How urbanization within the Hamilton & Toronto regions between 1987 and 2005 have affected the Urban Heat Island

Josh Valenti

Applied Climatology, Department of Geography, Brock University

ABSTRACT: Since the beginning of the industrial era, society has grown to favour urbanization. In 2011 53% of the world's population lived in urbanized cities and by 2035 it is estimated that 62% of the world's population will reside within urbanized cities (UN 2012). This has caused a continuous increase of global mean surface temperature through extensive Green House Gas emission, and change in the natural physical characteristics of the earth's surface (a change from permeable surfaces to impermeable surfaces). In this study, Landsat TM images were acquired from 1987 and 2005 over the Hamilton and Toronto regions. These images provided the land-use/land-cover (LULC) of the two regions as well as surface brightness temperatures. The two sets of data allowed in determining the impact that the Urban Heat Island has on two growing cities, and how much of an impact a change in LULC has on the surface temperatures. Results show that the UHI effect has become more prominent in areas of rapid urbanization. The distribution of the UHI has localized with growth in the Built-up classification.

Keywords: Urban Heat Island (UHI); Land-use/Land-cover change (LULCC); Surface Temperature; Remote Sensing

1 Introduction

Since the industrial era, urban areas have been sprawling outwards from the downtown core. As cities of greater magnitude have developed across the globe, it is estimated that by 2035, 62% of the world's population will be living in urban areas, compared to the 53% in 2011 (UN, 2012). The exponential growth of urbanization does not just affect the climate through extensive Green House Gases (GHG's) emitted into the atmosphere, but also from changing the natural, physical characteristics of the earth's surface. From the beginning of the 19th century the global mean surface temperature has been continuously increasing (Chen et al., 2006). The physical characteristics of the earth's surface ultimately determine the atmospheric conditions (temperature, humidity, wind speed, and weather phenomena's) through the surfaces thermal, and radiative properties (Grawe et al., 2013). These characteristics contribute to the local and regional climates, and by changing the land-use/land-cover (LULC) of the surface; it results in a changing climate. Previous studies be Pielke et al., (2002) conclude that a change in land-use/land-cover may have a significantly greater impact on the climate than GHG's will in years to come.

Urban areas impact local climates; one of the most significant impacts is that of the urban heat island (UHI). The UHI effect refers to temperatures of urban (impermeable) surfaces being significantly greater than that of its suburbs (permeable surfaces) (Li et al., 2013). The Intergovernmental Panel on Climate Change (IPCC, 2007) calculated an increasing global mean surface-air temperature by 0.74°C from 1906 to 2005, with an evident warming during the past 25 years. The UHI is a result of modifying the surface energy and radiation balances through changes in geometry, heat storage capacity, albedo, and anthropogenic heat emissions (Grawe et al., 2013). Hoffman et al., (2013) concluded that UHI intensities are dependent on the morphology and size of the urban area and related to patterns of land-use/land-cover changes (LULCC).

Urban features (impermeable land: buildings, asphalt, roads, etc.) increase the surfaces heat capacity, trapping radiation within, reducing the vertical exchange due to a reduced wind speed, and anthropogenic heat release (Yow, 2007) from that of permeable features. Table 1 summarizes differences in surface albedos (how much energy a surface reflects), resulting in how much energy is absorbed and transferred into heat. Impermeable objects reflect more than that of permeable surfaces, however impermeable surface absorb and return heat at a slower rate, while permeable features utilize this energy in photosynthesis (Jäkel et al., 2013). This results in the strongest UHI effect during nights and winter months and weakest during the summer months (Kim et al., 2002).

According to the EPA (2012) the UHI effect can increase the average air temperature of an urban area by 1-3°C to that of its surrounding suburb during the day, while at night it can be as great as a 10-12°C difference. A study done by Reidat (1971) concluded that from 1931-1960 the urban area of Hamburg witnessed temperature differences of 1°C from the outer rural area (Hoffman et al., 2013). A more recent study done from 1990-1999 by Schlünzen (2010) found that the UHI effect within the Hamburg, Germany area witnessed a minimum temperature difference of 1°C from urban and rural locations.

UHI intensity is related to the patterns of land-use/land-cover (LUCC) and the changes they undergo. The objective of this paper is; to classify five different land-use/land-cover types within the two regions, calculate the surface temperatures across the regions, and analyze surface temperature patterns to LULC patterns. Ultimately this will relate how a change in the LULC will impact the urban heat island effect. This will be done using remotely sensed data of the Hamilton and Toronto regions.

Table 1 - Summary of different surface albedo

Surface	Albedo (% reflected)
Fresh Snow	80-95
Cropland	10-25
Asphalt	5-10
Forest	10-15
Water	50-60
Soil	5-25

2 Data and methods

2.1 Study Area

The Toronto Region (Toronto, Peel, and part of York census districts) is the largest city in Canada with a population of 2,192,721 in 1986, growing to 2,503,281 in 2006 (an increase of 310,560) (Statistics Canada, 1987; Statistics Canada 2006). The Toronto Region lies at 43°42′N 79°24′W, on the north shore of Lake OntarioA second region, south of the Toronto Region was selected, the City of Hamilton. The City of Hamilton lies on the south shore of Lake Ontario. Hamilton had a population of 306,728 in 1987 and by 2006 this population had grown by 197,831 to a total population of 504,559 (Statistics Canada, 1987; Statistics Canada 2006).

