, with 16 land cover classes, based on 30m resolution Landsat satellite data. NLCD land cover classes were divided into categories indicating ‘urban’ or ‘rural’ characteristics. Figure 3.5 shows the GIS that was established containing the 177 corrected GLOBE school locations established as part of Objective 1, and the National Land Cover Dataset raster depicting the land cover for the project area.
The first step in classifying each school as ‘urban’ or ‘rural’ was to determine the predominate land cover type within proximity to the school. Using the spatial analyst tool in ArcMap, a 3-km buffer polygon was generated for each school centroid. The Calculate Geometry tool was used to calculate the total area of each 3-km buffer such that the percent urban/rural coverage could be calculated for each school later in this analysis. The 3-km buffer also served as a boundary to clip and quantify the land cover near each school. Figure 3.6 shows the results of the spatial analysis that was performed using the Extract by Mask tool to clip the NLCD raster by the 3-km polygon resulting in a land cover subset around each school.
Figure 3.6: NLCD clipped by 3-km buffer of each GLOBE School in order to determine the predominate land cover around each school.

The resulting clipped NLCD dataset contained 15 land cover classes ranging from developed land to deciduous forest. The clipped NLCD raster was converted to vector polygons using the Raster to Polygon tool in ArcMap so that the area of each land cover type could be calculated. In order to quantify the UHI potential around each school the land cover classes were reclassified into two classes called ‘urban’ and ‘rural’ based on their potential contribution to UHI. Classes such as evergreen forest and deciduous forest were placed in the rural classification due to their cooling effect (Xian and Crane, 2005). Classes such as developed and open space were placed in the urban category based on their potential for asphalt, blacktop and other UHI contributing land cover characteristics.
(Imhoff, Ping, Wolf, and Bounoua, 2010). The NLCD land cover types in the resulting vector were updated with the reclassified values, ‘urban’ or ‘rural, using the Field Calculator tool. Figure 3.7 shows the resulting vector with urban and rural classifications. The following table, Table 3.2, depicts the final land cover reclassification scheme.

Table 3.2: NLCD land cover classes were reclassified as urban or rural in order to quantify percent urban or rural influence around each school.

<table>
<thead>
<tr>
<th>National Land Cover Dataset Class</th>
<th>New Class</th>
<th>National Land Cover Dataset Class</th>
<th>New Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergent Herbaceous Wetlands</td>
<td>Rural</td>
<td>Deciduous Forest</td>
<td>Rural</td>
</tr>
<tr>
<td>Woody Wetlands</td>
<td>Rural</td>
<td>Open Water</td>
<td>Rural</td>
</tr>
<tr>
<td>Cultivated Crops</td>
<td>Rural</td>
<td>Barren Land</td>
<td>Urban</td>
</tr>
<tr>
<td>Hay/Pasture</td>
<td>Rural</td>
<td>Developed, High Intensity</td>
<td>Urban</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>Rural</td>
<td>Developed, Medium Intensity</td>
<td>Urban</td>
</tr>
<tr>
<td>Shrub/Scrub</td>
<td>Rural</td>
<td>Developed, Low Intensity</td>
<td>Urban</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>Rural</td>
<td>Developed, Open Space</td>
<td>Urban</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td>Rural</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A series of steps were used to dissolve, intersect and join tables to the resulting vector in order to calculate the urban/rural land cover percentage for each school. Specifically, the reclassified land cover polygon was dissolved by the reclassification value so that the resulting vector contained a single urban and rural boundary across the entire study area. Next, the resulting urban/rural vector was intersected with the 3-km buffer polygon such that each school location had an associated clipped urban and rural polygon feature. The acreage of the resulting urban/rural features by school were calculated and compared to the total 3-km buffer acreage to determine the percent urban/rural coverage for each school. The Summary Statistics tool was used to calculate the percent urban/rural coverage. Finally, schools were assigned an urban or rural designation based on the percent, greater than 50.1%, of urban or rural coverage within 3-km of the school. The following figure, Figure 3.7, depicts a zoom-in of the Toledo,
Ohio focus area showing a subset of schools classified as urban or rural based on the results of the land cover reclassification.

Figure 3.7: Example of Land Cover Reclassification and Final GLOBE School Classification near Toledo, Ohio. Schools with predominately urban land cover are classified as urban and schools with predominately rural land cover are classified as rural.
3.4 Landsat Data Acquisition and Correction

Landsat TM/ETM’s band 6 has commonly been used for surface temperature mapping and is often compared to in-situ surface temperature measurements (Rigo, Parlow and Osch, 2006). This objective sought to utilize GLOBE surface temperature measurements in conjunction with Landsat-5 TM’s band 6 imagery with GLOBE surface temperature measurements to test the viability of GLOBE data to study UHI. GLOBE surface temperature data located within Ohio, Michigan, Pennsylvania, and West Virginia were selected for this project. The student data includes a latitude/longitude coordinates associated with the school’s study site as well as a description of surface cover, sky conditions, cloud type and percent cover, and snow depth observations (Czajkowski, 2014). Accuracy of the coordinates of the study location is vital to the comparison of ground measurements to the satellite imagery. The sample locations were plotted in a GIS and visually checked against a recent aerial photograph, at a scale of 1:2,400 to verify accuracy of reported location. Study sites located within a reasonable walking distance of the listed school address were considered reasonable. School locations that appeared incorrect, for example hundreds of miles from the school, were manually moved to the address of the school. Since the derived thermal imagery is at 120m resolution the approximation of the study site, when corrected, seemed reasonable for this application. Finally, in order to aid with the selection of satellite imagery, the frequency of data by date was summarized. Sample dates with a high number of measurements were compared to available satellite imagery in order to select imagery with overlapping GLOBE observations.
This study utilized Landsat-5 TM satellite imagery because of its 16-day pass frequency, 120m resolution thermal band and historic archive of imagery available from the USGS (Barsi Et Al, 2007). Landsat-5 TM imagery was selected for dates with GLOBE surface temperature measurements taken within the same path/row for the image. Images were selected that have low cloud cover and relatively higher availability of GLOBE data reported. The image selected for this study was located at Path 20, Row 31 and included eight overlapping GLOBE measurements for that date. Imagery was downloaded from the USGS Global Visualization Viewer (GloVis, 2014). The following table outlines the location, image date, path/row of imagery, number of GLOBE surface temperature measurements that align with the date/time of the imagery and the satellite platform utilized (Table 3.1). Landsat 7 ETM+ imagery were considered. However the dates with the most concurrent GLOBE surface temperature measurements were from Landsat-5 TM imagery dates.

