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Investigating the Magnitude and Range of the Urban Heat Island within Gettysburg, Pennsylvania

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Cities experience UHIs due to the thermal properties (albedo, thermal emittance, radiative flux, and heat capacity) of human-made substances and urban geometry. This study investigated the existence of an urban heat island (UHI) in Gettysburg, Pennsylvania. The goal of this project was to assess whether a small-scale city like Gettysburg demonstrates an UHI effect and, if present, the extent and magnitude of the UHI. We hypothesized that (1) temperatures within the city are significantly higher than the surrounding area, (2) the magnitude of the UHI will diminish as distance from the city center increases, and (3) the UHI will not extend further than 0.5 miles outside the city center. Air temperatures were collected using digital thermometers over four weeks along two different transects that each extended one mile from the center square of Gettysburg. Our results show that Gettysburg, despite its small size, has an UHI. A linear regression model shows that there is a strong correlation between temperature and distance from the center square. The magnitude of the UHI lessens with increasing distance from the center of town. The first two hypotheses were supported while the hypothesis that the UHI will be localized was not. Statistically analyses show that the temperature change remains significant past 0.5 miles. The results of this study demonstrate that even a small-scale city like Gettysburg create a UHI.

Keywords

Urban Heat Island, UHI, Climate Change

Disciplines

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Comments

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Investigating the Magnitude and Range of the Urban Heat Island within Gettysburg, Pennsylvania

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I affirm I have upheld the highest principles of honesty and integrity in my academic work and have not witnessed a violation to the Gettysburg College Honor Code.

Abstract

Cities experience UHIs due to the thermal properties (albedo, thermal emittance, radiative flux, and heat capacity) of human-made substances and urban geometry. This study investigated the existence of an urban heat island (UHI) in Gettysburg, Pennsylvania. The goal of this project was to assess whether a small-scale city like Gettysburg demonstrates an UHI effect and, if present, the extent and magnitude of the UHI. We hypothesized that (1) temperatures within the city are significantly higher than the surrounding area, (2) the magnitude of the UHI will diminish as distance from the city center increases, and (3) the UHI will not extend further than 0.5 miles outside the city center. Air temperatures were collected using digital thermometers over four weeks along two different transects that each extended one mile from the center square of Gettysburg. Our results show that Gettysburg, despite its small size, has an UHI. A linear regression model shows that there is a strong correlation between temperature and distance from the center square. The magnitude of the UHI lessens with increasing distance from the center of town. The first two hypotheses were supported while the hypothesis that the UHI will be localized was not. Statistically analyses show that the temperature change remains significant past 0.5 miles. The results of this study demonstrate that even a small-scale city like Gettysburg create a UHI.

Introduction

With the surmounting scientific evidence that humanity has an impact on global climate, scientists have begun to highlight a specific recurring phenomena that exemplifies our influence on local climate (Arnfield 2003). These recurring phenomena are referred to as urban heat islands. An urban heat island (UHI) refers to the significantly higher temperatures measured within urban cities compared to surrounding rural areas (Arnfield 2003; Souch 2006). With the increasing interest in investigating the impact human structures have on local climate, UHI studies have been conducted in many of the world's largest city centers. UHIs have been identified within various Asian cities such as Nanjing, China or Seoul, South Korea (Kim and Baik 2004, 2005; Chung et al. 2004; Shi, B. et al. 2012). European countries have also been shown to experience UHIs within cities like Lisbon, Portugal (Alcoforado and Andrade 2006), Prague, Czech Republic (Beranova and Huth 2005), Debrecen, Hungary (Bottyán et al. 2005). Several cities within the Americas such as Buenos Aires, Argentina (Bejarán and Camilloni 2003) and New York City, USA (Gedzelman et al. 2003) have also been studied to compare different urban geometry impacts on the magnitude of the UHI effect.

While each individual UHI is unique there are defining characteristics responsible for the initial formation of UHIs. One particular set of defining characteristics are the thermodynamic properties of human-made surfaces (USEPA 2008). Radiative flux, solar reflectance, or albedo are examples of such properties (Souch 2006). Radiative flux refers to the amount of power in photons radiated from a given surface (Souch 2006). Human-made surfaces used in architecture possess inherently more reflective properties than natural surfaces thus aid in creating UHIs. Solar reflectance, or albedo, is a specific type of radiative flux that refers to the percentage of solar energy reflected by a surface (USEPA 2008; Souch 2006). Because a large portion of the sun's energy is emitted in visible light the coloration of surface materials directly influences the amount of albedo (USEPA 2008; Souch 2006). Thermal emittance is another thermodynamic characteristic responsible for the formation of UHIs. Thermal emittance is the ability of a surface to shed energy in the form of long-wave, infrared radiation (heat) to its surroundings (USEPA 2008). Surfaces with high thermal emittance values will shed heat more readily thus heating the surrounding area to a larger degree (USEPA 2008). A material's heat capacity, or its ability to store thermal energy, also influences the physical qualities of an UHI (USEPA 2008). Human-made materials often have higher heat capacities than natural materials thus increasing the ambient heat stored within the physical environment within an urban setting than a rural one.

Thermodynamics of surface materials play an important role in the existence of UHIs but are not the only physical influences on UHIs. Urban geometry, or the physical dimensions of and between human-made structures, often compounds and exacerbates the creation of UHIs (Souch 2006; USEPA 2008). Urban geometry is important in understanding UHI characteristics due to the influence urban geometry has on wind flow, energy absorption, and dispersal of radiation into space (USEPA 2008). Within urban geometry, scientists have scrutinized a particular physical characteristic, known as urban canyons, that have large impacts on UHI intensity (Barring and Mattsson 1985; Oke 1981). Urban canyons refer to large open spaces, often along streets, that are entirely or mostly enclosed by reflective human made surfaces (Souch 2006; Barring and Mattsson 1985). These canyons serve as a type of oven where air is trapped within and constantly heated by the reflected light from the surrounding buildings (Barring and Mattsson 1985). The negative influences of urban canyons are particularly drastic at night due to the obstruction of ambient heat from dispersing (USEPA 2008). One recent innovation within studying the characteristics of urban canyons and their effect on UHIs have been quantifying sky view factors. The sky-view factor (SVF) is the measure of the degree of sky visibility within a study site (Chapman and Thornes 2004). It is critical to effectively and systematically quantify the relationship between the SVF and ambient heat dissipation to quantitatively understand how to mitigate UHIs (Chapman and Thornes 2004; Souch 2006).

Notable environmental influences on UHIs include wind intensity and cloud cover, both of which reduce the intensity of UHIs (Souch 2006; Rencz 2012). This reduction is likely due to the ability of wind to dissipate heat through convection, which increases as wind speed increases and increased cloud cover prevents heat absorption by limiting the interaction between the sun's radiation and the urban surface (Souch 2006). Seasonal climate also plays a large role on the intensity of UHIs (Souch 2006). During winter months all communities intrinsically consume more fuel and energy to heat buildings and cars. This increased fuel consumption generates a localized greenhouse effect creating a greater temperature difference between the urban environment and the surrounding rural environments. Additionally, UHI affects the temperature of the soil, which shows more intense temperature effects with increasing soil depths (Shi et. al, 2012; Stewart 2011). UHIs are often separated into two distinct groups based on how they are quantified (USEPA 2008). These two generic groups are surface and atmospheric UHIs (USEPA 2008). Because the thermodynamics of solids and gases differ significantly, the properties of surface and atmospheric UHIs also differ.

Surface UHIs are strongest during the day while the sun is constantly heating the thermally absorbent human-made environments and weakest at night (USEPA 2008). While both surface and atmospheric UHIs are influenced by seasons, surface UHIs are strongest during summer when the sun's intensity is at its highest (USEPA 2008). On average, surface UHIs experience a temperature difference of 18-27°F during the day and a difference of 9-18°F during night (USEPA 2008: Roth, Oke and Emery 1989). Atmospheric UHIs often vary at a lower intensity than surface UHIs usually experiencing a temperature difference of 1.8-5.4°F (USEPA 2008; Oke 1997). Atmospheric UHIs also experience a more drastic difference between rural areas during winter months likely due to the larger thermal absorbance and emittance of human-made surfaces heating the surrounding air (Souch 2006; Hinkel et al. 2003). These same factors that trap heat within the urban area, usually urban canyons, are also responsible for atmospheric UHIs being more prominent at night (Oke 1973; Taha 1997). Atmospheric UHIs are also further subdivided into two separate categories of canopy and boundary layer UHIs (USEPA 2008). The canopy layer UHI is the a UHI existing within the ambient atmosphere in which humans live, from ground floor to below the tree and roofline (USEPA 2008). The boundary layer UHI exists from the tree and roof tops and extends to the point at which the urban environment no longer influences the atmosphere (USEPA 2008).

The goals of this study were to determine the existence of and quantify the magnitude, and define the thermal characteristics of an atmospheric UHI within Gettysburg, Pennsylvania. We investigated the following questions: “Does the Borough of Gettysburg have an urban heat island, despite its small size?”, “How drastic is the heat differential?”, and “What is the scope of the UHI?” We had three hypotheses: (1) there is a significant difference between air temperatures within the city canopy layer and surrounding rural canopy layer, (2) the magnitude of the UHI will diminish as the distance from the city center increases, and (3) the UHI will be localized and not extend further than 0.5 mile outside the city center.

Study Site

The borough of Gettysburg measures 1.66 square miles and is located in Cumberland Township of Adams County within south-central Pennsylvania (Figure 1). This town is where the Battle of Gettysburg took place during the Civil War in 1863 and is known for where

Abraham Lincoln gave the Gettysburg Address. Today, the town is home to the Gettysburg National Military Park that attracts many forms of tourist urban development within town and the surrounding area. The borough has a population of 7,608 people (US Census Bureau 2015). The area of our study has a humid temperate climate and is approximately 500 feet above sea level (NatGeo 2016, Brown 2006). The majority of the borough of Gettysburg is moderately developed, and the surrounding areas are predominantly residential suburbs and agricultural fields (Figure 2; U.S. Geological Survey).

