FINAL

Key Climate Indicators for Halton Hills

Report

Michael Roth, PhD, PEng

Meiring Beyers, PhD

Klimaat Consulting & Innovation Inc.

Nov 23, 2018

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1 *Executive Summary*

A detailed climate change data analysis was performed for the Town of Halton Hills municipality by using an ensemble of global climate models and historical meteorological data. This analysis feeds directly into strategic climate change adaption and resilience planning efforts. The key climate change characteristics apparent from the study are highlighted below:

- Consistency: Similar to the findings of the IPCC AR5 reports, a local warming trend of +1.7°C to +6°C is expected by the end of the century, based on peak-and-decline (RCP 2.6) and business-as-usual (RCP 8.5) global emission outlooks, respectively.

- Mid-century scenario divergence: Regardless of the global emissions scenario assumed, generally the same climate change characteristics will develop by mid-century. From the 2050s onwards, the characteristics may stay similar, or even improve (for an optimistic RCP 2.5 scenario), or rapidly deteriorate with more business-as-usual global emissions (RCP 8.5).

- Human heat stress: Human health impacts from increased heat events are likely to rise substantially. It is estimated that the number of heat waves (3 days with average temperatures above 30°C) would rise from 1 per year today to 6 and 8 per year by the 2050s and 2080s, respectively, for the business-as-usual scenario (RCP 8.5). This would likely have a significant impact on heat stress-related illness, mortality, and productivity, especially for vulnerable populations such as the elderly.

- Heat stress and energy: Mitigating increasing heat (for one, to reduce human heat stress) through air-conditioning will likely increase the building average and peak cooling energy demand. Cooling degree days are projected to double by 2050 and almost quadruple by 2100 for the business-as-usual scenario. Increased energy demand may also affect water consumption required for energy production, although that may not be a local impact depending on the sources of the energy.

- Building energy usage: Currently, buildings are typically designed to a Climate Zone 6 designation. However, this designation is expected to change to Climate Zone 5 by 2050 and to Climate Zone 4 by 2100 for a business-as-usual scenario. This will likely have significant implications for how buildings should be designed and built: to be warm in winter (albeit for a shorter duration than currently) while also to be well-ventilated and comfortable in summer.

- Nighttime building cooldown: In addition to the increased daytime temperatures detailed above, it is expected that the number of Tropical Nights (nights with minimum temperatures >20°C) will increase from one day per year to 10 days per year by 2050 and

60 days per year by 2100. This effect may reduce the capacity for urban centres (or individual buildings) to shed heat at night.

- Agriculture and heat: The changing climate will likely provide new opportunities for agriculture. It is expected that the growing season duration will lengthen by approximately 12% by 2050 and 25% by 2100. The number of frost days will similarly decrease. The probability of frost impacting early bud growth will likely remain similar, but it will likely happen earlier in the year.
- More rain, except in summer: Marginal increases are expected in extreme precipitation with modest decreases in summer rain volume. More pronounced increases are expected for winter and spring rain volumes. Wet spring conditions may impact early season planting schedules for agriculture.

2 *Background*

The Halton Hills Climate Change Adaption plan requires a research-based analysis of the future climatic conditions expected for the municipality. Klimaat Consulting & Innovation Inc. was retained to perform the climate data analysis for the Town, the work forming part of the effort led by the Canadian Urban Institute (CUI) to develop the climate change adaption and resilience plan and strategy.

This document serves two purposes:

1. Provide a scientific data analysis of available observational and model climate data representing both the present and future of Halton Hills;

2. Form a high-level climate synthesis and narrative using the information developed in 1.

3 *Representative Concentration Pathways (RCP)*

In order to project into the future, global climate models (GCM) require specification of the concentration levels of key greenhouse gases, such as carbon dioxide, methane, and nitrous oxide. All the GCMs reported in the latest IPCC Assessment Report (AR5) were driven with a consistent set of four Representative Concentration Pathways (RCP), each assuming a different mixture of technology, energy, resources, and socioeconomic factors (van Vuuren et al. 2011). The impact of a change in concentration level of a greenhouse gas can be converted to an equivalent effective increase in the earth's radiation balance: the energy arriving from the sun (Watts) minus that radiated out to space. This imbalance, termed radiative forcing (W/m^2), is what drives global warming. That is, the earth responds to the added heat input by increasing its temperature in order to radiate more energy to space.

Each RCP is labelled by the level of radiative forcing in the year 2100:

- RCP 2.6: The so-called "peak-and-decline" scenario in which radiation forcing peaks at 3.1 W/m^2 in mid-century, declines to 2.6 W/m^2 by the year 2100, and continues to decline thereafter. The aim is to keep global warming below 2°C, a target beyond which the more dangerous effects of climate change are anticipated. Indeed, in this scenario, the average global temperature is projected by global climate models to increase by between 0.3°C to 1.7°C by the year 2100. This scenario requires stringent climate policies to limit and reduce emissions and, later in the century, to actually remove existing carbon dioxide from the air.

- RCP 4.5: A "low-range" scenario that peaks at 4.5 W/m^2 around the year 2070 and holds steady thereafter. Global average temperature projections range from 1.1°C to 2.6°C by the year 2100.

- RCP 6.0: A "mid-range" scenario that rises to 6.0 W/m^2 by the year 2100 and holds steady thereafter. Global average temperature projections range from 1.4°C to 3.1°C by the year 2100.

- RCP 8.5: A "business-as-usual" scenario that sees greenhouse gas emissions continuing unabated, with the resulting radiation forcing levels rising rapidly to 8.5 W/m^2 by the year 2100 and continuing to rise in the century following. Global average temperature projections range from 2.6°C to 4.8°C by the year 2100.

The current world emission pathway lies between that of RCP 6.0 and 8.5. Further details can be found in Wayne (2013).

Global average temperature projections typically underestimate local conditions, e.g. for the Town of Halton Hills. The world is 70% water, which responds very slowly (hundreds to thousands of years) to the radiative forcing, and over which temperature rises are projected to be significantly lower than the global average. This implies that the projected temperature rise over land will be significantly higher than the global average, as quantified later in this report.

Note that purposely missing in the RCP framework was any discussion of the socioeconomic conditions necessary to achieve a given RCP. For the next IPCC assessment (AR6), expected in 2022, five new Shared Socioeconomic Pathways (SSP) (Riahi et al. 2017) will be utilized, each with a specific narrative. Each narrative imagines how population, economic growth, education, urbanization, and technological development could change in future. Each SSP is then evaluated on its capability of achieving a given target RCP, including the ones above and several new ones.

4 *Data Sources*

The key climate indicators used in this report require a fairly complete dataset of daily high and low temperatures and total daily precipitation. The datasets used in this analysis include daily observational (historical) meteorological data from Environment Canada and statistically downscaled climate scenario data for 1950 to 2100 from the Pacific Climate Impact Consortium. These two datasets, described below, were selected based on the quality and availability of daily data and local relevance.

- *Environment Canada (EC)*

  Environment Canada[1] provides daily observational (measured) station data at a number of locations in and around the Town of Halton Hills (indicated by open circles in Figure 1), but only a few of the stations provide sufficient data to calculate the above indices (named circles filled with red).

  Historical station data provide "ground truth" but may only be representative within a very small radius due to poor siting of the station, e.g. in close proximity to buildings or trees or located near steep terrain. That said, Environment Canada weather monitoring stations are typically extremely well-sited, i.e. in relatively flat locations, cleared of vegetation.

[1] http://climate.weather.gc.ca/historical_data/search_historic_data_e.html

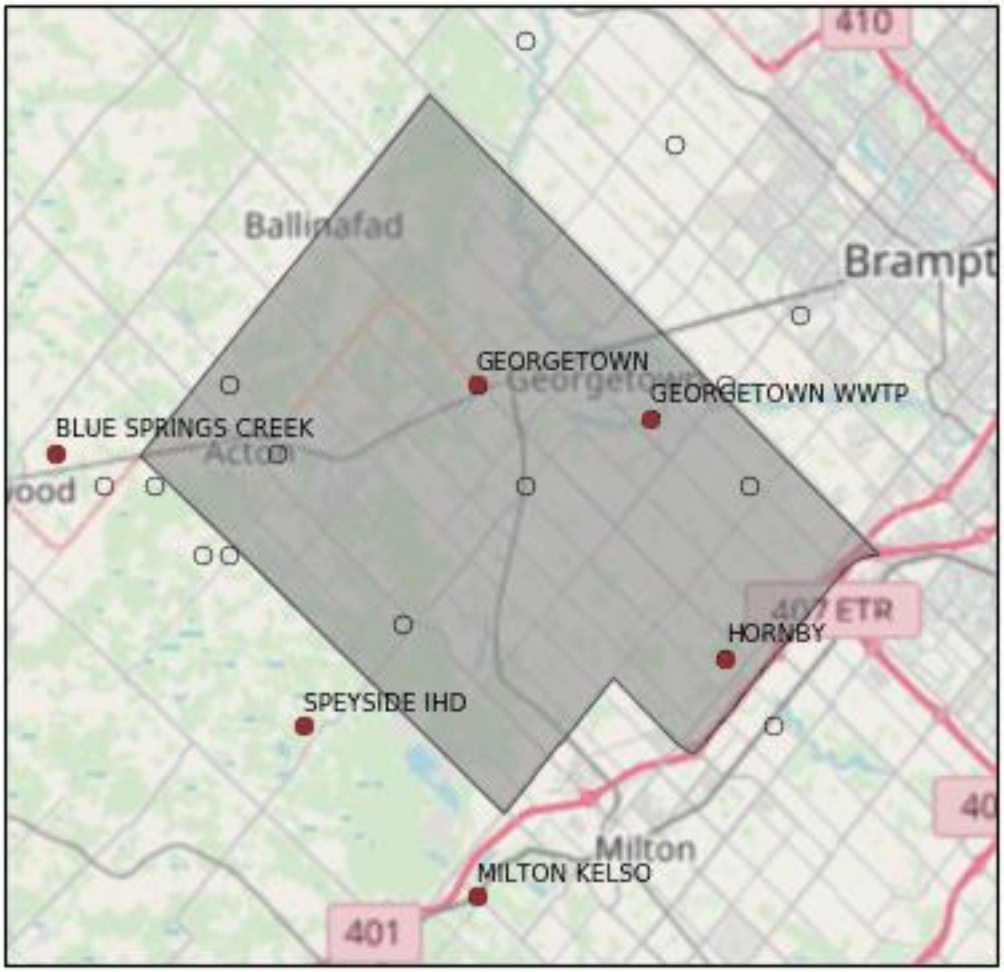

Figure 1: Environment Canada Weather Monitoring Stations

- *Pacific Climate Impacts Consortium (PCIC)*

  From the Pacific Climate Impacts Consortium (PCIC),[2] statistically-downscaled climate scenarios are provided for RCP 2.6, RCP 4.5, and RCP 8.5 on a Canada-wide 10km×10km grid for the years 1950 to 2100. Data is derived from between 9 and 12 coarse-level GCMs, depending upon RCP, and further refined or "downscaled" to 10km, by building a statistical relationship between historical observations and GCM historical estimates at a given location. This statistical relationship is then driven by future GCM projections in order to estimate the projections at the given location (Werner and Cannon 2015).

  It is well known that any given model alone will be unlikely to be a best estimate of the state of the climate. For this reason, for every estimate, we choose the median, or middle, model result from year to year. This "ensemble" approach has been shown to dramatically improve the predictive power of models (see Flato (2011)).

[2] https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios

Halton Hills can be completely covered by twelve (12) 10km×10km grid boxes. We use these 12 cells to both represent the spatial variability across Halton Hills and, when calculating a Town-wide result, to provide a best estimate.

Note that the projected results in a given grid cell box can, at best, be considered representative averages of the area spanned by the cell. Climate within each box can be expected to vary significantly depending upon proximity to buildings, vegetation, and steep terrain.

NASA GISS[3] is one of many centres producing estimates of historical global and local temperature changes based on land and ocean-based thermometers. Here we use this dataset to compare the average local monthly temperature rise since 1880 against the available Environment Canada station measurements. We have also used the dataset to compare local changes, representative of the Town of Halton Hills, with changes seen worldwide.

[3] Goddard Institute for Space Studies https://data.giss.nasa.gov/gistemp/

5 *Historical and Projected Average Monthly Climate Changes*

In Figure 2 (top) we present the monthly average temperature anomalies based on the NASA GISS product since 1880 alongside all available Environment Canada station data.

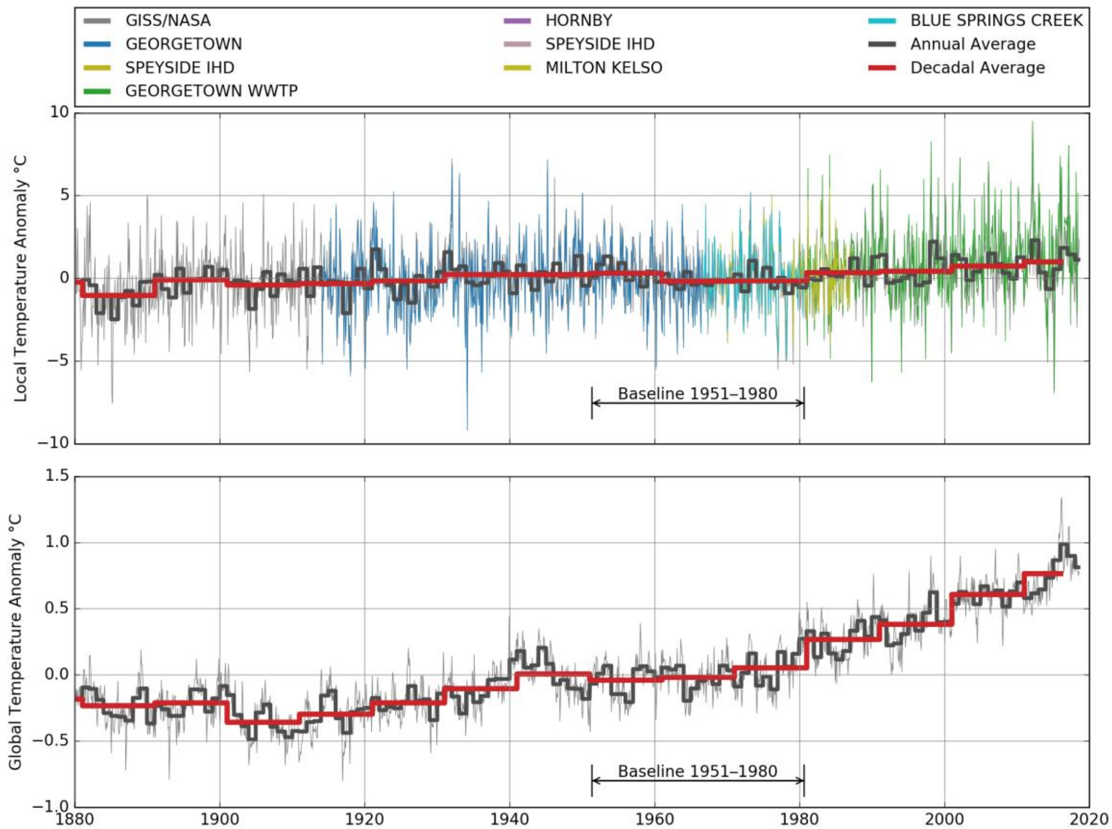

Figure 2: Monthly Temperature Anomalies (Historical)

Note that temperature changes are typically presented as "anomalies" rather than as absolute values. These anomalies represent the difference against a baseline long-term climatic average, here the period from 1951–1980. For example, to calculate an anomaly for a given January, the average temperature of all Januarys between 1951 and 1980 are subtracted from the monthly temperature of that January. While absolute temperatures can vary over very short distances (e.g. within Georgetown), anomalies remain fairly consistent over larger regional distance (e.g. on the order of 100 km).

As seen in the figure, local temperature monthly anomalies vary dramatically from month to month, varying between -5 and +5°C. Indeed, as is often the case with climate analysis, it can be difficult to differentiate the noise from the climate change signal. When one examines the average annual temperature anomalies (black line), the variability from year-to-year is seen to be reduced to within ±1°C. To emphasize the longterm trends, one can also examine the decadal averages. Since the 1980, the decadal average temperature anomaly has trended towards +1°C for Halton Hills.

Figure 2 (bottom) shows the global temperature rise over the same period. Statistically, it is much easier to separate the noise from the signal when combining thousands of measurements. Here, the global warming signal is readily apparent, exhibiting as a consistent rising trend in temperature, with the hottest year on record, 2016, having seen a temperature rise of +1°C against the 1951–1980 baseline. These recent global temperature changes should be placed in context against global efforts and policies to limit the climate-average temperature rise to less than +2.0°C — we are already approximately half-way towards this limit (IPCC 2018).

Adding the impact of model projections, Figures 3 through 5 show the monthly-average temperature and precipitation anomalies against the 1960s (1951-1980) baseline for the Town of Halton Hills, under the three representative concentration pathways.

We isolate four time periods corresponding to 30-year "windows". The first, centered on the "1990s" (1981-2010), represents recent history while the next three are projections for the "2020s" (2011–2040), the "2050s" (2041–2070), and the "2080s" (2071–2100).

For temperature we include the high and low temperatures in addition to their average. Daily low temperatures typically occur immediately before sunrise while daily high temperatures typically occur in mid-afternoon. Due to changes in clouds and other climate drivers, the change in high and low temperatures are not necessarily synchronized. Indeed, for the Town of Halton Hills, while the rise in average daily high temperature is fairly consistent throughout the year, the rise in average daily low temperature is amplified in the winter months. That is, the average daily swing in temperature is decreased in the winter months versus the summer months.

Precipitation is the total amount of water, in its many forms, that reaches the ground. In order to split precipitation into its rain and snow components, we have developed a simple statistical model based on available observational rain and snow data for the Environment Canada stations; that is, given the daily mean temperature, the model determines the fraction of precipitation that is snow and the fraction that is rain. Snow is assumed to have an average density of 10% of liquid water.

A consistent feature of the data is a warming signal that is amplified during the winter months. This warming has two significant impacts on the hydrological cycle: winters see more precipitation and more of that precipitation falls as rain instead of snow.

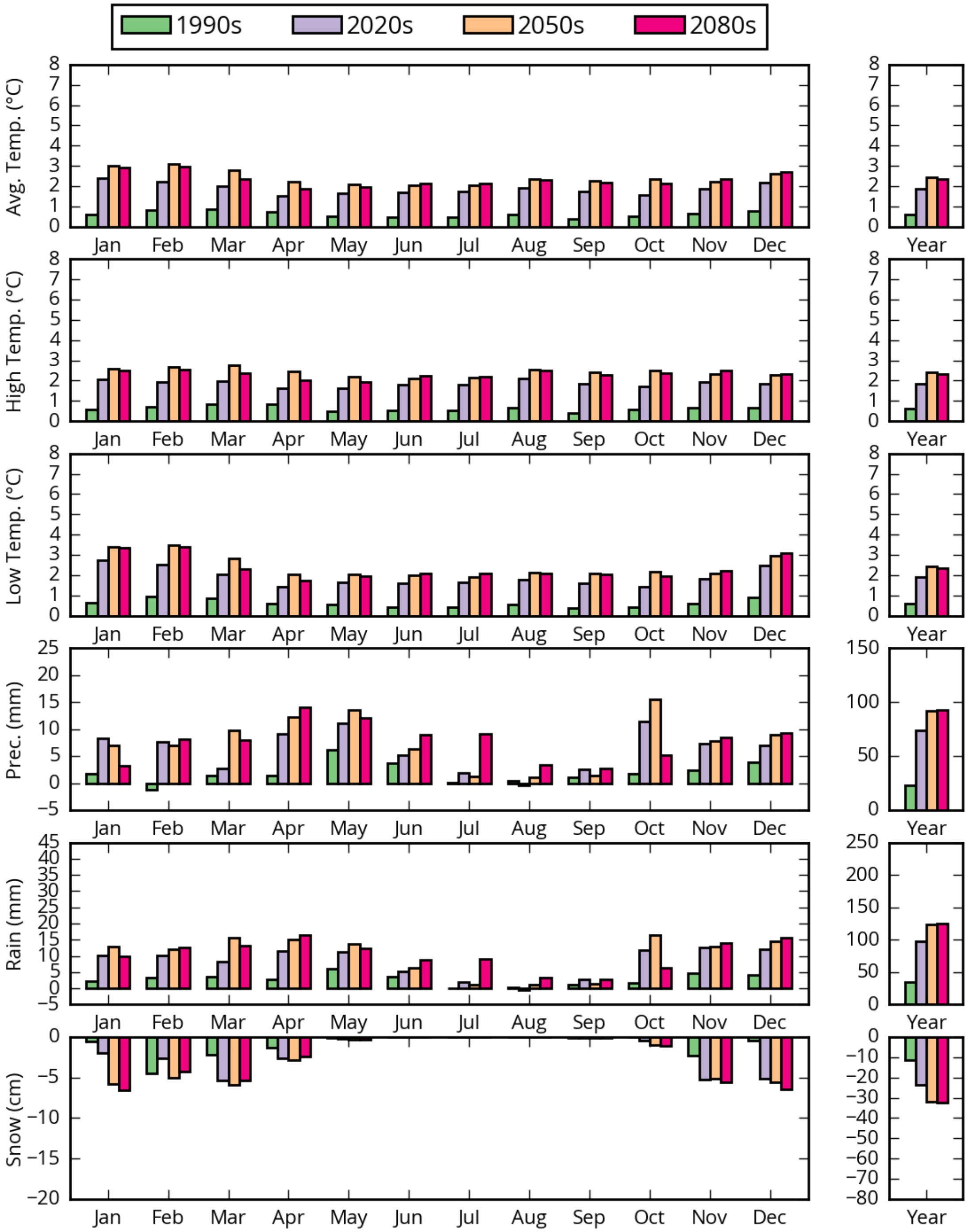

Figure 3: Monthly Anomaly Summary (RCP 2.6)

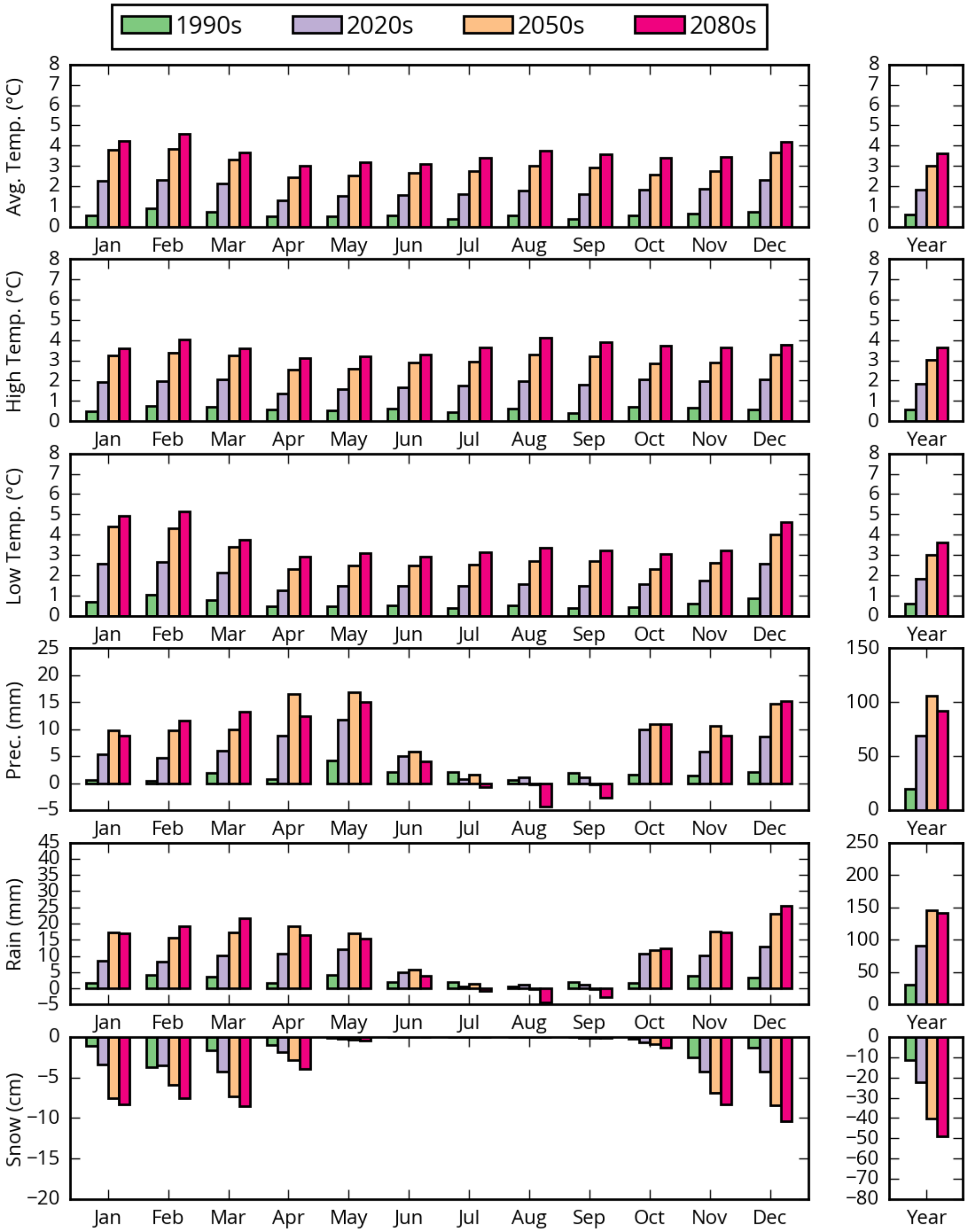

Figure 4: Monthly Anomaly Summary (RCP 4.5)

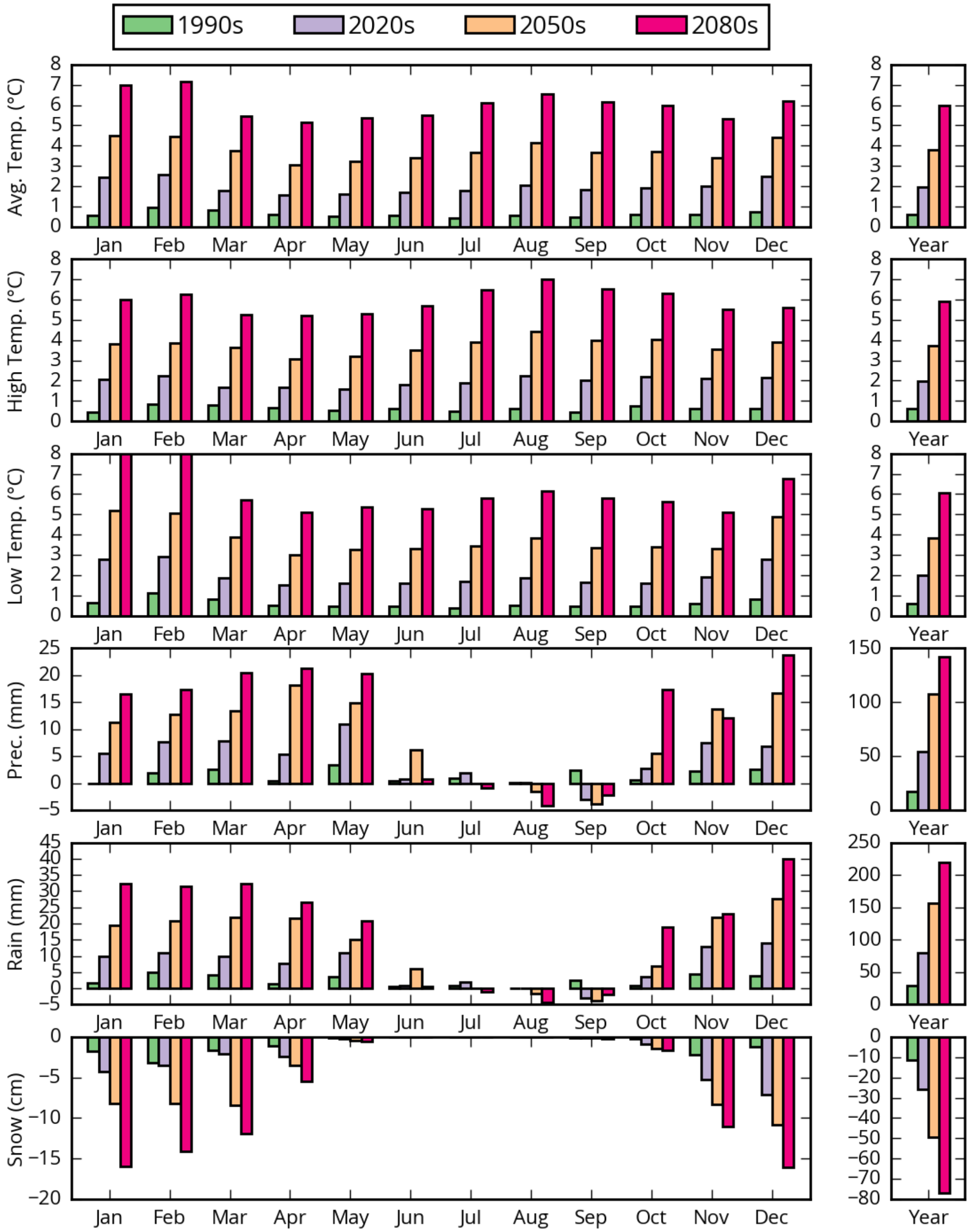

Figure 5: Monthly Anomaly Summary (RCP 8.5)

Derived from the Figures above, Figure 6 provides a one-page summary of the expected seasonal changes for the 1990s, 2020s, 2050s, and 2080s for temperature and precipitation.