3.5 Image Calibration and Thermal Processing:

In order to extract surface temperature from the imagery the raw Band 6 Landsat-5 TM imagery was calibrated and post-processed for surface temperature. Generally, the thermal band for each image was calibrated using a published calibration constant, converted into radiance and then converted to degrees Kelvins and then to degrees Celsius using published conversion factors. All image processing was performed using ERDAS Imagine ® image processing software. This study utilized the Revised Landsat-5 Thematic Mapper Radiometric Calibration procedure for calibration of Landsat-5 TM thermal imagery (Chandler, 2007). The extraction of surface temperature from Band 6 involves converting from digital number (DN) to radiance using the following equation:
\[ Q = G \times L\lambda + B \]

Where \( L\lambda \) is spectral radiance, which is the amount of light emitted from a particular surface at the sensor’s aperture, \( Q \) is raw quantized voltage (DN), and finally \( G \) and \( B \) are published gains and rescale coefficients. After DN was converted to radiance, the resulting raster was converted from radians to kelvins (K) and then to Celsius (C) in order to be compared to the student data. Figure 3.8 illustrates the workflow to convert Landsat-5 TM imagery to surface temperature using the software ERDAS Imagine 9.2.

![Flowchart for Landsat-5 TM thermal calibration and conversion to surface temperature in Celsius. Based on the Revised Landsat-5 Thematic Mapper Radiometric Calibration (Chandler, 2007).](flowchart.png)

The resulting imagery from the calibration process represents the surface temperature in Celsius for Toledo, Ohio and Cleveland, Ohio. The three calibrated images were placed in a GIS with the intersecting GLOBE surface temperature measurements. The next section describes the comparison of GLOBE surface temperature measurements to the thermal imagery taken on the same day.
3.6 Testing viability of GLOBE data for study of UHI

Objective 2. Determine viability of GLOBE student surface temperature data in the study of UHI

In this section, the methods to implement Objective 2 will be discussed. Objective 2 sought to test the viability of GLOBE student surface temperature observations in the detection of UHI using Landsat thermal imagery as a validation source. This objective was approached in two steps. The first step was to determine if GLOBE observations are reasonable when compared to Landsat surface temperatures. Previous sections of this paper calibrated and processed Landsat TM thermal imagery for four dates in 2005. Focusing on a single image date, May 4, 2005, GLOBE observations were compared to Landsat surface temperatures across an urban and rural landscape to determine if the GLOBE measurements are reasonable. This was achieved by drawing transects that intersect the GLOBE location and extend across the urban or rural landscape. Landsat surface temperatures were plotted along the transect at an interval of 500m to generate a temperature profile of Toledo, Ohio and a rural section of Northwest Ohio. GLOBE observations were plotted along the profile and any surface cover observations were noted. GLOBE observations with surface cover conditions were compared to similar homogeneous areas along each transect for greater clarification. Each area of interest identified along the transect was at least 120 x 120m of homogeneous land cover equivalent to the land cover at the GLOBE site. For each area of interest along a transect, a point was placed to later extract Landsat surface temperature at that location. Each point of interest also received a short description about the type of land cover at that location identified using a recent aerial photograph. For example, where GLOBE
observations reported surface cover of “short grass” an equivalent area along the transect that covered an area of short grass such as a golf course, cemetery or Metropark was called out in the profile for comparison. This method allows GLOBE measurements to be directly compared to Landsat imagery at the same location as well as adjacent surface temperatures extending across the varying landscape. The following figure illustrates the May 4, 2009, unprocessed, Near Infrared (NIR) Landsat image for path 20, row 31 over Toledo Ohio showing the available GLOBE student observations for that date (Figure 3.9).
The second part of the approach to satisfy Objective 2 was to determine if the GLOBE data is detecting the same UHI as Landsat for observations made on the same day. Previous sections of this paper classified GLOBE school locations based on land cover within 3-km of the school. As a result schools were assigned the classification of “urban” or “rural” based on predominate land cover around the school. The GLOBE student observations for April 18, 2005, May 4th 2005, May 20, 2005 and November 14,
2005 were mapped against a Landsat-5 TM thermal image processed and calibrated for surface temperature.

Table 3.3: Summary of Landsat Imagery

<table>
<thead>
<tr>
<th>Location</th>
<th>Image Date</th>
<th>Path/Row</th>
<th>GLOBE Surface Temperature Measurements</th>
<th>Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toledo, Ohio</td>
<td>4/18/2005</td>
<td>20/31</td>
<td>9</td>
<td>Landsat-5 TM</td>
</tr>
<tr>
<td>Toledo, Ohio</td>
<td>5/4/2005</td>
<td>20/31</td>
<td>10</td>
<td>Landsat-5 TM</td>
</tr>
<tr>
<td>Toledo, Ohio</td>
<td>5/20/2005</td>
<td>20/31</td>
<td>4</td>
<td>Landsat-5 TM</td>
</tr>
<tr>
<td>Cleveland</td>
<td>11/14/2005</td>
<td>18/31</td>
<td>8</td>
<td>Landsat-5 TM</td>
</tr>
</tbody>
</table>

There are a total of 31 GLOBE surface temperature measurements taken on the same date and location of Landsat thermal imagery. GLOBE surface temperature measurements were compared to the Landsat surface temperature measurements at the same location to determine if GLOBE measurements are detecting the same UHI effect as the Landsat imagery. Consideration was made for time of GLOBE measurement, surface cover condition, and time of Landsat pass time. The strengths and weaknesses of the GLOBE data in comparison to Landsat data will be discussed.

3.7 Urban-Rural and Surface Cover Surface Temperature Comparison

Objective 3: Analyze the effects of surface cover on surface temperature in both urban and rural setting using GLOBE student surface temperature measurements

This objective seeks to analyze GLOBE student surface temperature measurements to explore the effect of surface cover on temperature. As part of the
GLOBE Surface Temperature Protocol students’ record surface cover type for each surface temperature measurement taken. This objective will compare surface temperatures taken on similar land cover types for urban and rural schools to determine the effect of surface cover on temperature. An ideal study scenario would be to consider observations from schools submitting surface temperature measurements collected on the same day from urban and rural schools on both vegetated and impervious surface conditions. The Table 3.4 below shows the GLOBE surface cover categories and the associated land cover group designated by this research as vegetated or impervious.

Table 3.3: GLOBE surface cover types and assigned land cover groups used to compare surface temperature measurements between impervious and vegetated cover types.