Figure 1 - Study Area: Toronto on the north shore and Hamilton on the south shore of Lake Ontario
◆ - Toronto Downtown Climate Station

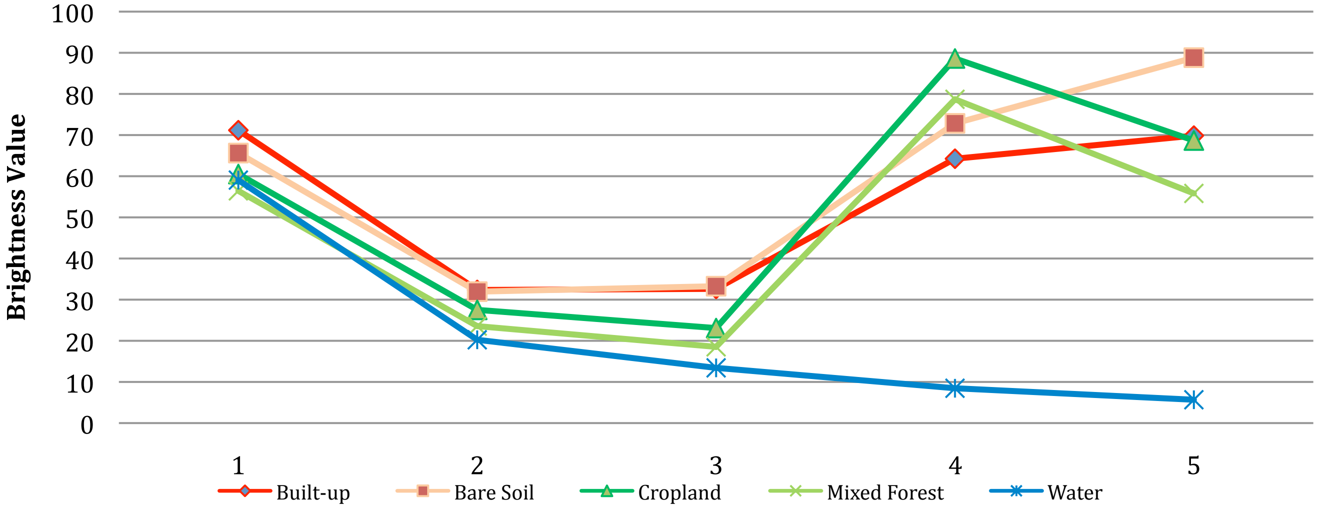

Figure 2 - Spectral signatures of LULC classifications

2.2 Satellite Imagery

Two images were acquired: May 5, 1987 and September 11, 2005. These images distinguish five different LULC (using bands 1-5) based on their reflectance values. Band 6 (thermal band) allowed for the surface temperatures were calculated in degrees centigrade (°C). To quantitatively measure the land surface temperature of the two study areas, the minimum temperatures were used as a reference, allowing for an acceptable comparison of both images. The images were obtained from Landsat5 TM sensors, containing data from bands 1-5 with a spatial resolution of 30m alongside band 6 that contained a spatial resolution of 60m. These images contain an 8-bit radiometric resolution and have been geometrically correct to WSG84 previous to this study.

2.2.1 Image pre-processing

Once the Landsat5 TM data were obtained, it went through various steps of preprocessing for further analysis. The images acquired have been previously georeferenced to WSG84 and have been corrected for atmospheric noise. Due to the difference in spatial resolution however, all bands (1-6) were re-sampled to a spatial resolution of 30m using the nearest neighbour algorithm in ENVI 5.0 classic to maintain data quality.

2.2.2 Derivation of brightness temperature

To analyze the UHI effect quantitatively, the thermal data (Band 6) must contain quantitative data. Thermal sensors on satellites, such as the TM used in this study, measure radiance at the top of the atmosphere, from which brightness values or blackbody temperatures can be obtained using Planks Law (Dash et al., 2002). ENVI 5.0 Classic calculated the brightness values of band 6 to radiance through the Landsat Calibration tool.

Water vapour content varies between the two images due to the change in seasons (Chen et al., 2005), and as such has been accounted for. It is not appropriate to directly compare temperatures represented by the brightness temperatures from different time periods. Therefore, the focus of the UHI intensity and its spatial patterns across the study region were done independently of each other however using the referenced values stated in section 2.2.3 overall comparisons were done.

2.2.3 Retrieval of Landsat 5 TM image surface temperature

The radiance values for both band 6 images from 1987 and 2005 band 6 were converted into surface temperature (°C) values according to Planks Law (Dash et al., 2002). Remote sensing band math was completed according to formula 1 produced by Yale University (2010):

$$(1)\ T_s = (\ 1260.56\ /\ \mathrm{alog}\ (((\ 607.76*0.95\ )\ /\ B6) + 1\ ))\ -\ 273.15K$$

Where:

T_s = surface temperature in degrees Celsius
B6 = Thermal band radiance values

To compare multiple images to one another, they need a reference point. The reference point used in this study was the corresponding minimum temperature of the complete image. The 1987 image had a minimum temperature of 13.01°C. The 2005 image had a minimum temperature of 24.34°C which were deducted from the corresponding surface temperatures.

2.3 Land-use/Land-cover classification

After the conversion of the brightness temperatures to surface temperatures (°C) (Figure 5-6), bands 1-5 were used to classify LULC using a maximum likely-hood supervised classification. Each LULC was classified based on their unique spectral signatures that were assigned through defined Regions of Interest (ROI's). As seen in Figure 2, all five bands contribute in distinguishing one classification from another. Bands 4 and 5 distinguish a reflectance value

