Urban Heat Island:

Mitigating the worst of increasing temperatures in Montreal

By Tuviere Onookome-Okome
Social Connectedness Fellow 2021
Samuel Centre for Social Connectedness
www.samuelconnectedness.org
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TABLE OF CONTENTS:

EXECUTIVE SUMMARY

This research sought to explore the relationship between income levels and heat in different neighborhoods, with a focus on Montreal, Canada. This was done via the use of heat sensors placed around the city. As a whole, this research found that lower income neighbourhoods in Montreal experience increased heat during the summer months, and especially during heat waves. Lower income areas are more likely to have decreased tree coverage and increased land-use variables, such as concrete and asphalt. The inherent built environment in lower income areas in Montreal are not well equipped or well-built in an increasingly hotter world. Moreover, through our validation analysis, we found that temperature from satellite estimates are generally in agreement with ground-level estimates of temperature. Collecting satellite based temperature estimates is a low-cost option, and this study provides further proof that satellites can be an easy and reliable way to measure temperature.

Recommendations for addressing these issues include creating a new heat alert system which prioritizes lower income neighbourhoods, installing more green spaces in lower income neighborhoods, a reinvestment in infrastructure that increases social networks during a heat wave, satellite based estimates of temperatures when designing heat mitigation plans, and finally, citizen science initiatives where residents can collect their own temperature data for future research.

INTRODUCTION

This research focused on exploring the effects of heat events on the lives of the residents of Montreal, particularly by understanding how different Montreal residents experience heat within their own neighbourhoods. Moreover, this study also addressed the question of *how* heat is currently measured, and if a monitoring campaign of ground level data would show different levels of temperature estimates as compared to satellite estimates.

My fellowship was conducted in partnership with the Samuel Centre for Social Connectedness, based in Montreal, and the Data-Driven EnviroLab ("DDL") at the University of North Carolina-Chapel Hill. DDL is a research group which uses data analytics to help solve some of the world's biggest environmental problems. They are also concerned about the issues of heat waves and urban environmental health, and have previously constructed a quantitative index incorporating the effects of the urban heat island in numerous cities around the world.

There is growing concern in the world of the effects of extreme weather, and in particular, concern around the rising trend of extreme heat events, and of rising temperatures as a whole. Since 1880, the average temperature globally has risen by 1.1-1.3 degree celsius per decade.[1] This rate has also nearly tripled since the 1990's.[2] In fact, 19 out of the last 20 years have been the hottest years on record, a trend that is, unfortunately, expected to continue.[3] In Canada, climate models show that 2051-2080 will

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[1] Hausfather Z. State of the climate: How the world warmed in 2019 | Carbon Brief [Internet]. Carbon Brief. 2020 [cited 14 August 2021]. Available from: https://www.carbonbrief.org/state-of-the-climate-how-the-world-warmed-in-2019
[2] Prairie Climate Center. Heat waves and health: A special report on climate change in Canada. Winnipeg: Prairie Climate Center; 2019 p. https://climateatlas.ca/heat-health-report.pdf.
[3] Ibid.

see at least 4 times as many 30 degree celsius plus days per year as compared to previous years.[4]

Globally, there is no consensus on the definition of heat waves; however, most agree that a heat wave is a prolonged period of unusually hot weather, often combined with extreme humidity. Environment Canada defines a heat wave as “a period of at least 3 days in a row which reaches 30 degree celsius or higher.”[5] Conversely the Canadian province of Quebec defines an extreme heat wave as “a period of 3 consecutive days in which the 3-day weighted moving average maximum as well as minimum temperatures reach a predefined temperature threshold that is based on expected excess mortality.”[6] In sum, for Quebec, depending on the region, a heat wave is defined as having consecutive maximum temperatures anywhere between 31 and 33 degrees celsius and minimum temperatures anywhere between 16 and 20 degree celsius.[7]

Quebec and Montreal as a whole have both seen increased frequency in the number of heat waves over the last two decades. Quebec, for example, experienced one of its worst heat waves in 2018. From July 1st to July 8th, the air was consistently above 35 degrees in many parts of Quebec, and the humidex, which measures both temperature and humidity level, peaked at 45 in Montreal.[8] At the height of the 2018 heat wave, emergency services in Montreal reported twelve hundred calls per day, mainly pertaining to the heat, a

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[4] Ibid.
[5] Centre-Sud-de-l’île-de-Montreal. CHALEUR ACCABLANTE OU EXTRÊME 2018 [Internet]. Montréal: Gouvernement du Québec; 2018. Available from: https://santemontreal.qc.ca/fileadmin/user_upload/Uploads/tx_asssmpublications/pdf/publications/9782550757948.pdf
[6] Ibid.
[7] Ibid.
[8] Spears T. Ottawa misses a heat record, but sets a humidex record. Ottawa Citizen [Internet]. 2018 [cited 19 August 2021];. Available from: https://ottawacitizen.com/news/local-news/ottawa-misses-a-heat-record-but-sets-a-humidex-record

number up 30% from the previous busiest days.[9] The 2018 heat wave also had deadly consequences, with up to 86 heat-related deaths being recorded throughout the province.[10]

Heat, and the role of heat in human health, is of growing importance in a rapidly warming world. The United Nations Intergovernmental Panel on Climate Change Working Group 1 report points a picture of clear devastation if we are not to curb the worst effects of a warming climate, and this is especially relevant when we look at extreme weather events such as heat waves.[11] In reviewing this new report, my study attempts to better understand how increased heat waves affects residents in Montreal. More specifically, it collects real time ground level temperature from the summer of 2019 and from numerous neighbourhoods in Montreal, and attempts to quantify how temperature values might differ from neighbourhood to neighbourhood.

This study focuses on the urban heat island effect in Montreal. For the purposes of this paper, the urban heat island effect is defined as "a phenomenon in which urban areas are significantly higher in temperature than surrounding areas."[12] In large part, this effect is due to the replacement of rural, vegetated areas with built up structures, which then can create areas within the city that are significantly hotter than surrounding rural areas. The next sections will better describe the urban heat island effect on the Island of Montreal, as well as the health and economic effects of heat.