Methods

Data Collection

To measure ambient air temperature, HYELEC MS6501 instant-read air temperature thermometers with sensor probes were used. Two transects across the city were used to collect data. These transects extended from the center square of Gettysburg, Pennsylvania to a mile from the square along Hanover Road going east and northwest along US-30 (Figure 3). Google Earth was used to measure increments of one tenth of a mile along the two main roads of our transects. Transect 1, north west of town along US-30, had 11 points. Transect 2, east of town along Hanover Rd, had 10 points due to safety concerns at the 0.8 mile location.

Air temperatures were collected approximately one and a half hours after the sun set to control for sun exposure on the test environment. Data at each increment of each transect was collected three days per week. These measurements were repeated for four weeks resulting in 12 separate temperatures for each point along each transect. On days where we started from city center and measured outwards, the city center temperature was re-measured immediately after the final point. This measurement allowed for correction to the natural environmental temperature dropping as the night progressed.

Laboratory Analysis

Microsoft Excel, Vassarstats, and IBM SPSS were all used to analyze our data. We used the temperatures for each transect interval to calculate the average temperature, standard deviation, and standard errors for each transect point. Vassarstats was used to perform a t-test on the average temperatures of each transect to determine if there was a significant difference between each transect. The differences between initial and re-measured air temperature of the city center were averaged for each transect to determine an environmental correction factor. This correction factor was used to accurately estimate total temperature change between start and end points.

A linear regression was used to investigate if there was a linear relationship between temperature and distance from the city center for both transects. An ANOVA with repeated measures was used to determine if distance from the city center significantly influenced the corresponding air temperature. A Mauchly's test for sphericity was conducted on each set of transect data to determine if the data met the assumption of sphericity required for this test. The Greenhouse-Geisser results of the ANOVA test were used to compensate for any lack of sphericity.

Differences between each transect interval were calculated for each transect to determine how the intensity of the UHI changed as distance from the city center increased. The total temperature change from the beginning and end of each transect were calculated to compare which transect changed the most. The environmental correction factor was used here to increase accuracy. For further analysis, we combined the temperature differences for each transect interval to analyze total UHI intensity. The intervals '0.7-0.8 mi' and '0.8-0.9 mi' for transect 1 were combined into one interval 0.7-0.9 mi since transect two was missing the 0.8 mi location.

Linear regression was used to compare the average temperature change between each interval against the corresponding distance from the city center to determine if there was a linear relationship. The resulting linear relationship was used to establish a linear model to describe the UHI intensity as the distance from the city center increases. This linear model was mapped spatially in ArcGIS to visually show relationship between UHI intensity and distance from Gettysburg, Pennsylvania.

Results

Over the four week collection period a total of 132 and 120 temperature measurements were taken for transect 1 and transect 2 respectively (Table 1a and 1b). The average temperatures for transect 1 were 49.3, 48.7, 48.0, 47.4, 46.6, 46.3, 46.1, 45.5, 44.9, 43.7, and 44.0°F in order of increasing distance from the city center (Table 2). The average temperatures for transect 2 were 50.3, 48.8, 48.3, 47.7, 46.8, 46.1, 45.3, 44.4, 45.6, and 45.7°F in order of increasing distance from the city center (Table 2). The t-test comparing the set of average temperatures of each transect showed there was no significant difference between the two transects ($p = 0.34$, $\alpha = 0.05$).

The linear regression model for the average temperatures of transect 1 showed a strong negative linear relationship between temperature and distance from the city center ($y = -5.5356x + 49.169$, $R^2 = 0.98$, $p < 0.0001$). Similar to transect 1, the linear regression model of transect 2 also showed a strong negative linear relationship between temperature and distance from the city center ($y = -4.8264x + 49.164$, $R^2 = 0.76$, $p = 0.0005$). Based on these models the total temperature change per mile for transect 1 is -5.5°F without accounting for environmental influence (Figure 1). The total temperature change per mile for transect 2 is -4.8°F without accounting for environmental influence (Figure 2). The starting points for each transect were re-measured for both transects to account for ambient temperature decrease over time (Table 1a and

1b). These observed differences were averaged to yield an ambient environmental difference of -1.7 and -1.8°F for transect 1 and 2 respectively (Table 3a and b). These environmental correction values indicate the temperature change per mile for transect 1 and 2 are -3.8 and -3.0°F respectively, accounting for the natural temperature change over time.

An ANOVA with repeated measures was used to determine if distance from the city center significantly influences temperature. The data met every statistical assumption needed for this particular statistical test except one, the assumption of sphericity. A Mauchly's test for sphericity was conducted on each set of transect data and showed that for transect 1: chi-square = 169.176, $p < 0.001$, df = 54, and for transect 2: chi-square = 111.764, $p < 0.001$, df = 44 (Table 4 and 5). Because of this violation the results of the more conservative Greenhouse-Geisser test were used to compensate for the lack of sphericity. The test showed that distances further from the city center had significantly lower temperatures, for transect 1: df = 2.152, F = 48.725, $p < 0.001$, and for transect 2: df = 1.689, F = 14.679, $p < 0.001$ (Table 6 and 7).

The observed temperature difference between transect intervals were analyzed to compare how different intervals along each transect vary in temperature. The average interval differences for transect 1 were -0.6, -0.8, -0.6, -0.8, -0.3, -0.2, -0.6, -0.6, -1.2, and 0.3°F in order of increasing distance from the city center (Table 8a). The average interval differences for transect 2 were -1.5, -0.5, -0.6, -0.9, -0.8, -0.8, -0.9, 1.2, and 0.0°F in order of increasing distance from the city center (Table 8b). Interval differences of transect 1 began at a moderate intensity and increased until 0.4-0.5 mi interval, at which it decreased drastically and then increased exponentially until the maximum difference at the 0.8-0.9 mi interval (Figure 6). Transect 2 differs slightly, the first interval of 0.0-0.1 mi has the largest temperature difference while the smallest difference is along the 0.1-0.2 mi interval, which then steadily increases until the 0.7-0.9

mi interval (Figure 7). Both transects experience positive increases in temperature from 0.9-1 mi in transect 1 and even earlier at the 0.7-0.9 mi interval for transect 2 (Figure 6 and 7).

Transect 1 had a slightly lower temperature difference, -5.4°F vs. -4.6°F, when comparing the total changes in temperature between the starting point and 1 mi point (Figure 8).With environmental corrections, transect 1 still had a larger temperature difference with a total temperature difference of 3.6°F while transect 2 had a total change of 2.8°F (Figure 9).When the temperature differences along each transect intervals were aggregated the means shifted. The aggregated temperature differences resemble the averages of transect 2 in the sense that the largest temperature difference is experienced from the 0.0-0.1 mi interval. The intensity of the temperature difference along the transect intervals decreases as the distance from the city center increases (Table 10). The only exceptions to this pattern are the 0.3-0.4 mi and 0.6-0.7 mi intervals that have larger temperature decreases than the preceding intervals (Table 10). When the temperature differences were compared to distance from the city center there was a positive linear relationship between the two variables: $y = 0.91x - 1.0317$, $R^2 = 0.66$, $p = 0.004$ (Figure 10). This model was mapped using ArcGIS to display the spatial relationship between UHI intensity and distance from the city center into an isotherm map of Gettysburg, PA (Figure 11).

Discussion

Our hypothesis that a UHI was present in Gettysburg was supported. The linear regression models showed a strong negative linear relationship between temperature and the distance from the city center for both transects. The ANOVA with repeated measures indicated that the temperatures at the city center are significantly higher than the temperatures on the outskirts of the city. Based on these results, we concluded that the high traffic activity and urban development in the center of the circle attributes to higher temperatures. There was, however, an unusual temperature increase along both transects' 0.9-1 mi interval and along the 0.7-0.9 mi interval for transect 2. These locations were all located at the bottom of hills. Lower altitudes tend to concentrate cooler air than those altitudes above (Largeron and Staquet 2016). It is likely that the higher elevations at these locations trapped the air in a small valley thus being responsible for the positive temperature increases at the end of both transects.

Large cities are known to produce intense heat islands (Maria et al. 2013). Despite size, small cities still have a large impact on local climate. Another small city, Shippensburg, Pennsylvania, has recently discovered a UHI. This city is located about twenty five miles west of Gettysburg and represents similar geographical area: a small urban area surrounded by agricultural fields (Doyle and Hawkins 2008). In a study by Doyle and Hawkins (2008), temperature sensors were set up at seven sites and the hourly temperature measurements were taken for about five months. The UHI was greater in May and September compared with June, July, and August. During 1900 to 0600 hours, these seven different weather stations displayed an average UHI effect to be 0.8°C or 0.44°F (Doyle and Hawkins 2008). Unfortunately we did not have enough time or resources to compare several different transects to calculate an average similar to Doyle and Hawkins (2008). However, we were able to compare average observed temperature difference between most urban and rural areas. The largest observed difference between most developed and most rural temperatures by Doyle and Hawkins (2008) was 1.9°C or 1.06°F compared to our corrected temperature differences of 3.6 and 2.8°F for each transect 1 and 2 respectively. It is interesting that such a similar city to Gettysburg has such a drastically lower average UHI effect. This stark difference could be due to several different factors. The most likely being the differences in seasonality of the two experiments.