The annual average temperature in the Town of Halton Hills has risen by approximately 0.6°C since the 1960s. Assuming a peak-and-decline scenario (RCP 2.6), models project a temperature rise of 1.9°C in the 2020s, 2.4°C in the 2050s (at peak), and 2.3°C in the 2080s (during the decline). Mid-range scenario models project a temperature rise of 1.8°C in the

2020s, 3.0°C in the 2050s, and 3.6°C in the 2080s. A business-as-usual scenario estimates temperatures rising by 2.0°C in the 2020s, by 3.8°C in the 2050s, and 6.0°C in the 2080s.

Total annual precipitation has increased by approximately 17–23mm since the 1960s. Assuming a peak-and-decline scenario, precipitation is projected to increase by 74mm in the 2020s, by 92mm in the 2050s, and by 93 mm in the 2080s. Given a mid-range scenario, models project an increase of 69mm in the 2020s, 106mm in the 2050s, and 92mm in the 2080s. Finally, business-as-usual scenario models project an increase of 54mm in the 2020s, 107mm in the 2050s, and 142mm in the 2080s. For context, the Georgetown WWTP typically records about 880mm of precipitation a year.

There has been approximately a 11–12cm decrease in total annual snowfall since the 1960s. Assuming a peak-and-decline scenario, snow is expected to further decrease by 24cm in the 2020s and by 32cm in the 2050s and 2080s. The mid-range scenario projects snow decreases of 22cm in the 2020s, 40cm in the 2050s, and 49cm in the 2080s. Finally, the business-as-usual scenario suggests total snow decreases of 26cm in the 2020s, 49cm in the 2050s, and 77cm in the 2080s. For context, the Georgetown WWTP typically records about 140cm of snow a year.

With a higher proportion of precipitation being rain during the winter, the total rainfall is expected to increase greatly. Since the 1960s, the Town of Halton Hills has since a general increase in rainfall of 29–34mm. Peak-and-decline scenario models suggest an increase in rainfall of 97mm in the 2020s, 124mm in the 2050s, and 125mm in the 2080s. Mid-range scenario models project an increase of 91mm in the 2020s, 146mm in the 2050s, and 141mm in the 2080s. Finally, a business-as-usual scenario suggests rainfall increases of 80mm in the 2020s, 157mm in the 2050s, and 219mm in the 2080s. For context, the Georgetown WWTP typically records about 740mm of rainfall a year.

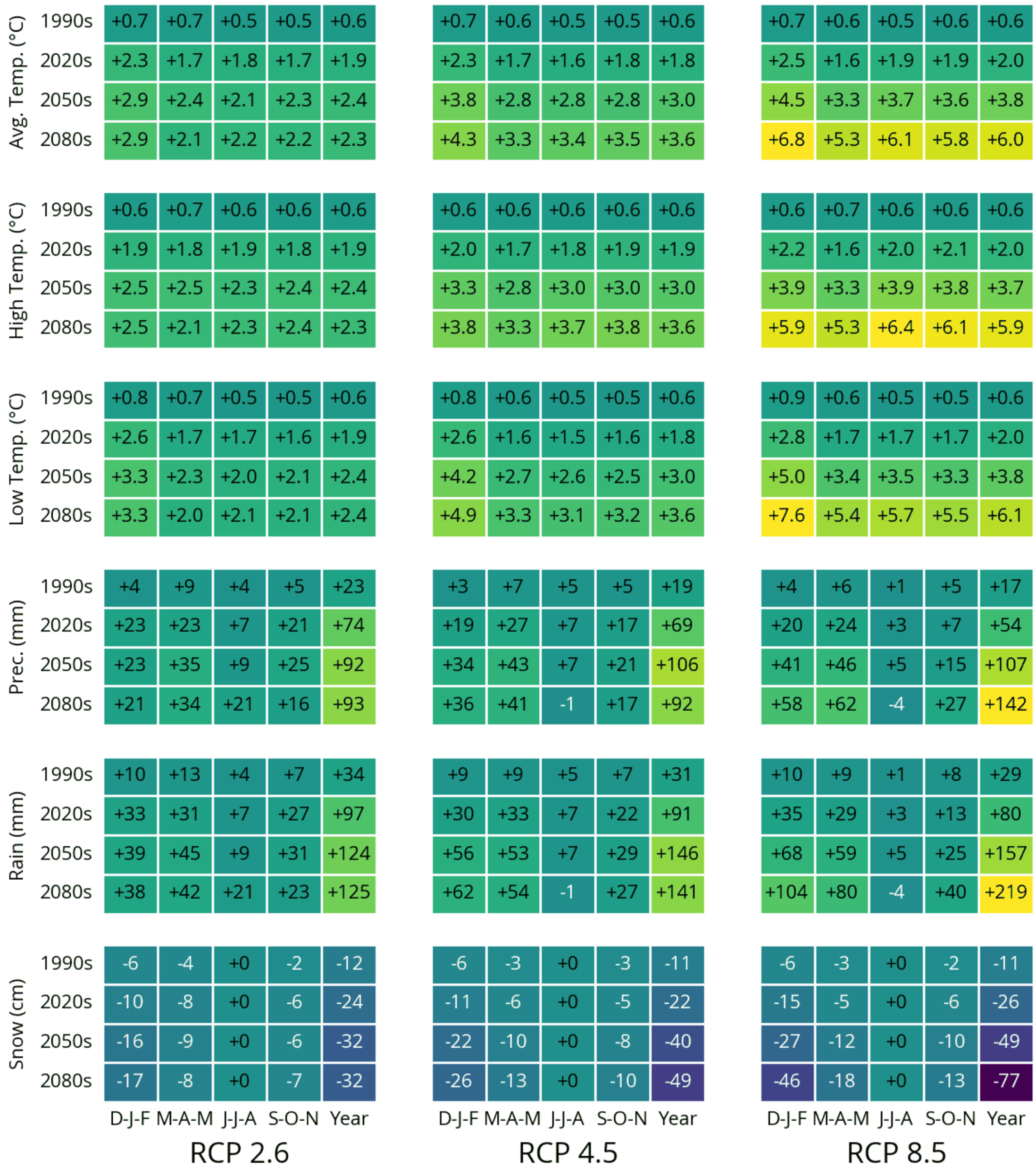

Figure 6: Seasonal Summary. "D-J-F" = Dec, Jan, Feb, "M-A-M" = Mar, Apr, May, "J-J-A" = Jun, Jul, Aug, "S-O-N" = Sep, Oct, Nov

5.1 Comparison to ICLEI Canada Report

It is useful to compare the results of this study against analogous ones provided to the Town of Halton Hills in the ICLEI Canada report (ICLEI 2016), in particular the expected seasonal temperature and precipitation changes.

At the time of writing ICLEI (2016), data for AR5 were unavailable and thus the prior scenarios B1 (low emission) and A2 (high emission) scenarios were utilized. However, for the purposes of comparison, B1 maps to RCP 4.5 while A2 maps to RCP 8.5.

For convenience, the analogous data from Exhibits 6 and 7 (projected seasonal temperature change) and Exhibits 15 and 16 (projected seasonal precipitation change) of ICLEI (2016) were copied into Figure 7 for direct comparison to Figure 6.

Note also that the ICLEI used a slightly different baseline of 1971–2000. Thus, while our results show changes since the 1960s, the ICLEI report is more suitable for changes since the 1980s. Thus we expect our projections for the 2020s, 2050s, and 2080s to be marginally higher than the equivalent for ICLEI, approximately by an amount equal to our projections for the 1990s.

While the overall temperature increases are consistent, the ICLEI results did not suggest much evidence of a seasonal effect, while our results indicate an enhanced warming signal in winter.

In terms of precipitation, the pattern of increased winter precipitation and little or reduced summertime precipitation holds.

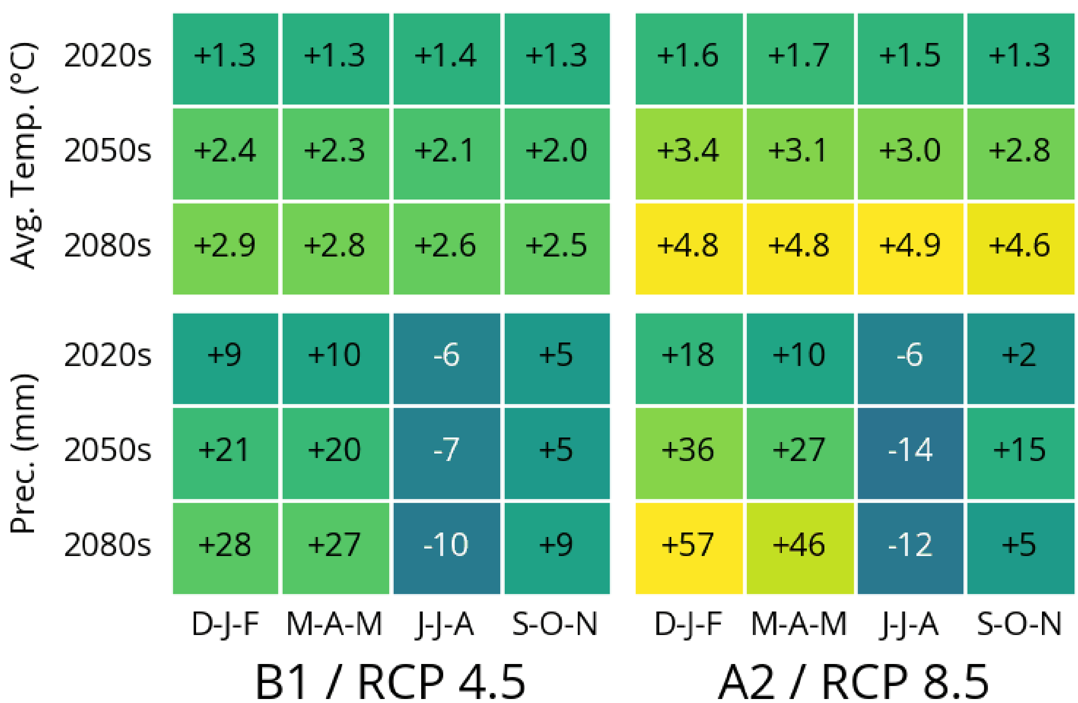

Figure 7: Seasonal Summary from ICLEI Report. "D-J-F" = Dec, Jan, Feb, "M-A-M" = Mar, Apr, May, "J-J-A" = Jun, Jul, Aug, "S-O-N" = Sep, Oct, Nov

6 *Historical and Projected Daily Temperature Variability*

An important aspect of climate change is not just the shift in average (mean) daily temperature but also an associated change in the variability or measure of deviation experienced day-to-day (variance). For temperature, the classic "bell curve" shape is typically applicable, which represents the probability of a given temperature. Assuming a perfect bell curve, the location of the peak represents the average while the width represents the variability, either of which can change with climate change. If the area under the bell is kept constant, increasing the variability (width) decreases the height of the peak, flattening the curve, making extreme values more probable.

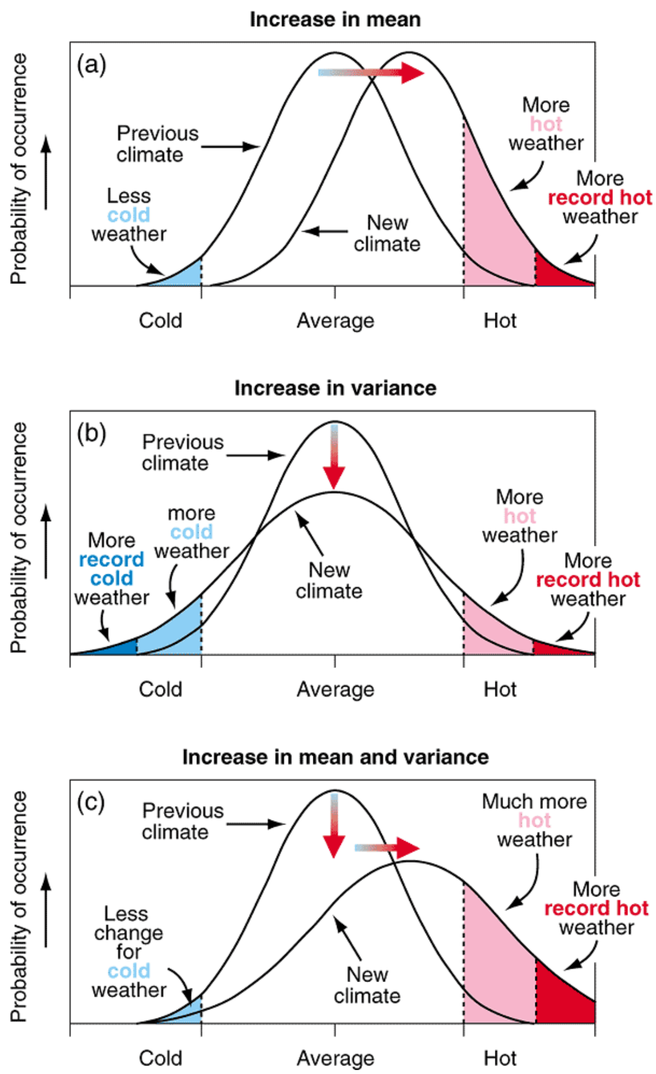

Figure 8: Effect on temperature when (a) the mean temperature increases, (b) the variance increases, and (c) when both increase[4]

[4] From IPCC TAR WG1 https://www.ipcc.ch/ipccreports/tar/wg1/088.htm

We plot the daily temperature anomaly for the aforementioned periods, seasons, and representative concentration pathways (see Figure 9–11). The baseline is 1951–1980 as before.

We see more variability (a flatter bell) in the shoulder seasons, spring and fall, due to the rapid changes in the length of day in comparison to summer and winter.

Also, as expected, we typically see a shift in the peak towards higher temperature anomalies as we move towards the end of the century, especially for the case of RCP 8.5. This is simply an illustration of the results in the previous section.

However, of particular importance is change in seasonal variability. During winter months, the variability in temperature is projected to *decrease*, as seen by the decreasing bell width (or equivalent, higher peak). This decrease is contrasted with an increase in variability seen in summer months. Spring and fall only see marginal increases in variability. These observations are particularly evident in RCP 8.5.

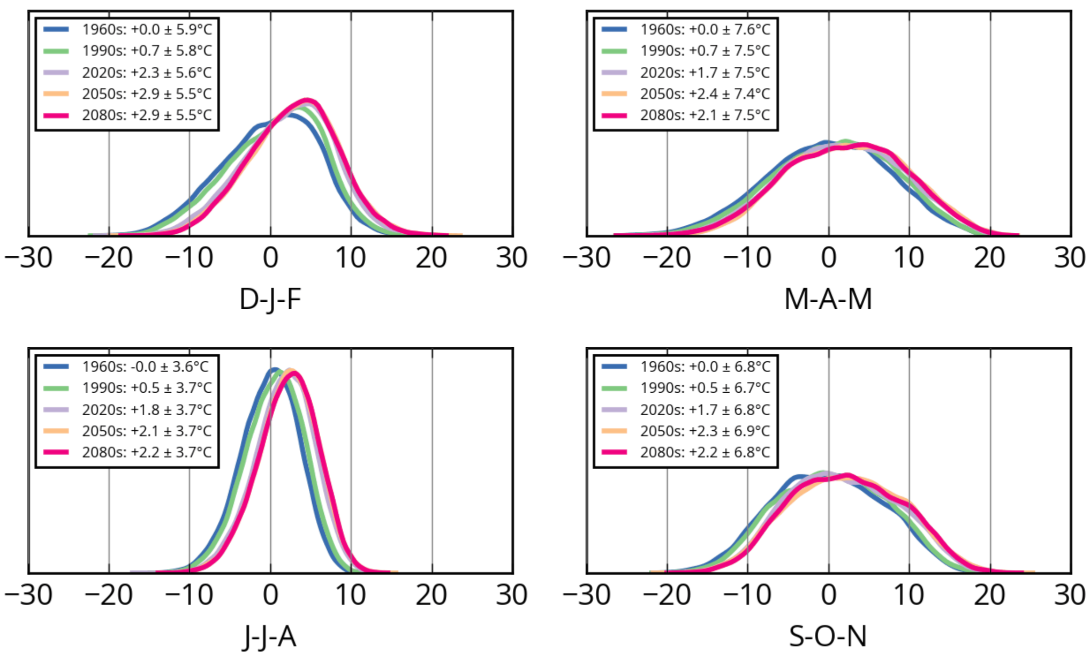

Figure 9: Histograms of Temperature Anomalies (°C) for RCP 2.6. "D-J-F" = Dec, Jan, Feb, "M-A-M" = Mar, Apr, May, "J-J-A" = Jun, Jul, Aug, "S-O-N" = Sep, Oct, Nov

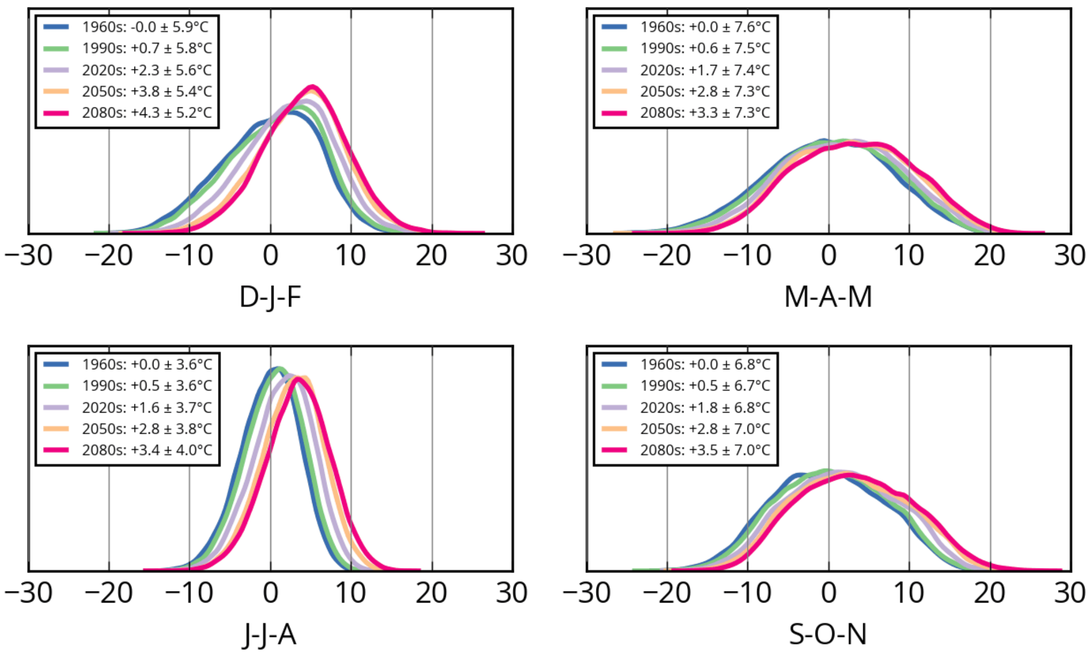

Figure 10: Histograms of Temperature Anomalies (°C) for RCP 4.5. "D-J-F" = Dec, Jan, Feb, "M-A-M" = Mar, Apr, May, "J-J-A" = Jun, Jul, Aug, "S-O-N" = Sep, Oct, Nov

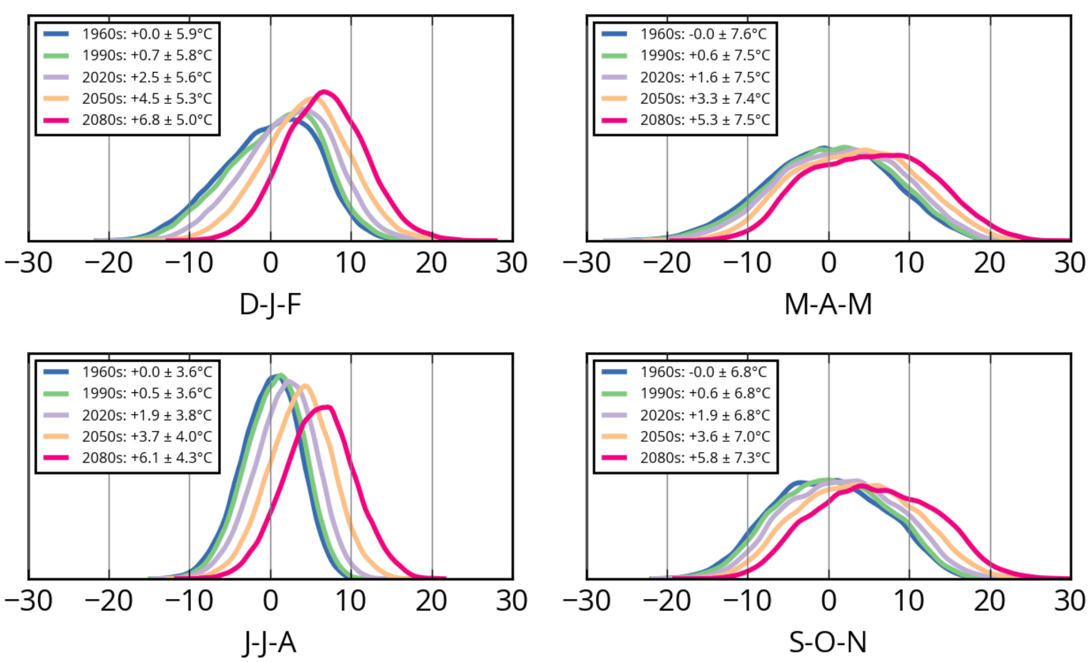

Figure 11: Histograms of Temperature Anomalies (°C) for RCP 8.5. "D-J-F" = Dec, Jan, Feb, "M-A-M" = Mar, Apr, May, "J-J-A" = Jun, Jul, Aug, "S-O-N" = Sep, Oct, Nov

7 Key Climate Indicators (KCI)

In order to examine how the climate in and around the Town of Halton Hills has evolved historically and is projected to change, we calculated a number of Key Climate Indicators, targeting those indicators which impact human health and place a strain on the built environment.

For each KCI, we provide:

- Time Series

  In order to show the evolution of the climate of Halton Hills, we calculate the corresponding yearly signal based on the PCIC data for each KCI, for each RCP, for each model, and for each grid box. Each light-gray line indicates a separate model and grid box location. The median of all these individual lines is shown by the black line. While this median represents the best model estimate, the spread shown by the gray lines indicates the range or uncertainty of this estimate.

  It should also be noted that even the historical PCIC results show a spread in values. That is, each model provides a different estimate of the historical record as they are not necessarily constrained to reproduce the exact timing of the observation record and thus free to vary.

  Finally, for comparison to the observational record, KCI values based on EC stations are superimposed on the PCIC results when sufficient data is available.

- Climate Maps

  In order to illustrate any spatial variability in the KCIs, we provide maps of the median of all model results in each PCIC grid box for a given period of time and a given representative concentration pathway. The maps are attached as Section 9.

  Generally, there is a fairly significant east-west divide, with temperatures to the east typically higher than in the west. This difference can largely be attributed to 1) proximity to the large urban centres of Brampton/Mississauga/Toronto to east and 2) the high elevations of the Escarpment to the west. These spatial patterns continue under all RCPs and temperature-based KCIs, including degree days and heat/cold waves.

  Generally, precipitation consistently tends to be higher to the west on the escarpment. Again, these spatial patterns continue under all RCPs and precipitation KCIs. As precipitation is more localized than temperature, precipitation can be expected to vary significantly within each grid cell based on local topography.

The "ClimDex", "Climate Extremes Indices", or "ETCCDI" indices are a set of 27 indicators of changes in temperature and precipitation (Karl, Nicholls, and Ghazi 1999). For this document we provide a smaller subset, removing those indices that do not provide any additional guidance. We also add a few extra building-related (e.g. degree days) and health-related indices (heat and cold waves) KCIs.

7.1 Summer Days (SU)

Summer Days represents the number of days in a given year when the daily high temperature is above 25°C. Hot days have an impact on the amount of energy used to cool buildings, and elevated temperatures may lead to an increase in hospital visits.

Historically (1960s), Halton Hills typically[5] experienced 56 [37–75] Summer Days per year. Now (circa 1990s), Halton Hills experiences 63 [42–83] Summer Days in a typical year. For the peak-and-decline scenario of RCP 2.6, models project a typical increase to 80 [58–100] days in the 2020s, 86 [63–105] days in the 2050s, and 85 [63–103] days in the 2080s. For the mid-range scenario of RCP 4.5, models project a typical increase to 78 [56–101] days in the 2020s, 94 [67–111] days in the 2050s, and 101 [73–118] days in the 2080s. For the business-as-usual scenario of RCP 8.5, models project a typical increase to 79 [58–98] days in the 2020s, 99 [77–123] days in the 2050s, and 124 [96–144] days in the 2080s.

[5] "Typically" here means the median value over a 30-year period, representing the "expected" value, accompanied by an interval in brackets indicating the 10th-percentile and 90th-percentiles values.

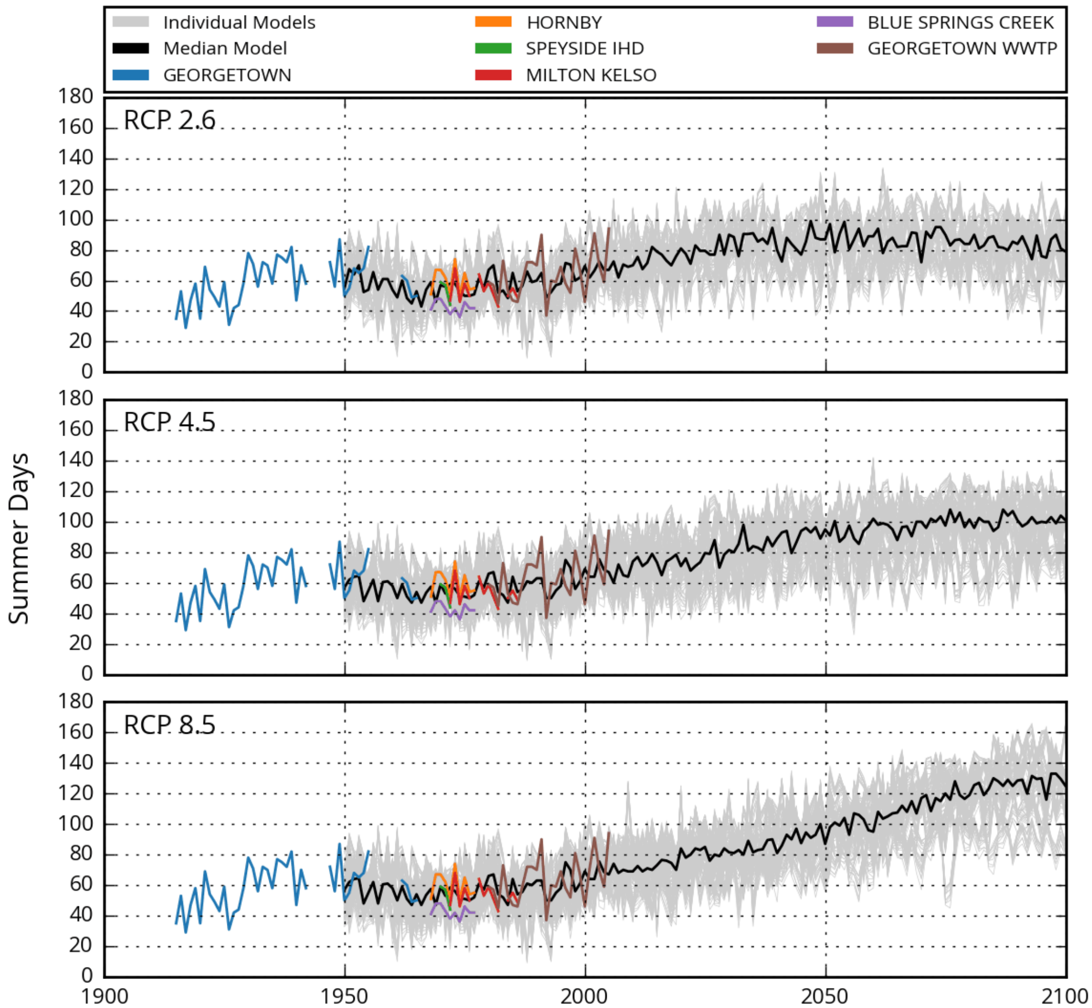

Figure 12: Evolution of Summer Days

7.2 Tropical Nights (TR)

Tropical Nights represent the number of nights when the minimum temperature is above 20°C. This parameter quantifies the changing capacity of the urban environment to relieve itself of the day's heat.