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[9] Ibid.
[10] Ibid.
[11] Intergovernmental panel on climate change (IPCC) [Internet]. Geneva: The United Nations; 2021. Available from: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf
[12] U.S. Environmental Protection Agency (EPA). Reducing urban heat islands: Compendium of strategies [Internet]. Washington DC: EPA; 2008. Available from: https://www.epa.gov/heat-islands/heat-island-compendium.

URBAN HEAT ISLAND AND MONTREAL

Currently, an estimated 55% of the world lives in cities.[13] By 2050, scientists expect this number to rise to 68% globally.[14] However, cities and their built environment are often more susceptible to the effects of heat waves, and the urban heat island effect is a direct result of urbanization. The susceptibility to heat is amplified in cities such as Montreal and Toronto, which are often closely packed with residents who live in buildings made of materials such as concrete and asphalt. These materials are excellent at trapping and eventually amplifying heat during heat events. In particular, materials like concrete trap heat during the day, and at night-time, release this heat back into the immediate environment.

In Montreal, the effects of the urban heat island can be directly linked to where individuals reside. More specifically, the western end of the Island is less prone to the effects of the urban heat island due to lower population density, as well as a lot more tree cover.[15] Those on the eastern part of the city, however, are the most affected by the effects of the urban heat island due to less tree cover.[16]

HEAT AND THE HUMAN BODY

Heat can be deeply harmful to the human body. Those especially susceptible to the effects of heat waves include older adults, those who live with chronic illnesses, and those who are socially isolated.[17] People over the age of 60 account for 82-92% of excess

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[13] The United Nations. 68% of the world population is projected to live in urban areas by 2050, says the UN. Geneva; The United Nations, 2018.
[14] Ibid.
[15] Suh C. The urban heat island in Montreal [Internet]. Data Driven lab; 2019. Available from: http://datadrivenlab.org/the-urban-heat-island-effect-in-montreal/
[16] Ibid.
[17] Lubik, A., & Kosatsky, T. Is mitigating social isolation a planning priority for the British. Columbia (CANADA) municipalities? BC Centre for Disease control; 2018.
BC Centre for Disease Control.

mortality during heat waves.[18] This was especially true in the context of the 1995 Chicago heat wave.[19] People over the age of 65 accounted for 72% of all deaths during this heat wave,[20] a statistic that is related in part to the fact that the body's ability to thermoregulate decreases as individuals age.[21] In turn, this decreased ability to maintain core temperature is linked to many physiological processes. Three main processes can explain this phenomenon: changes in sweating capacity, changes to fitness ability and finally, changes in skin blood flow. Notably, older individuals overall seem to have a delayed sweat threshold,[22] which can be dangerous as sweating and the process of evaporation are the main ways humans cool themselves down during increased external temperatures.[23.] Moreover, an individual's ability to easily engage in physical activity diminishes by 10 percent each decade, beginning during their 20's.[24] Therefore, when individuals age, their ability to participate in strenuous physical activity decreases, with decreased ability to participate in physical activity being linked to the body's decreased ability to properly handle high temperatures. Finally, the control of skin blood flow is paramount for dissipating

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18 Balmain B, Sabapathy S, Louis M, Morris N. Aging and Thermoregulatory Control: The Clinical Implications of Exercising under Heat Stress in Older Individuals. BioMed Research International. 2018;2018:1-12.

19 Lubik, A., & Kosatsky, T. Is mitigating social isolation a planning priority for the British. Columbia (CANADA) municipalities? BC Centre for Disease control; 2018.

20 Ibid.

21 Health Canada. Extreme Heat Events Guidelines: Technical Guide for Health Workers [Internet]. Ottawa: Health Canada; 2011. Available from: https://www.canada.ca/en/health-canada/services/environmental-workplacehealth/reports-publications/climate-change-health/extreme-heat-events-guidelinestechnical-guide-health-care-workers.html#a1.1

22 Havenith G. Temperature regulation, Heat Balance and Climatic Stress. In: Kirch W, Menne B, Bertollini R, ed. by. Extreme Weather Events and Public Health Responses. 1st ed. 2005. p. 69-80.

23 Ibid.

24 Health Canada. Extreme Heat Events Guidelines: Technical Guide for Health Workers [Internet]. Ottawa: Health Canada; 2011. Available from: https://www.canada.ca/en/health-canada/services/environmental-workplacehealth/reports-publications/climate-change-health/extreme-heat-events-guidelinestechnical-guide-health-care-workers.html#a1.1

heat in the body.[25] When body temperature increases due to external heat, the body's natural response is to increase blood flow as a way to stimulate sweating. Aging is also associated with reduced capacity of many organs, such as the skin. A Health Canada report on heat has pointed to changes in microcirculation (blood flow from the arterioles, capillaries and venules) in older adults.[11] Decreases in the microcirculation process, such as decreased skin blood flow, can further lead to problems with regulating temperature.[26]

People who live with chronic illnesses are also at increased risk of the effects of extreme heat events.[27] This is especially true for those who have a weakened cardiovascular system; as heat causes increases in cardiac output, any external factors which lead to more work for the heart can be detrimental for those with chronic cardiac problems.[28] Additionally, chronic illness and disabilities can sometimes lead to increased body fat, which has been associated with a decreased ability to properly gauge heat in the body, and also to adjust to it.[29]

Finally, those impacted by heat include those who live in social isolation, defined as "a situation in which individuals feel a sense of disconnection from social networks, institutional connections and community participation."[30] This can be illustrated by the 1995 Chicago heat wave, wherein most elderly people who died were those who also lived in

