Guide to Conducting a Climate Change Analysis at the Local Scale: Lessons Learned from Durham Region

A Guidance Document for Ontario Municipalities, Conservation Authorities and Broader Community on Developing Local Climate Projections

ONTARIO CLIMATE CONSORTIUM

Supported by Toronto and Region Conservation Authority

Prepared by: Ontario Climate Consortium

Prepared for: Regional Municipality of Durham

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Executive Summary

Changes to the Earth's climate system over the last few decades have resulted in unprecedented trends in global temperatures. These changes have been felt across Canada, including in the Province of Ontario, and are impacting local communities. Warming temperatures, increasing precipitation and more extreme weather events are all expected to increase by the end of the century (McDermid et al., 2015). This will have a significant impact on Durham Region, leading to localized flooding, ecosystem changes, loss of electrical supply, threats to human health and safety, to name a few (Durham, 2016). As such, while the impacts of climate change are already being felt, future changes in climate will also have a significant impact on Durham Region.

Between 2012 and 2014, the Region of Durham undertook a climate modeling exercise with SENES Consultants Ltd. to predict future climate in the Region for the 2040-2049 period. This study was one of the first steps towards the development of the *Durham Community Climate Adaptation Plan* (DCCAP). At the time of the study, SENES used the most credible climate emissions scenarios called the Special Report on Emissions Scenario (SRES), which have since been updated with the latest scientific climate scenarios called Representative Concentration Pathways (RCPs). In 2018, the Region of Durham hired the Ontario Climate Consortium to develop a report examining how climate change considerations were being integrated into natural environment-related policies and plans. One of the recommendations that came out of the report was the need for the Region of Durham to undertake a climate modeling exercise to update the current climate projections to include both Global and Regional Climate Models through an ensemble approach. These updated climate projections would then be used to inform future updates to policies and plans. Durham Region has therefore identified the need to update their climate projections to support the ongoing implementation of climate adaptation initiatives across the Region. Funding for this initiative was received through the Greenbelt Foundation.

The need for a guidance document was also identified to provide municipalities within Durham, as well as other Greenbelt municipalities with an opportunity to undertake their own climate modeling exercises, to improve consistency in the climate modeling approach used across Ontario municipalities. This report also supports the climate change goals and policies outlined in the Greenbelt Plan (2017).

The following are the general objectives associated with this project:

1. To create a clear and replicable approach for climate change analyses, which allows for a range of climate projections, for the short, mid, and long term;
2. To provide climate model output data that will inform or could be used as inputs for Durham Region's climate change adaptation planning efforts; and
3. To provide a consistent approach across Durham Region that can be utilized by Regional staff, lower-tier municipalities, conservation authorities, and the broader community for decision-making and analysis.

The OCC developed criteria that determined the North American Coordinated Regional Climate Downscaling Experiment (NA-CORDEX) as the best-suited climate model ensemble to conduct the climate modeling for Durham Region. The criteria included:

- The data had the ability to capture the influence of the Great Lakes, since Lake Ontario has a great influence on Durham Region's weather and climate patterns;
- The data were used in other climatological studies in the Great Lakes Basin and in Ontario;
- The data were derived through dynamical downscaling, to capture the Great Lakes;
- The data were driven by multiple models and model runs (i.e. takes an ensemble approach) to ensure more robust results were generated;
- The data had a spatial resolution of 25 km by 25 km or finer;
- The data included projections for both climate change scenarios RCP 4.5 (stabilizing emissions scenario) and RCP 8.5 (high emissions scenario), and was available up until 2100; and
- There were hourly data available.

In order to understand how this project differs to that of the previous SENES study, the OCC conducted a comparison between the 2019 Durham Climate Modeling Project and the previous SENES study. A summary of some of the notable differences are outlined in Table 1.

Table 1: Differences between the SENES Study and Durham Climate Modeling Project

Factors	Durham SENES Study	Durham Climate Modeling Project
Climate Models	1 GCM (HadCM3 Model) 1 RCM (Hadley PRECIS Model) 1 Weather Forecasting Model (WRF)	8 different GCMs 5 different RCMs
Emissions Scenarios	SRES Scenario A1B (older)	RCP 8.5 and RCP 4.5 (latest)
Time Period	2040-2049	2020's, 2050's, and 2080's
Baseline	2000-2009	1971-2000
Regional Averages	Used Whitby as proxy station for all of Durham	Uses all climate stations in Durham Region to develop averages
Climate Parameters	Extreme precipitation, extreme rain, extreme snowfall, extreme heat, extreme cold, wind chill, degree days, extreme wind, humidex, potential for violent storms	Mean temperatures, maximum temperature, minimum temperature, extreme heat, extreme cold, total precipitation, extreme precipitation, dry days, growing season, agriculture variables, freeze-thaw cycles and ice potential

The following figure (Figure 1) provides an overview of the approach used to develop the climate change projections for Durham Region.