<table>
<thead>
<tr>
<th>GLOBE Surface Cover Categories</th>
<th>Land Cover Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Grass (&lt; 0.5m)</td>
<td>Vegetated</td>
</tr>
<tr>
<td>Tall Grass (&gt; 0.5m)</td>
<td>Vegetated</td>
</tr>
<tr>
<td>Barren Land</td>
<td>Vegetated</td>
</tr>
<tr>
<td>Shrubs</td>
<td>Vegetated</td>
</tr>
<tr>
<td>Dwarf Shrubs</td>
<td>Vegetated</td>
</tr>
<tr>
<td>Concrete</td>
<td>Impervious</td>
</tr>
<tr>
<td>Asphalt</td>
<td>Impervious</td>
</tr>
</tbody>
</table>

In order to make a comparison of urban and rural schools taking measurements on vegetated and impervious surfaces a thorough query of the available GLOBE surface temperature database was made. For each focus area five dates were selected that had a high number of student observations from urban and rural schools on both vegetated and impervious surface. Effort was also made to find dates that were consecutive or semi-consecutive. The mean surface temperature for each cover type was calculated and
compared by urban and rural schools. An overall UHI effect was also estimated for each focus area based on the average temperature difference between vegetated and impervious sites at urban and rural schools.
Chapter 4

Results and Discussion

4.1 Classification of GLOBE schools as Urban and Rural

GLOBE schools were classified into urban and rural in section 3.3 based on the predominate land cover within 3-km of each school. Ideally a focus area will have an equal number of urban and rural schools distributed evenly across the landscape. Due to the nature of the student-generated dataset, ideal distribution of sample locations is not always feasible. The Toledo and Cleveland focus areas had more schools classified as urban than rural and the Central Mountains and Southern Ohio focus areas had a larger percentage of measurements from schools classified as rural. The resulting distribution of schools by focus area is summarized in Table 4.1. The following figures, Figure 4.1 to Figure 4.5, feature a zoom-in at each focus area to show a subset of schools and the resulting National Land Cover Dataset (NLCD) reclassification and the final school classification.
Table 4.1: Number of urban and rural schools by focus area after classification based on land cover within 3-km of each school.

<table>
<thead>
<tr>
<th>Focus area</th>
<th>School Classification</th>
<th>Number of Schools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Mountains</td>
<td>Urban</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>11</td>
</tr>
<tr>
<td>Cleveland, Ohio</td>
<td>Urban</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>19</td>
</tr>
<tr>
<td>Lake Michigan</td>
<td>Urban</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>4</td>
</tr>
<tr>
<td>Toledo, Ohio</td>
<td>Urban</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>20</td>
</tr>
<tr>
<td>Southern Ohio</td>
<td>Urban</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Rural</td>
<td>18</td>
</tr>
</tbody>
</table>
Figure 4.1: Zoom-in map showing municipal boundaries, urban and rural land cover within 3-km of each school, and the resulting classification of a subset of GLOBE schools for the Central Mountains Focus Area. This is not intended to show the entire focus area.
Figure 4.2: Zoom-in map showing municipal boundaries, urban and rural land cover within 3-km of each school, and the resulting classification of a subset of GLOBE schools for the Cleveland, Ohio Focus Area. This is not intended to show the entire focus area.
Figure 4.3: Zoom-in map showing municipal boundaries, urban and rural land cover within 3-km of each school, and the resulting classification of a subset of GLOBE schools for the Lake Michigan Focus Area. This is not intended to show the entire focus area.
Figure 4.4: Zoom-in map showing municipal boundaries, urban and rural land cover within 3-km of each school, and the resulting classification of a subset of GLOBE schools for the Southern Ohio Focus Area. This is not intended to show the entire focus area.
Figure 4.5: Zoom-in map showing municipal boundaries, urban and rural land cover within 3-km of each school, and the resulting classification of a subset of GLOBE schools for the Toledo, Ohio Focus Area. This is not intended to show the entire focus area.

The resulting classification of schools was based on a 3-km buffer around each school containing the National Land Cover Database land cover classes grouped as urban and rural categories. This approach is a coarse approach to grouping schools into focus areas located generally within urban land cover and generally in rural areas. The literature suggests a 10-km reach of UHI effect. However a 10-km buffer on each school seemed too large and was reduced to a more conservative distance of 3-km. Surface temperature averages from urban schools will be grouped and compared to averaged surface
temperature measurements from rural schools in a broad approach to describe and compare an urban-rural temperature difference.

4.2 Focus Area Development

The following figures illustrate each focus area and the distribution of urban and rural schools. Figure 4.6 depicts the Lake Michigan focus area characterized by one major urban area, Grand Rapids, Michigan, and the coast of Lake Michigan running north to south along the west side of the focus area. The Lake Michigan focus area had the smallest sample size with 28 urban measurements and 18 rural measurements.
Figure 4.6: Location of all GLOBE schools within the Lake Michigan Focus Area classified as Urban or Rural.

In contrast. Figure 4.7 shows the Cleveland, Ohio focus area with greater availability of GLOBE surface temperature measurements. Characterized by two major urban areas, Cleveland Ohio and Akron, Ohio, it also boarders Lake Erie to the north.
Figure 4.7: Location of all GLOBE schools within the Cleveland, Ohio Focus Area classified as Urban or Rural.

Figure 4.8 depicts the Southern Ohio focus area and its three major urban areas, Cincinnati, Ohio, Dayton, Ohio and Columbus, Ohio. The distribution of schools is more dispersed for this focus area. Urban schools are more weighted toward the northern portion of the focus area and rural schools are distributed more evenly across the focus area.
Figure 4.8: Location of all GLOBE schools within the Southern Ohio Focus Area classified as Urban or Rural.

Figure 4.9 depicts the Toledo, Ohio focus area and is characterized by Lake Erie to the east and four major urban cities Anne Arbor, Michigan, Warren, Michigan, Detroit, Michigan, and Toledo, Ohio. Primarily, the GLOBE schools are centered on Toledo, Ohio. Urban schools are generally clustered around Toledo, Ohio and Detroit, Michigan however there are eight rural schools distributed fairly equally beyond the urban areas.
.Figure 4.9: Location of all GLOBE schools within the Toledo, Ohio Focus Area classified as Urban or Rural.

.Figure 4.10 shows the Central Mountains focus area located just west of the Appalachian Mountains and covering an area that includes one major city, Pittsburgh, Pennsylvania. However the distribution of schools is such that the urban school is located in the extreme south and the rural schools are located in the northern portion which may affect the temperature difference.
Figure 4.10: Location of all GLOBE schools within the Central Mountains Focus Area classified as Urban or Rural.