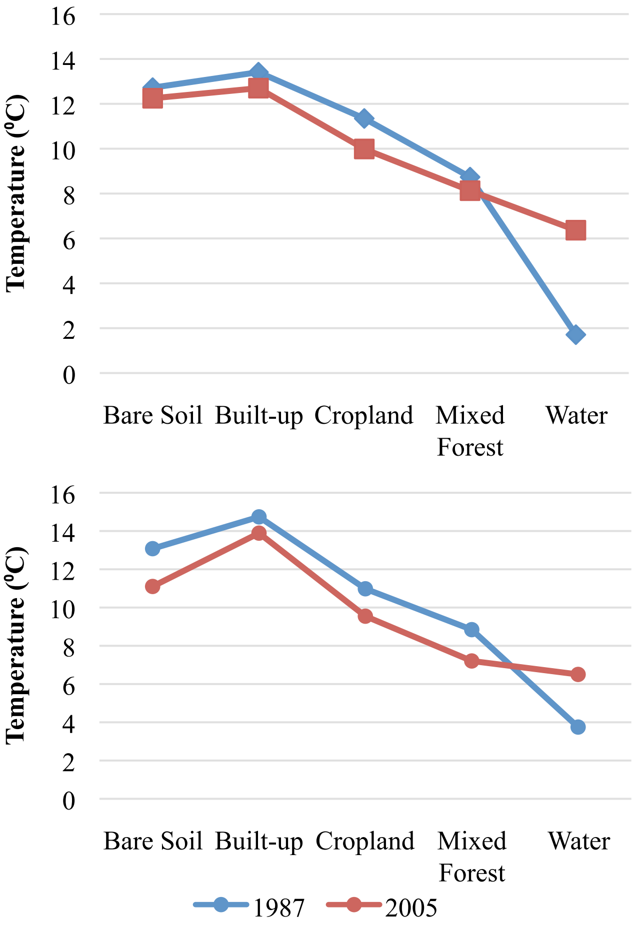

Figure 3 - LULC mean surface temperatures, top: Hamilton region; below: Toronto region

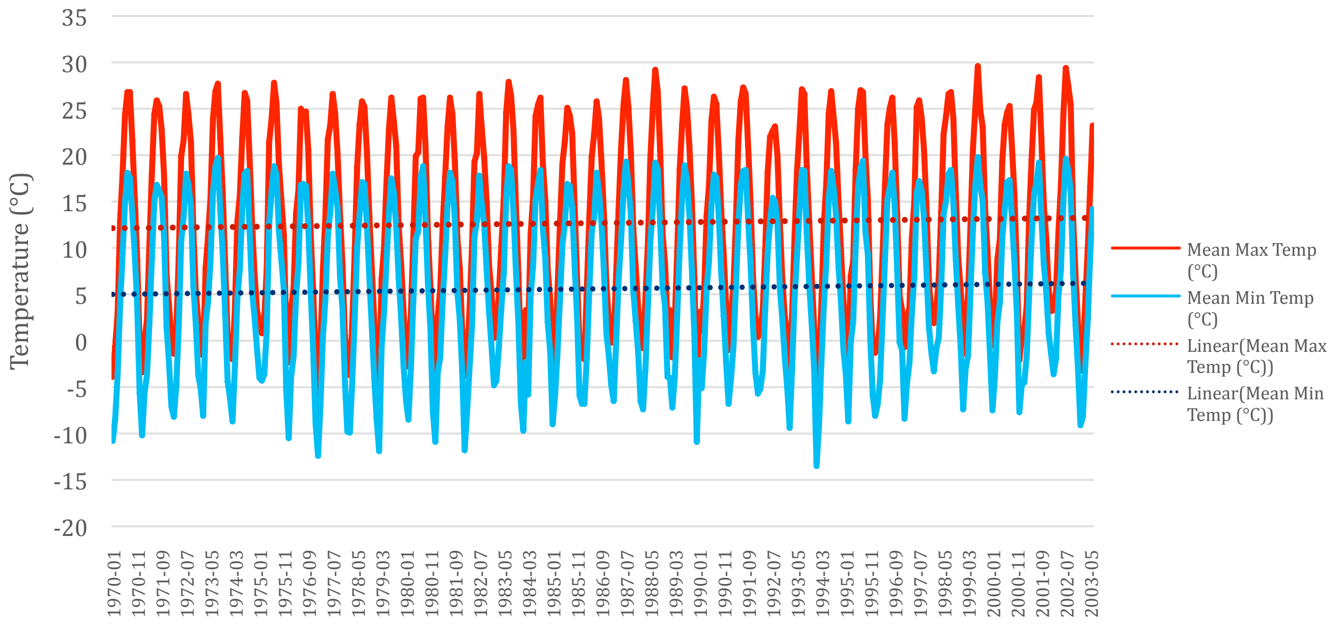

Figure 4 - Air temperatures recorded from the downtown Toronto Climate Station from 1970-2003, both the maximum and minimum temperatures have an increasing trend. Derived from Environment Canada (2014).

Table 2 - Statistics of the Toronto region of different LUL

	Surface Area (km^2)		Mean Surface Temperature (°C)		Change (2005 – 1987)		
Land-use/Land-cover	1987	2005	1987	2005	Surface Area (km^2)	Absolute Surface Area (%)	Absolute Surface Temperature (°C)
Bare Soil	852.20	125.20	14.66	7.679	-727	32%	6.99
Built-up	625.63	1010.67	16.63	10.62	385	17%	6.01
Cropland	575.63	874.80	12.83	5.82	299	13%	7.02
Mixed Forest	231.02	274.67	10.72	3.44	43	2%	7.28
Water	3.15	2.30	5.92	2.80	-0.86	0%	3.12
Total	2287.64	2287.64	-	-	-	-	-

distinctly different for Cropland and Mixed forest as well as between the Built-up and Bare Soil classifications. Band 1 also contributes in distinguishing Bare Soil to that of Built-up LULC and that are important for having the highest accuracy possible. The built-up classification was the region of most interest and was compared to the remaining four classifications. The Built-up classification contains impermeable land surfaces such as buildings, concrete surfaces, and asphalt surfaces. The Bare Soil class contains arid land, and the Water class includes all types of water bodies. Next the agricultural surfaces (permeable land) were further classified into two different LULC: Cropland (grasslands, & agricultural fields) and Mixed Forest (coniferous and deciduous trees). Each unique spectral signature can be seen in figure 2. Within this classification technique there is probability of error between each classification that was calculated to be above 98% for all classified images.