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[25] Havenith G. Temperature regulation, Heat Balance and Climatic Stress. In: Kirch W, Menne B, Bertollini R, ed. by. Extreme Weather Events and Public Health Responses. 1st ed. 2005. p. 69-80.
[26] Health Canada. Extreme Heat Events Guidelines: Technical Guide for Health Workers [Internet]. Ottawa: Health Canada; 2011. Available from: https://www.canada.ca/en/health-canada/services/environmental-workplacehealth/reports-publications/climate-change-health/extreme-heat-events-guidelinestechnical-guide-health-care-workers.html#a1.1
[27] Ibid.
[28] Ibid.
[29] Ibid.
[30] National Seniors Council. Who's at risk and what can be done about it? A review of the literature on the social isolation of different groups of seniors [Internet]. Ottawa: Government of Canada; 2017. Available from: https://www.canada.ca/en/national-seniors-council/programs/publicationsreports/2017/review-social-isolation-seniors.html

social isolation. Notably, it was Black elderly people in Chicago who were at the highest risk,[31] as elderly Black residents in Chicago did not have the same access to communities that could support them in moving to cooling centers, or help them to mitigate the worst effects of the heat wave.[32] While Chicago is not the only place to experience a devastating heat wave, nor the only place in which the Black population, particularly Black older adults, experienced more profound negative impacts of heat, Chicago serves as a case study for the particular devastation that heat waves can wreak when heat is combined with social isolation. Going beyond the Chicago context, those who are socially isolated often also suffer from other mental afflictions such as stress, anxiety and depression.[33] Feelings such as this can be especially dangerous during emergencies such as heat events, because there can be a lack of support or resources for mental health challenges. As well, those who are socially isolated also often belong to the lowest income brackets, and as a result, do not have the financial resources to afford equipment such as an air conditioner.[34] They may also live in poor housing which has little air flow.[35.] Tying it all together, older individuals have been shown to experience the highest levels of social isolation.[36] Social isolation, combined with the physiological changes that come with aging, can be extremely detrimental in the event of extreme heat. In summary, while heat can have a detrimental impact on individuals from all walks of life, it is those who are already experiencing

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[31] Lubik, A., & Kosatsky, T. Is mitigating social isolation a planning priority for the British. Columbia (CANADA) municipalities? BC Centre for Disease control; 2018.
[32] Ibid.
[33] Ibid.
[34] Yardley J, Sigal R, Kenny G. Heat health planning: The importance of social and community factors. Global Environmental Change. 2011;21(2):670-679.
[35] Ibid.
[36] Lubik, A., & Kosatsky, T. Is mitigating social isolation a planning priority for the British. Columbia (CANADA) municipalities? BC Centre for Disease control; 2018.

vulnerabilities, be it due to age, health status, social isolation, or a combination of the above factors, that are most at risk to adverse reactions to heat.

MEASURING HEAT IN MONTREAL

The first section of this report evaluates the health and the economic costs of heat waves. However, *how* we measure heat is paramount to mitigating the worst effects of this weather phenomenon. To date, temperatures in cities have been measured using satellite imaging and/or by using a fixed site temperature monitor, usually located at the outskirts of the city. Satellite imaging can estimate city temperatures by measuring the heat energy given off by land, buildings, and other surfaces within the city.[37] However, the main limitation in using satellite imaging is that while they can provide estimates for temperature, they often cannot provide the finer details of variations within and between certain neighbourhoods.[38] Moreover, trees or tall buildings may prevent satellites from capturing accurate ground level temperatures.[39] Finally, satellites only collect data at specified time intervals, which correspond to when the specific satellite passes the city, and are only available during clear weather.

Another way in which temperature in cities can be measured is through a fixed temperature site. In the Montreal context, this site is located at the Montreal airport, which is outside of the city in Dorval. All individuals in the city are then given the same temperature estimate coming from this fixed monitor. The main issue with this mode of measurement is that it cannot take into account land use variables, such as building

[37] United States Environmental Protection Agency (EPA). Measuring heat islands. Washington D.C.: EPA; 2021.
[38] Ibid.
[39] Ibid.

density, types of building materials, and green spaces.[40] By giving everyone on the Island of Montreal the same temperature value, we forget that residents in the Montreal neighbourhood of say, Mont-Royal, for example, have very different land coverage (a lot of parks and vegetated areas) as compared to the neighbourhood of Montreal-Nord (a lot of concrete pavement). Using this fixed monitor, we cannot account for how different neighbourhoods could see large variations in temperature.

As explained in the above paragraphs, these two measurements of temperature do not allow for fine-scale estimates of temperatures. The main goal of this section is to utilize a large-scale monitoring campaign of ground-level heat monitors to better characterize variations of temperatures in the different neighbourhoods in Montreal. The methods section will explore this new way of measuring temperature.

INCOME DISPARITIES BY NEIGHBORHOOD IN MONTREAL

The ways in which people experience heat differs depending on what postal code an individual lives in Montreal. DDL has collected satellite estimates of temperature in Montreal, and have found that the western end of the Island of Montreal is less prone to the urban heat island effect due to a much lower population density, as well as having a lot of tree cover.[41] On the other hand, the central part of the Island, as well as the eastern part of the island, are *more* susceptible to the effects of the urban heat island, due in part to differences in overall population, as well as a greater absence of tree cover.[42] In the section below, a map serves to highlight and detail which parts of the Island are in fact most affected by the urban heat island effect.

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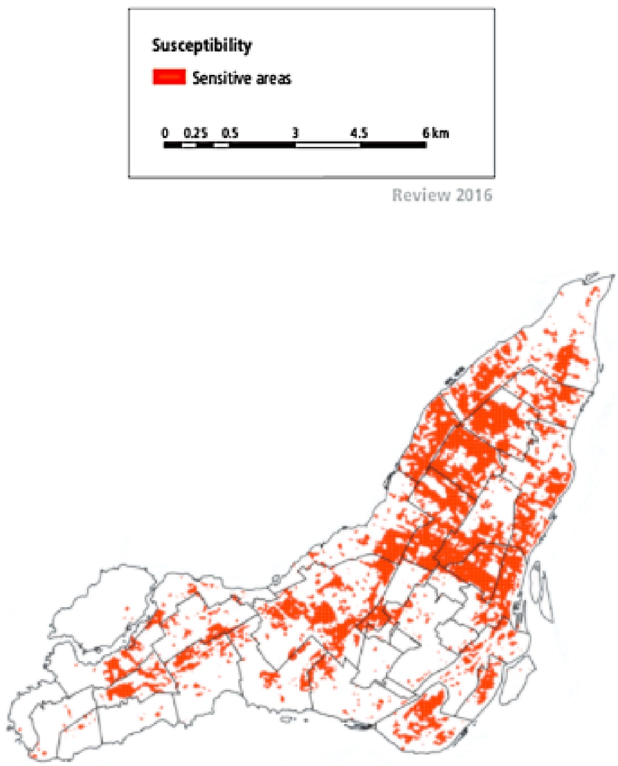
[40] Ibid.