The resulting focus areas were intended to group schools based on climate and physiographic regions. Generally, schools located in a focus area receive similar climate and regional influence on surface temperature. This research is meant to take a coarse approach to comparing schools to determine if GLOBE measurements are comparable to Landsat thermal imagery and if surface cover affects surface temperature.
4.3 Testing viability of GLOBE data for the study of UHI

Objective 2 seeks to test the viability of GLOBE student surface temperature observations to detect UHI. This objective was approached in two steps. The first step sought to determine if GLOBE surface temperature measurements are reasonable when compared to Landsat thermal imagery at the same location and also at equivalent homogeneous areas across the thermal landscape. Landsat surface temperature measurements were plotted along a surface temperature profile and compared to GLOBE measurements taken at the same location. The purpose of this comparison was to visualize the GLOBE measurement in relation to Landsat measurements at the same location along the profile. The objective was to determine if GLOBE measurements generally fell within range of the Landsat imagery. This step utilized GLOBE observations and Landsat thermal imagery for May 5, 2005. There were four schools located near Toledo, Ohio: Keyser Elementary, The University of Toledo, Whiteford Agricultural School and Whitmer High School reporting data on May, 4th 2005. There were also two schools south and east of Toledo, Ohio, Eastwood Middle School and Saint Boniface, reporting observations on the same date. This distribution of schools naturally lent itself to an urban and rural comparison. Transects were drawn from each Toledo school through downtown Toledo and out to the rural outskirts to show any temperature variance across the urban landscape. The two rural schools were connected by a single transect to show a surface temperature profile across the rural landscape. The following figure depicts the processed and calibrated Landsat surface temperature with the GLOBE school locations reporting observations for May 4, 2009 (Figure 4.11).
Figure 4.11: GLOBE student observations from May 4, 2005 corresponding to Landsat-5 TM Thermal Imagery taken on the same day. Urban schools are depicted in orange points and rural schools are depicted as green points.

Six schools reported a total of 10 observations on May 4, 2005 for this image path/row. Many schools also reported surface cover type as part of their observation. In order to extend the comparison between GLOBE observations and Landsat surface temperature at the same location a second location of similar land cover type was identified and compared. The following figure depicts the resulting transects for each school and the NLCD land cover dataset for reference of surface cover along the transect (Figure 4.12).
Figure 4.12: GLOBE Schools with observations for May 4, 2005, mapped on NLCD land cover raster, and transects drawn to generate surface temperature profiles to illustrate temperature gradient across an urban and rural landscape.

Additionally, GLOBE surface temperature measurements were plotted along the surface temperature profile and any available surface cover information was noted. Keyser Elementary was classified as an urban school in a previous section of this paper based on the predominate land cover within 3-km of the school. Students reported a surface temperature of 17.2°C at a site characterized by short grass (<0.5m). The Landsat surface temperature at this site was recorded at 23.6°C. The school is within 1,000m of
several large commercial buildings and large parking areas. The higher Landsat surface temperature measurements could be influenced by the nearby commercial development. One explanation for the cooler temperature is that the Keyser Elementary observation was made 0:57 minutes earlier in the day than the Landsat imagery pass time. The following figure and profile showing the Keyser Elementary Transect and the resulting Landsat and GLOBE surface temperature profile with areas of interest indicated (.Figure 4.13).
Figure 4 13: a) Keyser Elementary School Transect for May, 4th 2005 depicting Landsat Thermal Imagery and points of interest along the transect. b) Keyser Elementary Transect temperature profile depicting Landsat surface temperature at a 500m interval and GLOBE student observations in Toledo, Ohio.
The next transect studied in this section was the University of Toledo transect. The University of Toledo was also classified as an ‘urban’ location based on predominate land cover surrounding the school. This transect starts at the Ottawa River in the west and moves south through the University of Toledo campus, downtown Toledo, Maumee River, the residential area of Oregon, Ohio, a large woodlot and cropland (.Figure 4.14). The GLOBE site reported two observations for this date at 23.8°C and 23.4°C on short grass. At this location Landsat is detecting a temperature 20.5°C. The University of Toledo is located in a fairly residential area and for other residential areas along this transect the temperature averages right around 20.3°C. The GLOBE observation is roughly 3°C warmer than the Landsat surface temperature at the same location. The GLOBE measurements 23.4°C and 23.8°C were collected at 17:34 and 16:57, respectively, whereas the Landsat imagery was collected at 16:04, earlier in the day. It would be expected that surface temperature would continue to increase after the Landsat pass time and account for a slightly warmer GLOBE surface temperature. The following figure depicts the University of Toledo Transect and associated temperature profile (.Figure 4.14).
Figure 4.14: a) University of Toledo Transect for May, 4\textsuperscript{th} 2005 depicting Landsat Thermal Imagery and points of interest along the transect. b) University of Toledo Transect temperature profile depicting Landsat surface temperature at a 500m interval and GLOBE student observations in Toledo, Ohio.
The Whiteford Agricultural School was classified as a rural school because the primary land cover within 3-km of the study site is primarily agricultural land. The Whiteford Agricultural School transect crosses Swan Creek at Woodlawn Cemetery, the TARTA garage, residential areas, downtown Toledo, the Maumee River and Woodville Shopping Center (Figure 4.15). Whiteford Agricultural School submitted two GLOBE observations, one at 31.4°C on asphalt and another 25.3°C on short grass, on May 5, 2005. The Landsat thermal imagery reports 20.54°C at the Whiteford Agricultural School study location, a difference of 10.9°C and 4.8°C. The GLOBE temperatures from this school are detecting temperatures warmer than Landsat surface temperature along the transect. There was a time difference between the GLOBE measurements and the Landsat overpass time. The two Whiteford Agricultural School observations were made roughly an hour earlier in the day. However the expected outcome would be that the GLOBE measurements taken earlier in the day would be cooler than the Landsat measurements. The surface temperature measurements at this school still seem relatively high when compared to an equivalent location along the transect. The following figure depicts the Whiteford Agricultural School Transect and temperature profile (Figure 4.15).
Figure 4.15: a) Whiteford Agricultural School Transect for May, 4th 2005 depicting Landsat Thermal Imagery and points of interest along the transect. b) Whiteford Agricultural School Transect temperature profile depicting Landsat surface temperature at a 500m interval and GLOBE student observations in Toledo, Ohio.
The Whitmer High School transect passes through residential areas, downtown Toledo the Maumee River and into agricultural fields. Whitmer High School was classified as an urban school. There were two GLOBE measurements submitted from Whitmer High School on May 4, 2005, 27.4°C on asphalt and 17.2°C on short grass. When plotted on the temperature profile generated for Whitmer High School, the GLOBE measurements straddle the Landsat surface temperature for that location at 20.98°C. Both Whitmer High School observations were made over 3 hours after the Landsat overpass time, in the late afternoon. Surface temperature measurements taken late in the afternoon could be expected to be warmer than observations made around noon when the Landsat image was flown. However just one of the Whitmer High School measurements, taken on asphalt, reflected a warmer temperature. The following figure depicts the Whitmer High School Transect, areas of interest, and resulting temperature profile (Figure 4.16).
Figure 4.16: a) Whitmer High School Transect for May, 4th 2005 depicting Landsat Thermal Imagery and points of interest along the transect. b) Whitmer High School Transect temperature profile depicting Landsat surface temperature at a 500m interval and GLOBE student observations in Toledo, Ohio.
Finally, the rural transect connecting Eastwood Middle School and Saint Boniface School shows the temperature profile across rural Northwest Ohio. The Eastwood Middle School to Saint Boniface transect passes through cropland, woodlots, a quarry, the Village of Elmore, the Portage River and the Village of Oak Harbor. There were two GLOBE observations made at Eastwood Middle School, one on asphalt (18.3°C) and one made on short grass (17.2°C). There was one GLOBE observation made at Saint Boniface School at 6.9°C made on asphalt surface cover. At Eastwood Middle School the Landsat thermal image is showing a temperature of 20.0°C, which is 1.7°C and 2.8°C warmer than the reported GLOBE surface temperatures. The Saint Boniface School has a surface temperature of 6.9°C which is 14.5°C cooler than the Landsat surface temperature. This is likely due to the nearly 3.5 hour difference between the time the GLOBE measurement was taken, 8:37 AM, and the Landsat overpass, 12:04 PM local time. The GLOBE measurements were taken at 8:37 AM, 9:21 AM and 10:33 AM local time and were 6.9°C, 17.2°C and 18.3°C, respectively, showing a general warming up throughout the morning. Despite the temperature difference between the GLOBE and Landsat, the student measurements do generally reflect the expected warming up trend leading up to the satellite pass. The following figure depicts the Eastwood Middle School to Saint Boniface Transect and associated temperature profile (Figure 4.17).
Figure 4.17: a) University of Toledo Transect for May, 4th 2005 depicting Landsat Thermal Imagery and points of interest along a transect. b) University of Toledo Transect temperature profile depicting Landsat surface temperature at a 500m interval and GLOBE student observations in Toledo, Ohio.
The comparison of GLOBE measurements to the May 4, 2005 Landsat imagery show mixed results. There is a variety of temperature differences between GLOBE measurements and Landsat. Crucial to the comparison of GLOBE student measurements to Landsat measurements is the time of measurement with respect to satellite over pass time. The Landsat overpass time is roughly 12:00 PM and the GLOBE measurements were collected both before and after 12:00 PM. GLOBE measurements, with respect to time of day, generally reflect the warming trend throughout the day. GLOBE measurements taken early in the day show a cooler surface temperature than the Landsat imagery taken around noon and conversely GLOBE measurements taken later in the day tend to be warmer than Landsat imagery. Furthermore, when the same school reports surface temperature on asphalt and short grass the measurement on asphalt is warmer. However, there were exceptions to these observations. One unexpected result came from measurements taken at Whiteford Agricultural School which were collected roughly an hour earlier in the morning but were 4.8 and 10.9 degrees warmer than the Landsat imagery. Generally, GLOBE measurements show a difference in surface temperature between asphalt and short grass and when compared to Landsat they are reasonable when time of day is considered. GLOBE measurements are closer to Landsat when collected on vegetated cover as opposed to impervious cover.