2.4 *Climatic Data*

To further analyze the UHI intensity, climatic data was acquired from Environment Canada at the Toronto Downtown station from 1970 and 2003. The maximum temperature trend demonstrates how the UHI is affected during midday events, while the minimum temperature trend demonstrates the increasing effect of the UHI intensity during night events (Figure 4).

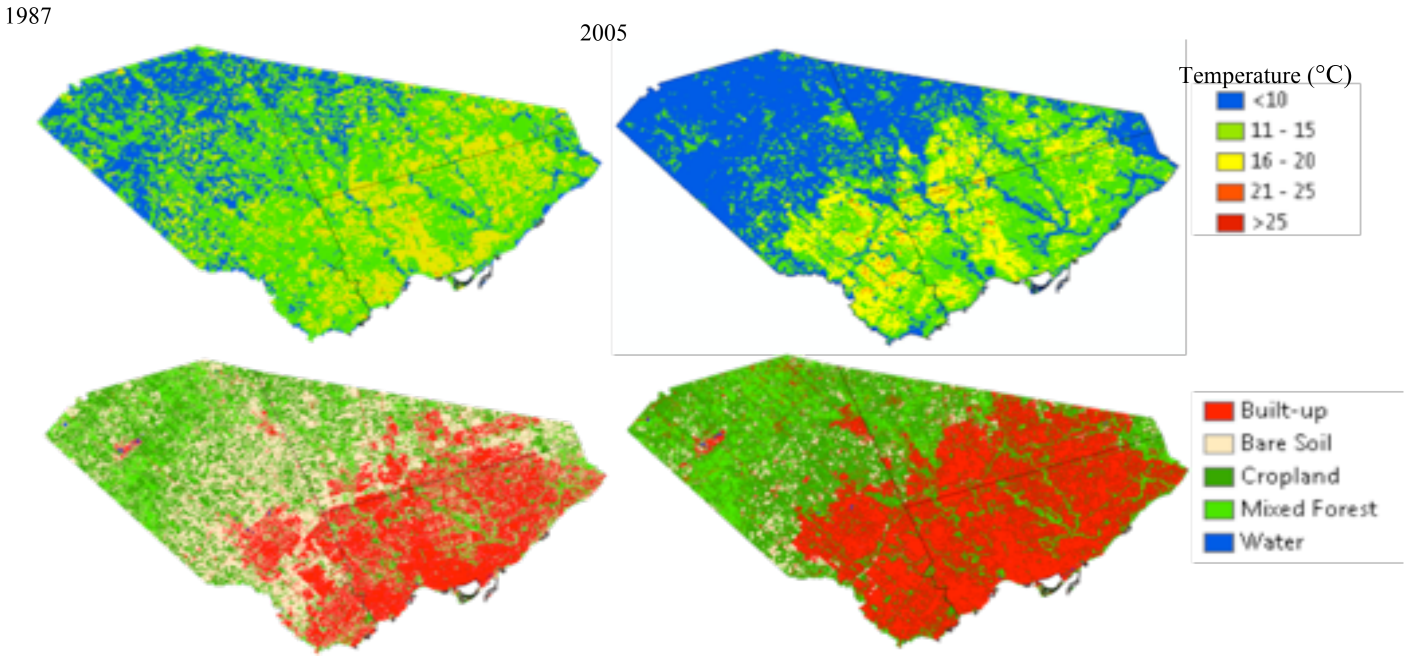

Figure 5 - Toronto region: above - surface temperature map, below - LULC map

Table 3 - Statistics of the Hamilton region of different LULC and surface temperatures

	Surface Area (km^2)		Mean Surface Temperature (°C)		Change (2005 – 1987)		
Land-use/Land-cover	1987	2005	1987	2005	Surface Area (km^2)	Absolute Surface Area (%)	Absolute Surface Temperature (°C)
Bare Soil	361.85	276.92	12.72	12.24	-84.94	7%	5.44
Built-up	295.76	318.55	13.41	12.69	22.78	2%	5.55
Cropland	318.55	334.42	11.34	9.98	15.87	1%	6.48
Mixed Forest	148.24	196.04	8.73	8.12	47.80	4%	6.49
Water	22.86	21.34	1.70	6.37	-1.52	0%	1.27
Total	1147.28	1147.28	-	-	-	-	-

3 Results & Discussion

3.1 LULC Changes

Since 1987 both the Hamilton and Toronto regions have expanded in population resulting in a growth of more urbanized land-use/land-cover. With a change in LULC to a built-up LULC, the anthropogenic heat sources are increased, increasing sensible heat storage, which allows for surface temperatures to increase as a quicker rate, as well as cool as a slower rate.

3.1.1 Hamilton Region LULC Changes

In the Hamilton Region, the largest change occurred with a decrease in the Bare Soil class (7%), and an increase of Agricultural land (both mixed forest and cropland) by 5%. This can be accounted for by the change in season from the 1987 spring image (early growing season) to an early fall image in 2005 (end of growing season) (refer to Figure 6 and Table 3). The remaining 2% can be accounted for by a growth in urban settings, increasing in the built-up LULC by 2%.