Tropical Nights have increased from one [0–5] per year to two [0–8] per year since climate records began. For the peak-and-decline scenario, models project Tropical Nights to increase to 6 [1–15] nights in the 2020s, 7 [1–17] nights in the 2050s, and 8 [2–18] nights in the 2080s. For the mid-range scenario, models project a typical increase of 5 [1–13] days in the 2020s, 11 [3–23] days in the 2050s, and 15 [4–34] days in the 2080s. For the business-as-usual scenario, models project a typical increase to 6 [1–16] nights in the 2020s, 17 [6–37] nights in the 2050s, and 40 [16–69] nights in the 2080s.

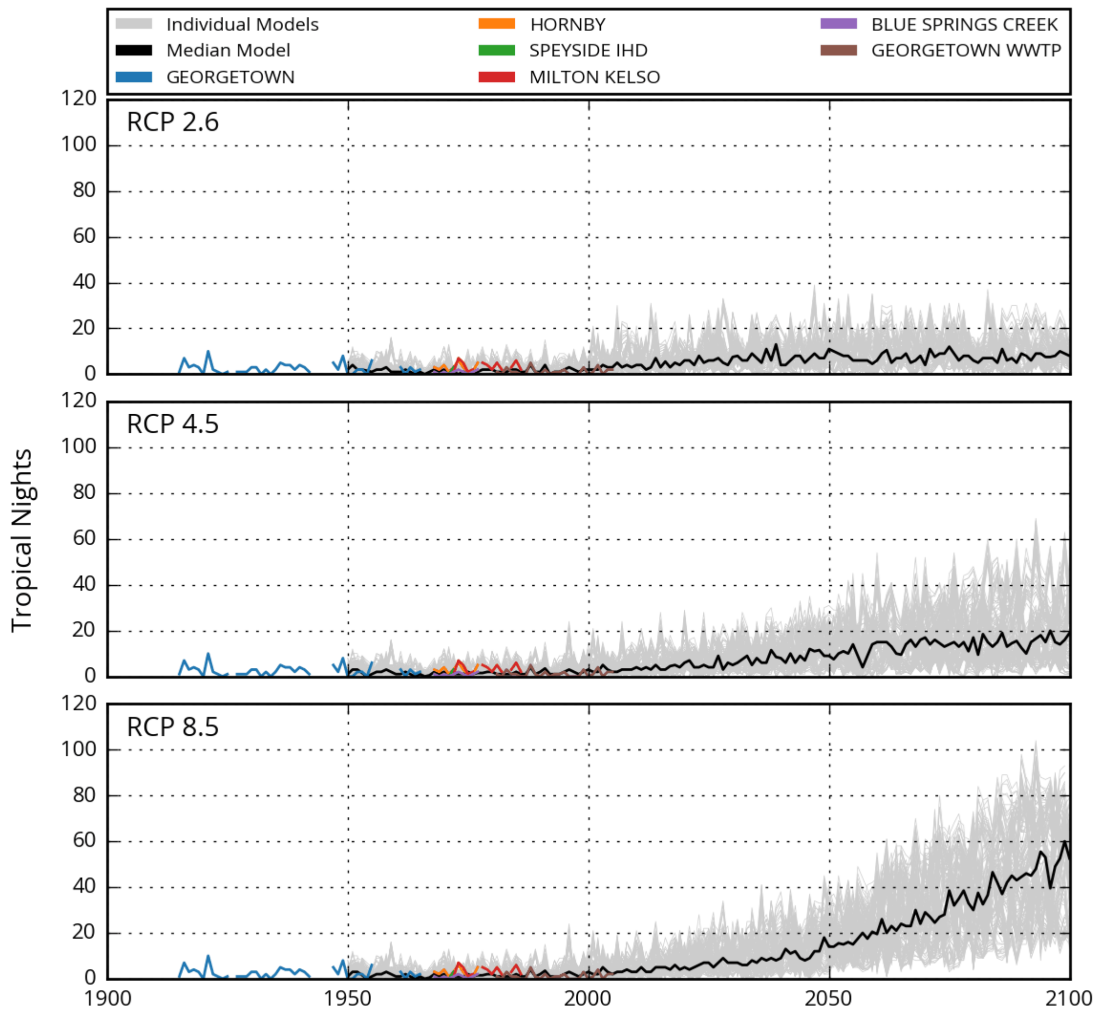

Figure 13: Evolution of Tropical Nights

7.3 Frost Days (FD)

Frost Days represent the number of days in a year when the daily low temperature is below freezing (0°C). More frost days increase risk to rural and urban ecosystems and agriculture.

Frost Days have already decreased from 157 [140–172] days per year in the 1960s to 150 [131–166] days today (1990s). For the peak-and-decline scenario, Frost Days are further projected to decrease to 133 [114–154] days in the 2020s, 128 [105–150] days in the 2050s, and 129 [106–149] days in the 2080s. For the mid-range scenario, Frost Days are projected to increase to 135 [112–156] days in the 2020s, 122 [94–144] days in the 2050s, and 114 [87–139] days in the 2080s. For the business-as-usual scenario, Frost Days are projected to decrease even more rapidly to 134 [108–156] days in the 2020s, 113 [84–137] days in the 2050s, and 88 [53–119] days in the 2080s.

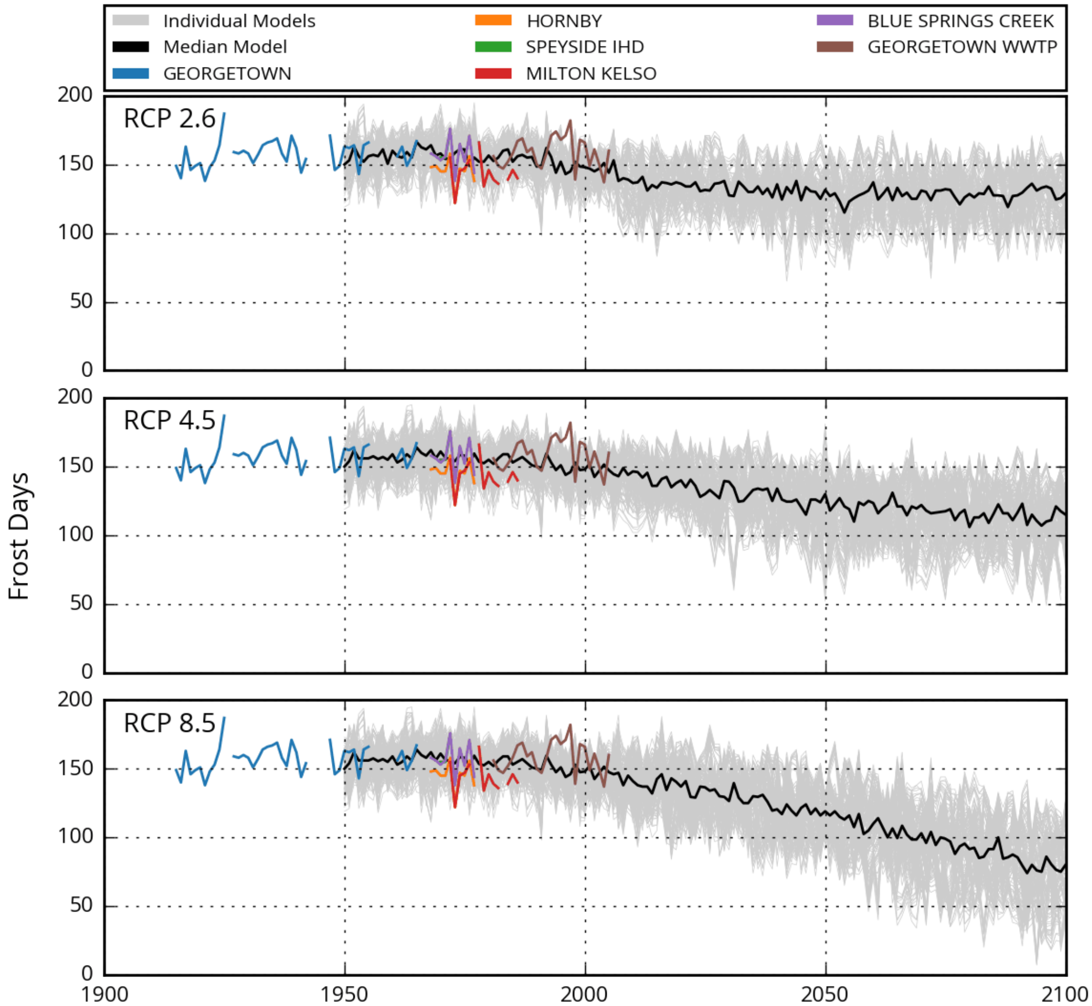

Figure 14: Evolution of Frost Days

7.4 Icing Days (ID)

Icing Days represent the number of days when the daily high temperature is below freezing (0°C). Icing Days pose many of the same risks as Frost Days, and are also days on which melting/snow is likely to remain.

Icing Days have already decreased from 67 [46–87] days per year in the 1960s to 61 [41–79] days today (1990s). For the peak-and-decline scenario, Icing Days are projected to decrease further to 49 [30–71] days in the 2020s, 45 [27–66] days in the 2050s, and 46 [28–66] days in the 2080s. For the mid-range scenario, Icing Days are projected to decrease to 50 [29–71] days in the 2020s, to 38 [19–61] days in the 2050s, and to 35 [15–57] days in the 2080s. For the business-as-usual scenario, Icing Days are projected to decrease to 49 [28–71] in the 2020s, to 35 [15–57] in the 2050s, and to 20 [2–43] in the 2080s.

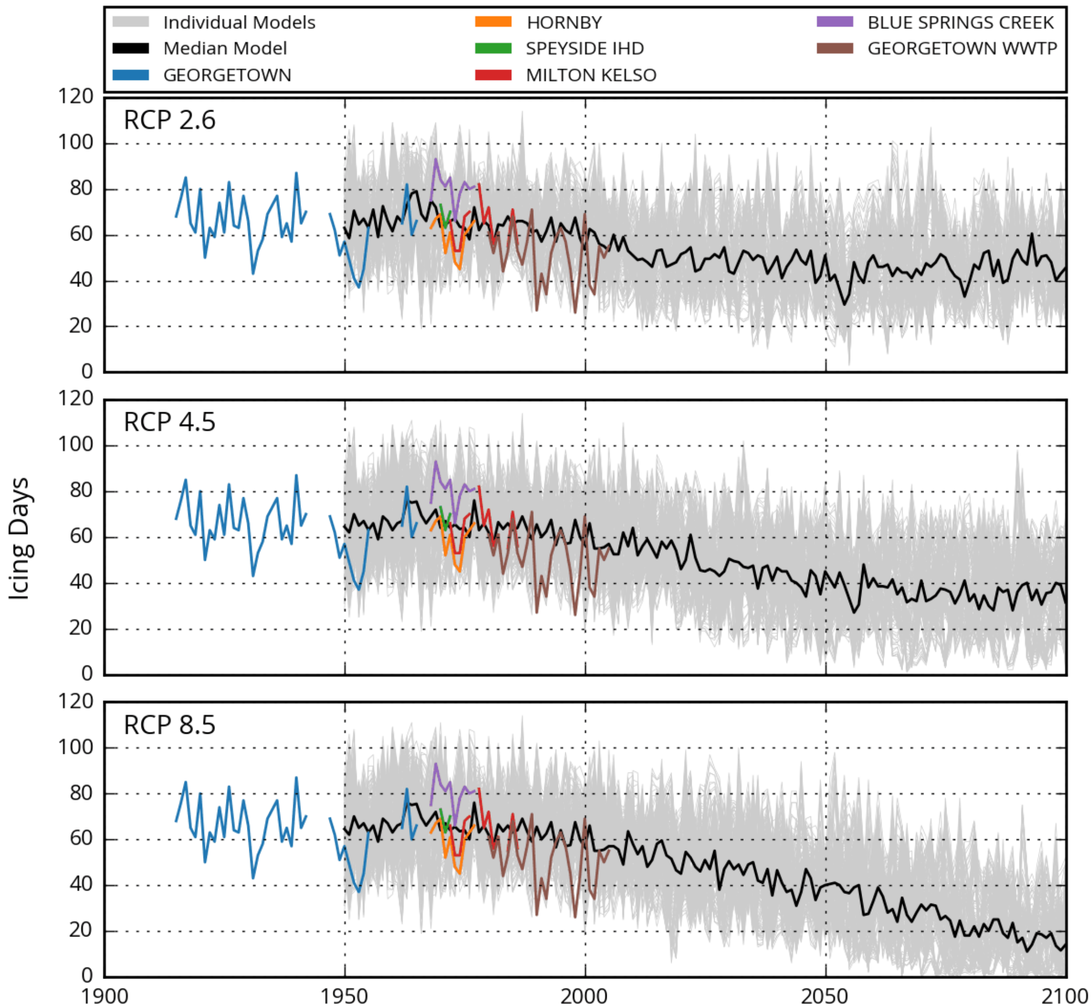

Figure 15: Evolution of Icing Days

7.5 Growing Season Length (GSL)

The Growing Season Length is defined as the number of days between the first span of six days above 5°C in spring and the first span of six days below 5°C in fall. An altered growing season length can dramatically impact the ecological inventory.

As the climate has warmed, the length of the growing season has increased by approximately a week, from 201 [180–224] days in the 1960s to 208 [183–236] days in the 1990s. For the peak-and-decline scenario, the growing season is expected to increase by three weeks by end-of-century, with 218 [194–247] days in the 2020s, 222 [200–257] days in the 2050s, and 221 [197–253] in the 2080s. For the mid-range scenario, the growing season is expected to lengthen to 218 [195–244] days in the 2020s, to 225 [201–259] days in the 2050s, and to 233 [207–269] days in the 2080s. For the business-as-usual scenario, the growing season is expected to increase by almost eight weeks by end-of-century, with 218 [193–247] days by the 2020s, 235 [206–277] days in the 2050s, and 255 [224–326] days in the 2080s.

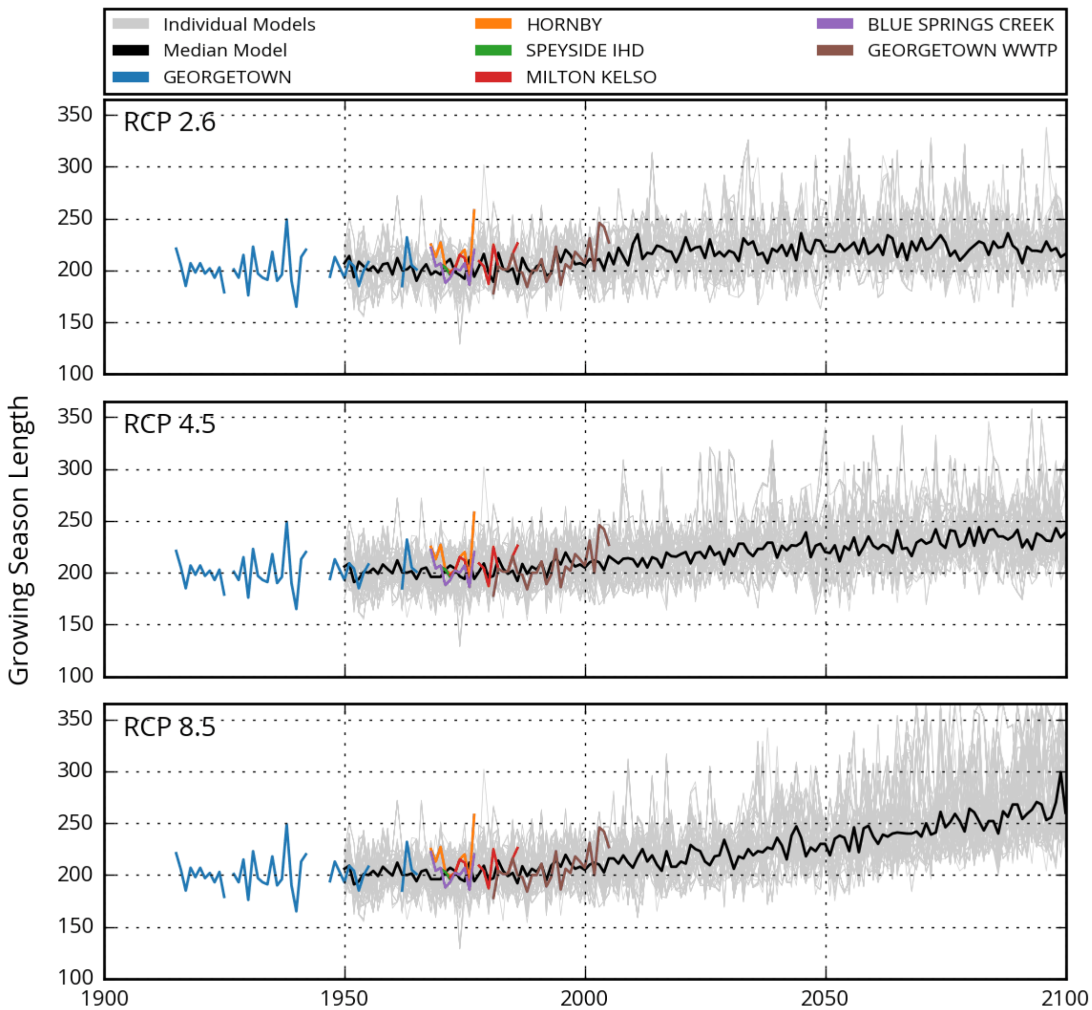

Figure 16: Evolution of Growing Season Length

7.6 *Highest Annual High Temperature (TXx)*

For a given year, TXx represents the extreme highest temperature experienced. Extreme high temperatures can negatively impact building cooling loads, electrical equipment, and human comfort/health.

In the past, annual extreme high temperatures were expected to not exceed 33°C [30–35°C]. Today, they still typically do not exceed 33°C [31–36°C]. Under a peak-and-decline scenario, the temperature is expected to rise marginally to 35°C [32–38°C] throughout the century. However, under a mid-range scenario the annual high temperature is expected to increase to 35°C [32–38°C] in the 2020s, to 36°C [33-40°C] in the 2050s, and to 37°C [34–41°C] in the 2080s. Worse, based on the business-as-usual scenario, the extreme annual high temperature is projected to increase to 35°C [32–38°C] in the 2020s, to 37°C [34–41°C] in the 2050s, and to 39°C [35–45°C] in the 2080s. Put another way, while in the past the chance of exceeding 35°C in a given year was 10%, by the end-of-century, this probability will be greater than 90%; further, the probability of exceeding 45°C in a given year will be 10%.

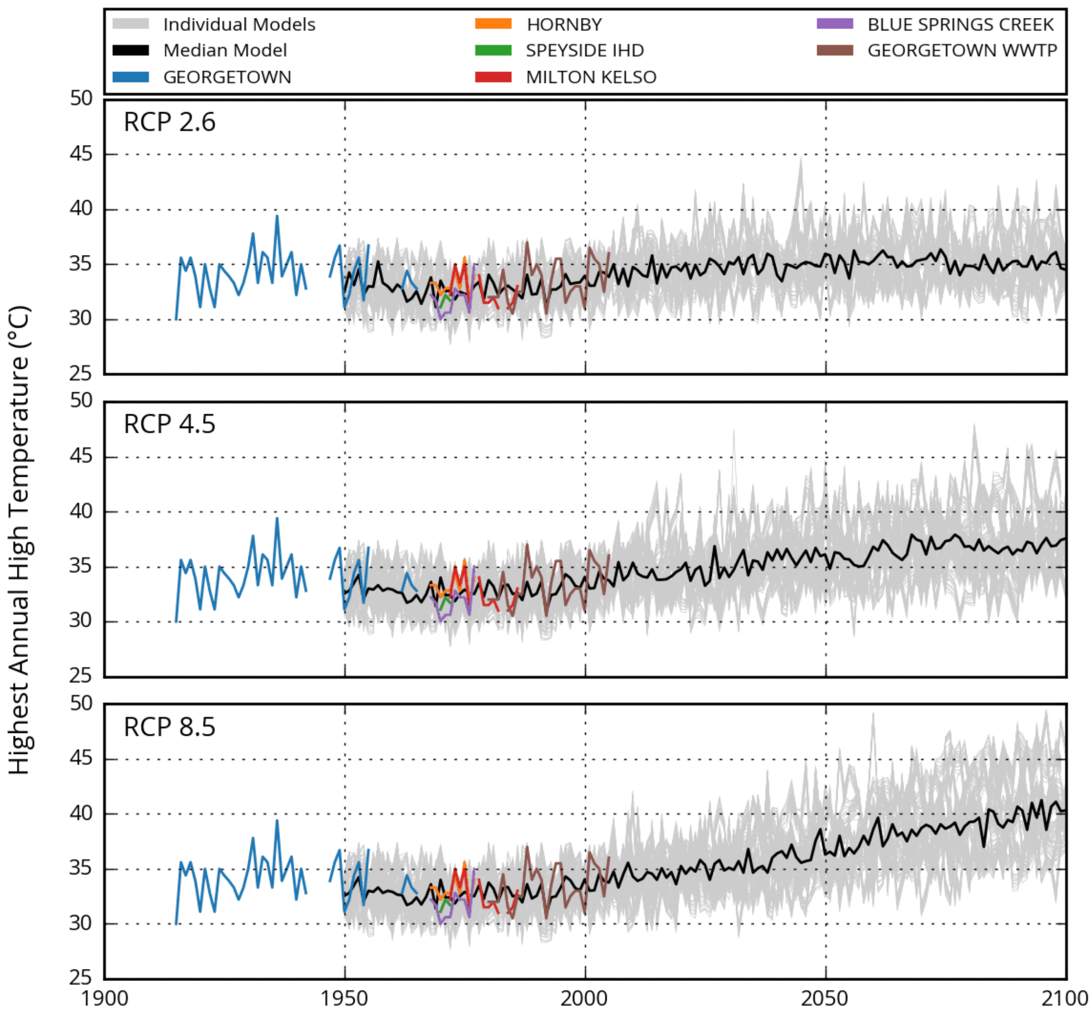

Figure 17: Evolution of Highest Annual High Temperature

7.7 Lowest Annual Low Temperature (TNn)

For a given year, TNn represents the extreme lowest temperature experienced. Rising extreme low temperatures will lessen excess building heating loads and reduce the probability of frozen pipes.

In the past, annual extreme temperatures did not typically go below -25°C [-30 to -21°C]. These extremes have not changed significantly in recent times, with temperatures still not expected to go below -25°C [-29 to -20°C]. For the peak-and-decline scenario, the low temperature is projected to rise to -22°C [-26 to -18°C] in the 2020s, to -21°C [-25 to -16°C] in the 2050s, and to level out at -21°C [-25 to -17°C] in the 2080s. A mid-range scenario would expect to see annual low temperatures of -22°C [-27 to -17°C] in the 2020s, -19°C [-24 to -15°C] in the 2050s, and -18°C [-23 to -14°C] in the 2080s. However, the business-as-usual scenario will see significant warming during winter, with typical annual low temperatures of -21°C [-26 to -17°C] in the 2020s, -18°C [-23 to -13°C] in the 2050s, and -14°C [-19 to -9°C] in the 2080s. Put another way, by the end of this century there will be a 10% chance that a given year will not see a temperature of less than -9°C.

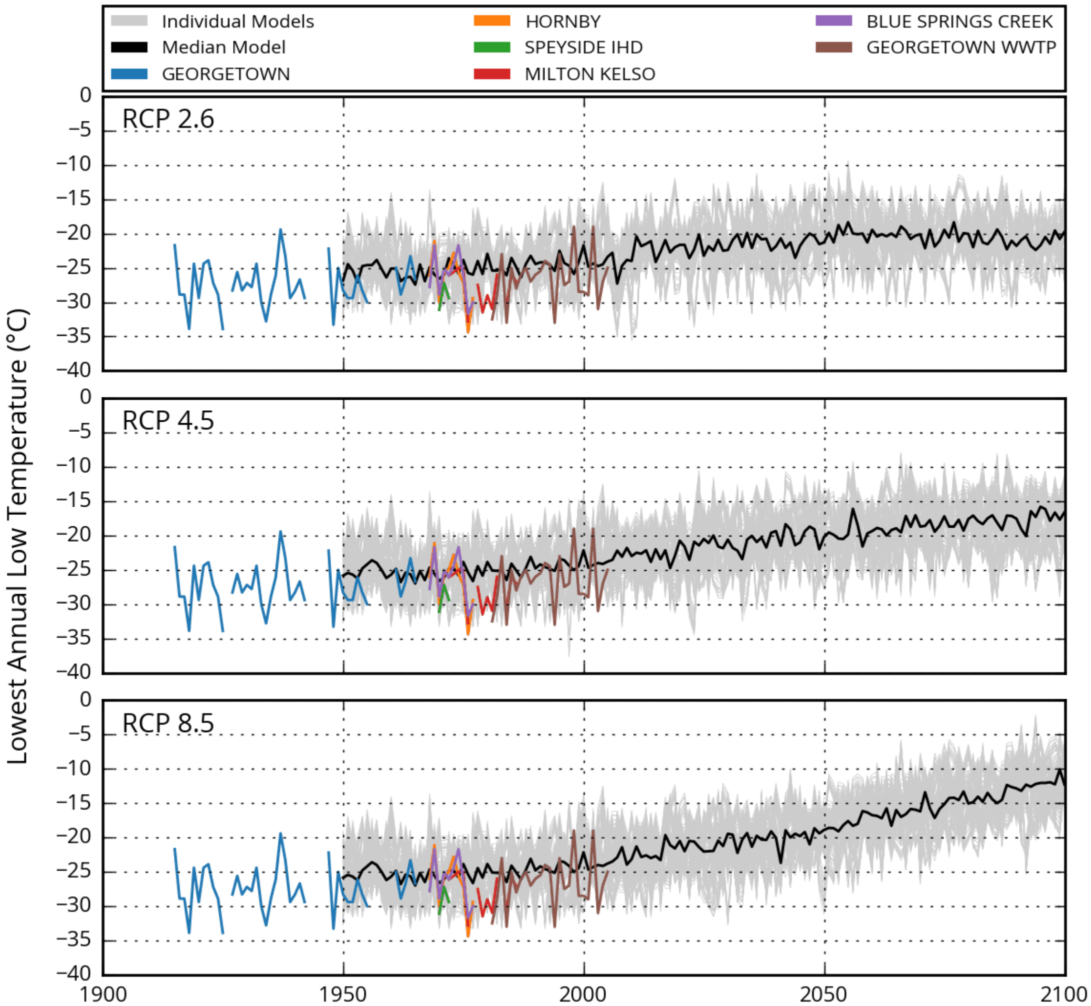

Figure 18: Evolution of Lowest Annual Low Temperature

7.8 Days with Precipitation > 10mm (R10mm)

R10mm indicates days when the total precipitation, whether rain or snow (in liquid form), exceeds 10mm (0.4in). High daily precipitation can indicate increases (decreases) in the hydrological cycle and subsequent risk of flooding (drought).