For the remaining image dates the GLOBE measurements were compared to Landsat but transects were not drawn. Time of observation, surface cover type and location of the school was considered when determining the validity of the GLOBE data. Where possible the detection of UHI was assessed at the GLOBE locations and
magnitude was calculated. For the April 18, 2005 Landsat imagery in Toledo, Ohio there was a small UHI effect detected a 1°C average temperature increase at urban locations. Initial comparisons between GLOBE observations and Landsat are not what would be expected. The GLOBE measurements are not picking up on the same UHI as the Landsat at the same locations. The largest temperature differences between GLOBE observations and Landsat occur at sites where the surface cover was impervious and the time difference between Landsat and GLOBE measurements are greatest. The Landsat overpass time was at 12:06 PM local time. In general GLOBE measurements are cooler than Landsat when collected earlier in the morning and warmer than Landsat when collected in the afternoon. As with the May 5th 2005 measurements the Whiteford Agricultural School measurements are reporting warmer temperatures than Landsat collected earlier in the morning. See Table 4.2, and Figure 4.18, below for a summary of the GLOBE and Landsat surface temperature measurements collected on April 18, 2005.

Table 4.2: Summary of GLOBE and Landsat Surface Temperature Measurements for April 18, 2005

<table>
<thead>
<tr>
<th>Rural Schools</th>
<th>Surface Cover (Setting)</th>
<th>GLOBE (°C)</th>
<th>Landsat (°C)</th>
<th>Temperature Difference (°C)</th>
<th>Image Date Time (Z-time)</th>
<th>GLOBE Time (Z-time)</th>
<th>Time difference (hh:mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastwood Middle School</td>
<td>Asphalt</td>
<td>23.9</td>
<td>25.4</td>
<td>-1.5</td>
<td>4/18/05 16:03</td>
<td>14:33</td>
<td>1:30</td>
</tr>
<tr>
<td>Whiteford Agricultural School</td>
<td>Asphalt</td>
<td>31.4</td>
<td>24.4</td>
<td>7.0</td>
<td>4/18/05 16:03</td>
<td>15:12</td>
<td>0:51</td>
</tr>
<tr>
<td>Whiteford Agricultural School</td>
<td>Short Grass</td>
<td>26.6</td>
<td>24.4</td>
<td>2.2</td>
<td>4/18/05 16:03</td>
<td>14:58</td>
<td>1:05</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>27.3</td>
<td>24.7</td>
<td>2.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban Schools</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The University of Toledo</td>
<td>Short Grass</td>
<td>27.0</td>
<td>25.3</td>
<td>1.7</td>
<td>4/18/05 16:03</td>
<td>20:09</td>
<td>4:06</td>
</tr>
<tr>
<td>Monroe High School</td>
<td>Asphalt</td>
<td>15.0</td>
<td>25.7</td>
<td>-10.7</td>
<td>4/18/05 16:03</td>
<td>12:48</td>
<td>3:15</td>
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<tr>
<td>Bryant Middle School</td>
<td>Short Grass</td>
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<td>25.4</td>
<td>-5.2</td>
<td>4/18/05 16:03</td>
<td>15:21</td>
<td>0:42</td>
</tr>
<tr>
<td>Keyser Elementary</td>
<td>Short Grass</td>
<td>23.2</td>
<td>26.2</td>
<td>-3.0</td>
<td>4/18/05 16:03</td>
<td>15:05</td>
<td>0:58</td>
</tr>
<tr>
<td>Monroe High School</td>
<td>Short Grass</td>
<td>16.1</td>
<td>25.7</td>
<td>-9.6</td>
<td>4/18/05 16:03</td>
<td>13:40</td>
<td>2:23</td>
</tr>
<tr>
<td>Monroe High School</td>
<td>Short Grass</td>
<td>29.5</td>
<td>25.7</td>
<td>3.8</td>
<td>4/18/05 16:03</td>
<td>17:08</td>
<td>1:05</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>21.8</td>
<td>25.7</td>
<td>-3.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The next observation date compared was for May 4, 2005 in Toledo, Ohio. Landsat is detecting a small UHI effect for this date, at 0.8°C average temperature increase at urban locations. GLOBE measurements are detecting a similar magnitude UHI temperature difference and are showing 1°C warmer temperatures at urban school locations (.Figure 4.19). There are several instances where GLOBE observations are two to three hours before or after the Landsat overpass which appears to be affecting surface temperature difference between the two sources. For example, Saint Boniface reported an observation 3:27 hours earlier than the Landsat imagery that was 14.5°C cooler than the Landsat Imagery collected at the same location later that day.
Figure 4.19: GLOBE School Locations and Landsat Thermal Imagery for April 18, 2005
Table 4.3: Summary of GLOBE and Landsat Surface Temperature Measurements for May 04, 2005