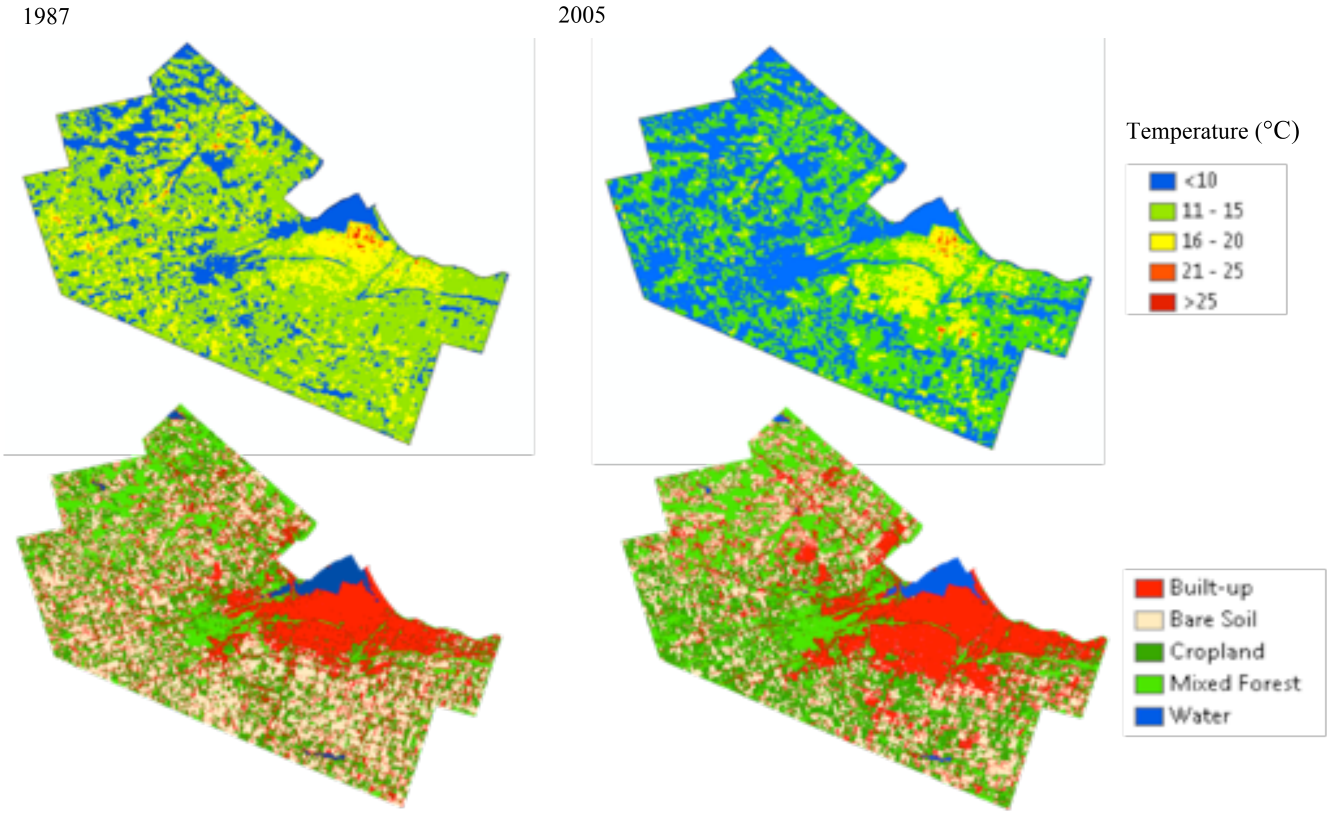

Figure 6 - Hamilton region: above - surface temperature map, below - LULC map

3.1.2 *Toronto Region LULC Changes*

From 1987 to 2005, the greatest changed occurred within the Bare Soil class. The Bare Soil class decreased 32% of its land from 1987 to 2005, which is a result due to the acquisition time of the images. The 1987 image was acquired prior to the growing season, while 2005 occurred near the end of the growing season when a majority of the agricultural fields were healthy. However, due to this study, the decrease in Bare Soil class is not a large factor in the UHI intensity. The Built-up LULC had a growth of 17% over the 18-year period, while the remaining change in loss of the Bare Soil class was accounted for by 13% growth in Cropland, and 2% growth in Mixed Forest.

3.2 *Surface Temperatures.*

3.2.1 *Hamilton Surface Temperatures*

In the Hamilton Region, the highest temperature corresponds to the Built-up LULC classification at 13.41°C above the minimum temperature in 1987 and 12.69°C above the minimum temperature of 2005. Bare Soil had similar results as the Built-up classification with a mean temperature of 12.72°C in 1986 and 12.24°C in 2005. As for the permeable LULC classifications (combination of Cropland and Mixed Forest classes), the average temperature in 1986 was 10.03°C and 9.05°C in 2006, over 2°C difference from permeable to impermeable surfaces.

3.2.2 *Toronto Surface Temperatures*

The Toronto Region followed the same temperature vs. LULC trends as the Hamilton region. Built-up classification had a mean temperature of 13.05°C over the two studied years while Bare Soil had an average of 12.48°C (Table 2). The permeable surfaces had an overall mean temperature of 9.55°C over the two study periods, again 2°C greater than that of the impermeable surfaces (Bare Soil and Built-up classifications).

3.2.3 *Surface Temperature Trends*

It was found, that in both regions the season had an impact on the UHI intensity. The 1987 image was taken in spring and had a greater UHI intensity in both the Toronto region and the Hamilton region for all LULC classifications except that of water. The Built-up classification had a greater temperature in both regions during the spring month of May compared to the fall month of September in 2005 (Toronto 0.85°C difference from 1987 to 2006 while Hamilton had a difference of 0.72°C). This shows that the UHI intensity changes with a change in season, with a greater impact coming in spring (May) over that of fall (September).