Doyle and Hawkins (2008) conducted their analysis in the summer months of May through September while our analysis focused on late winter to spring. Previous studies have shown that winter and spring months tend to have more pronounced UHI effects than summer months (Souch 2006). Another interesting point is that while the average temperature difference over five months was around 1.06°F in the months of May and September, the two coldest of the months sampled, there was a nighttime average temperature difference of 5.4°F (Doyle and Hawkins 2008). These results were comparable to our observe temperature change without environmental correction of 5.4°F for transect 1. In summation, the total average differences were different due to the difference in seasonality between the two experiments but when analyzed on a monthly scale the results between our two studies are comparable to one another. It would be interesting in future studies to increase the timespan of our experiment to see if it aligns more with the Doyle and Hawkins (2008) experiment. Compared to larger cities, Gettysburg has a relatively large UHI relative to its size. Two comparisons can be made between Gettysburg and larger cities: Gettysburg compared to an large international city in a drastically different location and Gettysburg compared to a large city within a national region.

An example of an international city UHI can be seen within Seoul, South Korea. We felt this would be a good proxy for international cities due to its significantly different region and climate compared to Gettysburg. Seoul has a total population over 10 million people and expands 11,704 km^2 compared to Gettysburg with a total population of 7,608 people and area of 4.3 km^2 (Kim and Baik 2005; US Census Bureau 2015). Seoul is considerably more densely populated and a much more expansive urban city so the observed UHI would be predicted to be much higher than Gettysburg. However, over a yearly period the average largest UHI effect observed was 2.5°C or 4.5°F, which is proportionally larger than our observed Gettysburg UHI of 3.6°F (Kim and Baik 2005). One caveat to this comparison is that while Kim and Baik (2005) calculated UHI magnitude at a similar time of day (2100 hours), they also collected over a larger timespan with larger seasonal variation while we focused solely on the winter spring months.

However, even when seasonality and time of day were accounted for, such as within the Gedzelman et al. study (2003) in New York, USA, the UHI intensity was still similar to our own findings. Within the winter months of the Gedzelman et al. (2003) study the average temperature difference between rural and urban environments were 3°C or 5.4°F. While this is larger than the maximum corrected temperature difference of 3.6°F it is unlikely proportionally larger compared to how much larger NY City is to Gettysburg. Interestingly, without our environmental corrections the maximum average UHI magnitude was also 5.4°F. While this is likely not the most conservative of estimates the fact that a UHI magnitude of this degree was seen at all raises questions about the influence of urban development on UHI magnitude.

One of the limitations of our study was time. Because we did not have weather station data, time restrained us to only four weeks of three days of data collection since we had to manually collect the data temperature. In the future, this study could be completed over one year to discover possible seasonal variation of the magnitude of the UHI. Although we observed an UHI effect, increasing the number of collection locations could provide more accurate results yielding a better representation of the magnitude and thermal characteristics of the UHI. Another limitation to our experiment was that the time that passed between the initial collecting site to the last collecting site along the transects. This limitation was proved valid as we saw a difference in temperature when we re-measured the square. The re-measurements of the square allowed us to correct the temperatures for a more accurate representation of the magnitude of the UHI by limiting environmental influences on our results.

Interestingly, nearly all of the studies physically describing UHIs preferred utilizing static weather stations to record temperatures over our method of recording measurements in the field (Alcoforado, M., & Andrade, H. 2006; Bärring, L. & Mattsson, J.O. 1985; Beranova, R. & Huth, R. 2005; Bottyán, Z. et al. 2005; Doyle, D. & Hawkins, T.W. 2008; Gedzelman, S.D., et al. 2003; Kim, Y.H., & Baik, J.J. 2005; Shi, B. et al. 2012). Because this method gives instantaneous temperature measurements, no other studies needed to perform environmental corrections to account for ambient temperature change over time. These limitations could be corrected in future experiments by placing a temperature sensor at each interval that could record the temperature of all locations at the exact same time. Also, temperature sensors could reveal how the UHI changes throughout the day and in response to different meteorological conditions. This project can also be improved by taking more measurements within the one mile range in order to explore which parts of Gettysburg are more heavily affected than others.

UHIs burden people living within urban areas. Not only can warmer temperatures be uncomfortable, but they also raise the amount of energy consumption due to cooling purposes. As human populations continue to rise, it is expected that 95% of urban expansion will occur in economically developing nations (Akbari et al. 2015). Action must be taken to reduce power demands and consumption of fuel. For example, implementing cool roofs, a surface reflecting higher solar amounts, is beneficial not only because homes do not need to use as much air condition, but this also reduces contribution to the UHI (Akbari et al. 2015). A green roof, a roof covered with vegetation, similarly prevents contribution to the UHI. Simulations also show that increasing amounts of vegetation deflects the sun’s rays. This deflection prevents buildings from absorbing heat and causing UHIs. Green roof systems allow the combination of both ideas

(Akbari et al. 2015). While these technologies will not eliminate UHI completely, they are sustainable ways to counter climate change.

Not only do UHIs have negative impacts on public health, local climate and energy consumption but they have recently become important due to their controversial role in the climate change debate. Because of this it has become paramount in understanding how and to what degree have UHIs influenced recent climate models and predictions (Parker 2010). By understanding the influence that UHIs have on climate change we can gain important insight into how to combat climate change on a local level. In recent years it has been shown that while there is a significant warming effect within urban areas, these temperatures compared to those previously are not significantly different (Parker 2010). This indicates that while UHIs do exist that they haven't changed significantly in previous years, while rural areas have (Parker 2010). This provides evidence that climate change is resulting within the natural environment rather than simply being a result of humans local influence on the environment (Parker 2010).

In terms of longer climate projections, such as those created by the IPCC, UHIs have been shown to minimally influence projections and are now able to be corrected for, further diminishing their influence on the accuracy of climate models (Parker 2010). However, there influence, no matter how minor, indicates that they are one small piece of the climate change puzzle needed to solve the issue in its entirety.

Conclusions

This study investigated and confirmed the existence of an UHI in Gettysburg, Pennsylvania. Transect 1 revealed a total 5.5°F (3.8°F with environmental corrections) decrease in temperature from the center square and one mile outwards. Transect 2 experienced a 4.8°F (3.0°F with environmental corrections) decrease when comparing the center square the one mile transect point. There was also a significant difference between the average temperature differences within transect intervals along both transects. Our results indicate that while overall there is a significant difference between the start and end of the transects that temperature decrease varies along each transect.

Despite Gettysburg's small size it has a significant UHI effect that can influence the local climate. Previous studies have shown that city size directly relates to the UHI effect but Gettysburg might prove to be an exception due to the large UHI effect observed (Oke 1973; Kim and Baik 2005; Gedzelman et al. 2003). If small cities such as Gettysburg have a disproportionately large UHI effect moderately sized cities might also be underestimated in terms of their influence on their surrounding environment. With human development being the main contribution to the UHI, building designs can and should be altered to counter small scale climate change and maintain the public health.

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Appendix

Table 1a. Recorded temperatures for transect number one at each location over the twelve days of measurement.

		Week 1			Week 2			Week 3			Week 4		
Transect 1	**Distance (mi)**	**2/27**	**3/1**	**3/21**	**3/23**	**3/25**	**3/27**	**3/29**	**3/31**	**3/3**	**3/6**	**3/8**	**3/10**
Square	0	45.9	63.3	54.1	39.6	64.3	62.1	49.5	44.9	31.5	46.9	57.9	32
7/11	0.1	45.3	62.3	54	38.3	64.1	61.9	48.8	43.8	31.3	46.4	57.4	31.3
Franklin	0.2	44.4	62.1	53.5	37.3	62.4	61.3	48.6	43.2	29.1	46.4	56.8	30.5
Dollar General	0.3	43.5	62.4	52.1	36.5	61.9	60.8	49	43.4	27.1	46.6	56.3	29.4
Post Office	0.4	41.2	62.4	49.7	36.3	60.9	60.3	49.3	43.1	27	46.2	55.7	27.2
Elm St.	0.5	41.7	61.7	48.8	36.1	59.2	60.5	48.7	42.6	27.9	46	54.6	27.7
N. Hay St.	0.6	42.1	62.1	48.4	35.4	58.9	59.9	48.4	42.4	27.1	46.4	53.9	28.1
~Seminary Ridge	0.7	41	62.6	47.8	35.9	58.4	58.1	47.8	41.7	26.2	45.3	53.3	27.4
Top of hill	0.8	41.2	62.2	47.3	35.3	57.6	57.9	46.9	41.3	25	43.7	52.8	27.3
Battle field	0.9	38.3	61	46.4	34.1	57.3	56.4	45.7	39.6	24.1	42.4	51.8	27
Reynolds Ave	1	37.8	60.8	46.9	34.8	57.4	56.7	46	39.8	24.9	43.1	52.1	27.1
Re-measure	0	40.3	-	53.2	-	-	-	47.9	-	31.2	-	57.6	-

Table 1b. Recorded temperatures for transect number two at each location over the twelve days of measurement.

		Week 1			Week 2			Week 3			Week 4		
Transect 2	**Distance (mi)**	**2/27**	**3/1**	**3/3**	**3/6**	**3/8**	**3/10**	**3/21**	**3/23**	**3/25**	**3/27**	**3/29**	**3/31**
Square	0	48.2	62.4	30	48.9	58.8	33.3	55.8	41.7	64.8	62.3	52.3	45.1
Hanover x Stratton	0.1	47.1	63.1	30.2	47.8	57.2	32	52.9	37	63.1	61.2	50.7	43.7
Hanover x Liberty	0.2	46.4	63	28.6	47.5	57.2	32	50.9	36.5	63.3	59.6	51.1	43.5
Hanover x 3rd	0.3	45.7	63.3	29.7	45.9	57.6	31.5	46.8	36.1	61.9	60.4	50.5	42.8
Hanover x 4th	0.4	43.5	63	29.1	46.2	56.3	29.3	45.9	34.3	61.4	59.9	50.4	42.6
Hanover x 5th	0.5	41.5	63.1	27.7	47.3	55.9	29.1	44.6	30.7	59.2	60	50.2	43.3
Hanover x 6th	0.6	39	63.1	28.8	46	54.9	29.3	43	30.2	58.9	58.8	49.6	41.7
Hanover x Municipal	0.7	36.5	62.8	28.7	45.9	55.2	29.5	42.1	28	56.4	58.2	47.3	42.1
Hanover x Latimer	0.9	40.3	63.3	27.7	45.3	54.5	29.3	48.4	32.4	57.6	58.1	48.6	42.1
Battlefield	1	42.6	63.1	27.5	45.1	53.4	28.4	47.8	35.4	57.1	57.9	47.8	41.9
Re-measure	0	-	-	-	48	57	32.7	51.8	36.7	-	-	52.2	44.8

Table 2. The average temperature and the corresponding standard deviation and standard error for each interval for both transects.