<table>
<thead>
<tr>
<th>Rural Schools</th>
<th>Surface Cover (Setting)</th>
<th>GLOBE (°C)</th>
<th>Landsat (°C)</th>
<th>Temperature Difference (°C)</th>
<th>Image Date (Z-time)</th>
<th>GLOBE Time (Z-time)</th>
<th>Time difference (hh:mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saint Boniface School</td>
<td>Asphalt</td>
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<td>21.4</td>
<td>-14.5</td>
<td>5/4/05 16:04</td>
<td>12:37</td>
<td>3:27</td>
</tr>
<tr>
<td>Eastwood Middle School</td>
<td>Asphalt</td>
<td>18.3</td>
<td>20.0</td>
<td>-1.7</td>
<td>5/4/05 16:04</td>
<td>13:21</td>
<td>2:43</td>
</tr>
<tr>
<td>Whiteford Agricultural School</td>
<td>Asphalt</td>
<td>31.4</td>
<td>20.5</td>
<td>10.9</td>
<td>5/4/05 16:04</td>
<td>15:01</td>
<td>1:03</td>
</tr>
<tr>
<td>Eastwood Middle School</td>
<td>Short Grass</td>
<td>17.2</td>
<td>20.0</td>
<td>-2.8</td>
<td>5/4/05 16:04</td>
<td>14:33</td>
<td>1:31</td>
</tr>
<tr>
<td>Whiteford Agricultural School</td>
<td>Short Grass</td>
<td>25.3</td>
<td>20.5</td>
<td>4.8</td>
<td>5/4/05 16:04</td>
<td>14:55</td>
<td>1:09</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>19.8</strong></td>
<td><strong>20.5</strong></td>
<td><strong>-0.7</strong></td>
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</table>

**Urban Schools**

<table>
<thead>
<tr>
<th>Rural Schools</th>
<th>Surface Cover (Setting)</th>
<th>GLOBE (°C)</th>
<th>Landsat (°C)</th>
<th>Temperature Difference (°C)</th>
<th>Image Date (Z-time)</th>
<th>GLOBE Time (Z-time)</th>
<th>Time difference (hh:mm)</th>
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</thead>
<tbody>
<tr>
<td>University of Toledo</td>
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<td>20.5</td>
<td>3.3</td>
<td>5/4/05 16:04</td>
<td>17:34</td>
<td>1:30</td>
</tr>
<tr>
<td>University of Toledo</td>
<td>Short Grass</td>
<td>23.4</td>
<td>20.5</td>
<td>2.9</td>
<td>5/4/05 16:04</td>
<td>16:57</td>
<td>0:53</td>
</tr>
<tr>
<td>Whitmer High School</td>
<td>Asphalt</td>
<td>27.4</td>
<td>21.0</td>
<td>6.4</td>
<td>5/4/05 16:04</td>
<td>19:14</td>
<td>3:10</td>
</tr>
<tr>
<td>Keyser Elementary</td>
<td>Short Grass</td>
<td>17.2</td>
<td>23.6</td>
<td>-6.4</td>
<td>5/4/05 16:04</td>
<td>15:07</td>
<td>0:57</td>
</tr>
<tr>
<td>Whitmer High School</td>
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<td>21.0</td>
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<td>19:47</td>
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<td><strong>Average</strong></td>
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<td><strong>21.3</strong></td>
<td><strong>0.5</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The next observation date compared was for May 20, 2005 in Toledo, Ohio. For this date there were only urban schools reporting data (Figure 4.20). However, observations between impervious surface and vegetated surface can be compared. GLOBE student observations made on vegetated surfaces are within 1 hour of Landsat and are roughly within 1°C of Landsat measurements (Table 4.4). GLOBE observations made on asphalt cover are not as close to Landsat with a 10-12 degree difference. Since there are no rural schools reporting observations for this date, UHI cannot be estimated. For this date GLOBE observations are comparable to Landsat surface temperature for vegetated surface cover only. The time difference between GLOBE observation and Landsat imagery is also small and does not explain the temperature difference on impervious surface.
Figure 4.20: GLOBE School Locations and Landsat Thermal Imagery for May 20, 2005

Table 4.4: Summary of GLOBE and Landsat Surface Temperature Measurements for May 20, 2005

<table>
<thead>
<tr>
<th>Urban Schools</th>
<th>Surface Cover</th>
<th>GLOBE (°C)</th>
<th>Landsat (°C)</th>
<th>Temperature Difference (°C)</th>
<th>Image Date Time (Z-time)</th>
<th>GLOBE Time (Z-time)</th>
<th>Time difference (hh:mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monroe High School</td>
<td>Asphalt</td>
<td>37.5</td>
<td>26.6</td>
<td>10.9</td>
<td>5/20/05 16:03</td>
<td>17:09</td>
<td>1:06</td>
</tr>
<tr>
<td>Whitmer High School</td>
<td>Asphalt</td>
<td>34.1</td>
<td>21.9</td>
<td>12.2</td>
<td>5/20/05 16:03</td>
<td>16:01</td>
<td>0:02</td>
</tr>
<tr>
<td>Average</td>
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<td>24.2</td>
<td>11.6</td>
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<td></td>
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<tr>
<td>Monroe High School</td>
<td>Short Grass</td>
<td>27.9</td>
<td>26.6</td>
<td>1.3</td>
<td>5/20/05 16:03</td>
<td>17:12</td>
<td>1:09</td>
</tr>
<tr>
<td>Whitmer High School</td>
<td>Short Grass</td>
<td>22.0</td>
<td>21.9</td>
<td>0.1</td>
<td>5/20/05 16:03</td>
<td>15:55</td>
<td>0:08</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>25.0</td>
<td>24.2</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The final observation date compared was for November 14, 2005 in Cleveland, Ohio. For this date there were only urban schools reporting data (Figure 4.21). However
observations between impervious surface and vegetated surface can be compared. The GLOBE student observations made on impervious surfaces were 3.9°C warmer than Landsat surface temperatures. In most cases, GLOBE observations taken earlier in the day were cooler than Landsat and later in the day were warmer than Landsat (Table 4.5). The GLOBE measurements that matched Landsat the closest were collected within an hour of the overpass time. Since there are no rural schools reporting observations for this date UHI cannot be estimated. For this date GLOBE measurements are most like Landsat measurements when they are taken closer to the time of Landsat image, within 1.5 hours, and are collected on vegetated cover.