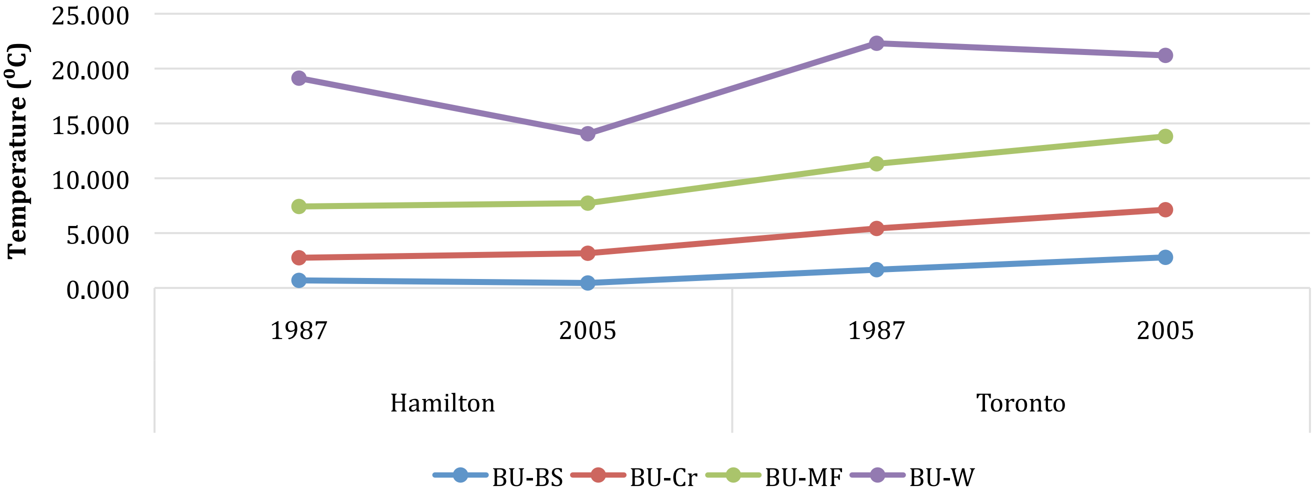

Figure 7 – Temperature difference between different LULC types (BU - built-up, BS - bare soil, Cr -cropland, MF - mixed forest, W - water

Table 4 - Temperature difference between different LULC types. BU - built up, BS - bare soil, Cr - cropland, MF - mixed forest, W - water

	Hamilton		Toronto		Average
	1987	2005	1987	2005	
BU	12.722	12.247	14.740	13.890	**14.097**
BU-BS	0.687769	0.450806	1.662	2.789	**1.540**
BU-Cr	2.06298	2.71057	3.760	4.343	**3.434**
BU-MF	4.676189	4.569075	5.897	6.684	**5.748**
BU-W	11.700139	6.330982	10.990	7.387	**9.400**

3.3 LULC Temperature variation

Due to the images being acquired during different months, the minimum temperature value was used as a reference and removed from all temperature values, allowing for a comparison between LULC types to be executed. To compare the UHI intensity LULC temperature values were compared to the Built-up classification temperature values to determine the intensity of the UHI (Table 4).

3.3.1 LULC Temperature variations in the Hamilton Region

In the Hamilton region during 1987 the mean Built-up temperature was 12.72°C while in 2005 it was 12.25°C. A minimal temperature variation occurred from the Built-up class to the Bare Soil type with a variation of 0.69°C in 1987 and 0.45°C in 2005.

The permeable surfaces had a greater variation of temperature. Cropland had a 2.06°C variation in 1987 and 2.71°C in 2005 while the Mixed Forest had a variation of 4.68°C in 1987 and 4.57°C in 2005.

3.3.2 LULC Temperature variations in the Toronto Region

In the Toronto region similar trends occurred, but with greater intensity. The UHI intensity was greater in Toronto, and this can be a result due to the extreme size of the city, resulting in much more Built-up LULC. The mean surface temperature of the Built-up LULC was 14.74°C in 1987 and 13.89°C in 2005. The Bare Soil variation was 1.66°C in 1987 and 2.79°C in 2005 (over an average of 1°C increase from the Bare Soil variation in the Hamilton Region). Cropland had a variation of 3.76°C in 1987 and 3.43°C in 2005 while the Mixed Forest had a variation of 5.99°C and 6.68°C.

3.3.3 LULC patterns

A further analysis of the UHI intensity was done, comparing the mean temperature variations over 1987 and 2005 in both the Hamilton and Toronto regions. Bare Soil had a mean variation of 1.54°C and the permeable surfaces had a mean temperature variation of 4.59°C. Again to show that the UHI effect increases with an increase of