Historically, Halton Hills typically sees 24 [17–31] days with at least 10mm of rain. This has remained largely true to the present day, increasing only slightly to 25 [19–32] days. Only marginal increases in this parameter are projected with 26 [19–34] days in the 2020s, 27 days in the 2050s, and 27 [19–35] days in the 2080s, for the peak-and-decline scenario. The mid-range scenario scenario shows very insignificant rises in high precipitation days with 26 [18–33] days in the 2020s, 27 [20–36] days in the 2050s, and 28 [19–35] days in the 2080s. The business-as-usual shows a slightly enhanced chance of high precipitation days, with 26 [18–33] days in the

2020s, 28 [20–36] days in the 2050s, and 29 [22–36] days in the 2080s. That is, high precipitation days are projected to remain relatively unchanged through the century, regardless of scenario.

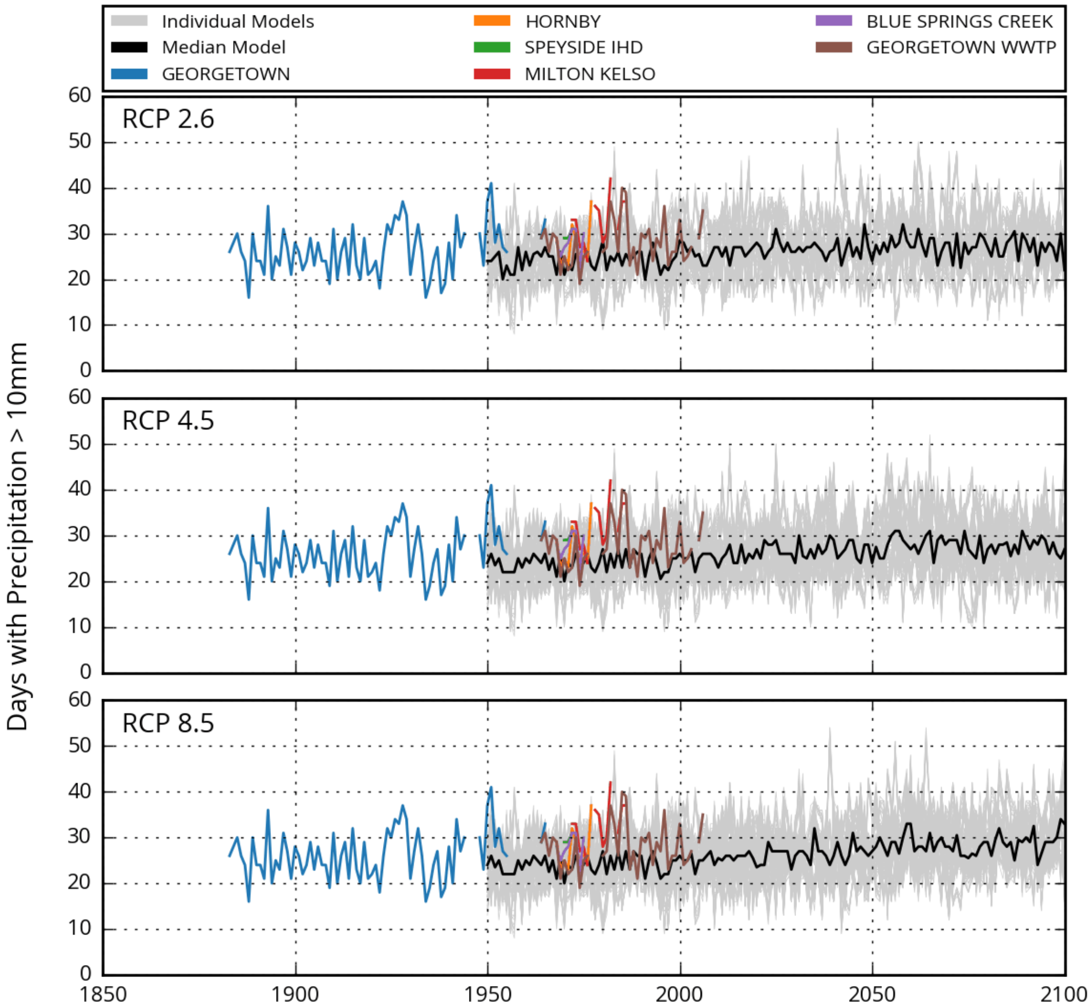

Figure 19: Evolution of Days with Precipitation > 10mm

7.9 Maximum 5-day Precipitation (Rx5day)

Rx5day provides the maximum total amount of rain in a given year that falls in a 5-day storm. A large amount of rain over a 5-day period can lead to an enhanced flooding risk, especially in early spring while the ground is still frozen.

Currently approximately 64 [46–93] mm of precipitation falls during a typical worst 5-day storm of the year. This has risen significantly in recently to 66 [50-103] mm. Under the peak-and-decline scenario, this parameter is projected to rise to 73 [51–118] mm in the 2020s, to 75 [52–123] mm in the 2050s, and to 76 [51–120] mm in the 2080s. Under a mid-range scenario, this parameter is projected to increase to 72 [52–120] mm in the 2020s, to 76 [54–120] mm in the 2050s, and to 74 [51–124] mm in the 2080s. Under a business-as-usual scenario, this parameter is projected to increase even more, to 72 [49–110] mm in the 2020s, to 78 [54–128] mm in the

2050s, and to 81 [56–144] mm in the 2080s. In summary, while the "typical" (50th-percentile) year's worst storm of the year is expected to increase marginally, the more significant increases in 90th-percentile values suggest a corresponding greater potential for even larger storms in a "bad" year as the century progresses.

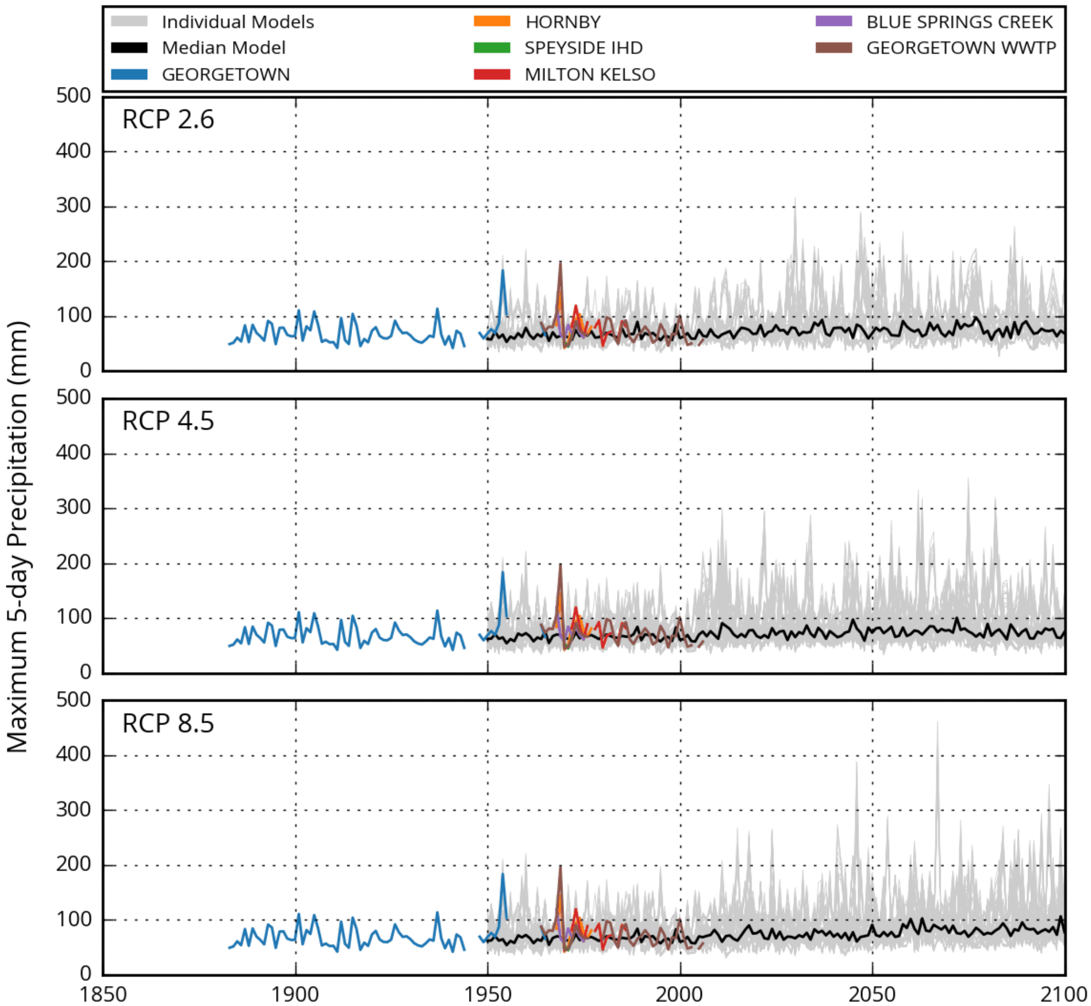

Figure 20: Evolution of Maximum 5-day Precipitation

7.10 Heating Degree Days (HDD10)

Heating Degree Days are defined as the sum of the differences between daily average temperatures and the base temperature of 10.0°C. Only days for which the mean temperature is less than 10.0°C are counted. There is a direct correlation between the amount of energy required to heat a building and HDD10.

Buildings designed in the past were based on heating requirements of 2290 [1950–2640] degree-days. Recent warming means buildings are now designed to 2160 [1810–2480] degree-days, representing a decrease of 6% relative to the 1960s. Future warming, under a peak-and-decline scenario, is projected to further decrease this number to 1880 [1570–2250] degree-days in the 2020s, to 1760 [1450–2150] degree-days in the 2050s, and to 1800 [1480–2130] degree-days in the 2080s, representing decreases of 18%, 23%, and 21%, respectively, relative to the 1960s. Under a mid-range scenario, heating degree days are expected to decrease to 1900 [1550–2250] degree-days in the 2020s, 1670 [1290–2020] degree-days in the 2050s, and 1560 [1200–1910] degree-days in the 2080s, representing decreases of 17%, 27%, and 32%, respectively. However, under a business-as-usual scenario, projections indicate heating degree days of 1880 [1490–2240] in the 2020s, 1550 [1180–1900] in the 2050s, and 1210 [790–1570] in the 2050s, representing decreases of 18%, 32%, and 47%, respectively. That is, under a business-as-usual scenario, heating requirements are projected to halve by the end of the century.

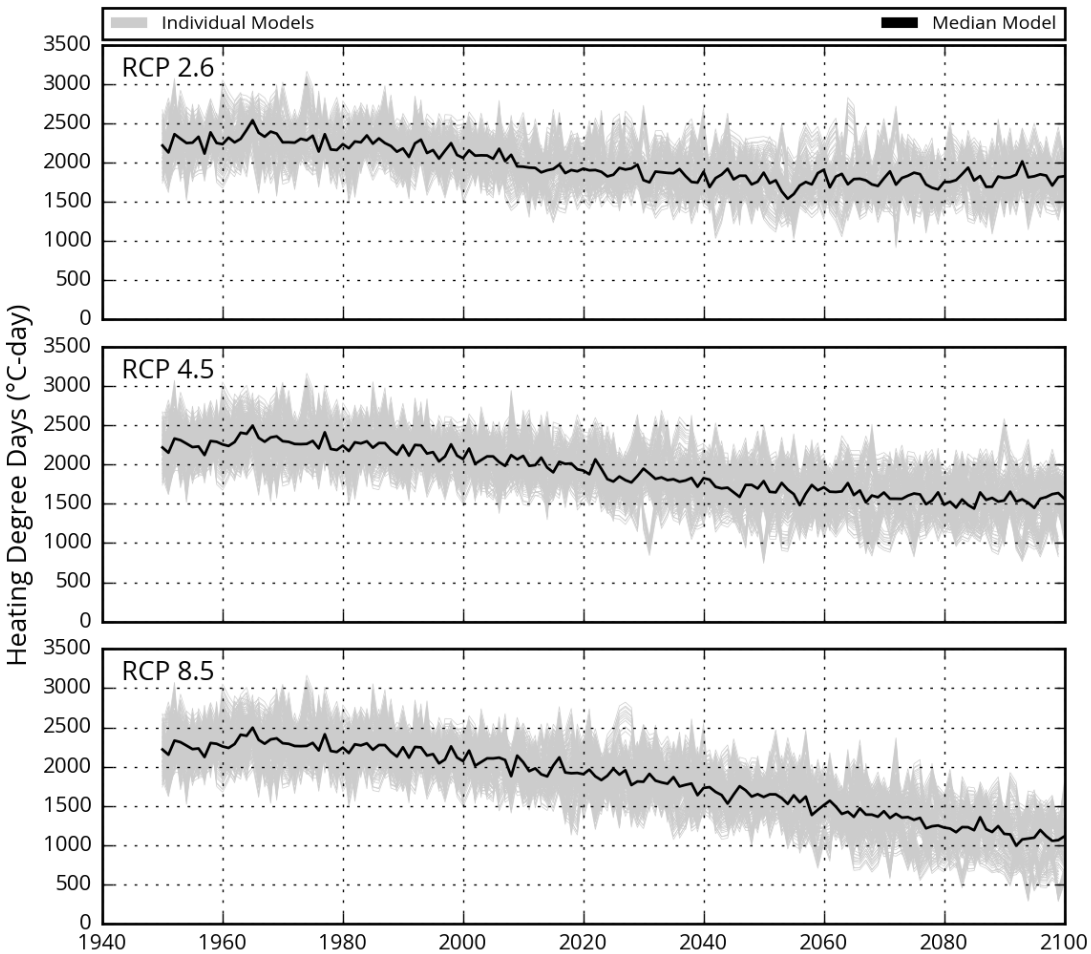

Figure 21: Evolution of Heating Degree Days

7.11 Cooling Degree Days (CDD18)

Cooling Degree Days are defined as the sum of the differences between daily average temperatures and the base temperature of 18.3°C. Only days for which the mean temperature is greater than 18.3°C are counted. There is a direct correlation between the amount of energy required to cool a building and CDD18, energy that is typically supplied through the electrical grid.

Air-conditioning units in the past were designed to cooling requirements of 170 [101–270] degree-days. Recent warming has increased this cooling requirement to 207 [120–310] degree-days, an increase of 22%. Under a peak-and-decline scenario, cooling requirements are expected to increase to 310 [190–450] degree-days in the 2020s, to 340 [210–500] degree-days in the 2050s, and to 350 [220–490] degree-days in the 2080s, representing increases of 78%, 99%, and 101%, respectively, relative to the 1960s. Under a mid-range scenario, cooling requirements are expected to increase to 290 [180–450] degree-days in the 2020s, to 410 [250–580] degree-days in the 2050s, and to 470 [280–710] degree-days in the 2080s, representing increases of 71%, 137%, and 172%, respectively. Even worse, under a business-as-usual scenario, cooling degree days are expected to rise to 310 [200–460] degree-days in the 2020s, to 490 [310–740] degree-days in the 2050s, and to 790 [460–1100] degree-days in the 2080s, representing increases of 80%, 184%, and 356%, respectively. That is, under a business-as-usual scenario, cooling load requirements are projected to increase three to four-fold.

Note that there are requirements in building codes (e.g. required wall insulation) based on climate zones. Currently, Halton Hills is classified as ASHRAE Zone “6”, based on current heating and cooling degree days. A decrease in heating degree days will shift Halton Hills from a “6” to a “5” (c.f. Boston, MA) for RCPs 2.6 and 4.5, and to a “4” (c.f. Washington, DC) for RCP 8.5.

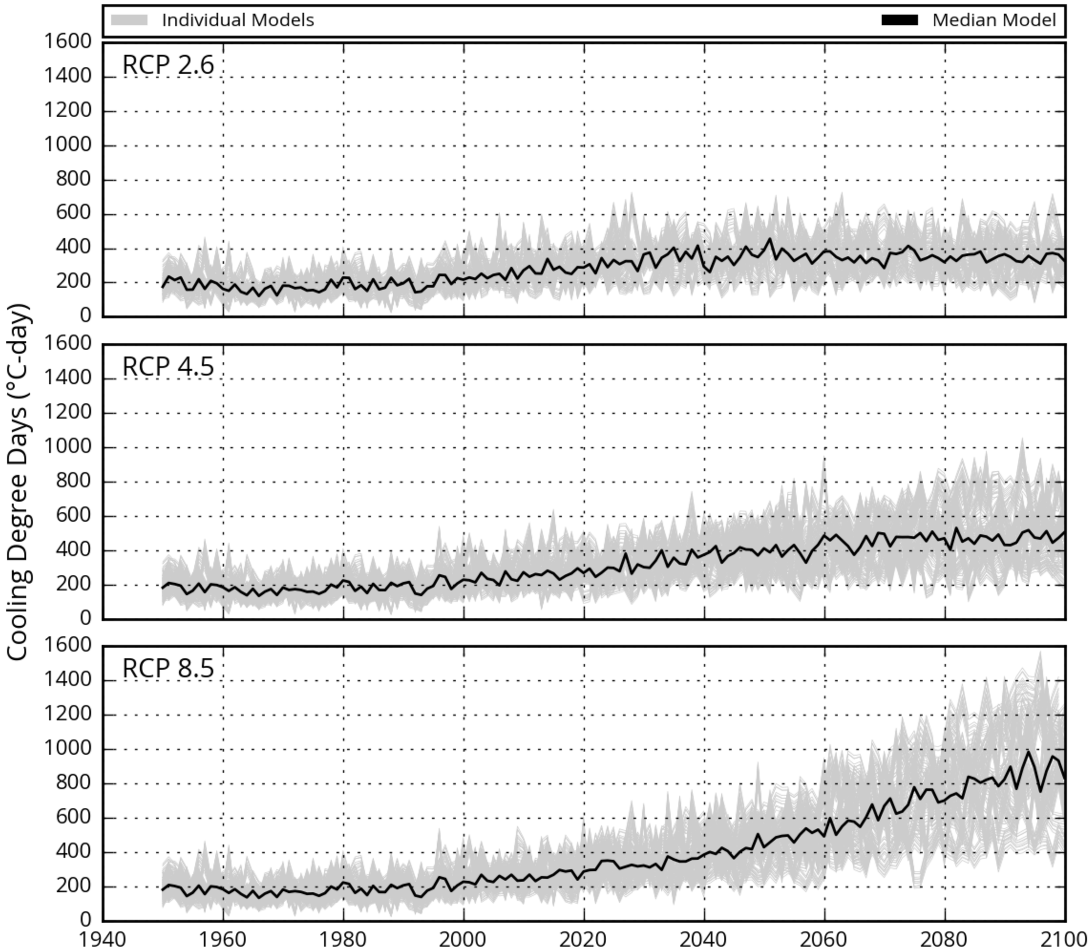

Figure 22: Evolution of Cooling Degree Days

7.12 Heat Waves (HW30)

Heat Waves are here defined as the number of times in a year for which the daily high temperature remains above 30°C for at least three days in a row. Heat waves place stress on human health and building energy (air-conditioning) usage.

We've typically experienced between zero and three heat waves per year from the 1960s to the present, with a single heat wave the most common. Under a peak-and-decline scenario, we can expect to see a rise in heat waves to 3 [0–6] through the century. Under a mid-range scenario, models suggest a rise in heat waves to 2 [0–6] in the 2020s, to 4 [1–8] in the 2050s, and to 5 [2–8] in the 2080s. However, under a business-as-usual scenario, the number of heat waves is expected to rise from 3 [0–6] in the 2020s, to 5 [2–9] in the 2050s, and to 7 [4–10] in the 2080s. Put differently, by mid-century, there will be a less than 10% chance that we will see any less than 2 heat waves and a 10% chance of seeing at least 9 or 10.

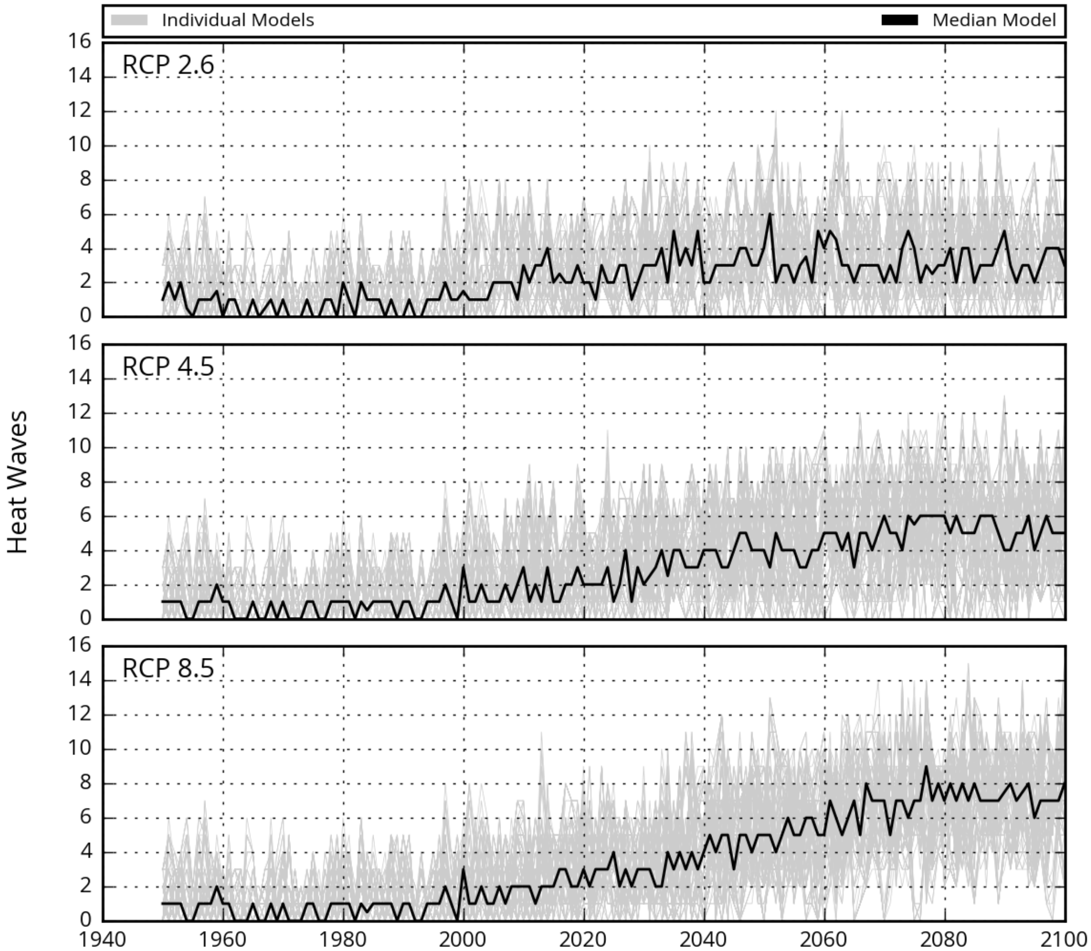

Figure 23: Evolution of Heat Waves

7.13 Cold Waves (CW15)

Cold Waves are here defined as the number of times in a year for which the daily low temperature remains below -15°C for at least three days in a row. As with heat waves, cold waves place stress on human health and extended periods of cold can place building systems at risk of freezing.

Halton Hills has typically experienced three [1–6] cold waves per year. Under a peak-and-decline scenario, this number is expected to decrease to one [0–3] cold waves(s) from the 2020s onwards. Under a mid-range scenario, this number is expected to decrease to 1 [0–4] cold wave(s) in the 2020s and to none [0–2] in the rest of the century. Under a business-as-usual scenario, we can expect one [0–4] cold wave(s) in the 2020s, none [0–2] in the 2050s, and their elimination in the 2080s.

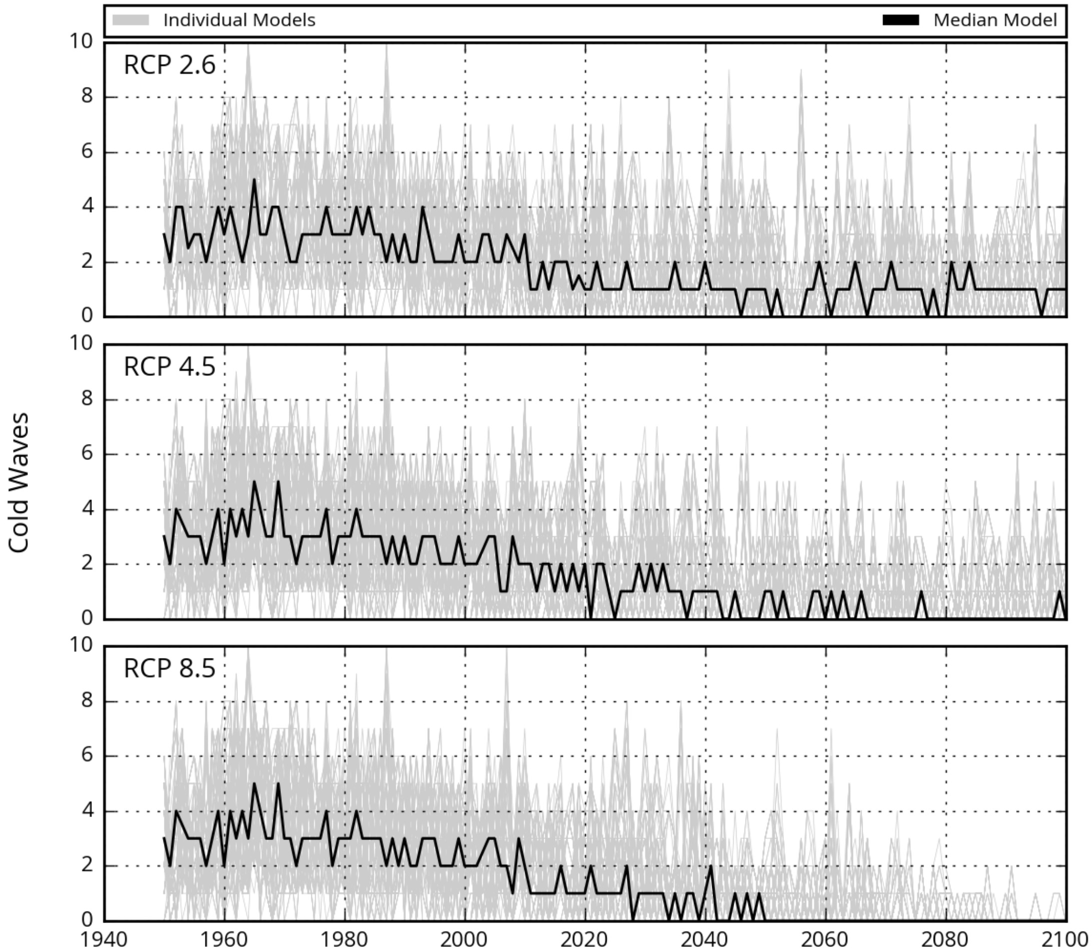

Figure 24: Evolution of Cold Waves

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9 Appendix – Maps

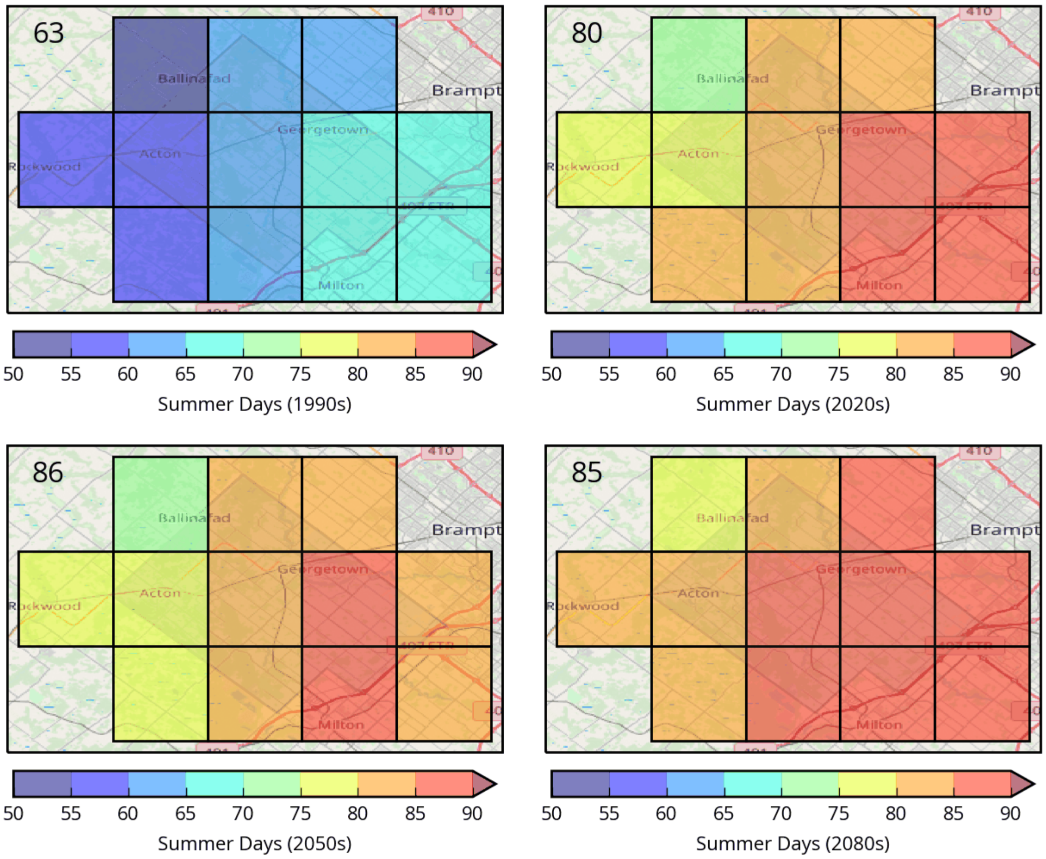

Figure 25: Maps of Summer Days (RCP 2.6)