[41] Suh C. The urban heat island in Montreal [Internet]. Data Driven lab; 2019. Available from: http://datadrivenlab.org/the-urban-heat-island-effect-in-montreal/

[42] Ibid.

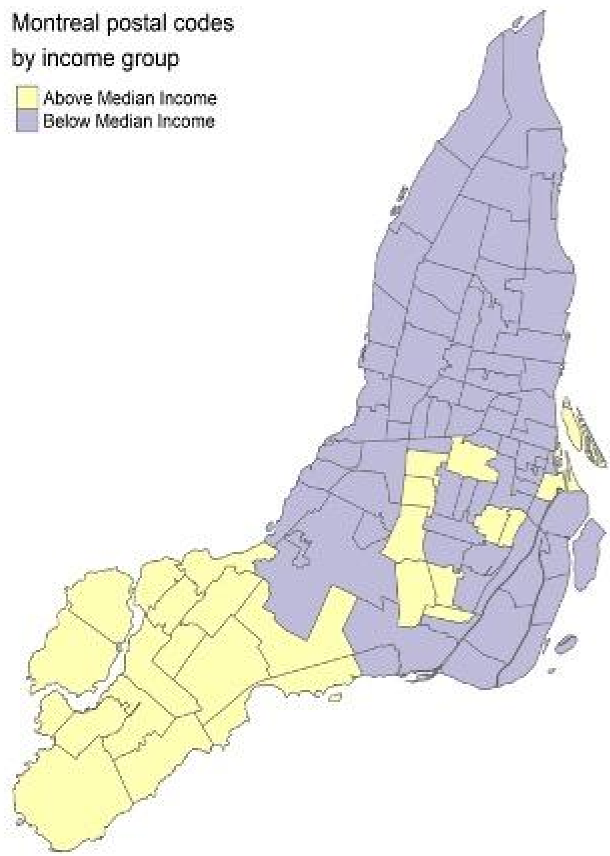
Figure 1: Neighbourhoods in Montreal most affected by the urban heat island

(Source: Climate Change Adaptation Plan for the Montréal Urban Agglomeration 2015-2020: 2017 Edition)



Another interesting observation as it relates to heat in Montreal is that areas with the strongest levels of the urban heat island effects are often in lower income populations. For example, the neighbourhoods with the weakest levels of the urban heat island effect were Rosemont-La-Petite-Patrie, Le-Plateau-Mont-Royal, and Saint-Leonard. All of the aforementioned neighbourhoods listed are in the central and eastern part of Montreal. The figure below shows a map of Montreal and separates neighbourhoods by those above and below the median household income pre-tax.

Figure 2: Montreal neighbourhoods divided into those above and below the median income



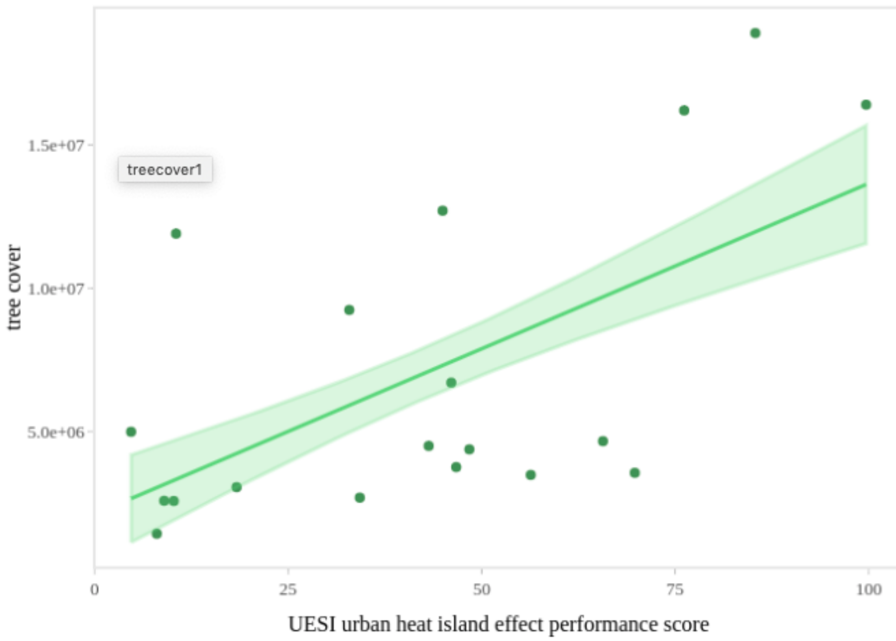
One application of the urban heat island effect is through the use of the urban environment and social inclusion index. The Urban Environment and Social Inclusion Index measures urban heat island effect performance using the 15-year (2003-2017) mean difference in daytime and night-time surface temperatures between urban land cover and non-urban land cover within the city in degrees Celsius (°C).[43] The index compares each neighborhood's urban heat island intensity to the overall intensity of the urban heat island

[43] Ibid.

effect across the entire city.[44] A higher UESI score is better, meaning the urban heat island effect is weaker in that neighborhood. DDL has also pointed to a linear positive association between tree cover and UESI, as described in Figure 3.

Figure 3: Relationship between UESI and tree cover

Source: Data-Driven EnviroLab[45]



STUDY OBJECTIVES

Given the implications on human health as well as the economic costs of increasing heat in Canada, this study attempts to better quantify heat in each neighbourhood as well as validate how heat has previously been calculated in cities. The study has two main components in the analysis:

[44] Ibid.
[45] Ibid.