	Transect 1			**Transect 2**		
Distance (mi)	**Average Temp**	**Stnd Deviation**	**Stnd Error**	**Average Temp**	**Stnd Deviation**	**Stnd Error**
0	49.3	11.40	3.29	50.3	11.34	3.27
0.1	48.7	11.50	3.32	48.8	11.49	3.32
0.2	48.0	11.71	3.38	48.3	11.61	3.35
0.3	47.4	12.08	3.49	47.7	11.54	3.33
0.4	46.6	12.25	3.54	46.8	11.89	3.43
0.5	46.3	11.71	3.38	46.1	12.30	3.55
0.6	46.1	11.72	3.38	45.3	12.10	3.49
0.7	45.5	11.74	3.39	44.4	12.10	3.49
0.8	44.9	11.79	3.40	-	-	-
0.9	43.7	11.78	3.40	45.6	11.72	3.38
1	44.0	11.65	3.36	45.7	11.32	3.27

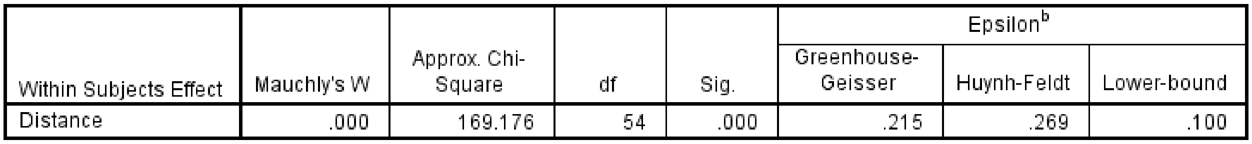
Table 3a. This table shows the measured temperatures for the square for Transect 1, the re-measurements, and the differences between the two. The average difference was a decrease in 1.7 °F.

Transect 1	**2/27**	**3/1**	**3/3**	**3/6**	**3/8**	**3/10**	**3/21**	**3/23**	**3/25**	**3/27**	**3/29**	**3/31**	**Average**
Square	45.9	63.3	31.5	46.9	57.9	32	54.1	39.6	64.3	62.1	49.5	44.9	49.3
Re-measure	40.3	-	31.2	-	57.6	-	53.2	-	-	-	47.9	-	46.0
Difference	-5.6	-	-0.3	-	-0.3	-	-0.9	-	-	-	-1.6	-	**-1.7**

Table 3b. This table shows the measured temperatures for the square for Transect 2, the re-measurements, and the differences between the two. The average difference was a decrease in 1.8 °F.

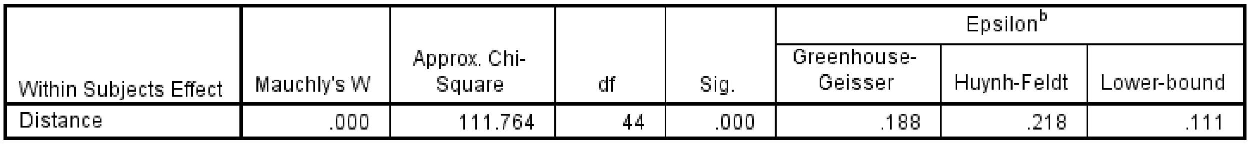
Transect 2	**2/27**	**3/1**	**3/3**	**3/6**	**3/8**	**3/10**	**3/21**	**3/23**	**3/25**	**3/27**	**3/29**	**3/31**	**Average**
Square	48.2	62.4	30	48.9	58.8	33.3	55.8	41.7	64.8	62.3	52.3	45.1	50.3
Re-measure	-	-	-	48	57	32.7	51.8	36.7	-	-	52.2	44.8	46.2
Difference	-	-	-	-0.9	-1.8	-0.6	-4	-5	-	-	-0.1	-0.3	**-1.8**

Table 4. Displays the results from the Mauchly's test of shericity for transect 1 average temperatures.



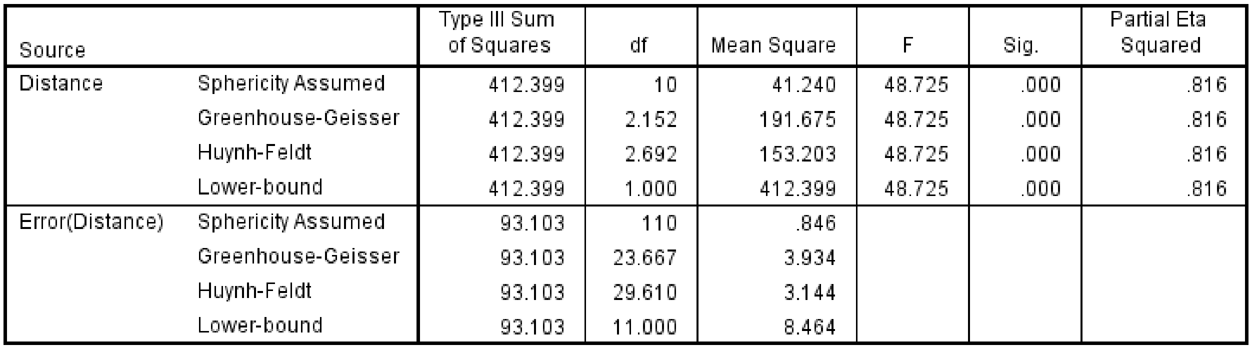
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon^b		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Distance	.000	169.176	54	.000	.215	.269	.100

Table 5. Displays the results from the Mauchly's test of shericity for transect 2 average temperatures.



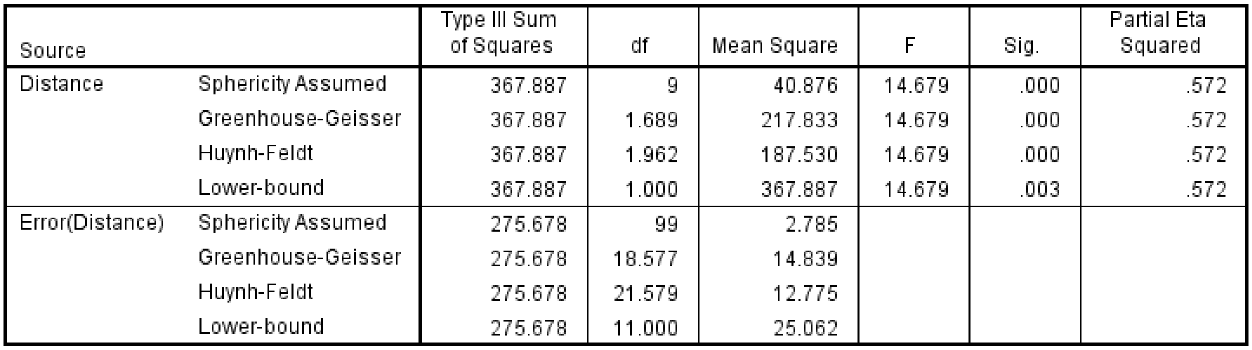
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon^b		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Distance	.000	111.764	44	.000	.188	.218	.111

Table 6. Displays the results of the ANOVA with repeated measures test performed on the average transect temperatures for transect 1.



Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Distance	Sphericity Assumed	412.399	10	41.240	48.725	.000	.816
	Greenhouse-Geisser	412.399	2.152	191.675	48.725	.000	.816
	Huynh-Feldt	412.399	2.692	153.203	48.725	.000	.816
	Lower-bound	412.399	1.000	412.399	48.725	.000	.816
Error(Distance)	Sphericity Assumed	93.103	110	.846			
	Greenhouse-Geisser	93.103	23.667	3.934			
	Huynh-Feldt	93.103	29.610	3.144			
	Lower-bound	93.103	11.000	8.464			

Table 7. Displays the results of the ANOVA with repeated measures test performed on the average transect temperatures for transect 2.



Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Distance	Sphericity Assumed	367.887	9	40.876	14.679	.000	.572
	Greenhouse-Geisser	367.887	1.689	217.833	14.679	.000	.572
	Huynh-Feldt	367.887	1.962	187.530	14.679	.000	.572
	Lower-bound	367.887	1.000	367.887	14.679	.003	.572
Error(Distance)	Sphericity Assumed	275.678	99	2.785			
	Greenhouse-Geisser	275.678	18.577	14.839			
	Huynh-Feldt	275.678	21.579	12.775			
	Lower-bound	275.678	11.000	25.062			

Table 8. Temperature change between each interval along Transect 1.