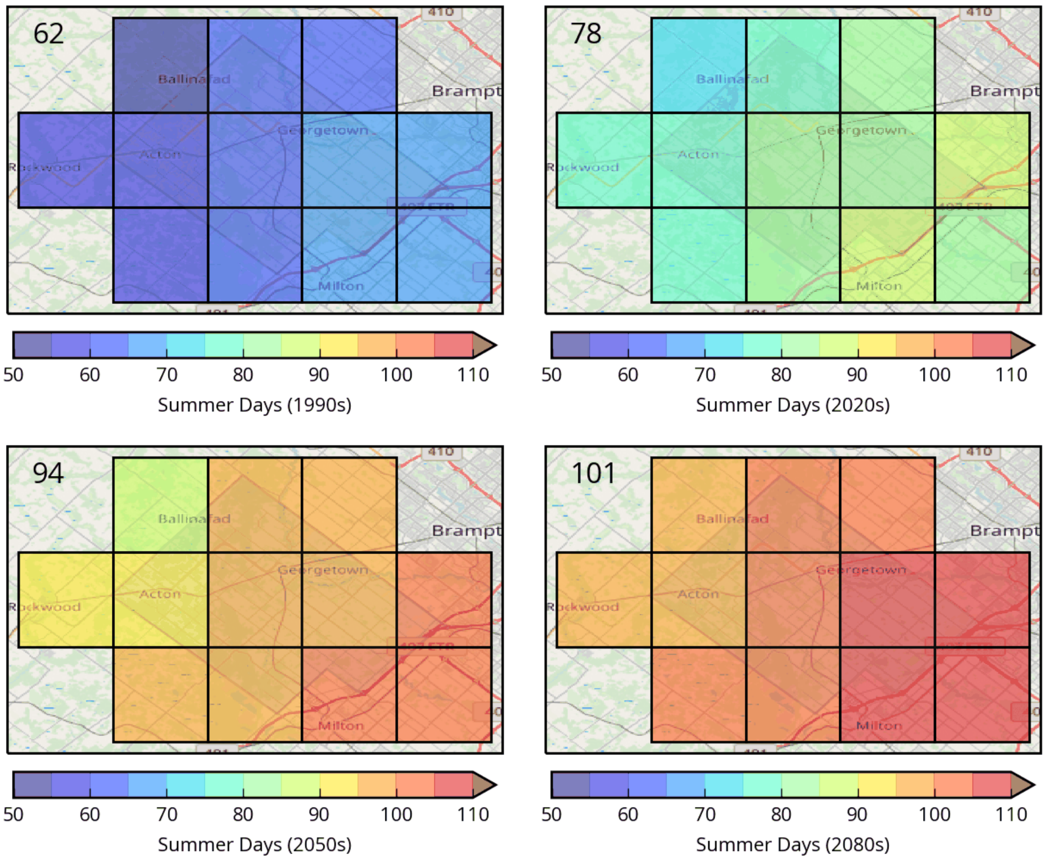

Figure 26: Maps of Summer Days (RCP 4.5)

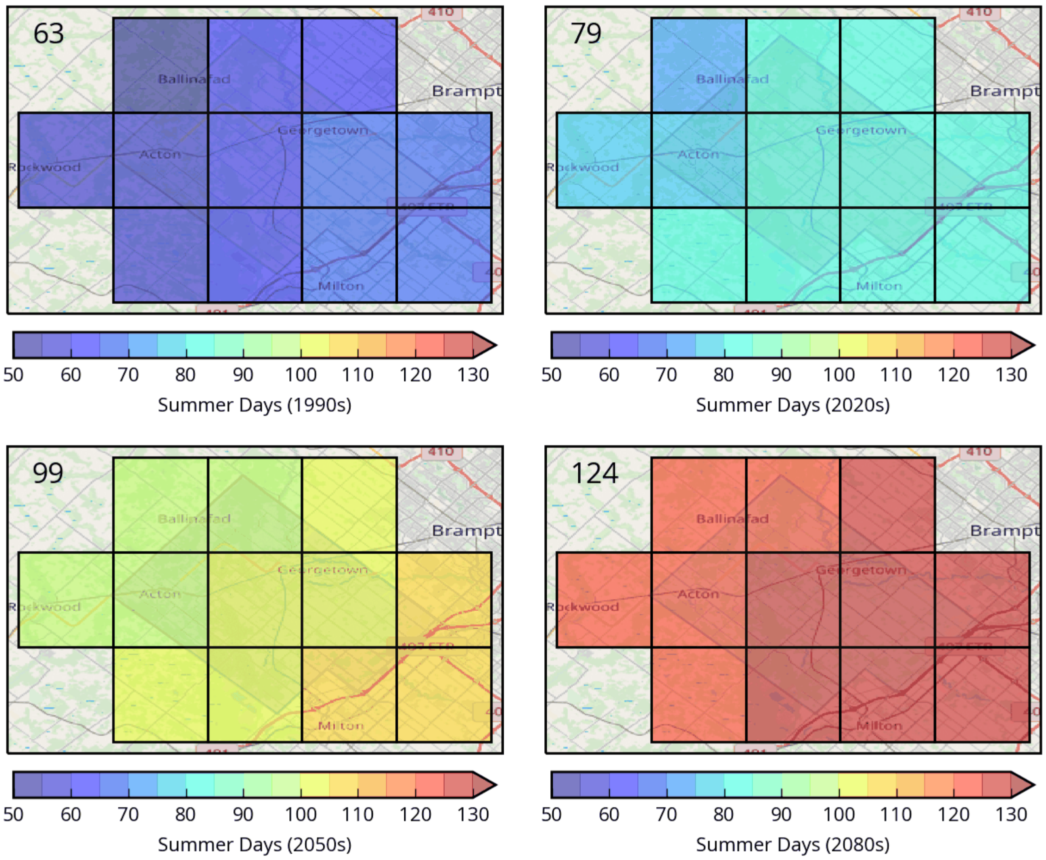

Figure 27: Maps of Summer Days (RCP 8.5)

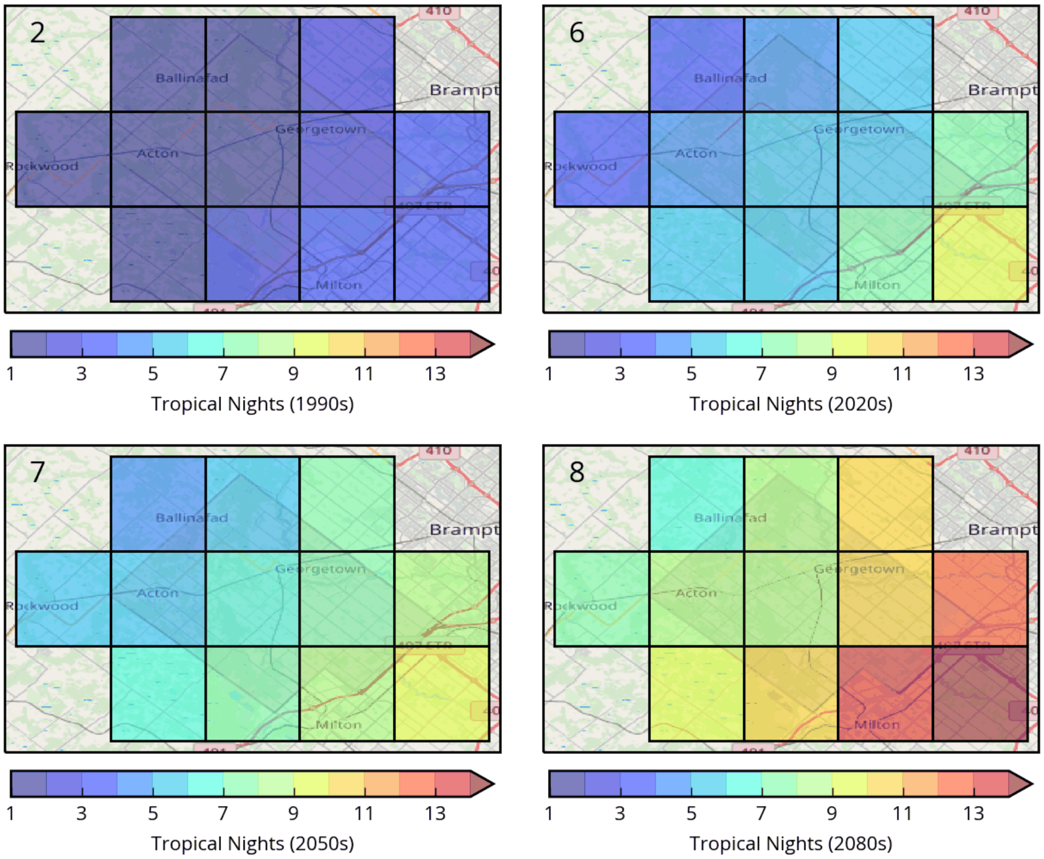

Figure 28: Maps of Tropical Nights (RCP 2.6)

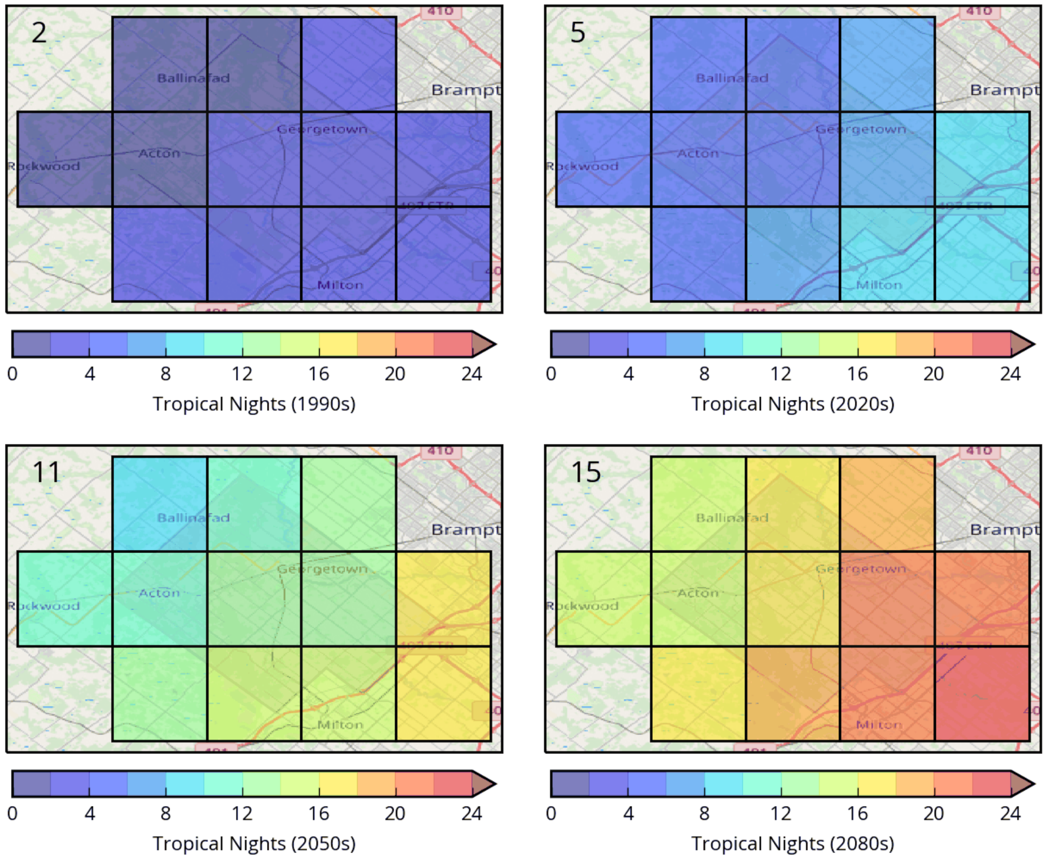

Figure 29: Maps of Tropical Nights (RCP 4.5)

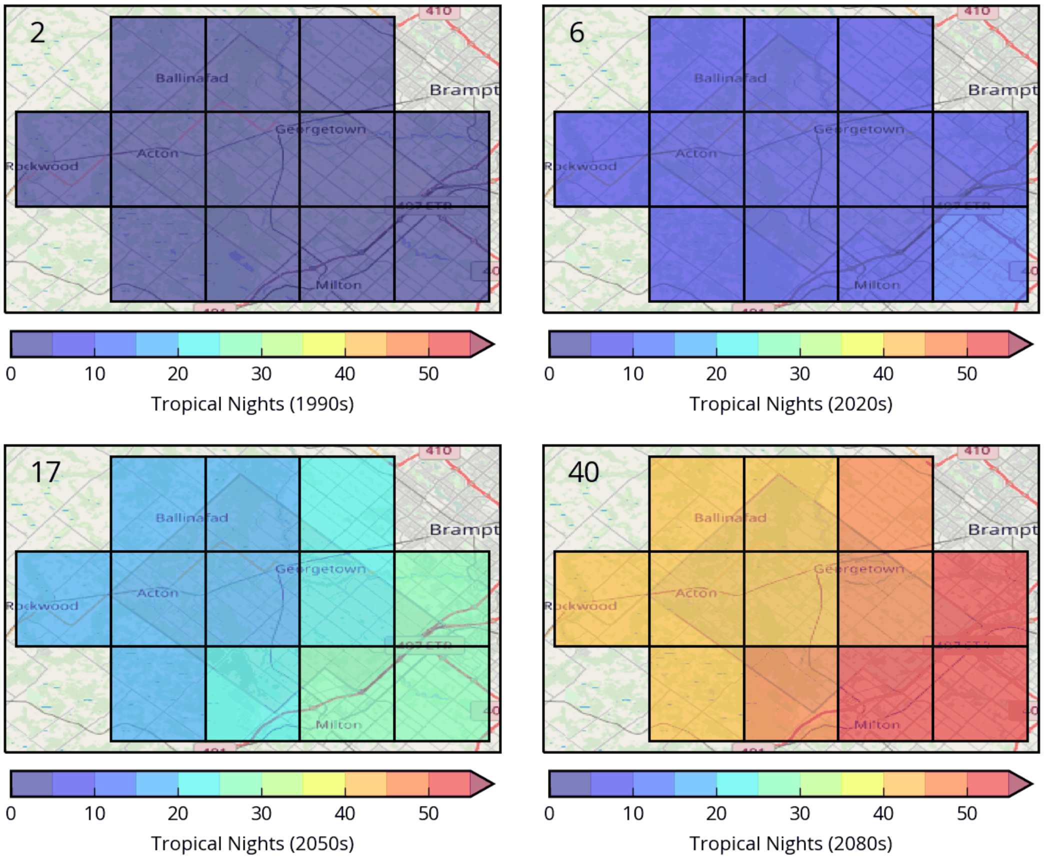

Figure 30: Maps of Tropical Nights (RCP 8.5)

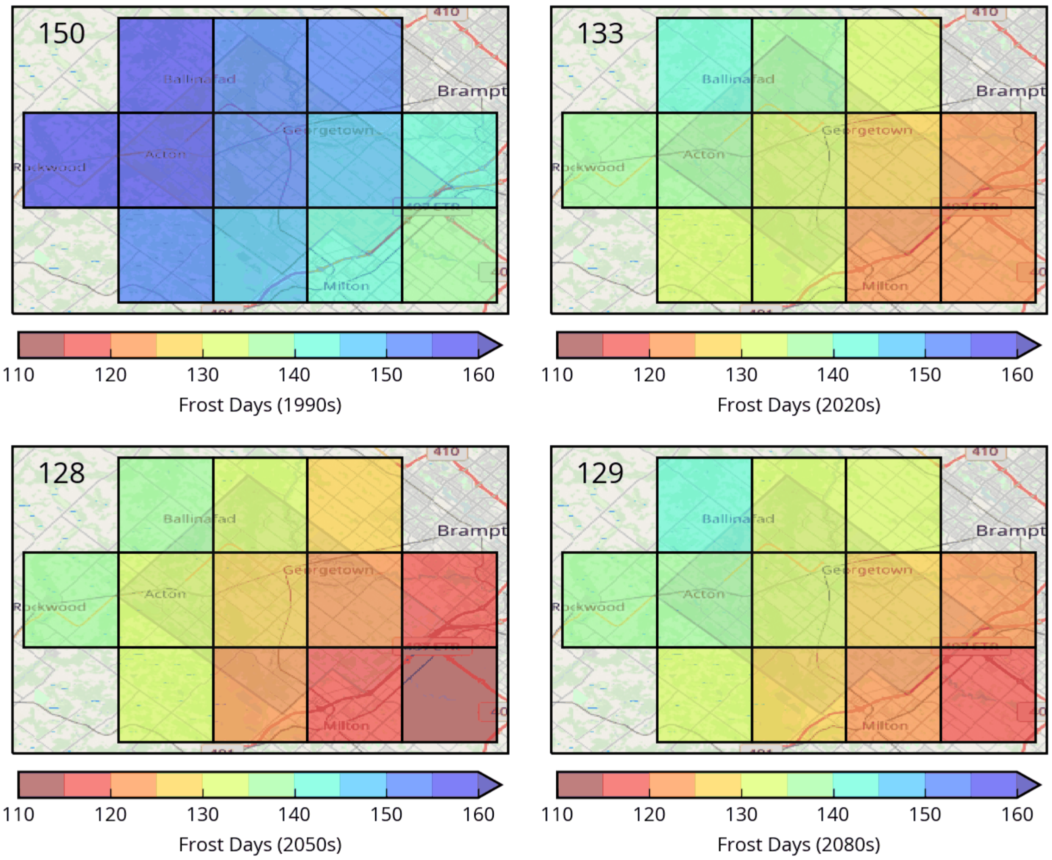

Figure 31: Maps of Frost Days (RCP 2.6)

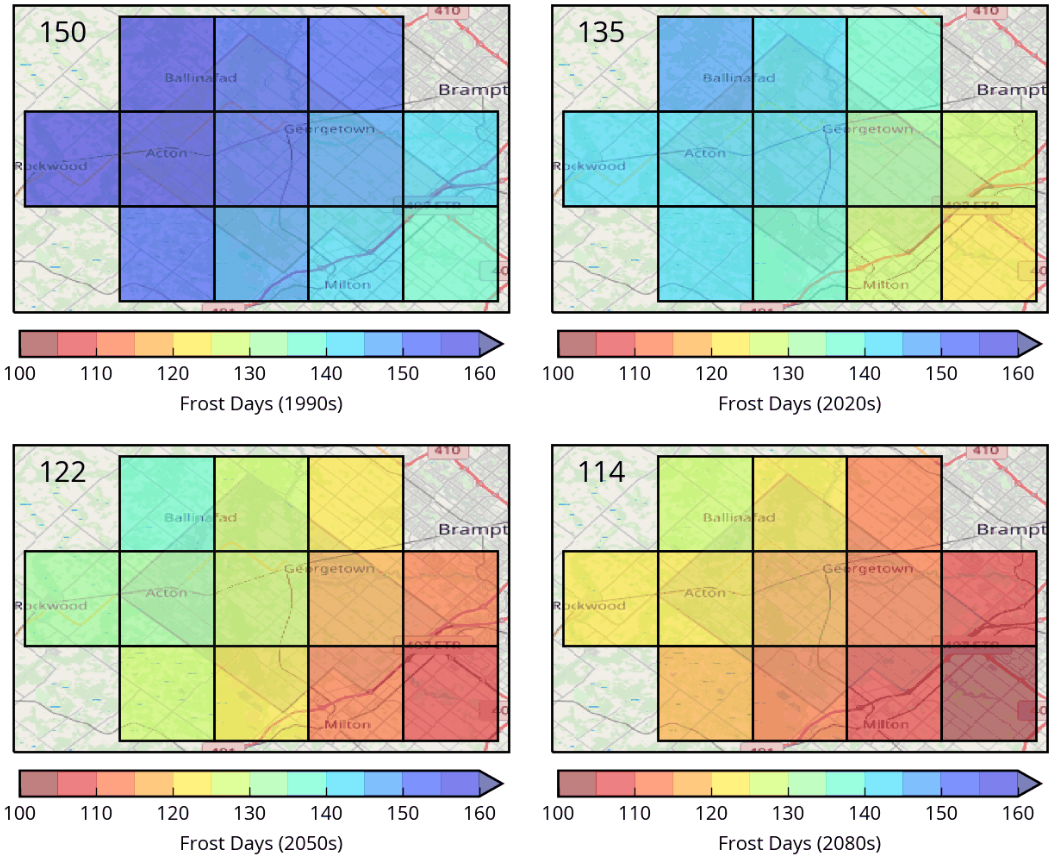

Figure 32: Maps of Frost Days (RCP 4.5)

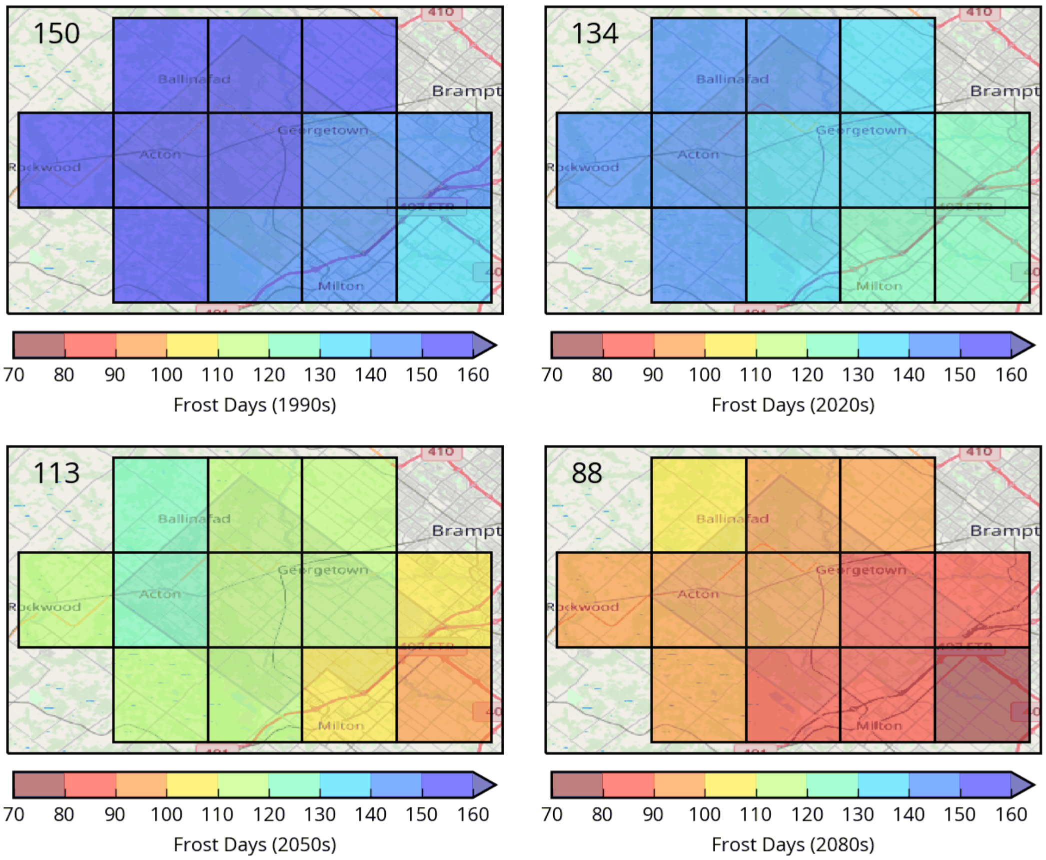

Figure 33: Maps of Frost Days (RCP 8.5)

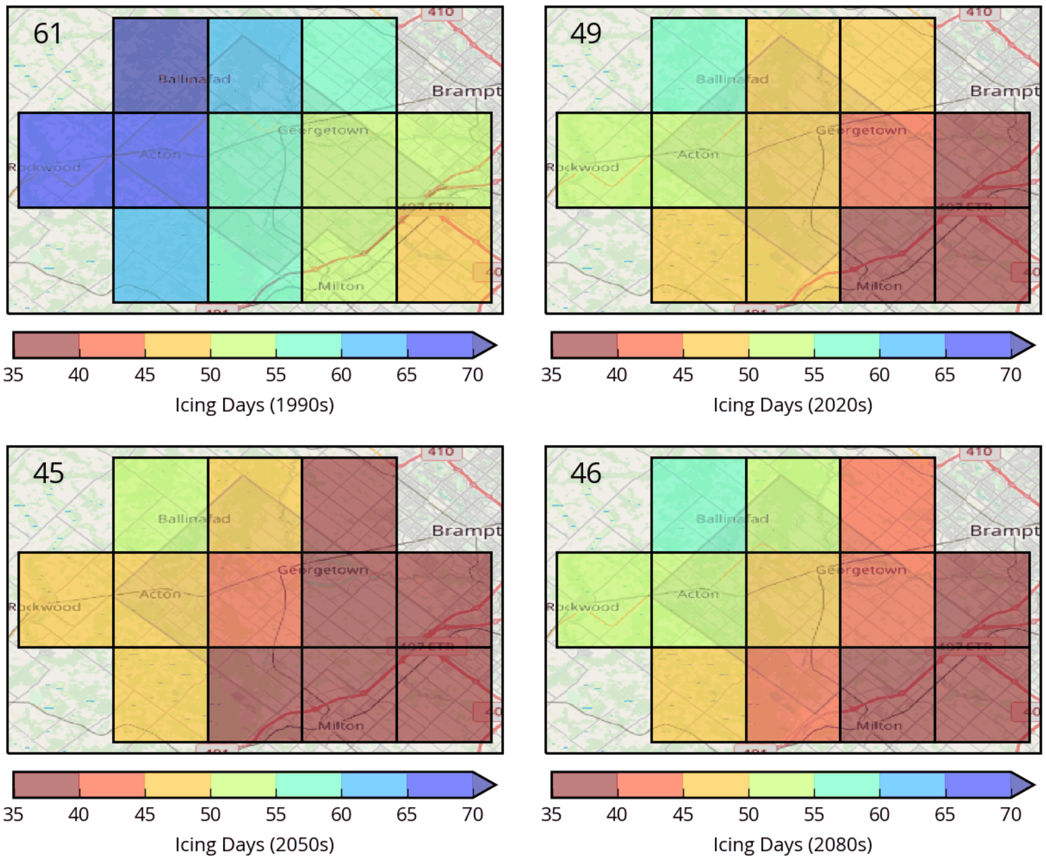

Figure 34: Maps of Icing Days (RCP 2.6)