1. Evaluate how minimum, mean, and maximum temperature might differ in neighbourhoods of different income levels for the 2019 summer months of June to September. Through this, explore in the literature why we might be seeing these temperature variations within the same Island of Montreal.
2. Compare and contrast temperature values (from June- September 2019) that we obtain from our ground level monitors versus satellite imaging as a way to validate how well satellite imaging captures temperature variation on the Island of Montreal.

METHODS

Part I: Monitoring campaign

A temperature monitoring campaign was conducted by the Weichenthal lab based out of McGill university. 200 hundred temperature monitors (the HOBO MX2201 temperature loggers; please see figure 5), were mounted around the whole Island of Montreal to ensure good spatial coverage. 8 monitors were lost in total, leaving 192 monitors, which provided data for our analysis. Monitors took temperature measurements at 30-min intervals, starting June 1st and ending September 31st. Daily average temperatures were then calculated for each day in which temperature values were collected, and were separated into daytime and night-time.

Figure 4: The HOBO monitor

Analysis

Income data for Montreal neighbourhoods were collected from the 2016 Canadian census. This dataset listed income for each distinct neighbourhood in Montreal, before and after taxes. For the purposes of this study, we used the pre-tax income. Median pre-tax household income on the Island was $61,790 CAD. With this in mind, neighbourhoods were divided into five quantiles using the median pre-tax household income as the reference. All in all, each neighbourhood was categorized into five groups. The table below explains the grouping of the neighbourhoods.

Table 1: Income categories for each neighbourhood group

Group	Income category
1	Less than or equal to $52,000
II	Greater than $52,001 but less than $66,650
III	Greater than $66651 but less than $75,959

IV	Greater than $75,960 but less than $84,203
V	Greater than $84,203

Analysis was then conducted to evaluate the minimum, mean, and maximum temperatures for each of the neighbourhood quintiles. We used the average daily temperature from the monitors, as well as the average night-time temperatures.

PART II: VALIDATION STUDY

Using the Google Earth engine, we were able to extract temperature estimates from the moderate resolution imaging spectroradiometer (MODIS) satellite. The MODIS satellite measures temperature by capturing the energy off of the land surfaces of a specific region.[46] In this case, we focused on the region of Montreal. Furthermore the MODIS satellite retrieves data at 1km pixels.[47] Each pixel it captures measures one kilometer, which would lead us to believe that this is a coarse measurement of temperature.[48] It also has an eight day return cycle, meaning it takes eight days for the satellite to complete its tour around the globe.[49] Temperature measurements for Montreal were then captured eight days apart. Finally, it collects land surface temperatures for daytime as well as night-time.

RESULTS

Part I

Below is the breakdown of each neighbourhood and the different quantiles they were assigned to.

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[46] The National Aeronautics and Space Administration (NASA). MODIS overview [Internet]. Washington D.C.: NASA; 2021. Available from: https://nsidc.org/data/modis/index.html
[47] Ibid.
[48] Ibid.
[49] Ibid.

Table 2: Neighbourhoods broken down into income groups

Group I	Group II	Group III	Group IV	Group V
Saint Leonard Verdun Montreal-Est Lasalle Montreal-Nord	Anjou Montreal La Chine Dorval Saint-Laurent	Senneville Laval Roxboro Pierrefonds	Pointe-Claire Dollard-des-ormeaux L'ile Bizard Saint-Genevieve	Hampstead Côte-Saint-luc Mont-Royale Kirkland Saint-Anne de Bellevue Outremont Baie d'urfe Rosemont Beaconsfield

In this analysis, we focused on comparing the daytime average temperature for each group, as well as the daily average night-time temperatures for each group. This is shown on Table 3.

Table 3: Day and night-time calculations of temperatures by income group using our temperature monitoring campaign

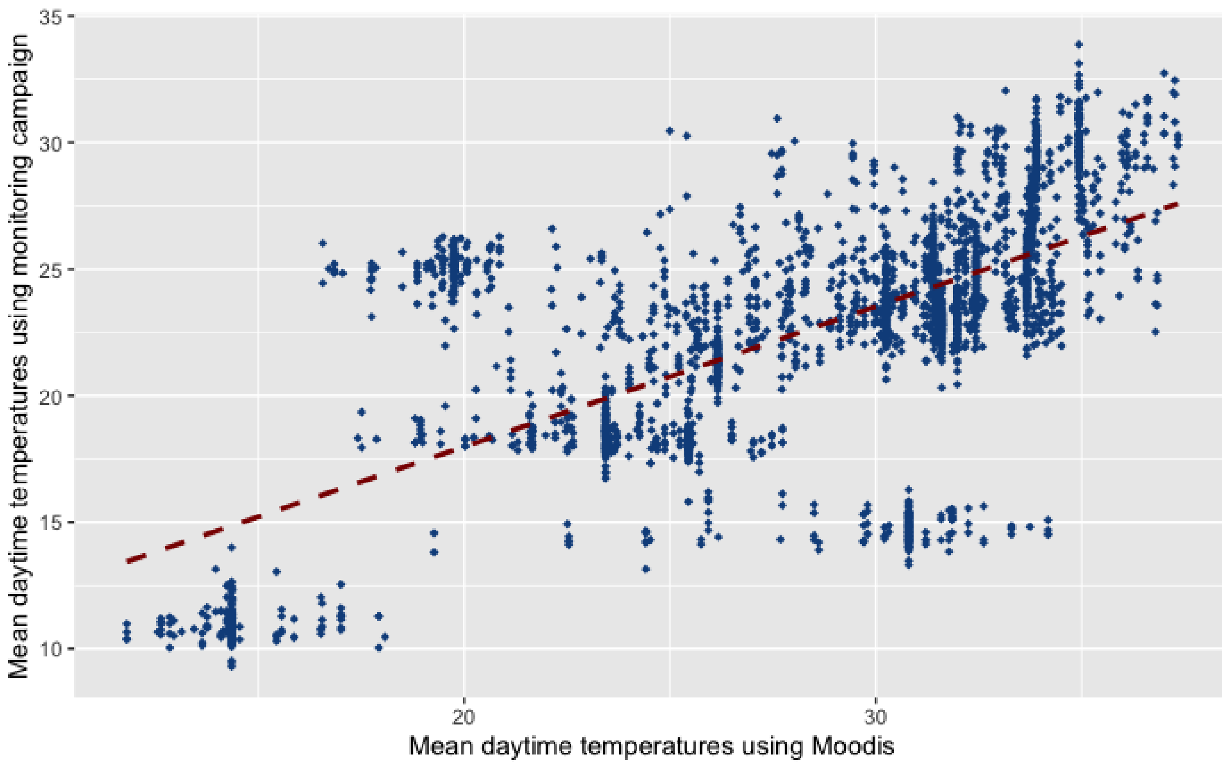
	Group I	Group 2	Group 3	Group 4	Group 5
Daytime average temperature	21.86	21.68	21.13	21.45	21.37
Daytime maximum temperature	32.74	33.87	30.68	31.76	32.04
Daytime minimum temperature	9.67	9.30	9.56	9.98	9.98
night-time average temperature	20.25	20.15	19.05	19.32	19.78
night-time maximum temperature	27.52	29.14	25.71	26.83	28.30