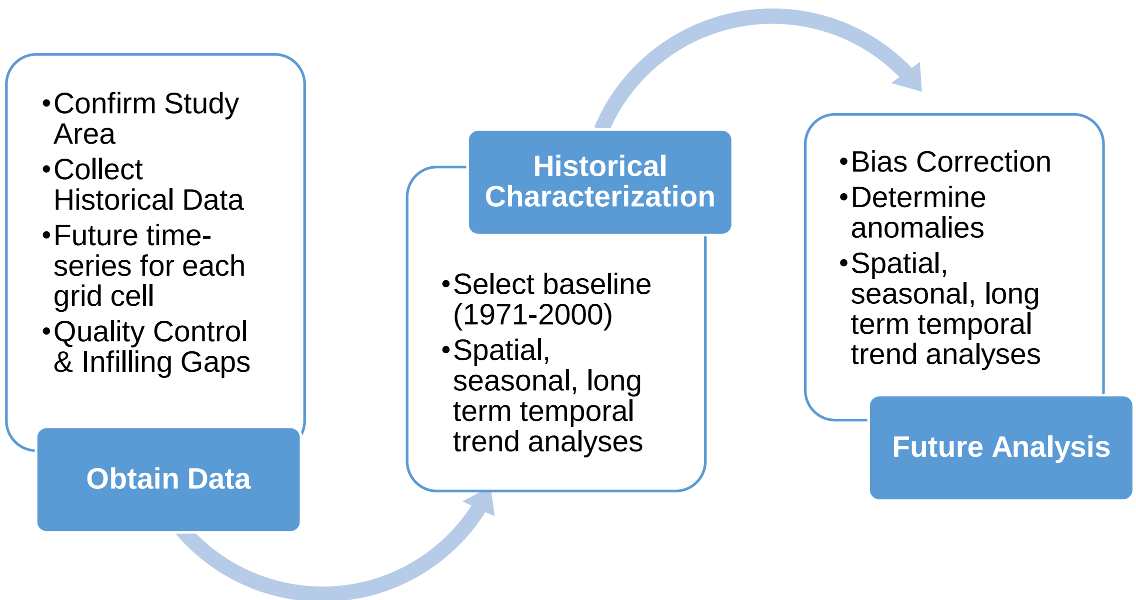


Figure 1: Durham Climate Change Modeling Project Process

Through climate modeling analysis, bias corrected climate projections were produced for 52 climate parameters for RCP 8.5 (business-as-usual, or high emissions) and RCP 4.5 (stabilizing) scenarios for the short (2011-2040), mid (2041-2070), and long (2071-2100) term. Table 2 summarizes a few of the major climate trends Durham Region can expect to see in the future, under the RCP 8.5 scenario. A complete list of climate parameters and results under the high emissions scenario can be found in Table 10.

Table 2: A summary of the NA-CORDEX's *top climate change parameters* for Durham Region in the highest emissions scenario (RCP 8.5) for all climate periods up until 2100. All parameters are averages of the NA-CORDEX's 16 model runs.

Climate Parameter	Historical (1971-2000)	Short Term (2011-2040)	Medium Term (2041-2070)	Long Term (2071-2100)	Climate Trend
Mean Annual Temperature (˚C)	7.1	8.6	10.1	12.1	↑
Annual Average Number of Days above 35˚C	0.2	1.2	4.0	10.8	↑
Annual Average Number of Days above 30˚C	7.6	15.9	27.4	46.9	↑
Annual Average Number of Days below -15˚C	22.7	13.1	7.9	2.6	↓
Annual Average Number of Days below -10˚C	49.0	34.3	23.5	11.3	↓

Total Average Annual Precipitation (mm)	952.4	1074.95	1117.48	1231.60	↑
Annual Average Maximum Amount of Precipitation Falling in 1 Day (mm)	33.8	35.4	40.4	44.0	↑
Annual Average Maximum Amount of Precipitation Falling in 3 Days (mm)	54.9	58.0	61.7	67.7	↑
Annual Average Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.8	2.9	3.2	↑
Average Growing Season Length for Climate Period	162 days	183 days	193 days	213 days	↑

This analysis demonstrates that Durham Region will likely experience a warmer and wetter climate, with a longer growing season. The Region is also expected to experience more variable weather patterns and experience higher intensity storms with greater amounts of precipitation in all seasons. This may impose threats to the health of communities, it's natural systems, infrastructure, agriculture, economy and services within the region. The following provides an interpretation of the study results for the short, medium and long term in Durham Region.