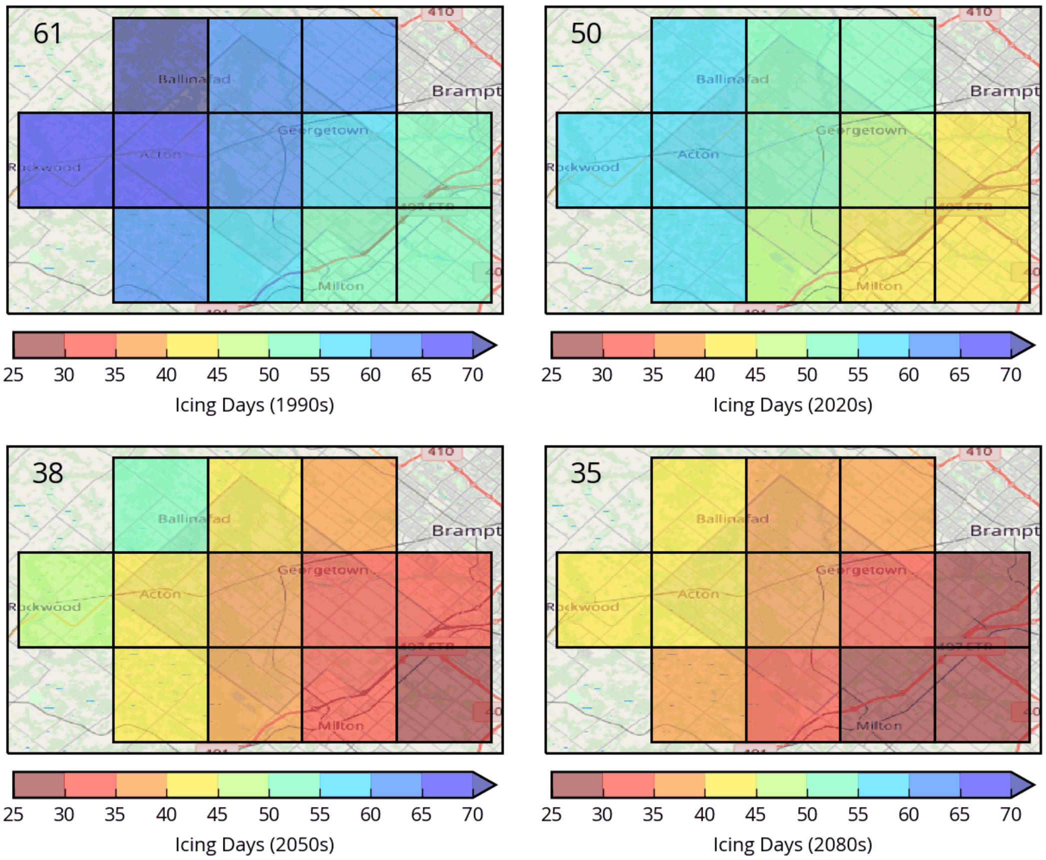

Figure 35: Maps of Icing Days (RCP 4.5)

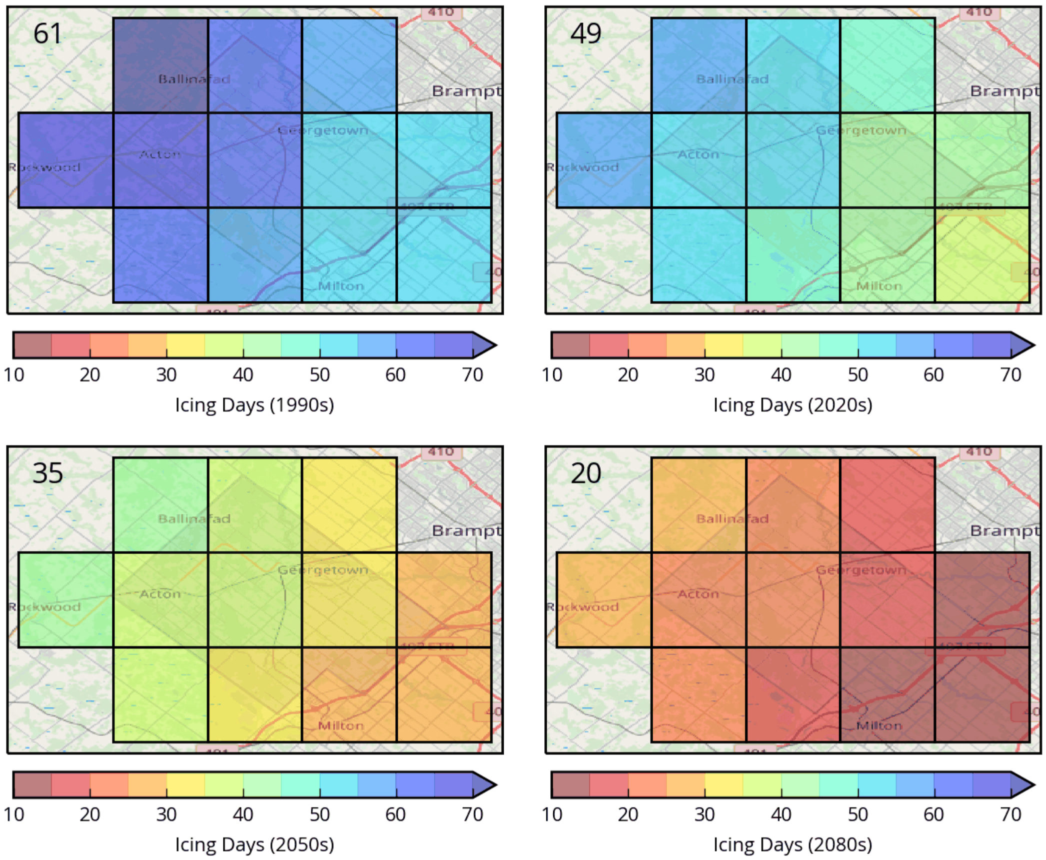

Figure 36: Maps of Icing Days (RCP 8.5)

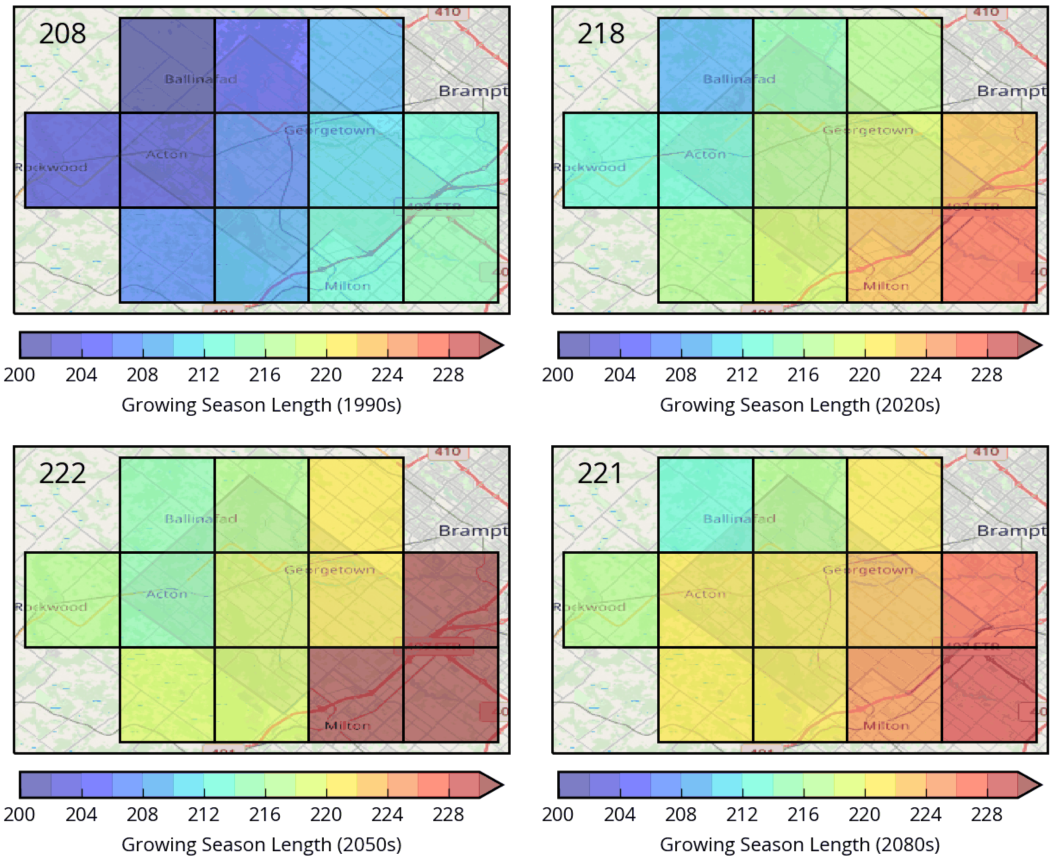

Figure 37: Maps of Growing Season Length (RCP 2.6)

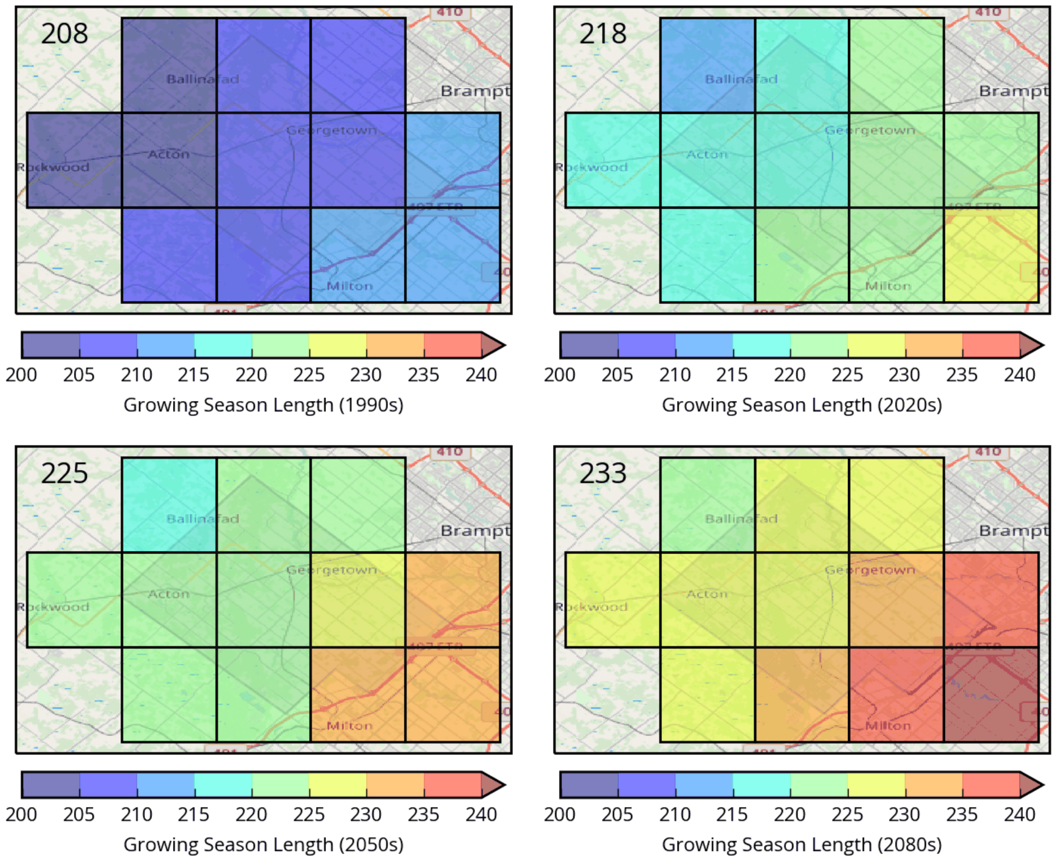

Figure 38: Maps of Growing Season Length (RCP 4.5)

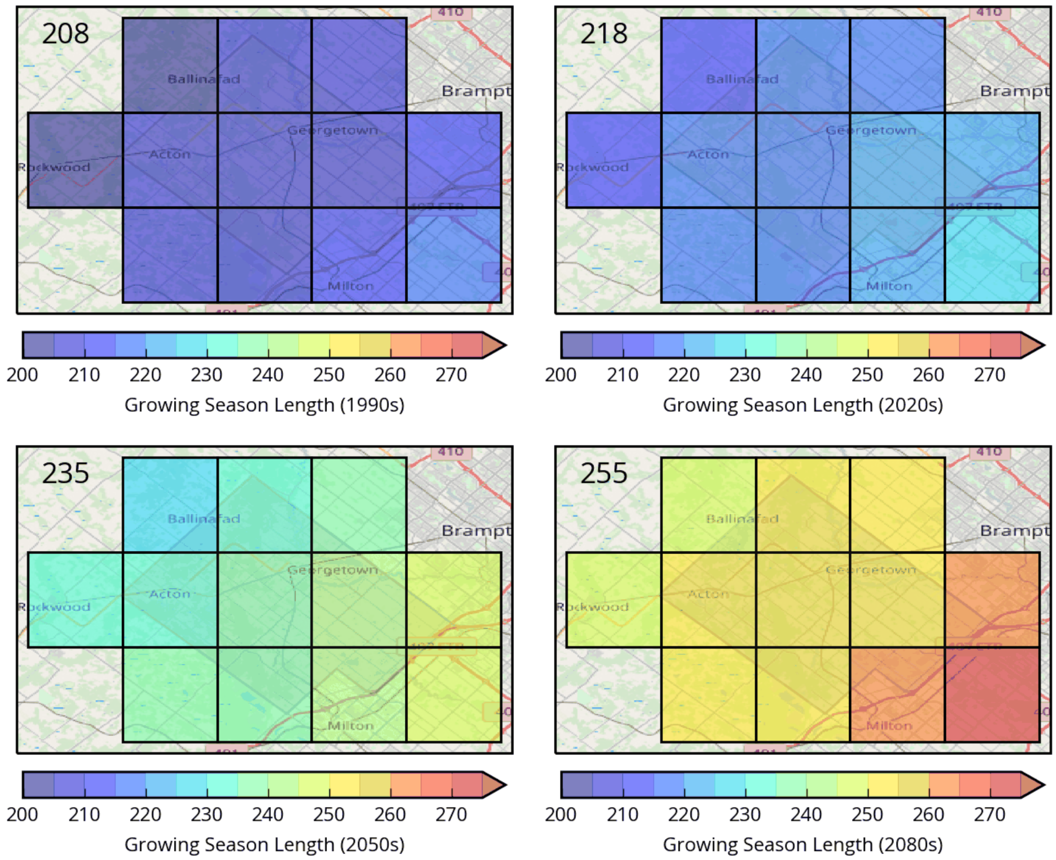

Figure 39: Maps of Growing Season Length (RCP 8.5)

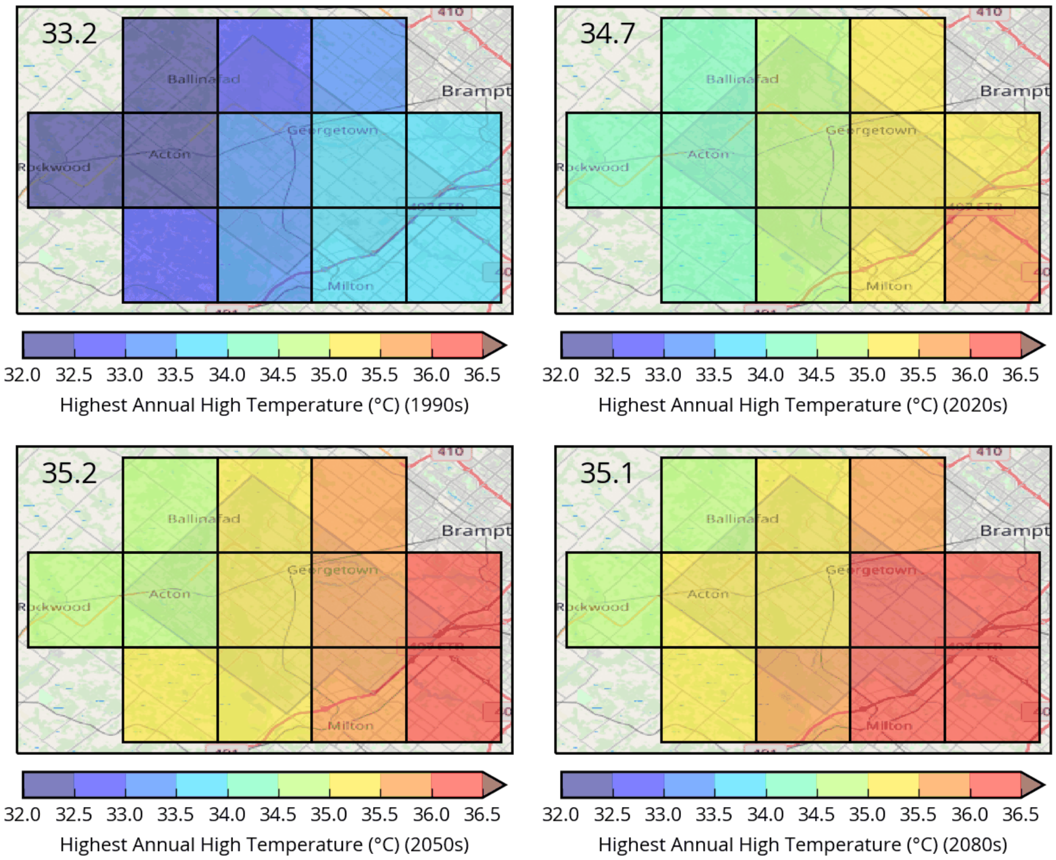

Figure 40: Maps of Annual High Temperature (RCP 2.6)

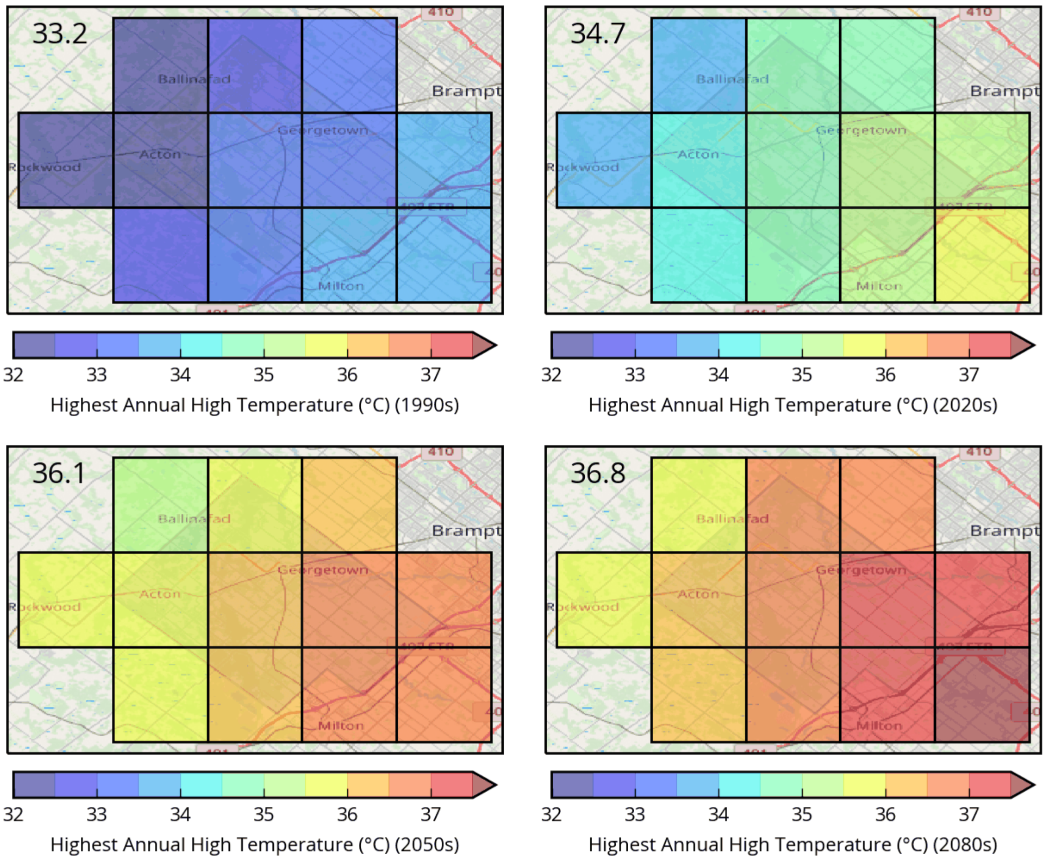

Figure 41: Maps of Annual High Temperature (RCP 4.5)

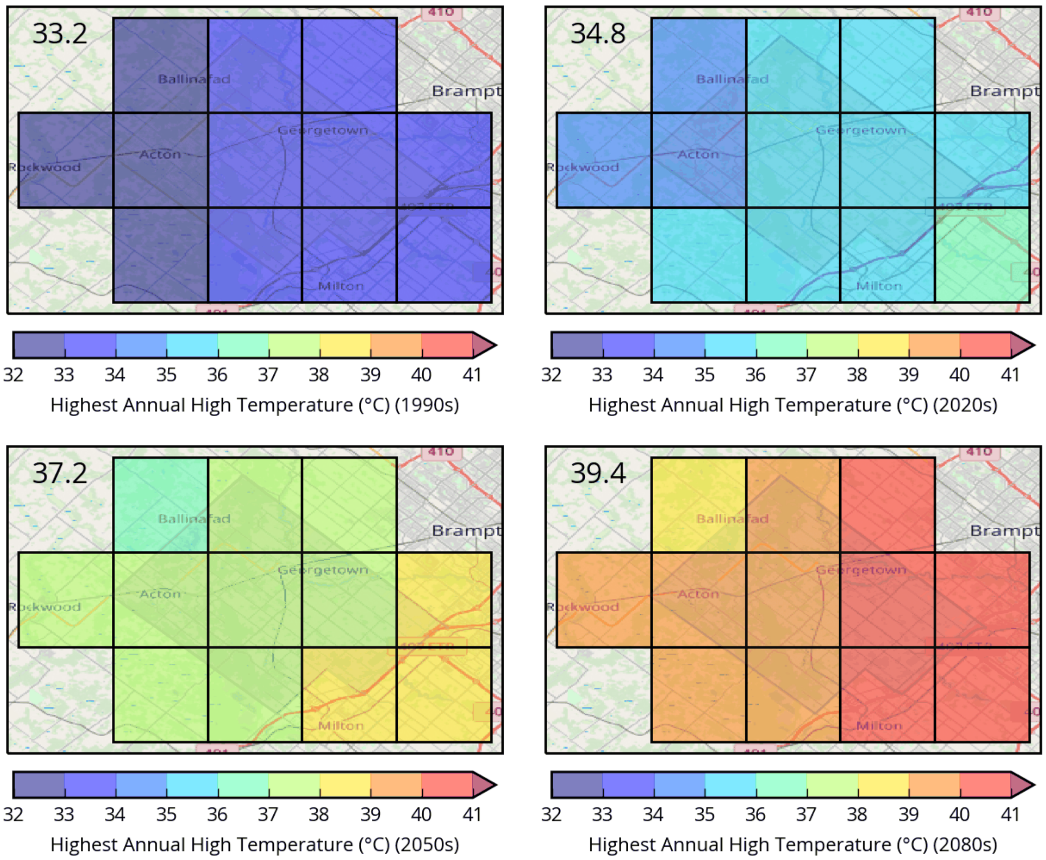

Figure 42: Maps of Annual High Temperature (RCP 8.5)

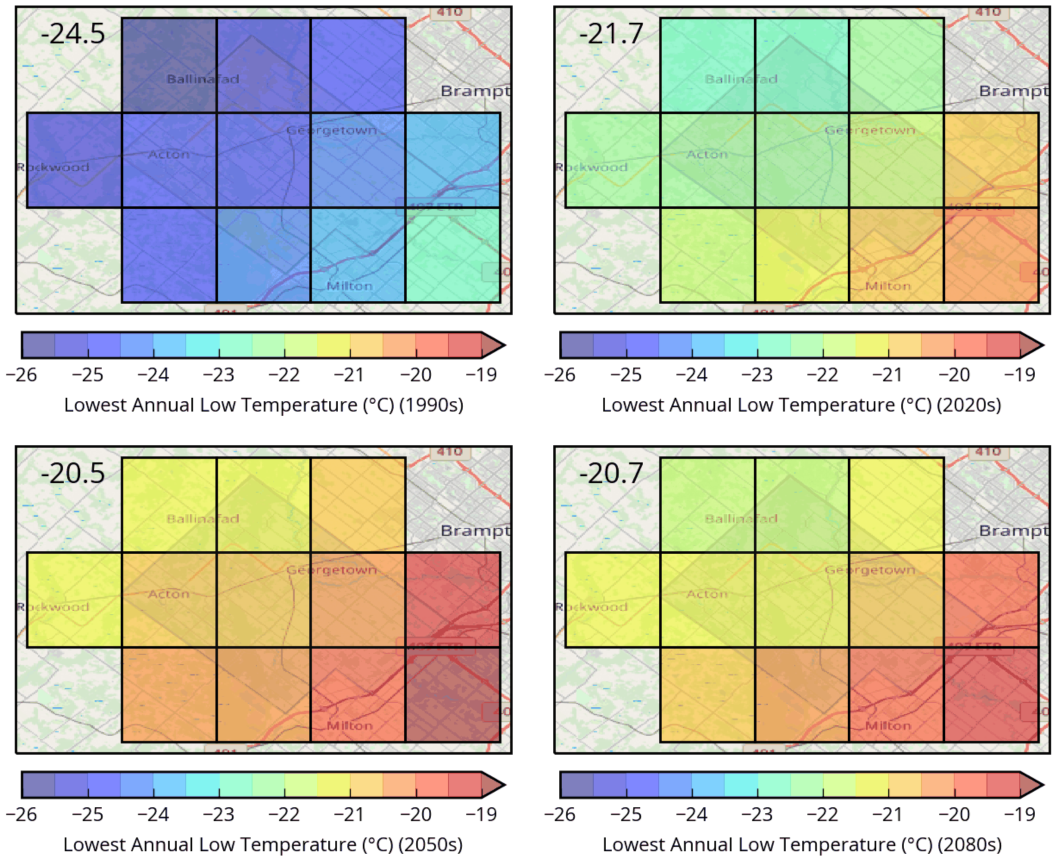

Figure 43: Maps of Lowest Annual Low Temperature (RCP 2.6)

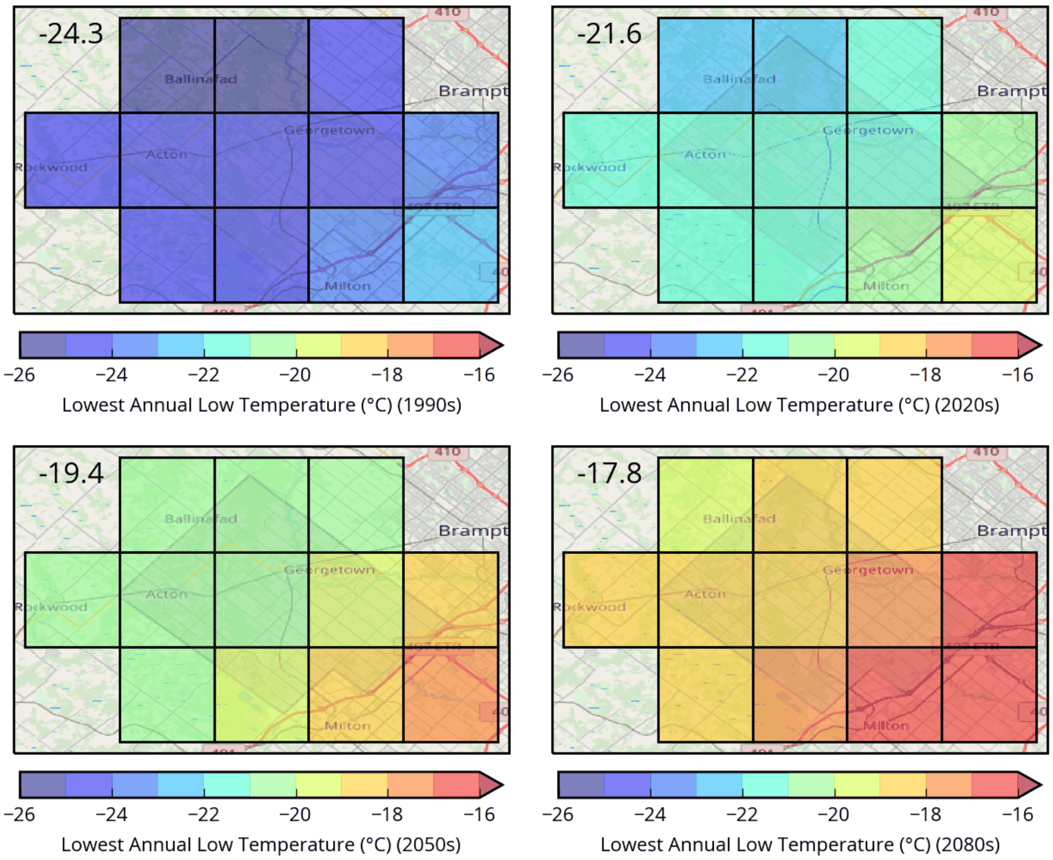

Figure 44: Maps of Lowest Annual Low Temperature (RCP 4.5)