night-time minimum temperature	9.31	8.99	9.00	9.13	9.44

Part II: Validation study

In the validation of the MODIS temperature, we wanted to compare the MODIS temperature data with the ground-level temperature data on the same date to see how much different they were, and if they were in fact correlated. Figure 5 shows this relationship for the daytime temperatures.

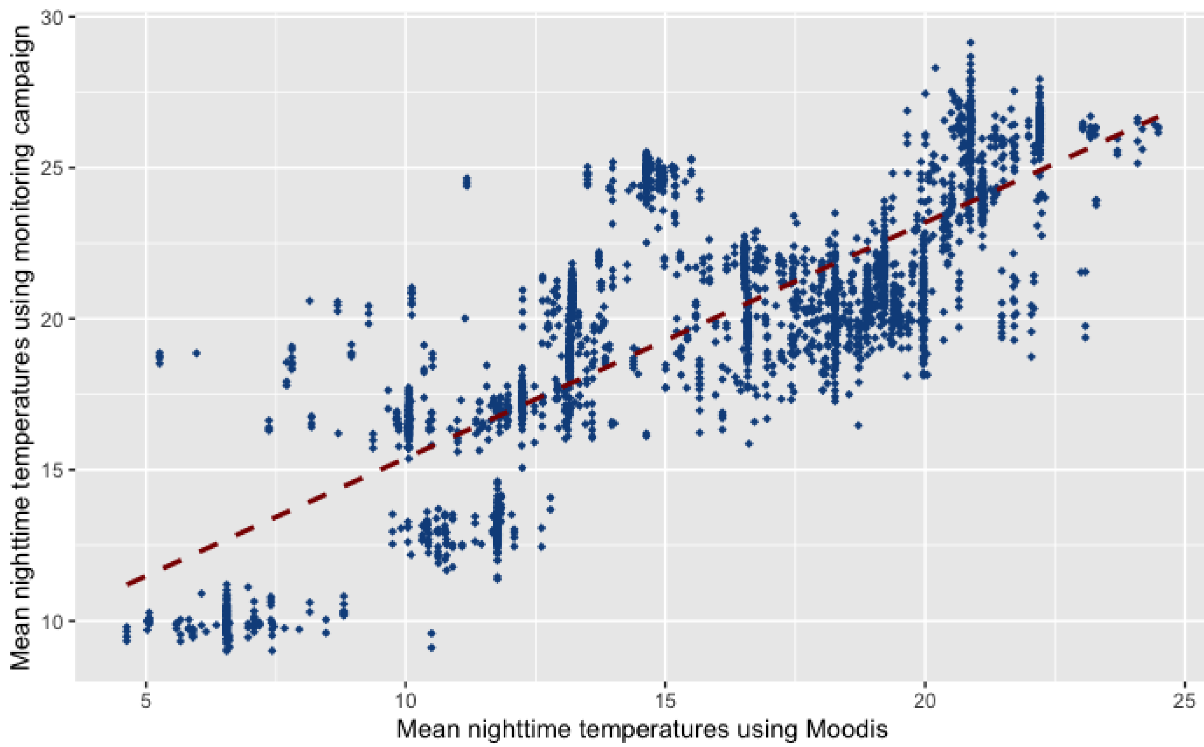
Figure 5: Scatterplot of daytime temperatures using temperature estimates from our monitoring campaign and the MODIS satellite.



Correlation = 0.6515712

Figure 6 shows the relationship between night-time measurements of temperature from our monitoring campaign and the MODIS satellite.

Figure 6: Scatterplot of night-time temperatures using temperature estimates from our monitoring campaign and the MODIS satellite.



Correlation = 0.8028392

Additionally, we wanted to evaluate if the estimates of temperature from the MODIS significantly different between the 5 income groups. Table 4 shows temperature estimates for each income group.

Table 4: Day and night-time calculations of temperatures by income group using the MODIS satellite

	Group I	Group 2	Group 3	Group 4	Group 5
Daytime average temperature	28.27	29.16	23.88	26.38	28.60
Daytime maximum temperature	37.00	37.27	35.51	35.97	37.34
Daytime minimum temperature	12.85	14.36	12.63	11.81	12.56
night-time average temperature	16.16	15.87	16.19	15.88	15.70
night-time maximum temperature	23.03	23.28	21.69	22.09	24.48
night-time minimum temperature	5.66	4.63	6.15	5.90	5.02

DISCUSSION

Current ways Montreal tries to mitigate the worst of heat waves in Montreal

In 2021, a new heat alert system was created in Montreal as a way to combat the health risks of heat waves.[50] Previously, a heat warning was in effect when a certain temperature threshold was reached. In this current system, temperature thresholds are the same all year round, regardless of the month.[21] However, many experts have pointed to numerous flaws in this system, because 32 degrees, for example, does not have the same

[50] Marin S. Quebec researchers propose a new heat wave alert system in response to climate change. The Toronto Star. 2021 :https://www.thestar.com/news/canada/2021/07/21/quebec-researchers-propose-new-heat-wave-alert-system-in-response-to-climate-change.html.

effect on the body in January as it does in the month of July. This is especially true when we take into account the humidity levels that are present in the month of July, versus in the month of January, and also because people may have had more time to acclimatize to the heat by the month of July versus the month of January. As a result of these criticisms, there are now adjusted thresholds for each month. These new thresholds were determined based on data from heat-related deaths, as well as hospitalizations.[51] One thing that this new system does *not* take into account is the way neighbourhood characteristics may influence how individuals experience heat.