	Transect 1 Interval										
	0-0.1	**0.1-0.2**	**0.2-0.3**	**0.3-0.4**	**0.4-0.5**	**0.5-0.6**	**0.6-0.7**	**0.7-0.8**	**0.8-0.9**	**0.9-1**	**0-1**
Week 1	-0.6	-0.9	-0.9	-2.3	0.5	0.4	-1.1	0.2	-2.9	-0.5	-8.1
	-1	-0.2	0.3	0	-0.7	0.4	0.5	-0.4	-1.2	-0.2	-2.5
	-0.2	-2.2	-2	-0.1	0.9	-0.8	-0.9	-1.2	-0.9	0.8	-6.6
Week 2	-0.5	0	0.2	-0.4	-0.2	0.4	-1.1	-1.6	-1.3	0.7	-3.8
	-0.5	-0.6	-0.5	-0.6	-1.1	-0.7	-0.6	-0.5	-1	0.3	-5.8
	-0.7	-0.8	-1.1	-2.2	0.5	0.4	-0.7	-0.1	-0.3	0.1	-4.9
Week 3	-0.1	-0.5	-1.4	-2.4	-0.9	-0.4	-0.6	-0.5	-0.9	0.5	-7.2
	-1.3	-1	-0.8	-0.2	-0.2	-0.7	0.5	-0.6	-1.2	0.7	-4.8
	-0.2	-1.7	-0.5	-1	-1.7	-0.3	-0.5	-0.8	-0.3	0.1	-6.9
Week 4	-0.2	-0.6	-0.5	-0.5	0.2	-0.6	-1.8	-0.2	-1.5	0.3	-5.4
	-0.7	-0.2	0.4	0.3	-0.6	-0.3	-0.6	-0.9	-1.2	0.3	-3.5
	-1.1	-0.6	0.2	-0.3	-0.5	-0.2	-0.7	-0.4	-1.7	0.2	-5.1
Mean	-0.6	-0.8	-0.6	-0.8	-0.3	-0.2	-0.6	-0.6	-1.2	0.3	-5.4

Table 9. Temperature change between each interval along Transect 2.

	Transect 2 Interval									
	0-0.1	**0.1-0.2**	**0.2-0.3**	**0.3-0.4**	**0.4-0.5**	**0.5-0.6**	**0.6-0.7**	**0.7-0.9**	**0.9-1**	**0-1**
Week 1	-1.1	-0.7	-0.7	-2.2	-2	-2.5	-2.5	3.8	2.3	-5.6
	0.7	-0.1	0.3	-0.3	0.1	0	-0.3	0.5	-0.2	0.7
	0.2	-1.6	1.1	-0.6	-1.4	1.1	-0.1	-1	-0.2	-2.5
Week 2	-1.1	-0.3	-1.6	0.3	1.1	-1.3	-0.1	-0.6	-0.2	-3.8
	-1.6	0	0.4	-1.3	-0.4	-1	0.3	-0.7	-1.1	-5.4
	-1.3	0	-0.5	-2.2	-0.2	0.2	0.2	-0.2	-0.9	-4.9
Week 3	-2.9	-2	-4.1	-0.9	-1.3	-1.6	-0.9	6.3	-0.6	-8
	-4.7	-0.5	-0.4	-1.8	-3.6	-0.5	-2.2	4.4	3	-6.3
	-1.7	0.2	-1.4	-0.5	-2.2	-0.3	-2.5	1.2	-0.5	-7.7
Week 4	-1.1	-1.6	0.8	-0.5	0.1	-1.2	-0.6	-0.1	-0.2	-4.4
	-1.6	0.4	-0.6	-0.1	-0.2	-0.6	-2.3	1.3	-0.8	-4.5
	-1.4	-0.2	-0.7	-0.2	0.7	-1.6	0.4	0	-0.2	-3.2
Mean	-1.5	-0.5	-0.6	-0.9	-0.8	-0.8	-0.9	1.2	0.0	-4.6

Table 10. Aggregation of the differences in temperature between each interval along both transects.

Transect Interval									
0-0.1	**0.1-0.2**	**0.2-0.3**	**0.3-0.4**	**0.4-0.5**	**0.5-0.6**	**0.6-0.7**	**0.7-0.9**	**0.9-1**	**0-1**
-0.6	-0.9	-0.9	-2.3	0.5	0.4	-1.1	-2.7	-0.5	-8.1
-1	-0.2	0.3	0	-0.7	0.4	0.5	-1.6	-0.2	-2.5
-0.2	-2.2	-2	-0.1	0.9	-0.8	-0.9	-2.1	0.8	-6.6
-0.5	0	0.2	-0.4	-0.2	0.4	-1.1	-2.9	0.7	-3.8
-0.5	-0.6	-0.5	-0.6	-1.1	-0.7	-0.6	-1.5	0.3	-5.8
-0.7	-0.8	-1.1	-2.2	0.5	0.4	-0.7	-0.4	0.1	-4.9
-0.1	-0.5	-1.4	-2.4	-0.9	-0.4	-0.6	-1.4	0.5	-7.2
-1.3	-1	-0.8	-0.2	-0.2	-0.7	0.5	-1.8	0.7	-4.8
-0.2	-1.7	-0.5	-1	-1.7	-0.3	-0.5	-1.1	0.1	-6.9
-0.2	-0.6	-0.5	-0.5	0.2	-0.6	-1.8	-1.7	0.3	-5.4
-0.7	-0.2	0.4	0.3	-0.6	-0.3	-0.6	-2.1	0.3	-3.5
-1.1	-0.6	0.2	-0.3	-0.5	-0.2	-0.7	-2.1	0.2	-5.1
-1.1	-0.7	-0.7	-2.2	-2	-2.5	-2.5	3.8	2.3	-5.6
0.7	-0.1	0.3	-0.3	0.1	0	-0.3	0.5	-0.2	0.7
0.2	-1.6	1.1	-0.6	-1.4	1.1	-0.1	-1	-0.2	-2.5
-1.1	-0.3	-1.6	0.3	1.1	-1.3	-0.1	-0.6	-0.2	-3.8
-1.6	0	0.4	-1.3	-0.4	-1	0.3	-0.7	-1.1	-5.4
-1.3	0	-0.5	-2.2	-0.2	0.2	0.2	-0.2	-0.9	-4.9
-2.9	-2	-4.1	-0.9	-1.3	-1.6	-0.9	6.3	-0.6	-8
-4.7	-0.5	-0.4	-1.8	-3.6	-0.5	-2.2	4.4	3	-6.3
-1.7	0.2	-1.4	-0.5	-2.2	-0.3	-2.5	1.2	-0.5	-7.7
-1.1	-1.6	0.8	-0.5	0.1	-1.2	-0.6	-0.1	-0.2	-4.4
-1.6	0.4	-0.6	-0.1	-0.2	-0.6	-2.3	1.3	-0.8	-4.5
-1.4	-0.2	-0.7	-0.2	0.7	-1.6	0.4	0	-0.2	-3.2
-1.029	**-0.654**	**-0.583**	**-0.833**	**-0.546**	**-0.488**	**-0.758**	**-0.271**	**0.154**	**-5.008**

Figure 1. Location of Gettysburg within South-Central Pennsylvania

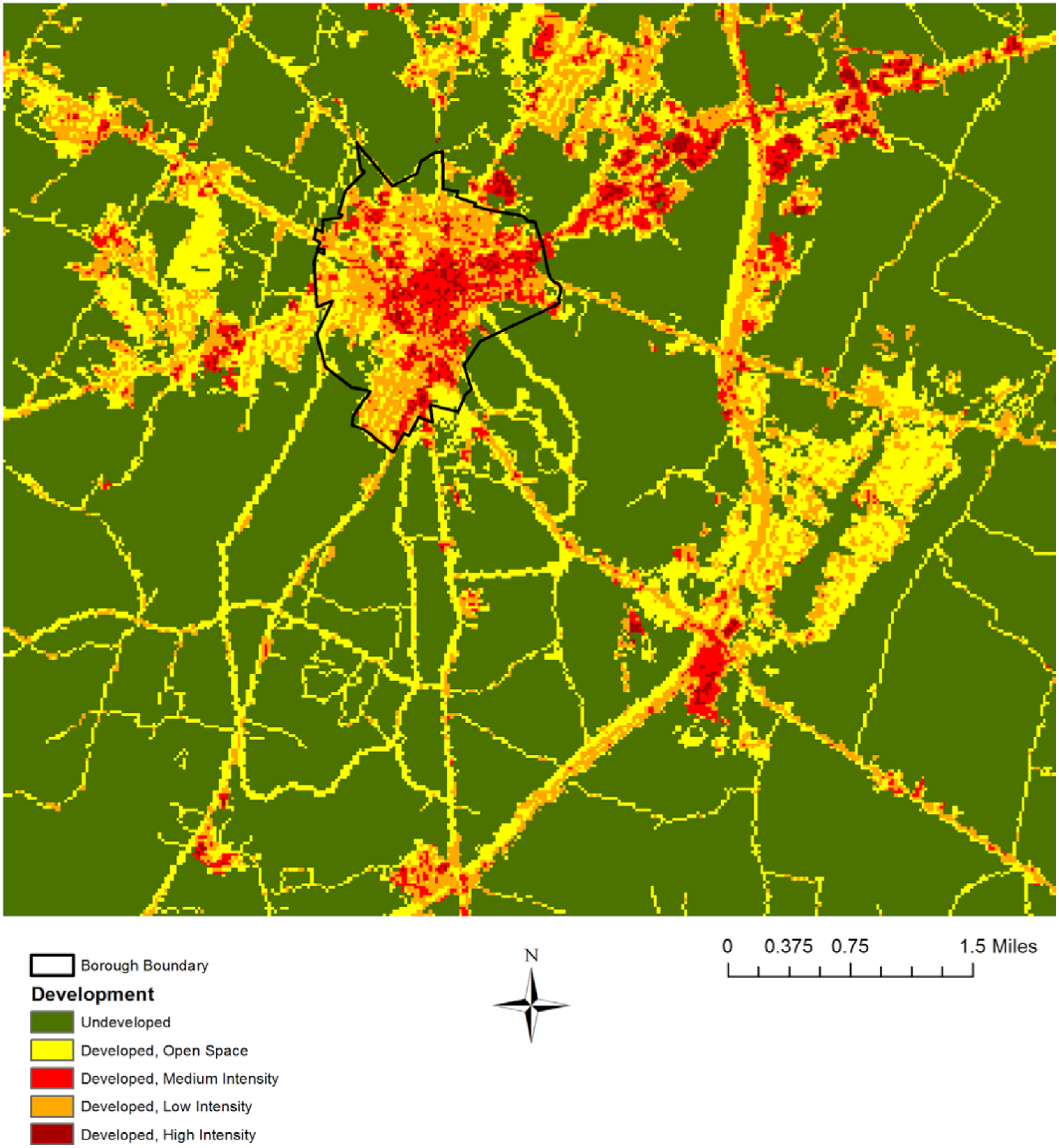


Figure 2. Map showing the intensity of development of the Borough of Gettysburg.