Figure 4.21: GLOBE School Locations and Landsat Thermal Imagery for November 14, 2005
The comparison of GLOBE measurements to Landsat imagery show mixed results. Crucial to the comparison of GLOBE student measurements to Landsat measurements is the time of observation with respect to satellite over pass time. In general, GLOBE observations made 2-3 hours earlier or later than the Landsat imagery were not capturing the same surface temperature. For all the images Landsat overpass time is around 12:00 PM local time. Generally, the GLOBE measurements taken early in the day show a cooler surface temperature than the Landsat imagery taken around noon and conversely GLOBE measurements taken later in the day tend to be warmer than Landsat imagery. With respect to surface cover type, when the same school reports surface temperature on asphalt and short grass, the measurements taken on asphalt is warmer. However, one unexpected result came from measurements taken at Whiteford Agricultural School which were collected roughly an hour earlier in the morning but were warmer than the Landsat imagery for both the May 4th, 2005 and April 18, 2005 images.
4.4 Comparison of Urban and Rural Surface Temperature Measurements by Cover Type

Objective 3 sought to utilize GLOBE student surface temperature measurements to show an urban/rural temperature difference by cover type. This objective focused on dates for each focus area with the most available urban and rural surface temperature measurements for consecutive dates. In some instances, dates were skipped over a weekend where students were not actively collecting data. A total of five sample dates for each focus area were selected and the average surface temperature measurements for urban and rural schools were compared. The following section is divided by focus area and depicts a graph showing average surface temperature for each study date and the calculated average overall temperature difference for the five dates. The following tables, Table 4.6 and Table 4.7, show each focus area, the dates and number of GLOBE observations recorded for each.

Table 4.6: Summary of GLOBE observation dates utilized for each Focus Area

<table>
<thead>
<tr>
<th>Focus Area</th>
<th>Study Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleveland, Ohio</td>
<td>4-Dec-06  5-Dec-06  6-Dec-06  7-Dec-06  8-Dec-06</td>
</tr>
<tr>
<td>Central Mountains</td>
<td>7-Dec-09  8-Dec-09  9-Dec-09  15-Dec-09  16-Dec-09</td>
</tr>
<tr>
<td>Lake Michigan</td>
<td>29-Nov-07  30-Nov-07  4-Dec-07  5-Dec-07  6-Dec-07</td>
</tr>
<tr>
<td>Southern Ohio</td>
<td>7-Dec-09  8-Dec-09  9-Dec-09  10-Dec-09  11-Dec-09</td>
</tr>
<tr>
<td>Toledo, Ohio</td>
<td>4-Dec-09  7-Dec-09  8-Dec-09  10-Dec-09  11-Dec-09</td>
</tr>
</tbody>
</table>
Table 4.7: Summary of the number of GLOBE observations by surface cover type and school classification

<table>
<thead>
<tr>
<th>Focus Area</th>
<th>Rural-Impervious</th>
<th>Rural-Vegetated</th>
<th>Urban-Impervious</th>
<th>Urban-Vegetated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleveland, Ohio</td>
<td>9</td>
<td>68</td>
<td>133</td>
<td>72</td>
</tr>
<tr>
<td>Central Mountains</td>
<td>11</td>
<td>18</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Lake Michigan</td>
<td>11</td>
<td>16</td>
<td>9</td>
<td>9</td>
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<tr>
<td>Southern Ohio</td>
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<td>Toledo, Ohio</td>
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<td>16</td>
<td>32</td>
<td>44</td>
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</table>

The Cleveland, Ohio focus area had the greatest availability of GLOBE surface temperature measurements for the study dates. The majority of schools are within a short distance of Cleveland, Akron and Canton, Ohio. The study dates considered for this research were in early December 2006, see Table 4.6 for specific dates. There were 289 observations made by GLOBE schools during these dates. There is not an UHI detected for these dates between urban and rural schools for the same cover type. Vegetated sites are within 0.1°C of each other and impervious sites are within 0.3°C of each other. Furthermore, for these dates the vegetated cover type was on average warmer than impervious cover samples. The following graphic shows the average surface temperature for each cover type for the Cleveland, Ohio focus areas (.Figure 4.22).
Figure 4.22: Average surface temperature by cover type for urban and rural schools in the Cleveland, Ohio focus area.

The Central Mountains focus area is characterized by the Appalachian Mountains to the east and has one major city, Pittsburgh, Pennsylvania. There were a total of 40 observations made by GLOBE students for the dates considered in this research. There is a detectible UHI at vegetated sites. The UHI effect in this focus area is 2.2°C warmer at urban-vegetated sites over rural-vegetated sites. The warmest cover types for these dates were the rural-impervious and urban-vegetated cover types. There were no available observations for urban-impervious samples. The following graphic show the average surface temperature for each observation date (Figure 4.23)
The Lake Michigan focus area had the most balanced distribution of urban and rural schools. Roughly half the schools located near Grand Rapids and the other half are in more rural areas along Lake Michigan. The Lake Michigan focus area had 45 observations during the five dates selected in late November and early December, 2007. See table for specific study dates (Table 4.6). There was a detectable UHI at impervious sample locations that were an average of 2.4°C warmer than rural-impervious sites. Urban-vegetated sites were only slightly warmer than rural-vegetated sites at 0.1°C on average. Impervious surface tends to have the greatest warming effect on surface temperatures for these dates. The following graphic shows the average surface temperature for each observation date for the Lake Michigan focus area (.Figure 4.24).
The Southern Ohio focus area has 3 major urban areas, Cincinnati, Ohio, Dayton, Ohio and Columbus, Ohio. The study focused on observation dates in early December 2009. See Table 4.6 for specific dates. The weakest UHI effect was seen at the Southern Ohio focus area. In fact, rural areas were slightly warmer than urban areas by an average of 1.7° C for impervious sites and 3.8° C for vegetated sites. For this focus area rural-vegetated sites have the warmest surface temperature measurements which goes against expected results. Urban schools in this focus area tend to be located in the northern part of the focus area whereas rural schools are distributed throughout the focus area. This weak UHI could be accounted for the distribution of the schools. The following two graphics show the average surface temperature for each observation date (Figure 4.25).
Figure 4.25: Average surface temperature by cover type for urban and rural schools in the Southern Ohio focus area.