Part I

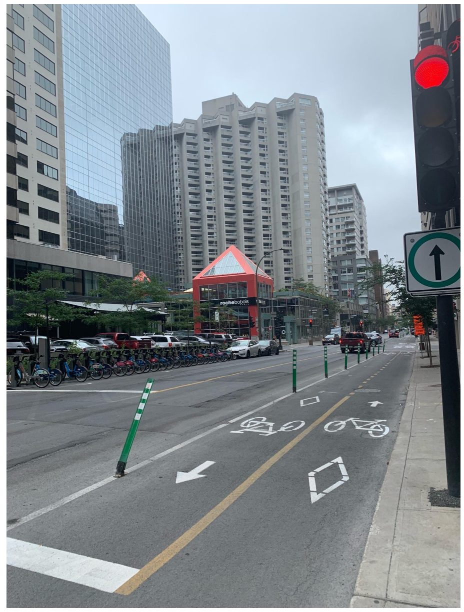
Looking at **Table 4**, above, there does not seem to be a great difference between lower and high income neighbourhoods when we look at the daily average temperatures. This obviously goes against what has previously been described in literature.[52] As a result of this, we cannot say anything definitive about the effects of heat by neighbourhood using this measure. Below in the limitations, I explain why this might have happened in our daytime estimates of temperature. On the other hand, when we look at the average temperature estimates from the night-time temperatures, we see that similarly to the literature, those in the lower income level seem to have high night-time temperatures. For example, neighbourhoods in the poorest income group saw a 1 degree difference in night-time temperatures as compared to neighbourhoods in the highest income group. Of particular concern were those in income group 2. In the night-time maximum temperatures, those in group 2 had about a 3 degree difference than those in group 5. Group 2 seemed to

[51] Ibid.
[52] Suh C. The urban heat island in Montreal [Internet]. Data Driven lab; 2019. Available from: http://datadrivenlab.org/the-urban-heat-island-effect-in-montreal/

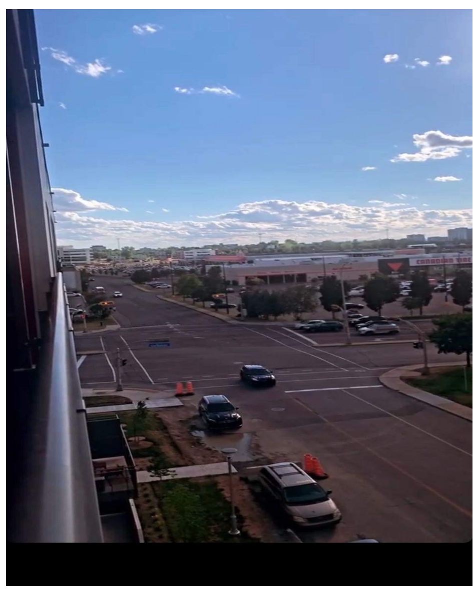
consistently have the highest recorded night temperatures. Coincidentally, group 2 includes the neighbourhood of Montreal where we have the downtown area located; this area would mostly be made up of asphalt and concrete buildings, leading to a greater release of thermal energy into the atmosphere. To better explore why these differences might be, we visited one neighbourhood from each group to capture the physical setting, and produced a photo series based on this.

Group 1: Verdun

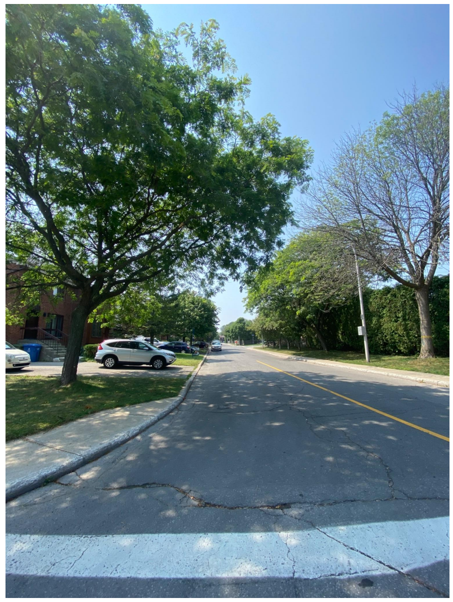
Group 2: Montreal (Downtown)



Group 3: Laval



Group 4: Pointe-Claire



Group 5: Outremont

One characteristic of higher income areas as compared to the lower income areas is overall increased tree cover. Many studies have previously shown the benefits of tree cover in mitigating the harmful effects of heat events.[53] Current urban tree cover seems to be higher in high income neighbourhoods as compared to low income neighbourhoods. This is also evident when looking at the tree cover in Outremont as compared to Montreal. Trees cool environments by acting as shades to materials such as concrete and asphalt, thus preventing release of heat and reducing the effects of the urban heat island.[54] Larger tree coverage in higher income neighborhoods could explain why they would be less susceptible to the urban heat island effect.