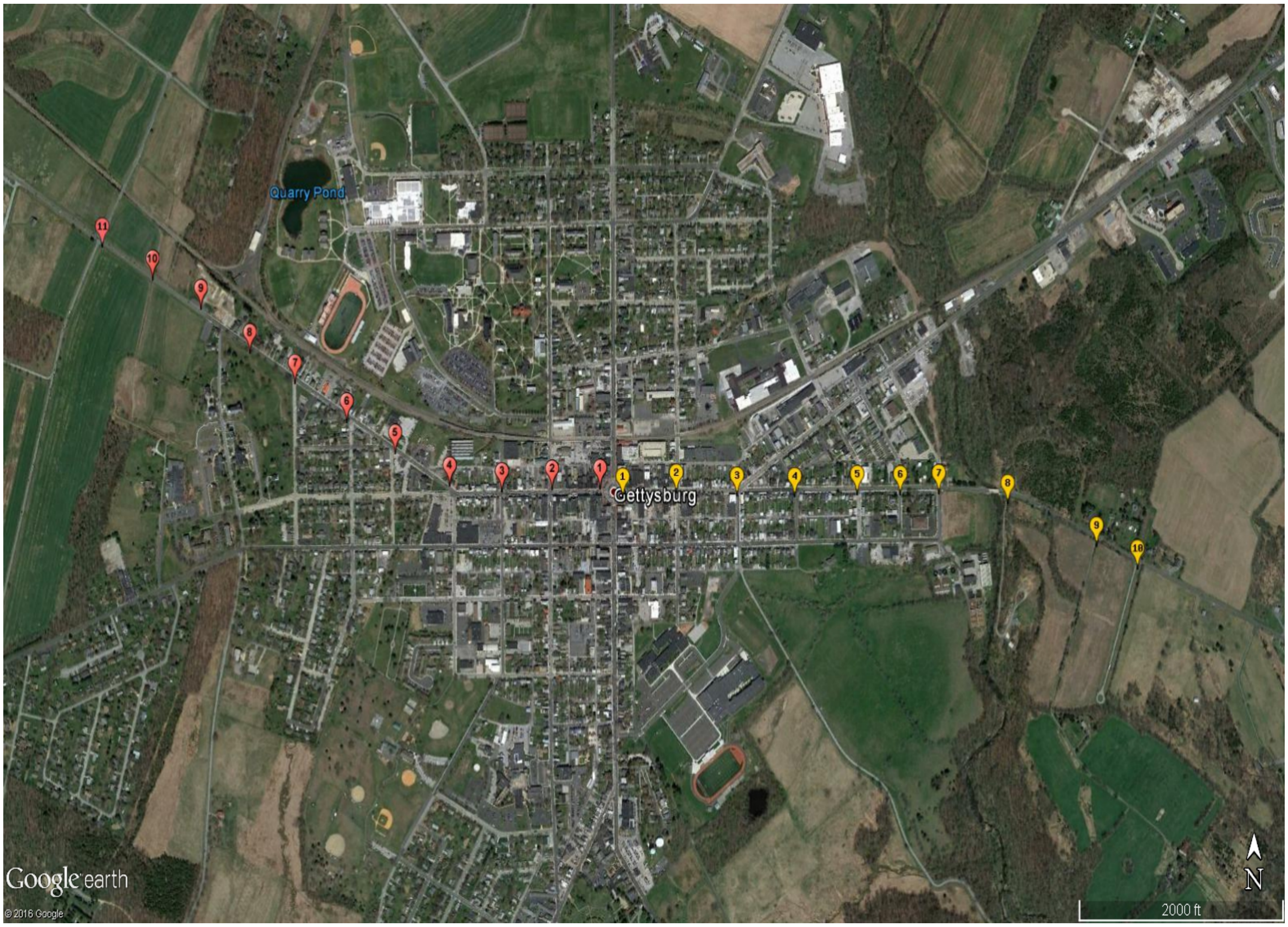


Figure 3. Map showing the two transects and locations where temperatures were taken in this study. Each transect reached one mile outwards from the center of Gettysburg, PA.

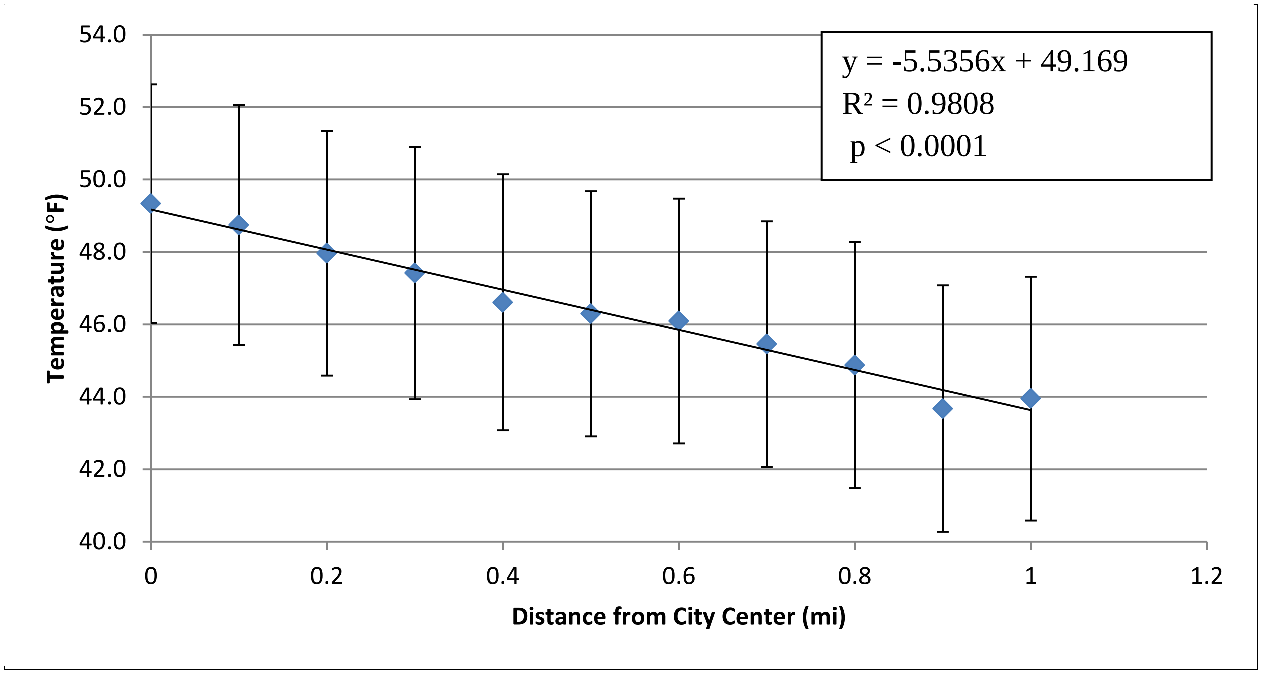


Figure 4. Linear regression analysis for the average temperatures for each interval of transect 1.

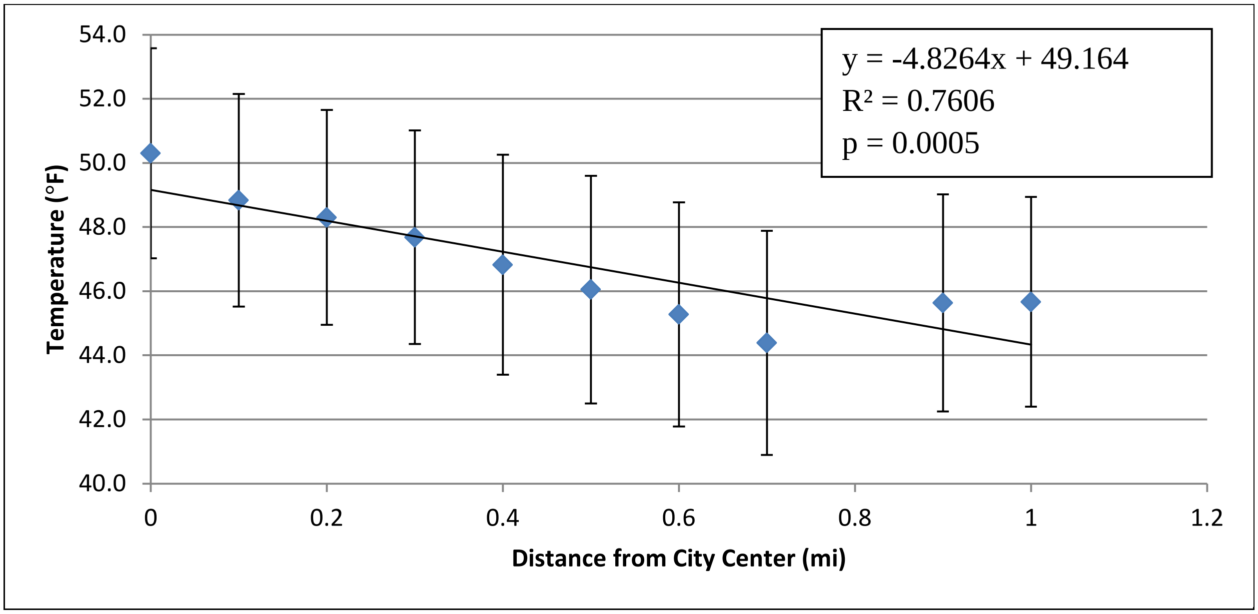


Figure 5. Linear regression analysis for the average temperatures for each interval of transect 2.