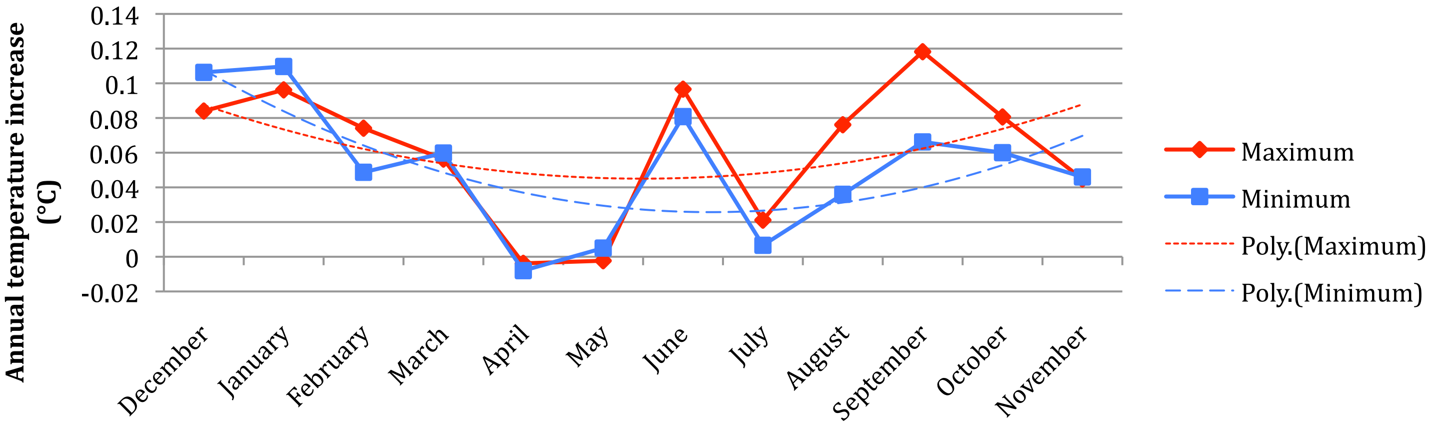

Figure 8 – representation of the monthly temperature trends from 1980-2003. The temperature trends for each month were calculated and plotted. The winter months have increased annual the most while the summer months have increased minimally. Displays the UHI is most effective during winter months and least effective during summer months.

permeable surfaces from impermeable surfaces.

3.4 Effect of UHI on Air Temperature trends

Air Temperatures obtained from Environnment Canada, for the Toronto Downtown weather station from 1970-2003 (Figure 4). From this data the maximum and minimum temperatures were analyzed. From 1970-2003 there was an increasing trend of both maximum and minimum temperatures. The maximum yearly temperature had an increasing trend of 0.0028°C per year, while the minimum temperature had an increasing trend of 0.003°C per year.

3.4.1 Monthly Air Temperature trends

Monthly trends are especially important to the UHI effect. Monthly trends show how the urban heat island intensities change over the year. Thus showing where it is strongest (winter months) and where it is weakest (summer months). As expressed in Figure 4 the air temperature increased between 1980 and 2003 agreeing with the literature phenomenon, that the winter months have seen a greater temperature increase than any other season in the Toronto Region. However there are two outliers in the trend. The months June and September have received an above normal temperature increase, both for their maximum and minimum temperatures, while months before and after fall within the trend.

As depicted in Figure 8 a polynomial trend line was used. This was used to show how the trend goes up and down over the course of a year, peaking during the winter and dropping during the summer.

The most noticeable trend occurred during December & January. The months of December, January and February received the largest impact (refer to Table 5) of the UHI in the Toronto Region. This results in warmer winter temperatures, and increasingly warmer temperatures results in an overall shorter winter.

April and May are the least impacted months by the UHI. The temperature trends for these two months have decreased minimally (refer to Table 5). July has received a minimum impacted during the summer months, however an increase in overall temperatures is occurring even within the summer months. July has received an increase in the maximum temperature of 0.0211°C and a minimum temperature increase of 0.00066C per year. August has also received a minimum impact however greater than that of July of a maximum increase of 0.0761°C and a minimum temperature increase of 0.036°C.

It can be seen in Figure 8 that the winter months are receiving the strongest effect of the UHI. The summer months have witnessed a minimal impact of the UHI effect however both impacts have been increasing along side the growth of built-up land.

Table 4 - monthly air temperature trends in the Toronto Region

	Maximum temperature trend (°C)	Minimum temperature trend (°C)
December	0.084	0.1063
January	0.0962	0.1097
February	0.0741	0.0487
March	0.0563	0.0598
April	-0.0038	-0.008
May	-0.0023	0.005
June	0.0966	0.0808
July	0.0211	0.0066
August	0.0761	0.036
September	0.1182	0.0662
October	0.0806	0.06
November	0.0448	0.046

3.5 Relationship between LULC and Surface Temperature

Analyzing these trends, it was found that the Built-up classification increased in both regions, with an increase of variation between opposing LULC classifications and the Built-up classification. The increase of Built-up area increased alongside an increasing surface temperature average by 4.59°C over both regions (Table 4).

One outlier of this trend lied within the Hamilton region. Within the Mixed Forest LULC class the temperature variation decreased from 1987 to 2005, opposite to the trend witnessed in Toronto. This may have occurred due to a 4% increase of area represented in the rural areas of region, having a change in the surrounding heat capacity capability.

3.6 Mitigation

With the increase of urbanization, this has caused a great deal of permeable surfaces to be altered to impermeable surfaces. Growth in impermeable surfaces is one of the causes increasing the UHI effect increasing over time. A lack of vegetation and open space facilitates the absorptions of solar heat (Wong et al., 2013). With the construction of large buildings, comes the obstruction of natural air patterns flowing though such spaces. Buildings have caused poor ventilation of fresh air, trapping pollutants at surface levels (Wong et al., 2013). This has the potential to have an UHI intensity of up to 10°C in urban locations (Kolokotsa et al., 2013).

However, an increase in the overall coverage of green space within urban cities could be a solution. Turning rooftops into "green roofs" could be a solution to mitigate against the increasing UHI effect. Green roofs are considered as a living layered vegetated roofing system. Plants can range from shrubs, trees and grasses with a layer of organic soil beneath.

Green roofs have been recognized as a valid practice to re-establishing the vanishing green space in urban locations. A study by Hui (2009) state that increasing the green space in Germany by 7% could cool cities by 2°C during the summer months, while in New York and Toronto transforming 50% of the rooftops could reduce the temperature by 0.8°C (Lie et al., 2005).