Part II

Our validation study produced very interesting results, as it had to do with the contrast between temperatures from our monitoring campaign and the MODIS satellite. First, when comparing the daytime measurements from the monitoring campaign to daytime measurements, we get a correlation value of 0.65. The correlation coefficient is a statistical measure of the strength of the relationship between two variables. With a 0.65 correlation coefficient, we can then say that we see a moderate positive relationship between the values of temperatures we obtained from our monitoring campaign and the values from MODIS. The night-time correlation is then of particular interest, as they may be more reliable ground-truth measurements for our study. The night-time correlation is 0.80 which then leads us to conclude that satellite based estimates of temperature are generally in agreement about the range of temperature observed, but with some important discontinuities between the two sources that will require further analysis. Moreover, we also calculated descriptive statistics using the MODIS satellite temperature estimates. The same

[53] McDonald R, Kroeger T, Zhang P, Hamel P. The Value of US Urban Tree Cover for Reducing Heat-Related Health Impacts and Electricity Consumption. Ecosystems. 2019;23(1):137-150
[54] Ibid.

relationship was observed as what we saw in the temperature monitoring campaign, in that lower income neighbourhoods, especially those in group 2, were more susceptible to higher temperatures. The only deviation from this conclusion is in the day and night-time maximum where group 5 seems to have higher temperature values. MODIS also seemed to estimate lower temperatures as compared to our monitoring campaign. This can be tied back to the limitations of satellites in estimating temperatures. This research project has laid the groundwork for further analysis for data comparisons between our ground-level temperatures and the MODIS estimate of temperatures in a cross comparable way with neighbourhood tags.

STRENGTHS

The temperature monitoring campaign is the largest temperature campaign to date, and as a result, this is the most accurate information to date of ground-level temperature estimates in Montreal. The monitoring campaign used to collect temperature data had great spatial coverage, which would mean that we were provided with high-quality coverage of the entire island.

LIMITATIONS

In terms of assessing exposure to temperature, we used the HOBO monitors, which we set as north-facing. While there was coverage for the HOBOs to protect them from the sun, it was much more expansive than the actual monitors. As a result of this, it is possible that many of the monitors overestimated daytime temperatures for many neighbourhoods leading to incorrect estimates.

RECOMMENDATIONS

This study informs several areas for improvement in heat mitigation in Montreal. To mitigate the worst of the effects of heat events would mean a refocus in lower income neighbourhoods, which have often lacked proper resources during heat waves. The recommendation section seeks to provide durable and concrete solutions by addressing the systematic reasons why certain neighbourhoods have increased temperature during the summer months. In reviewing my study, I have five main recommendations, which are of particular relevance for policy-makers:

1. Create a new heat alert system which prioritizes neighbourhoods that are lower income and experience more heat. To further expand, during heat events, emergency services should concentrate more resources to neighbourhoods which will experience the worst of heat effects and have less resources in terms of air conditioning and/or cooling centers. More efforts should also be put in to send community members to check in on members in these neighbourhoods who are more susceptible to the effects of heat.
2. Create a new effort to install more green spaces in lower income neighbourhoods. This could also be tied into providing more spatial coverage of cooling centers in neighbourhoods which experience the hottest temperatures during heat waves. Many studies have pointed to increased availability of air conditioners for lower income neighbourhoods as a way to cool down. I would be remiss in this recommendation, given the fact that for air conditions to work the way they are intended to, all people would have to

have access to an air conditioner. As well, the energy used and released by air conditioners increases outdoor temperatures.

3. Tying this back to the role that social connectedness could have on heat outcomes, more infrastructure should be created in ensuring that lower income residents have the social networks to receive aid during heat waves. This means more investment in community centers where older residents can socialize with their community. This could also mean creating opportunities for the community itself to organize groups who can check in on those most susceptible during heat events.
4. Satellite based estimates when designing heat mitigation can be and should be used as this is a low cost option for estimating heat within a city. However, validation studies should be conducted so as to estimate the limitations of satellite based temperature estimates.
5. Integrate heat sensors with existing infrastructure to better monitor real-time heat conditions on the ground. This could look like citizen science initiatives in which residents living in a city collect and measure heat in their own neighbourhoods. Initiatives such as this have already been implemented in cities such as Chapel hill, North Carolina. These initiatives can act as a means of both diminishing social isolation as well as generating usable heat data.

IMPACT

The Samuel Centre for Social Connectedness (SCSC), has, in supporting this report, already played a vital role in highlighting and reducing potential health disparities which exist during heat events. Looking at the case study of the Chicago heat wave, those who were in lower income groups saw the most mortality, and also lacked the appropriate resources to protect themselves and their community. Even more so, the surveys conducted in Montreal for our community engagement initiative served as a reminder that experience of heat can differ wildly according to postal code.

SCSC can also further understand the experience of heat by supporting the collection of more ground level estimates in different cities around the world, and validating satellite based estimates of temperatures. What this report does is provide further evidence of the infrastructure that needs to exist during heat waves especially for those in lower income areas. While this report was written in the context of Montreal, it could easily be transferred to other cities around the world.

CONCLUSION

Increasingly, regular heat waves have become the norm in both Canada and Montreal. This trend exists within the broader backdrop of increased income inequalities. Throughout this report, the relationship between heat waves and income disparities has been highlighted, and in the years to come, this relationship is one that will only become more deeply-rooted. It is also evident throughout this paper that the consequences of climate change will disproportionately affect the most marginalized. The above recommendations provide a starting framework on how we can combat this problem right here in Montreal, and how we must go forward in better quantifying heat within cities.

FUTURE STUDIES

Future studies of ground-level monitoring campaigns should be conducted in cities in which we see greater levels of the urban heat island effect. These studies would provide better understanding on how postal codes have real consequences on our overall health. Future studies would also find benefits in better quantifying the amount of tree cover in cities, and estimating how this affects heat. Future studies should also attempt to create a correction factor for satellite based temperature estimates based on ground-level collection of temperatures. These studies could help validate and correct the marginal errors which can be found in satellite based temperature estimates and can lead to a cheaper form of temperature collection within cities. Finally, another possible point for future studies is digging into the variation in relationship between HOBO and MODIS more to see if the relationship itself is patterned across different built infrastructure settings, that correspond potentially to socioeconomic or demographic features of Montreal.

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