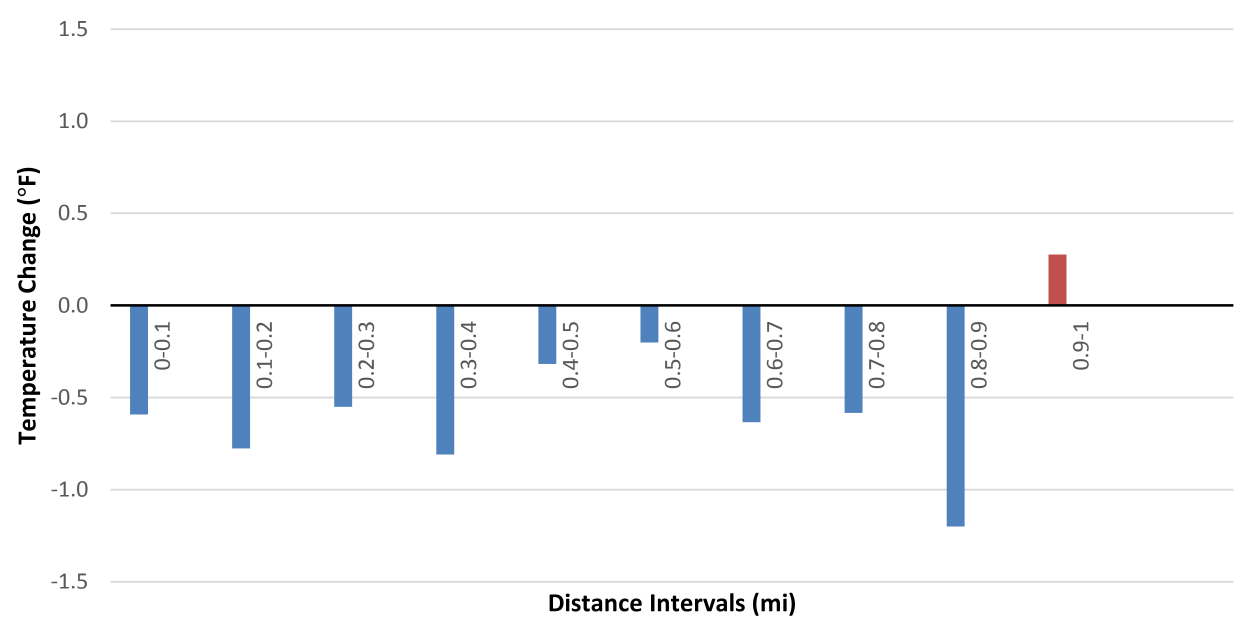


Figure 6. The average temperature difference between each interval for transect 1.

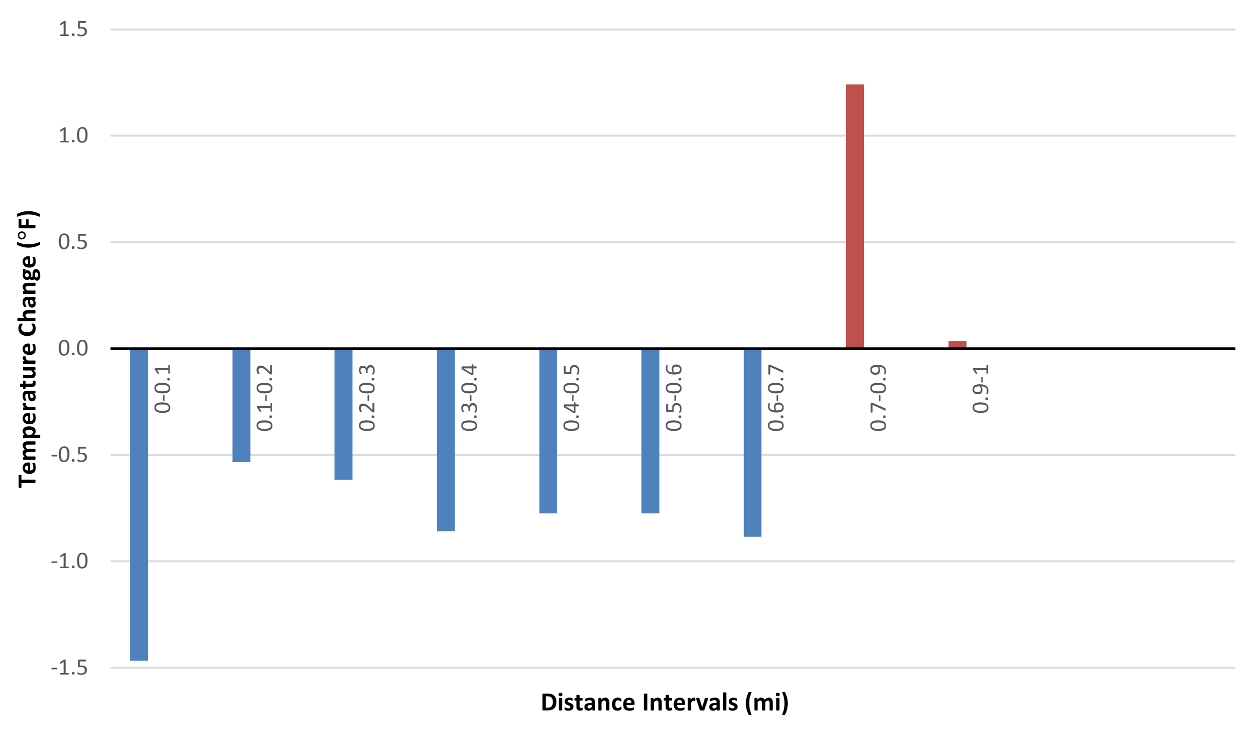


Figure 7. The average temperature difference between each interval for transect 2.

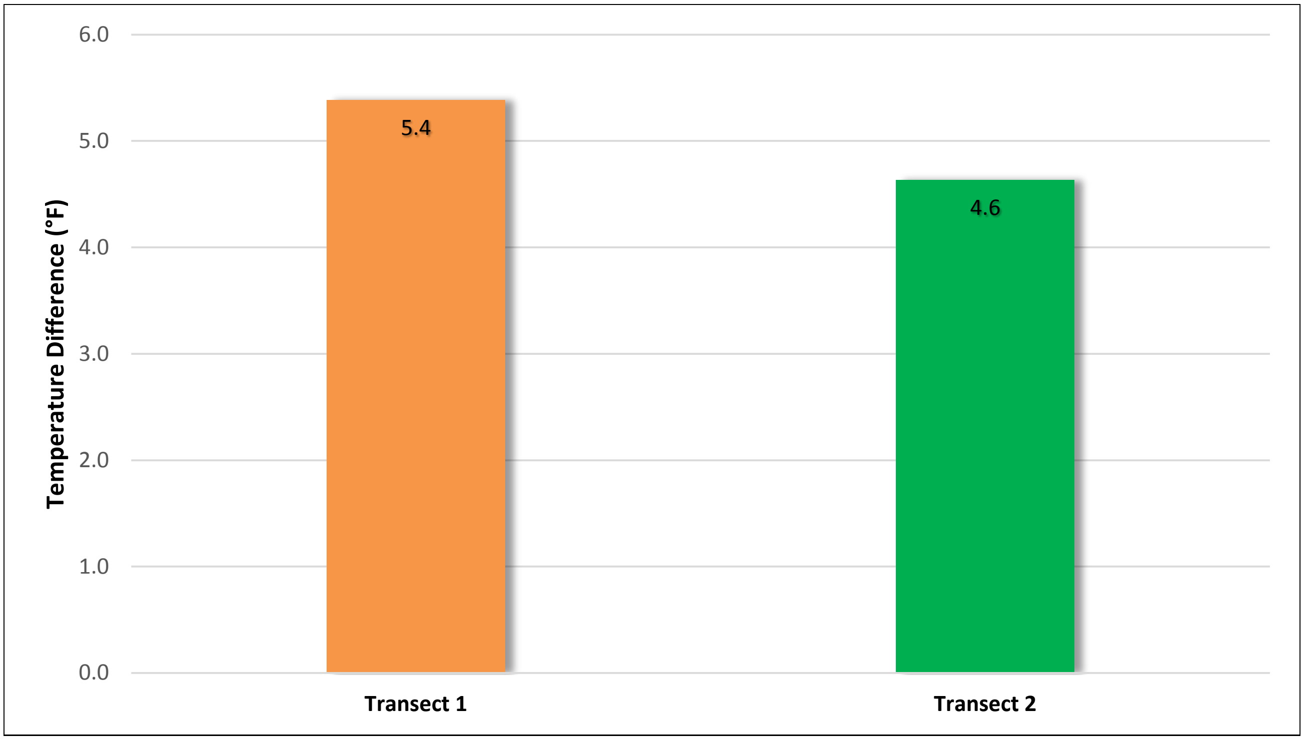


Figure 8. Chart showing the average total temperature decrease between the start and end of each transect.