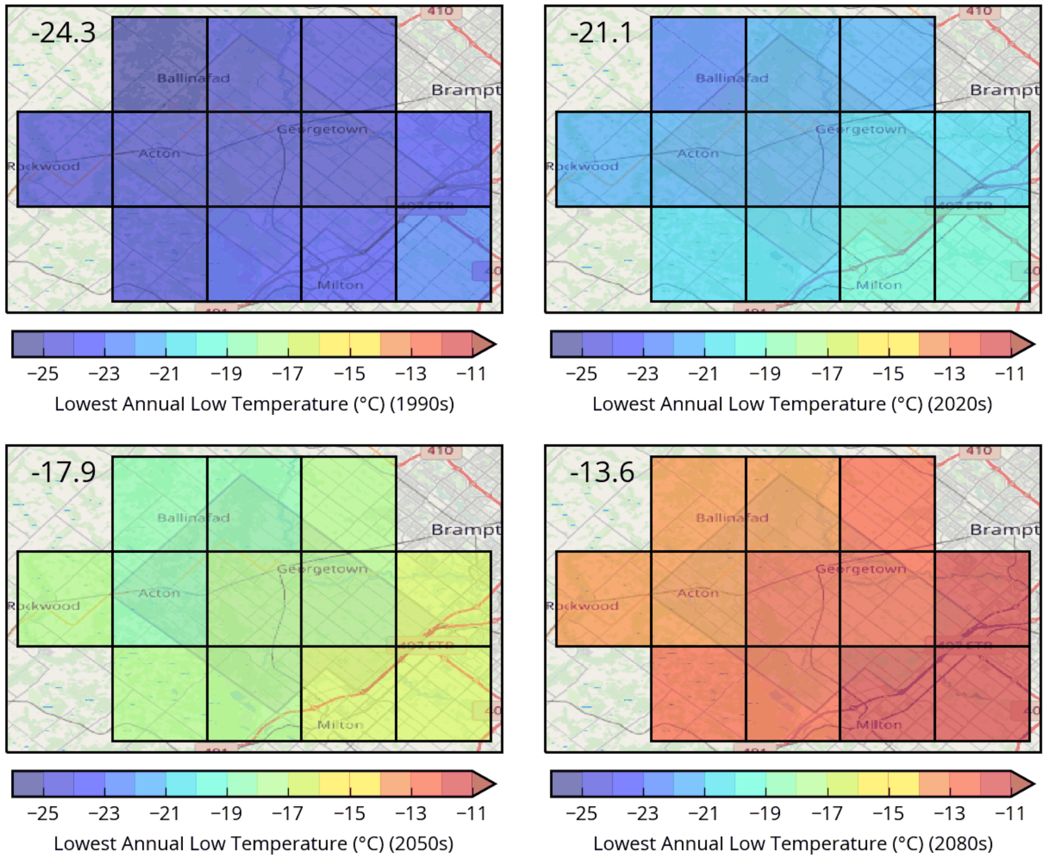

Figure 45: Maps of Lowest Annual Low Temperature (RCP 8.5)

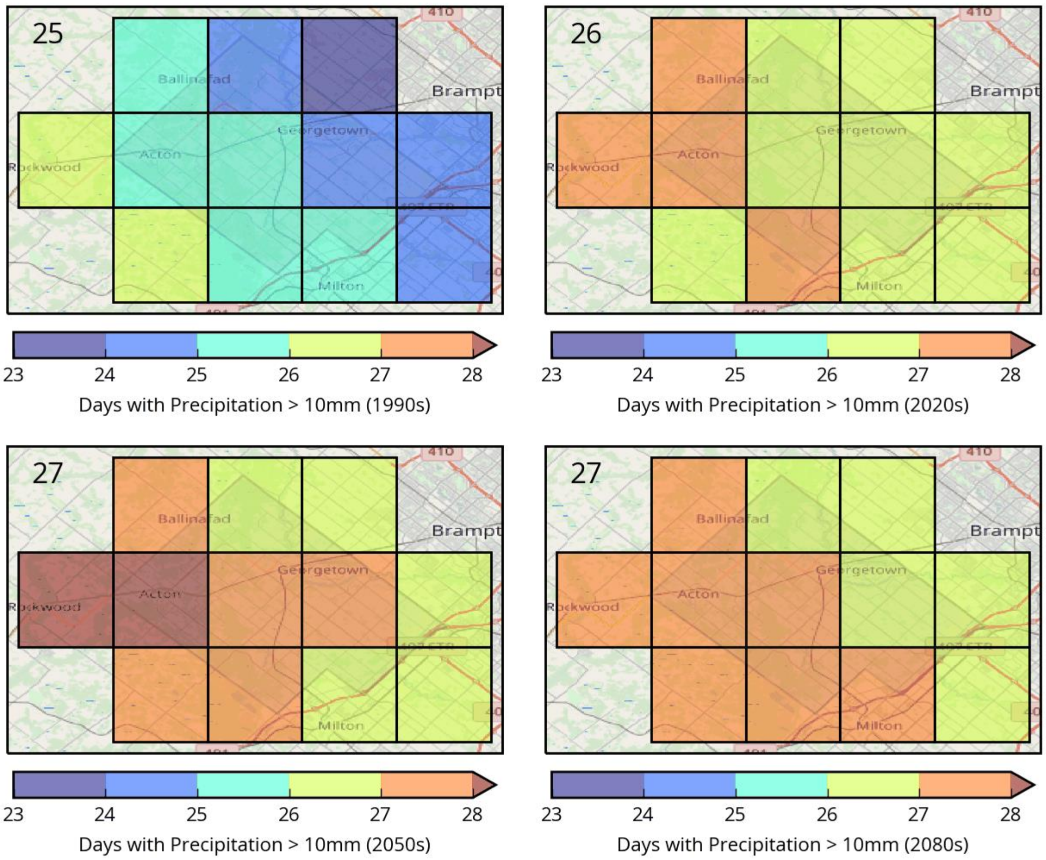

Figure 46: Maps of Days with Precipitation > 10mm (RCP 2.6)

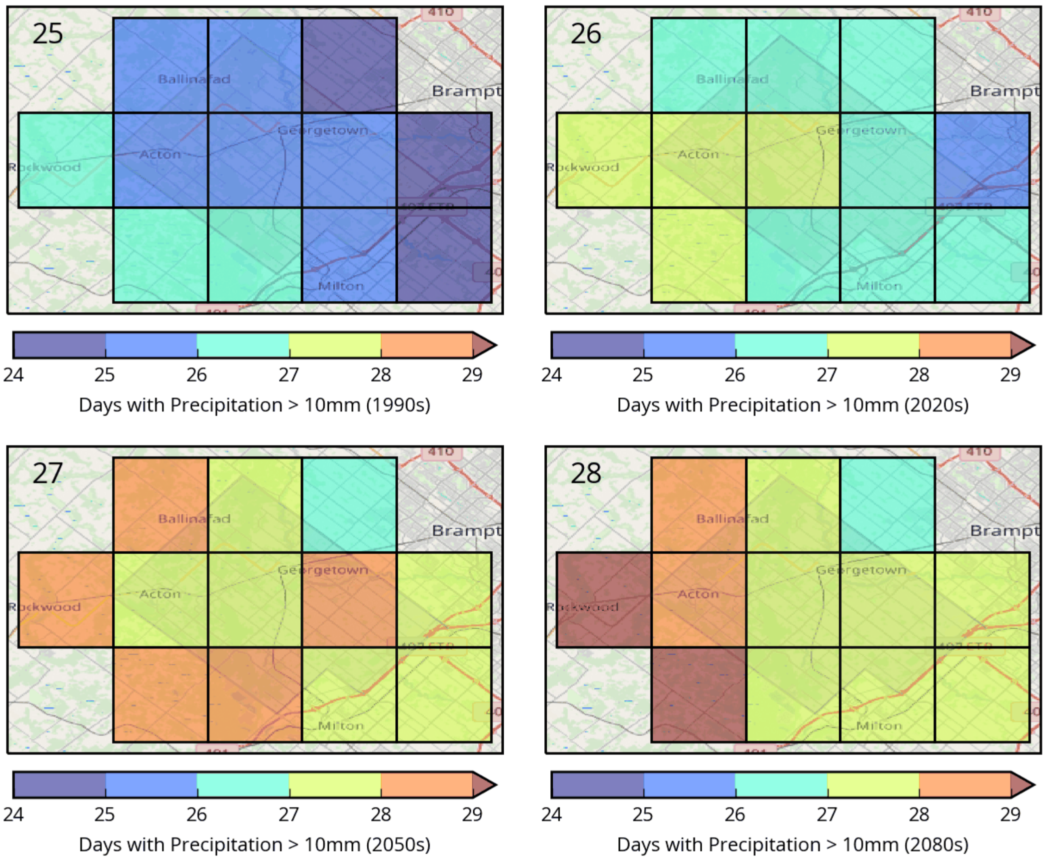

Figure 47: Maps of Days with Precipitation > 10mm (RCP 4.5)

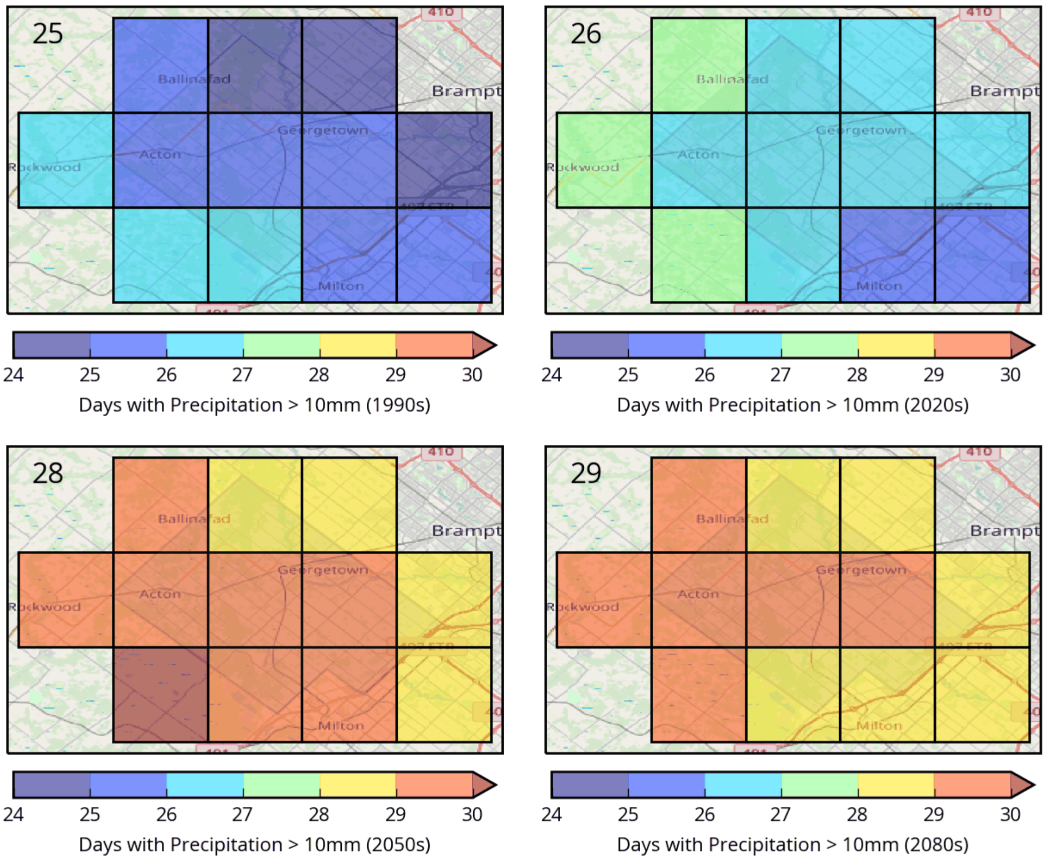

Figure 48: Maps of Days with Precipitation > 10mm (RCP 8.5)

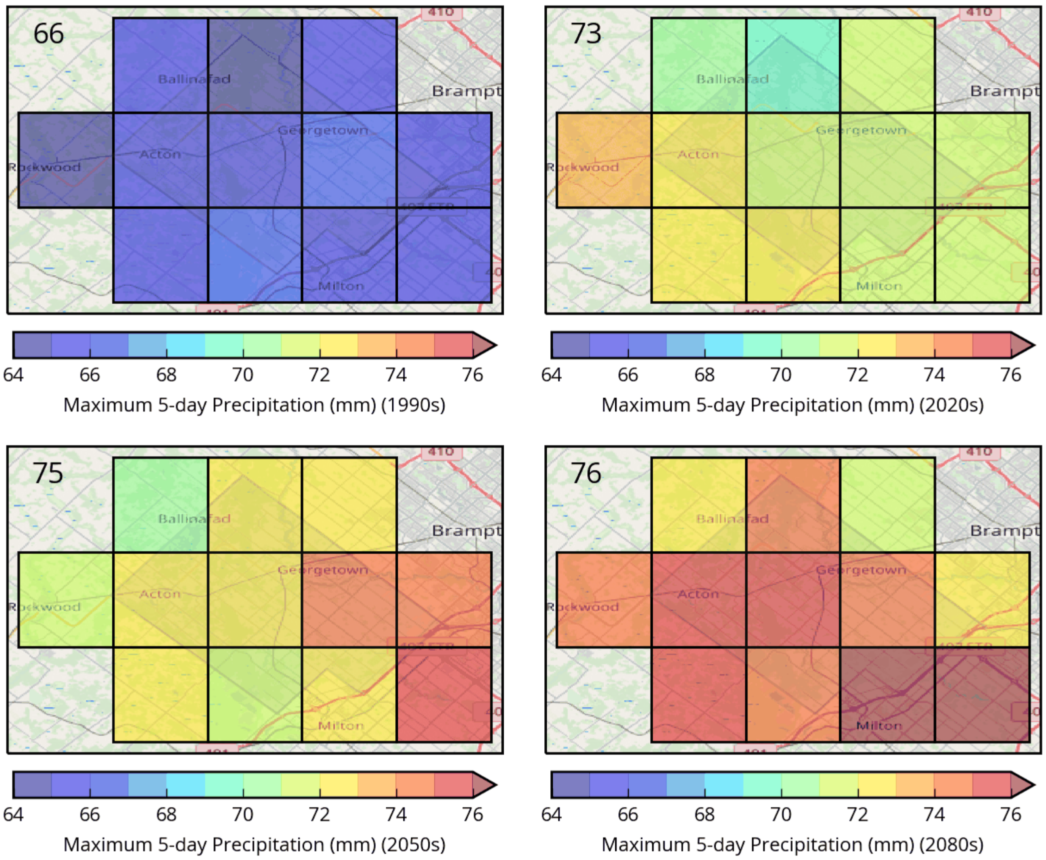

Figure 49: Maps of Maximum 5-day Precipitation (RCP 2.6)

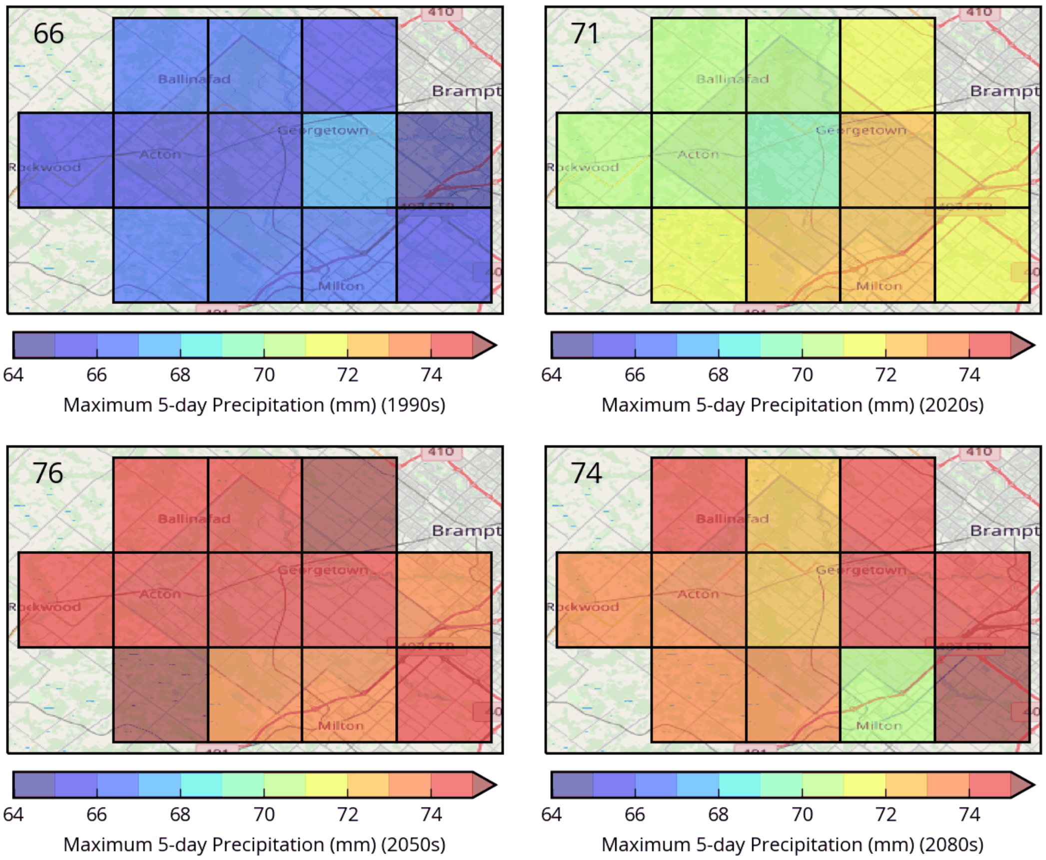

Figure 50: Maps of Maximum 5-day Precipitation (RCP 4.5)

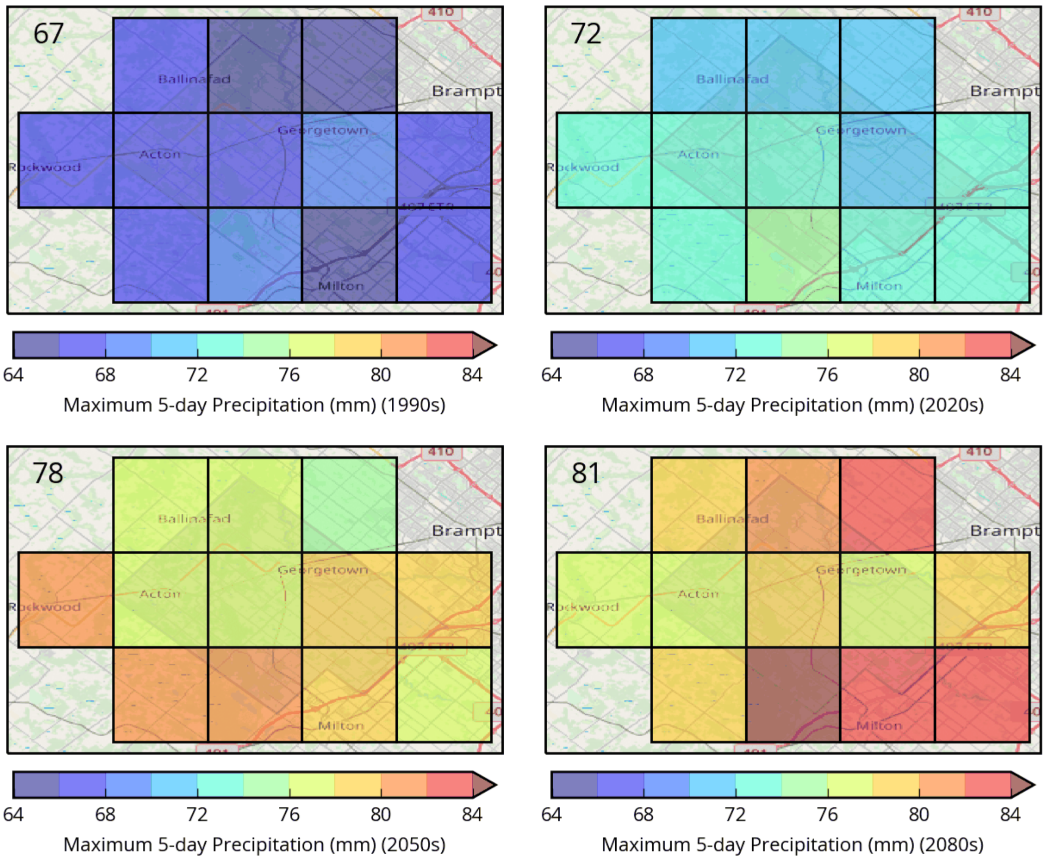

Figure 51: Maps of Maximum 5-day Precipitation (RCP 8.5)

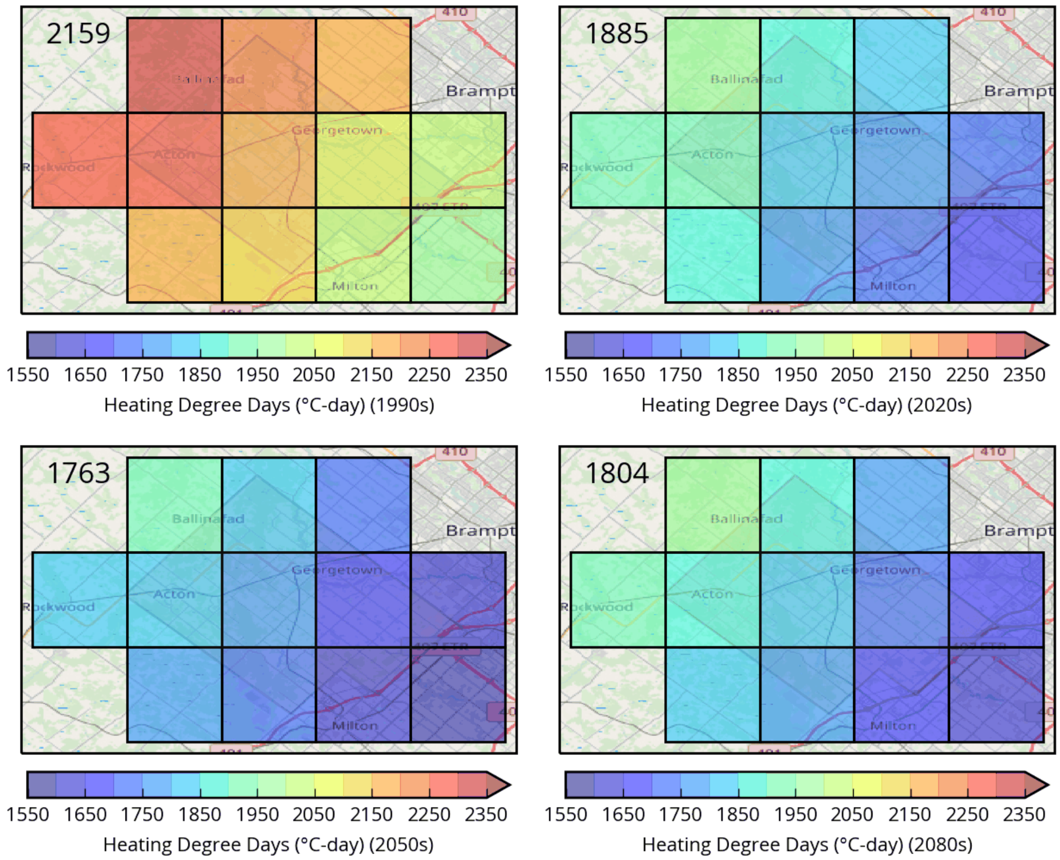

Figure 52: Maps of Heating Degree Days (RCP 2.6)

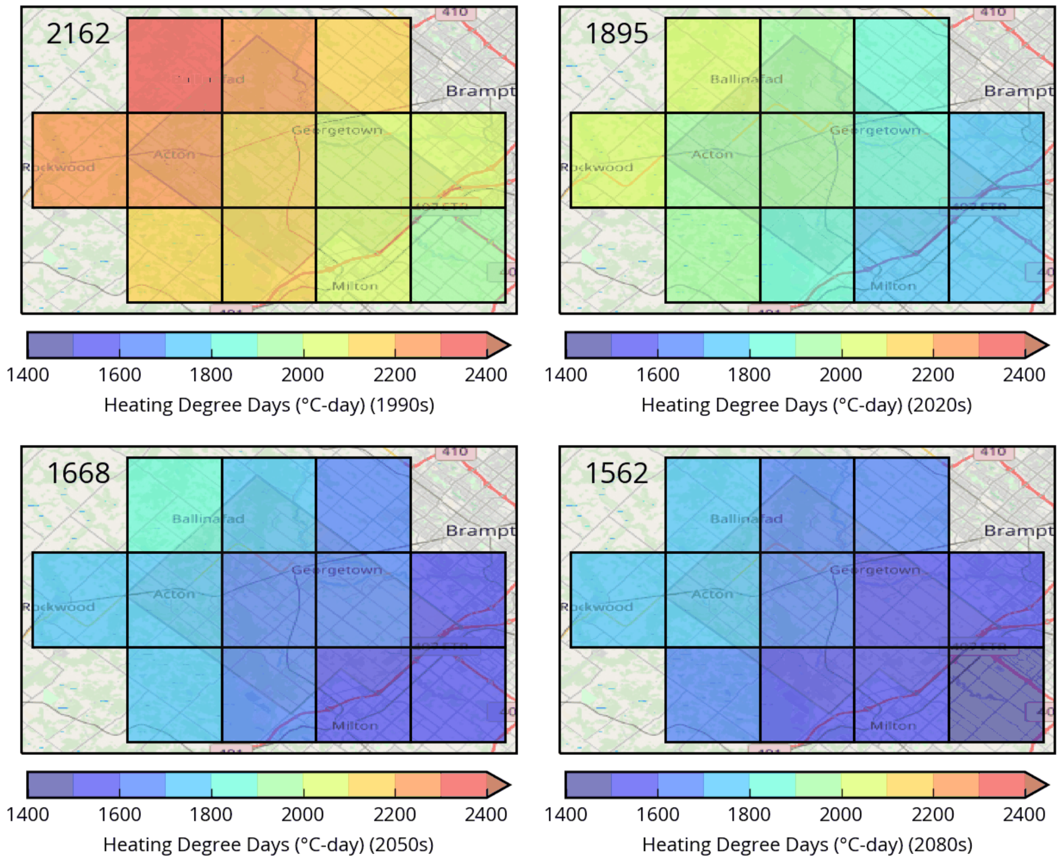

Figure 53: Maps of Heating Degree Days (RCP 4.5)