4 Conclusion

In this study, both qualitative and quantitative analyses were done in order to compare the relationships of LULC changes and the changes in UHI intensities. The study focused on two regions in southern Ontario, one on the north shore of Lake Ontario and another on the south shore. From the two regions studied, the Toronto region had a much greater growth in urban sprawl from 1987-2005 to that of the Hamilton region. The results conclude that a change in LULC does have an impact on the surface temperature, and to the UHI effect. This impact was shown to increase the UHI intensity with the growth of urbanized areas.

In the Toronto region, the UHI intensity was greater than that of the Hamilton region, which can be a result due to the large growth of urbanized areas and built-up land that occurred within the Toronto Region.

The Built-up classification had the greatest surface temperature within both regions, on average 1.5°C greater than the Bare Soil class, and upwards to an average of 9.4°C above the Water class. As the LULC changes over time to favour the Built-up class, the temperature of the surface, and ultimately the global surface temperature, will increase.

Further more the growth of built-up land also resulted in the air temperature to increase over time. The air temperature results from 1980-2003 show that winter months are greatly impacted by the UHI while the summer months do see an impact one, but one of minimal magnitude.

This study was based on remote sensed interpretation, which does contain room for error, but also allows for the interpretation of a surface rather than just point data, which has been done using climate stations. The purpose of this study was to quantify the UHI effect on a regional basis covering a surface, which has led to the conclusion that built-up regions are in fact much warmer and do play a significant role in the UHI effect, as well as global warming.

5 References

Chen, X., Zhao, H., Li, P., & Yin, Z. 2006. Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes.(Report). Remote Sensing Of Environment, (2), 133. doi:10.1016/j.rse.2005.11.016

Dash, P., Gottsche, F. -M., Olesen, F. -S., & Fischer, H. 2002. Land surface temperature and emissivity estimation from passive sensor data: Theory and practice—current trends. International Journal of Remote Sensing, 23(13), 2563–2594.

Environment Canada. 2014. Toronto Weather Station 1970-2003 Monthly data. Acquired from http://climate.weather.gc.ca/

EPA. 2012. *Heat Island effect.* United States Environmental Protection Agency:http://www.epa.gov.hiri/

Grawe, D., Thompson, H., Salmond, J., Cai, X., & Schlunzen, K. 2013. Modelling the impact of urbanisation on regional climate in the Greater London Area. International Journal Of Climatology, 33(10), 2388-2401.

Hoffmann, P., & Schlünzen, K. 2013. Weather Pattern Classification to Represent the Urban Heat Island in Present and Future Climate. Journal Of Applied Meteorology & Climatology, 52(12), 2699-2714. doi:10.1175/JAMC-D-12-065.1

Hui, S. C. M. 2009. Study of thermal and energy performance of green roof systems: Final report. Hong Kong: Department of Mechanical Engineering, The Universityof Hong Kong.

IPCC. 2007. Fourth Assessment: Summary. **Report for Policy Makers**. www.ipcc.ch

Jäkel, E. E., Wendisch, M. M., & Mayer, B. B. 2013. Influence of spatial heterogeneity of local surface albedo on the area-averaged surface albedo retrieved from airborne irradiance measurements. Atmospheric Measurement Techniques, 6(3), 527-537. doi:10.5194/amt-6-527-2013

Kuscu. C., & Sengezer. B. 2011. Determination of Heat Islands from Landsat TM Data: Relationship between Surface Temperature and Urbanization Factors in Istanbul.

Kolokotsa, D., Santamouris, M., & Zerefos, S. (2013). Green and cool roofs' urban heat island mitigation potential in European climates for office buildings under free floating conditions. Solar Energy, 95118-130.

Landsat. 1986. Landsat5 0800905280314_00005, Standard Geometrically Corrected, USGS. May 5, 1987.

Landsat. 2005. Landsat5 9990812020001_00070, Standard Geometrically Corrected, USGS. September 11, 2005.

Li, C., & Yin, J. 2013. A Study on Urban Thermal Field of Shanghai Using Multi-source Remote Sensing Data. Journal Of The Indian Society Of Remote Sensing, 41(4), 1009-1019.

Liu, K., & Bass, B. 2005. Performance of green roof systems. Toronto, Canada: National Research Council Canada, Report No. NRCC-47705.

Pielke RA, Marland G, Betts RA, Chase TN, Eastman JL, Niles JO, Niyogi DS, Running SW. 2002. The influence of land-use change and landscape dynamics on the climate system: relevance to climatechange policy beyond the radiative effect of greenhouse gases. Philosophical Transactions of the Royal Society of London. SeriesA – Mathematical, Physical and Environmental Sciences 360(1797): 1705–1719.

Reidat R. 1971. Temperature, Niederschlag, Staub. Deutscher Planungsatlas. Band VIII. Hamburg, Lieferung 7. Gebrüder Jänecke, Hannover

Schlunzen, K., Hoffman, P., Rosenhagen, G., Riecke, W. 2010. Long-term changes and regional differences in temperature and precipitation in the metropolitan area of Hamburg. *International Journal of Climatology,* 30, 1121-1136.

Statistics Canada. 1986. Census Population.

Statistics Canada. 2006. Census Population.

UN. 2012. World Urbanisation Prospects: The 2011 revision. United Nations Population Division. United Nations, Department of Economic and Social Affairs, Population Division: New York.

Wong, J., & Lau, L. 2013. From the 'urban heat island' to the 'green island'? A preliminary investigation into the potential of retrofitting green roofs in Mongkok district of Hong Kong. Habitat International, 3925-35. doi:10.1016/j.habitatint.2012.10.005

Yale University. 2010. Converting Landsat TM and ETM+ thermal bands to temperature. Acquired from: http://www.yale.edu/ceo/Documentation/Landsat_DN_to_Kelvin.pdf.

Yow, D. M. 2007. Urban heat islands: Observations, impacts, and adaptation. Geogr. Compass, 1, 1227–1251.