The Toledo, Ohio focus area is characterized by Lake Erie to the east and four major urban cities Anne Arbor, Michigan, Warren, Michigan, Detroit, Michigan, and Toledo, Ohio. The study dates considered for this research were in early December 2009, see Table 4.6 for specific dates. There were a total of 102 GLOBE observations made during the five-day window. Average surface temperatures were compared for samples collected on impervious surface and vegetated surface cover types to determine degree of UHI. The data show that the urban-impervious was 0.30 °C warmer at rural impervious sites than urban impervious sites. Urban-vegetated sites were 3.7°C warmer than rural-vegetated sites. It appears that urban locations and impervious cover types have the
This objective sought to determine the effect of surface cover on surface temperature. Generally, the greatest warming influence on surface temperature tended to be impervious surface and urban setting. Cleveland, Ohio saw the smallest variance in
temperature for all groups and did not see a strong UHI influence. Central Mountains
Schools saw an increase in temperature at impervious surface cover but did not see a
strong UHI influence. Lake Michigan saw a warming influence in both impervious
surface and saw detectable UHI. Southern Ohio had unexpected results indicating warmer
temperatures at vegetated sites and rural schools. Finally the Toledo, Ohio focus area saw
a strong UHI influence and a strong warming trend in impervious surface over vegetated
surface.

4.5 Limitations of Study

Generally, with regard to this paper, the approach of classification of schools and
creation of focus areas can be considered a coarse approach. The focus areas were
designed with climate and physiographic regions in mind but were also developed based
on available GLOBE data with the intention to capture a large number of available
observations. The unequal size of each focus area did not allow for uniform comparison
in terms of spatial extent. The polygon boundary was hand digitized based on
generalizations of available GLOBE data, climate mapping and physiographic regions.
The attempt was to capture and utilize as many GLOBE observations as possible while
maintaining a defensible method for grouping the schools. A possible alternative
approach for future study would be to establish a uniform comparison in terms of spatial
extent. For example a grid might be created across over the study area and the focus
could be directed to small uniform subsets of the GLOBE dataset. For example, a study
comparing Landsat imagery to GLOBE data could use the spatial extent of the path/row
for a satellite image as the spatial extent.
The classification of schools as ‘urban’ or ‘rural’ was based on a 3-km buffer search of land cover within range of the school. A school was classified as urban if the land cover within 3-km of the school was more than 50% urban. This 3-km buffer distance was not based on published methodology for classifying a location as urban or rural. The literature references that UHI can have up to a 10-km reaching effect on the surrounding landscape. This research chose to use a 3-km buffer because it was a number that was slightly more conservative and resulted in a distribution of schools that visually made sense. The choice to make the division of urban and rural at 50% cover was also not based on published methodology, rather as a generalized approach for dividing schools. A possible alternative approach would consider population density around the school location either to categorize schools as urban or rural.

Furthermore when making comparisons between GLOBE observations and Landsat-5 TM satellite imagery, time of observation appeared to explain large temperature differences between the two data sources. Generally, as the time difference between GLOBE observations and Landsat overpass increase the larger the temperature difference between the two data sources. For example, for the April 18th, 2005 Landsat image there were two GLOBE observations made approximately 2:23 and 3:15 hours before the imagery was collected. These observations were 9.6°C and 10.7°C cooler than the Landsat imagery collected later in the day. Since surface temperature varies throughout the day it is important to consider the time of observation as well as satellite overpass time. This research recommends that future studies, in which GLOBE observations are compared to satellite imagery, carefully consider the satellite overpass time as well as the GLOBE observation time.
Chapter 5

Conclusion

This paper sought to establish a study area for GLOBE data in the Great Lakes region, test the validity of GLOBE student data and analyze the effect of surface cover on surface temperature using the GLOBE surface temperature database. This study developed a focus areas to study GLOBE schools with similar climate and physiographic influence. The overall objective of this study was to validate GLOBE student observations as a viable dataset for the study of UHI.

The first objective utilized available GLOBE data in the Great Lakes region, climate mapping and the physiographic regions of the use to define study areas in which to compare GLOBE schools in the context of UHI studies. The resulting outcome was five focus areas in the Great Lakes region that had a selection of urban and rural schools. The Toledo, Ohio, Cleveland, Ohio, and Lake Michigan focus areas had a relatively even distribution of urban and rural schools across the focus area. The Central Mountain and Southern Ohio focus areas, however, had a more uneven distribution of schools. The Southern Ohio focus area had urban schools more generally located toward the north and only rural schools in the southern portion of the focus area. The southern rural schools
could receive warmer weather than schools in the northern portion of this focus area which might throw off the detection of UHI in urban schools to the north.

The second objective sought to test the viability of GLOBE data for the study of UHI. This objective compared 31 GLOBE surface temperature measurements corresponding to the date of four 120m resolution Landsat thermal images. Time of GLOBE measurement became a crucial component when comparing measurements to Landsat imagery. The results of this comparison found that the GLOBE measurements were most similar to Landsat Imagery for measurements collected on vegetated sites within 1 hour of the Landsat overpass time. The expected temperature difference between Landsat Thermal Imagery and \textit{in-situ} ground measurements is around 2.7°C (Goetz, 1997). GLOBE observations were able to detect cooler temperatures in the morning and warmer temperatures later in the day, relative to Landsat imagery. Generally, Landsat overpass time was around 12:00pm local time, GLOBE observations made earlier in the day were cooler than Landsat and GLOBE observations made later in the day were warmer. GLOBE measurements collected on impervious surfaces tended to have a greater difference of temperature from Landsat imagery. Therefore the findings of this study are that GLOBE surface temperature measurements are most comparable to Landsat thermal imagery within 1 hour of pass time and on vegetated cover.

The third objective sought to determine the effect of cover type on surface temperature. The greatest warming influence on surface temperature tended to be impervious surface and an urban setting. For example the Lake Michigan focus area, on average, was 2.4°C warmer at urban impervious sites than vegetated sites. Urban areas
tended to have a warming effect and when coupled with impervious surface cover there was a strong warming effect. For example, Toledo Ohio saw a 2.1°C temperature increase at urban-impervious sites over rural-vegetated sites. The greatest magnitude UHI detected was in the Toledo, Ohio with a 5.9°C UHI detectable at impervious cover sites and 3.7°C UHI for vegetated sites.

While satellite remote sensing has been used for decades to study Urban Heat Islands it lacks the unique perspective of field surface temperature observations. GLOBE observations, with its wide spatial distribution, large historical dataset and ease of access to data are well suited to supplement the use of traditional sources of surface temperature data. The GLOBE dataset has inherent limitations such as the potential for instrument bias, time of observation, data gaps, human error and locational accuracy issues. GLOBE student observations provide a valuable contribution of field observations for surface temperature and land cover conditions. This research has demonstrated that GLOBE surface temperature measurements can be used in conjunction with Landsat thermal imagery to add greater context to the surface temperature of a location at varying times of day, to the study of the effect of surface cover on surface temperature and to make broad observations about urban and rural temperature differences.
References