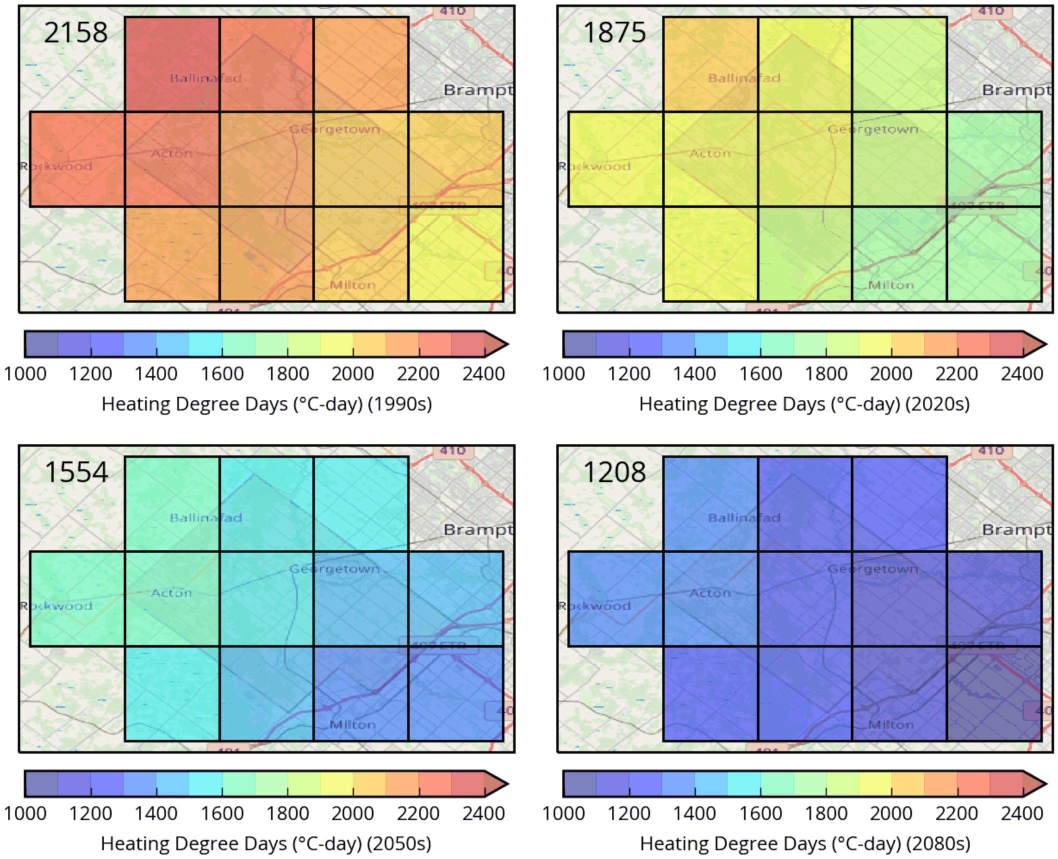

Figure 54: Maps of Heating Degree Days (RCP 8.5)

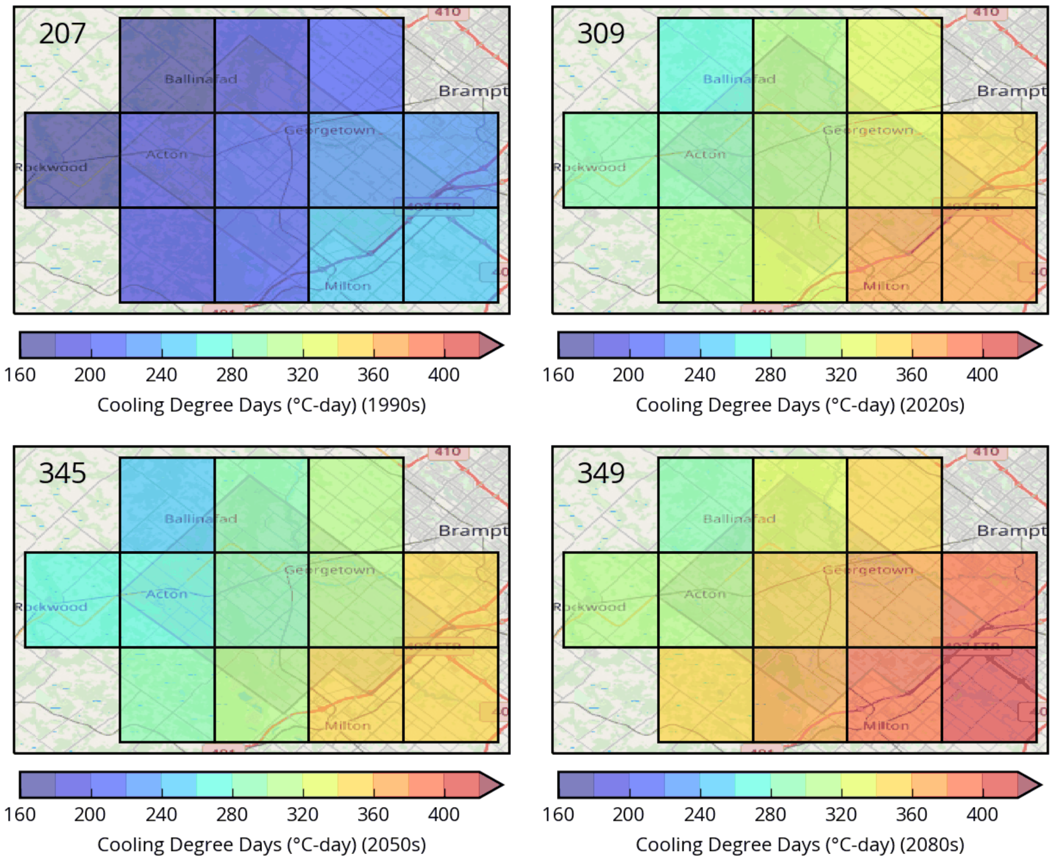

Figure 55: Maps of Cooling Degree Days (RCP 2.6)

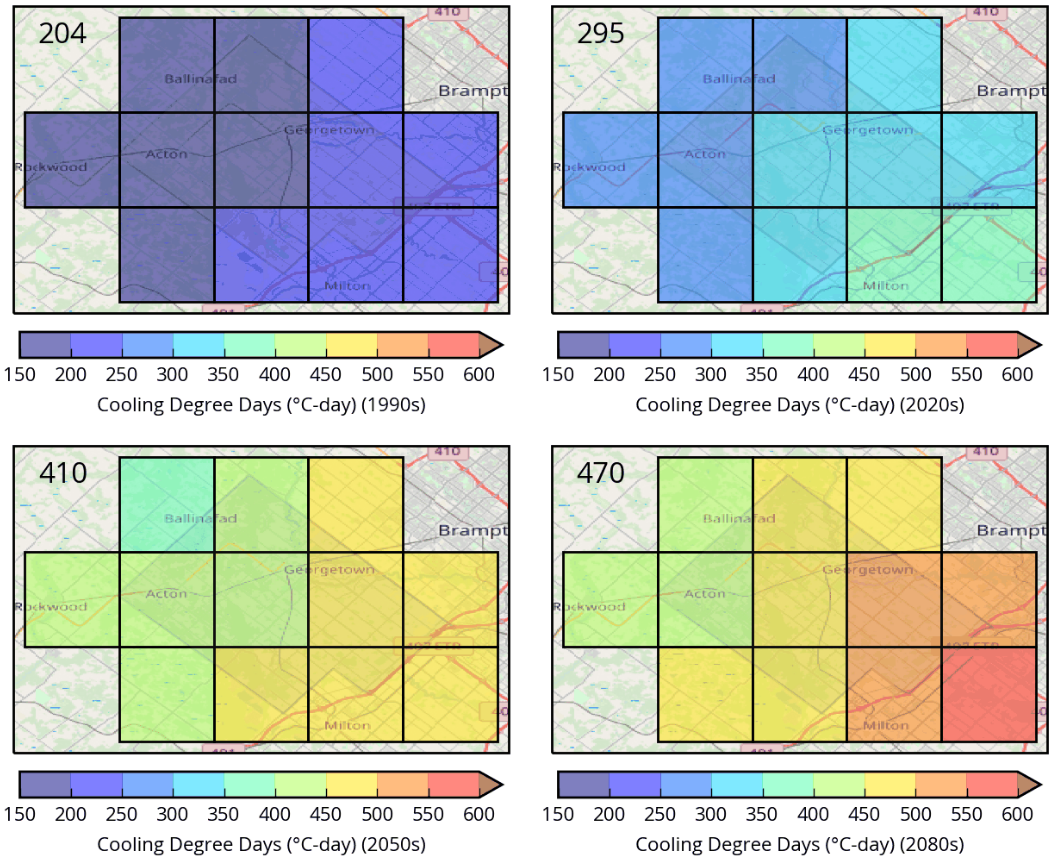

Figure 56: Maps of Cooling Degree Days (RCP 4.5)

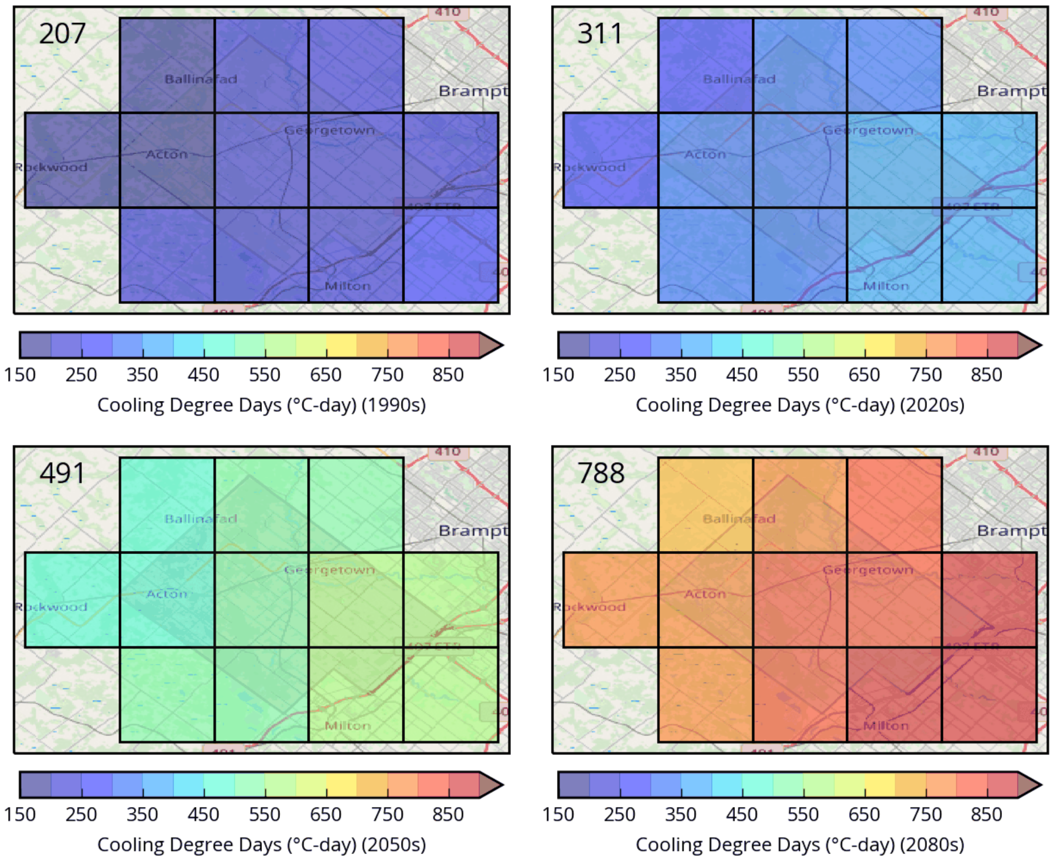

Figure 57: Maps of Cooling Degree Days (RCP 8.5)

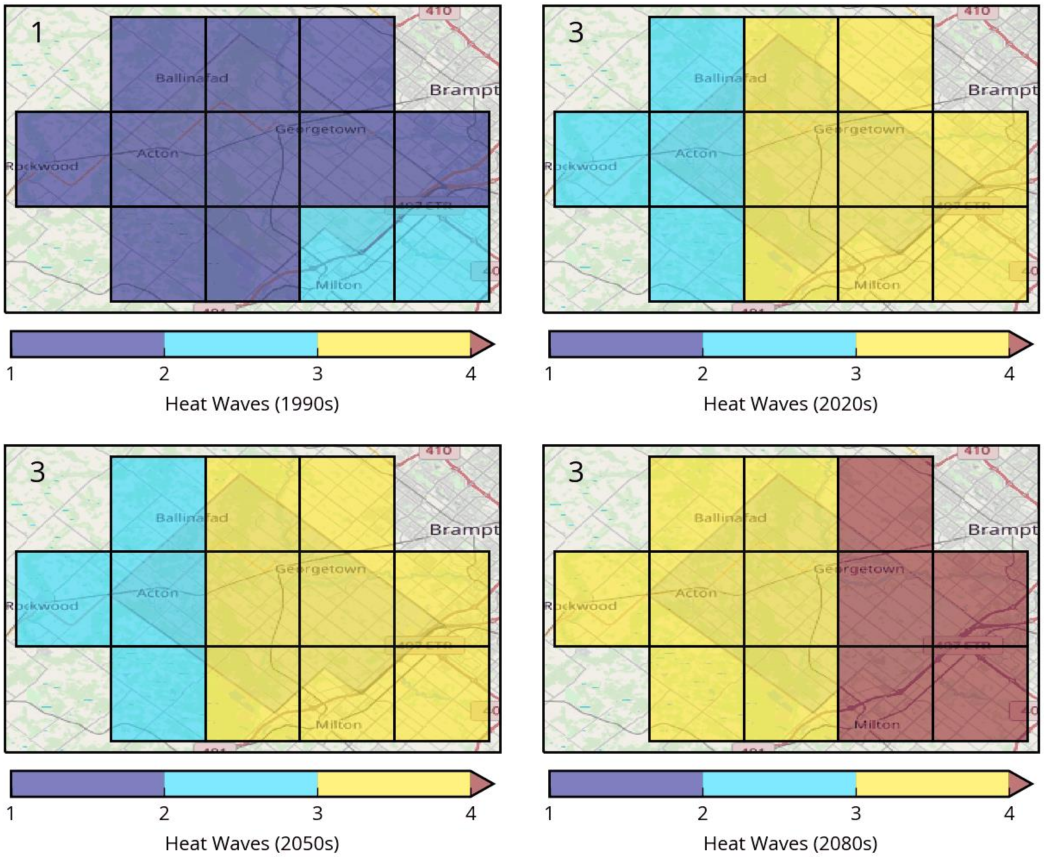

Figure 58: Maps of Heat Waves (RCP 2.6)

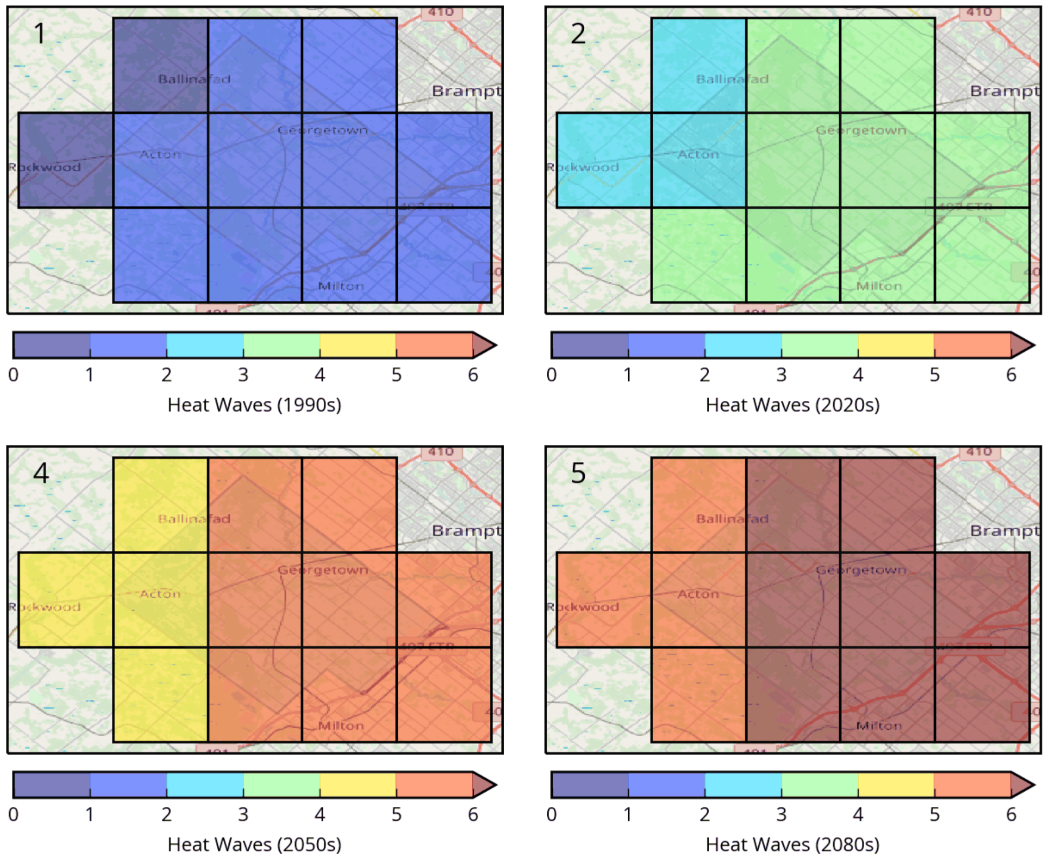

Figure 59: Maps of Heat Waves (RCP 4.5)

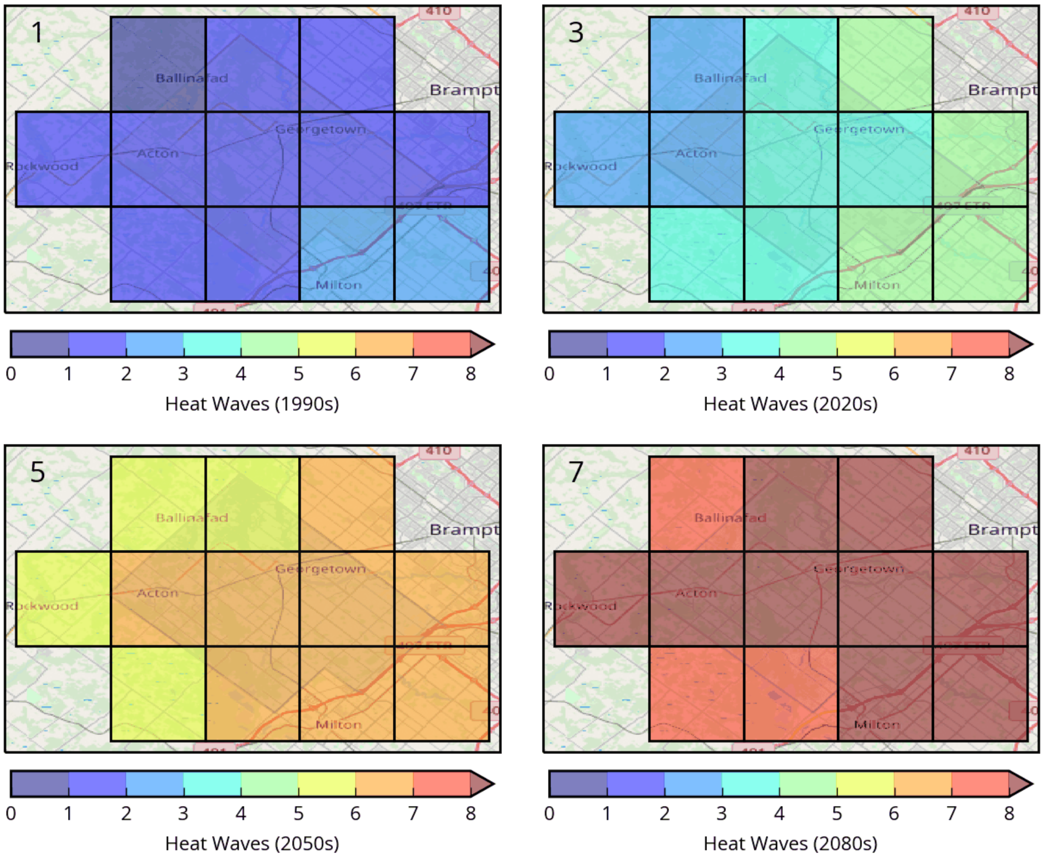

Figure 60: Maps of Heat Waves (RCP 8.5)

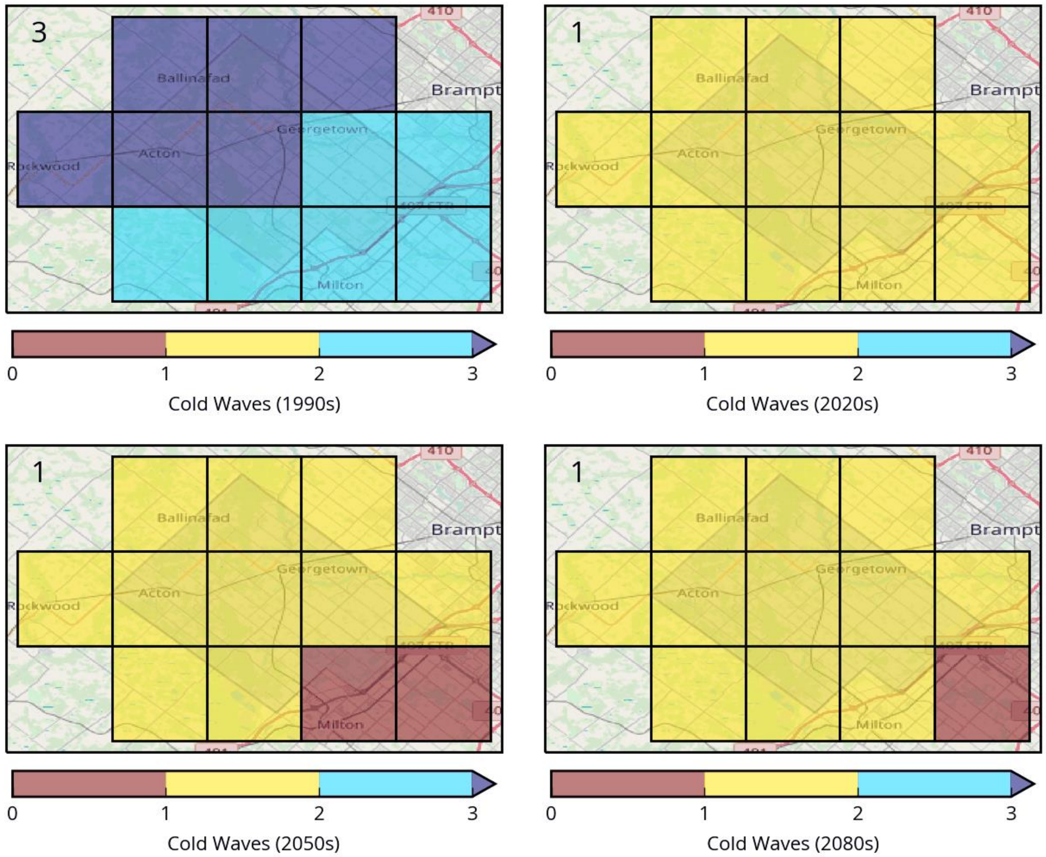

Figure 61: Maps of Cold Waves (RCP 2.6)

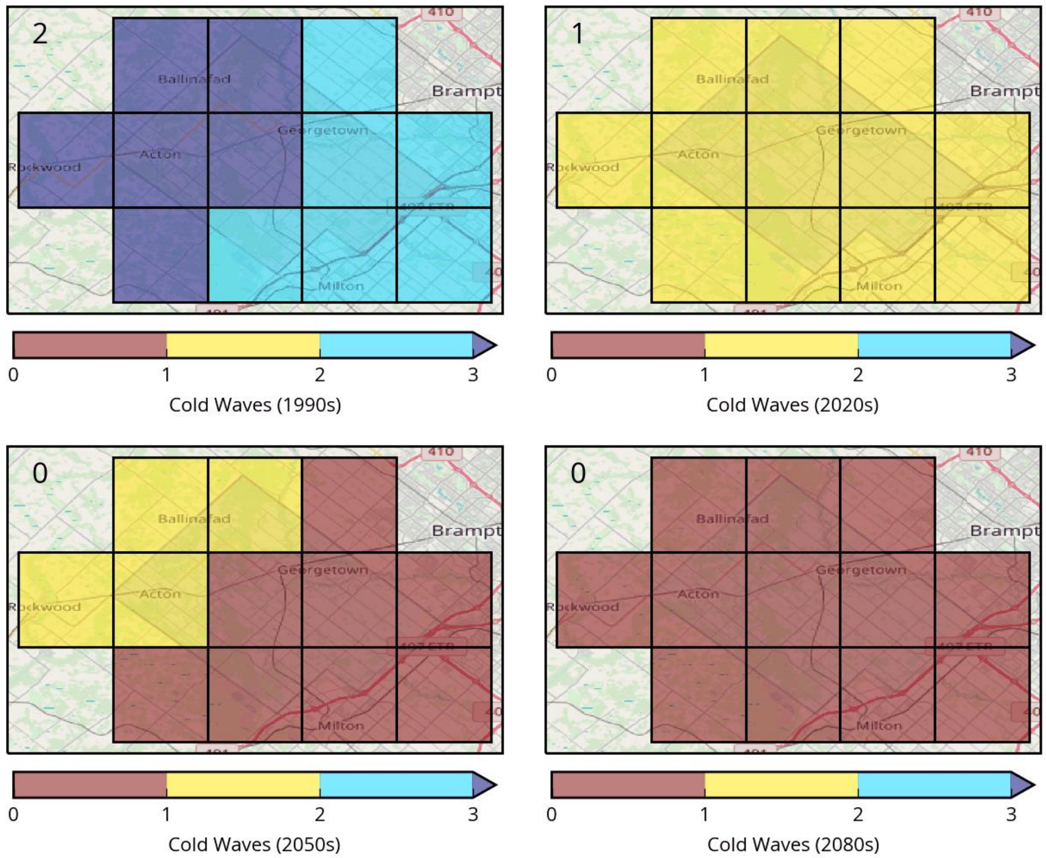

Figure 62: Maps of Cold Waves (RCP 4.5)

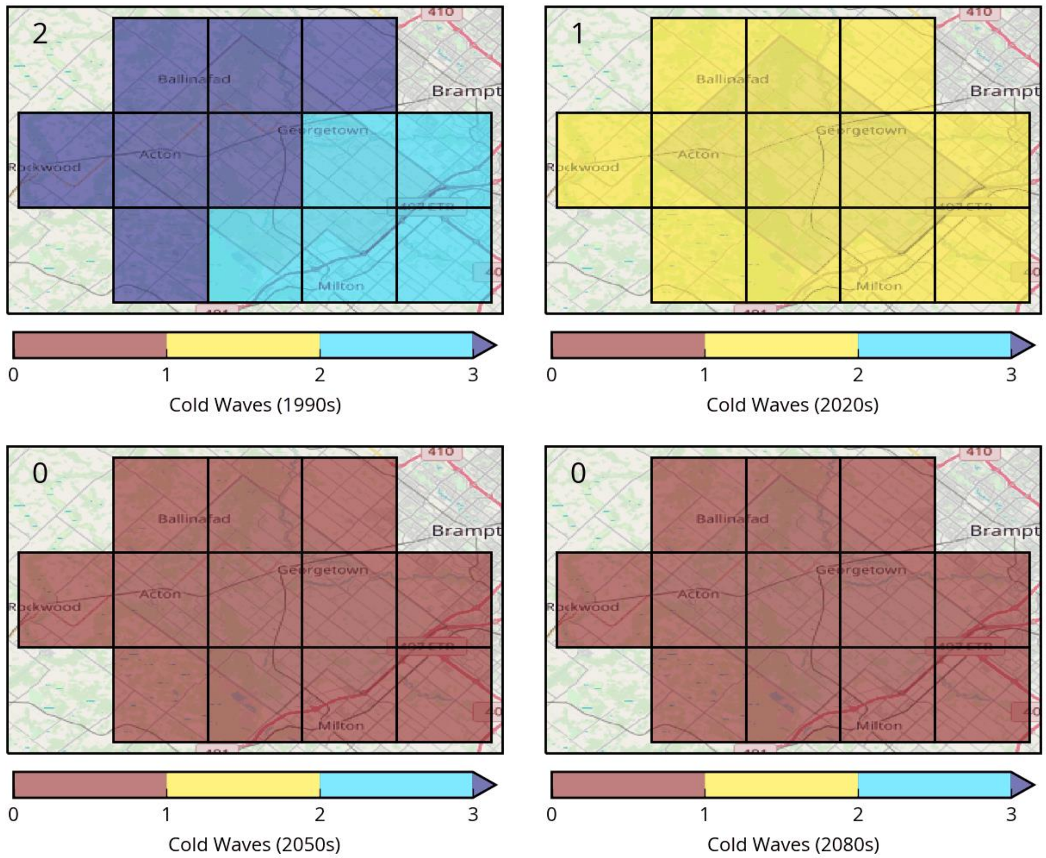

Figure 63: Maps of Cold Waves (RCP 8.5)