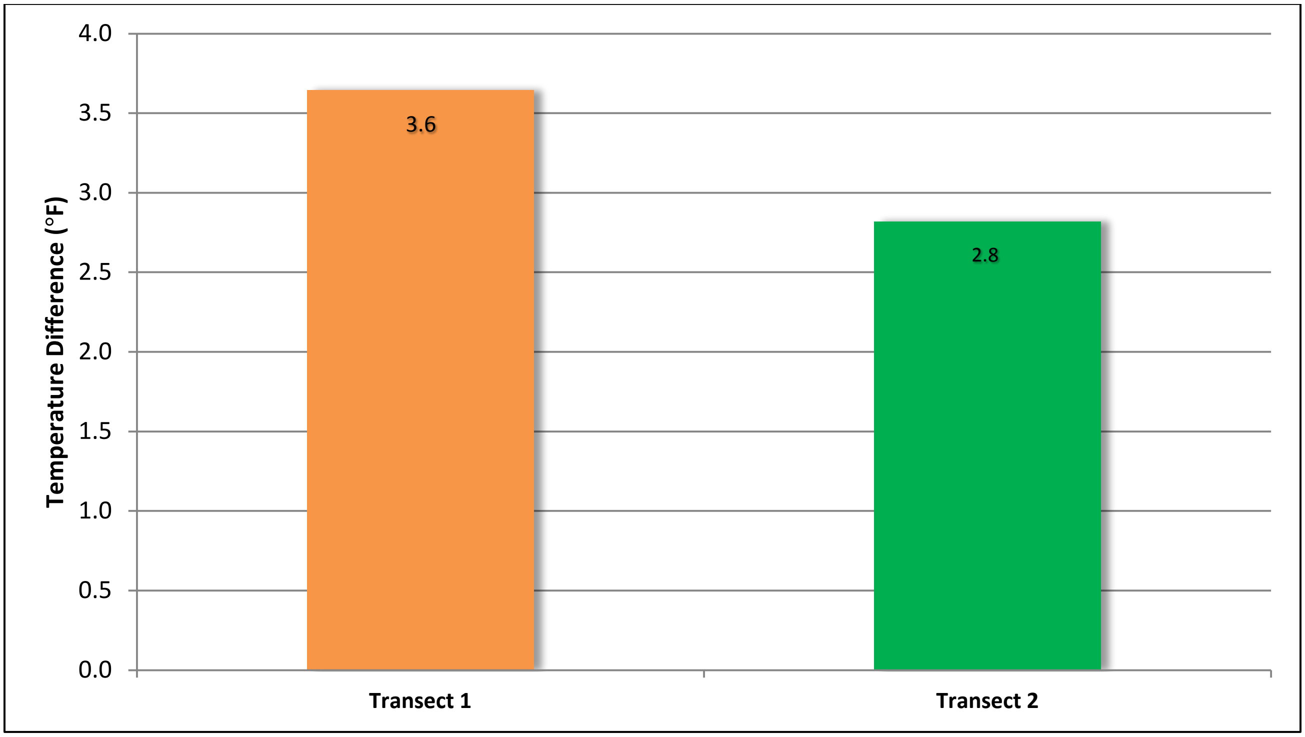


Figure 9. Chart showing the average total temperature decrease between the start and end of each transect when accounting for environmental corrections.

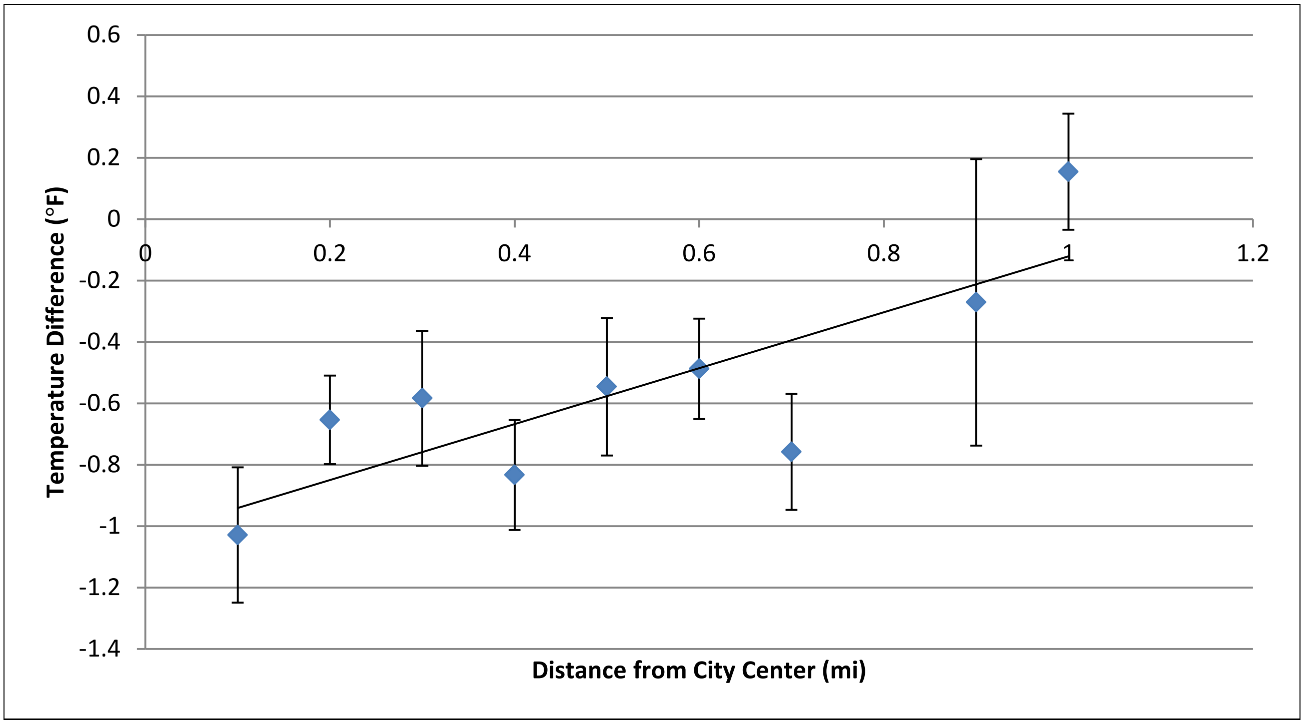


Figure 10. Displays the linear regression analysis of the temperature difference experienced between the transect intervals compared to their respective distance from the city center ($y = 0.91x - 1.0317$, $R^2 = 0.6638$, $p = 0.004$).

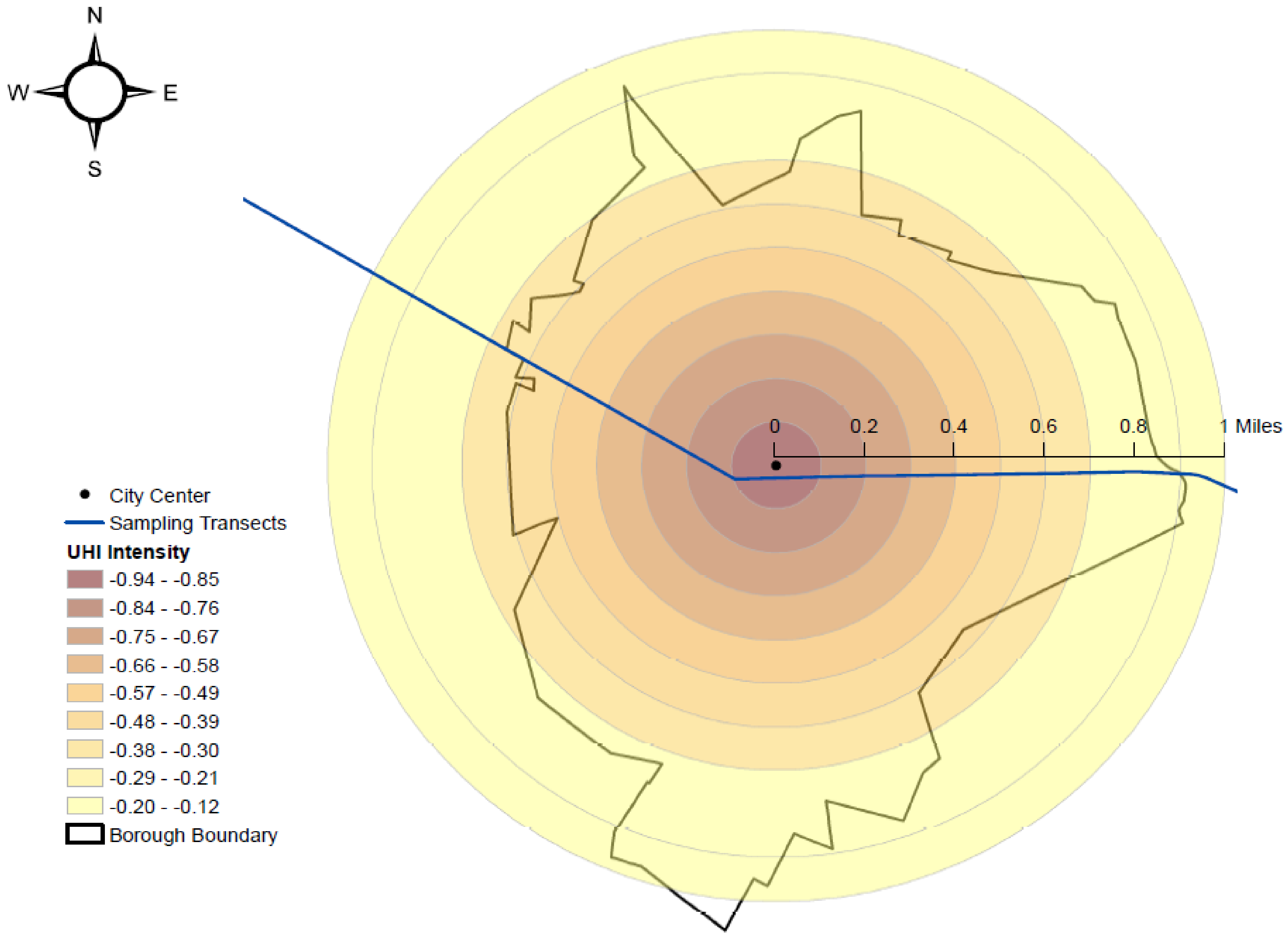


Figure 11. An isotherm map displaying the modeled temperature change as distance from city center increases.