Durham Region's Climate in the Short Term (Now until 2040)

Regardless of how emissions might be reduced in the future, the climate is expected to change. Average annual **air temperatures** across Durham Region are expected to rise 1.5℃ in the short term on average over the 30-year period. Consistent with other climate modeling studies across the Southern Ontario, minimum temperatures are projected to rise the fastest, increasing by 2.2℃ in the winter season based on an average of all ensemble models. Historically, minimum temperatures in the winter season average around -8℃ in Durham, but as the climate warms, this is expected to be around -5.8℃ in the coming decades. This implies that winter variability in weather will be particularly important moving forward. The timing and amount of precipitation may shift from snowfall to rainfall during winter months, increasing the potential for flooding and overflow conditions in the Region's water systems. Maximum air temperatures are also projected to rise. Across all seasons, maximum temperatures are expected to rise the most in the summer season with temperatures projected to increase by 1.6℃ compared to historical conditions. This result implies that heat, and the vast impacts associated with it, are expected to be prevalent as we move into the future. Health-related conditions associated with extremely hot days, ecosystem-related impacts such as heat stress and warming of waters could also be expected to become more common.

Extreme heat related conditions show significant changes moving into the future as well. Historically, Durham Region has about 7.6 days per year exceeding 30℃. In the short term, this is expected to more than double to about 16 days. Days where temperatures exceed 25℃ show the same trend. Historically, Durham Region averages around 42 days, mostly across the summer season that meet this condition, and this is expected to rise by almost 3 weeks more in the short-term. Warm nights, or nights when Durham residents may want to run air-conditioning more frequently to feel comfortable, there has historically been around 3 months where temperatures exceed 20℃, but this is expected to rise by another half a month (16 days) in the short term.

On the other hand, **extreme cold** conditions are expected to decline rapidly. The number of days where air temperatures are below -20℃ are projected to be cut in half, from about 8.6 days historically to around 4 days per year in the near future. This has implications for winter recreational activities, the amount and duration of snowpack across the Region and revenue for the municipalities (e.g. tourism). Likewise, it is projected that there will be almost four weeks fewer days where temperatures are below freezing on average (0℃). Historically, the Region sees around 5 months (not necessarily in a row) where temperatures are below freezing, but this is projected to become around 4 months by 2040.

Total precipitation is also projected to increase across the year, and across all seasons. Durham Region typically observes around 952mm of precipitation on average. By 2040, it is projected that the Region could see 13% more. The largest increase is projected in the winter and spring seasons, with much lesser change in the summer and fall. This has significant implications for our water resources. For instance, as temperatures warm and precipitation totals rise, this may advance the timing of the spring freshet, increase rain-on-snow events, and require earlier flood warnings and procedures to be put in place (which we are already observing today).

Extreme precipitation indicators reflect similar trends as well. In the short term, maximum 1-day precipitation is projected to increase by about 12%, and maximum 3-day precipitation is projected to increase by 6%. Examining precipitation intensities indicates that the winter and spring season intensity rates (mm/day) are projected to increase the most. For example, historically, Durham Region sees an average intensity of around 2.5mm/day but this is projected to rise to about 2.9mm/day in the near future. While these may seem small at a glance, it is important to remember these are the rates at which precipitation is falling, not totals, and that this trend is rising across the short, medium- and long-term time periods in the future. Coupled with the largest increases in total precipitation from above, this indicates a much more variable and demanding winter to spring season as it pertains to water management.

In the short term, **freeze-thaw** cycles are projected to remain largely consistent with historical conditions (around 80 cycles per year). This implies that freeze-thaw cycles will continue to be problematic on infrastructure systems and on municipalities for managing damages as a result. If the Region has freeze-thaw cycles coupled with increased precipitation, this may cause cascading impacts (e.g., a thaw, an extreme rainfall event, followed by a freeze), this can be particularly damaging to infrastructure and roads.

Trends related to **dry conditions** are more or less unchanging. Projections of total dry days (where precipitation is zero) is projected to more or less remain the same in the short term. The same trend was found for the maximum number of consecutive dry days, which historically is around 18 days. A brief comparison to other climate trends studies in the GTA indicates that this is largely consistent. The Region of Peel's study for example, determined the same trend in this parameter. However, the authors would caution that increased heat and evaporation in the summer season may indicate the possibility of increased variability and thus developing this parameter to undertake a water balance or to estimate flows could yield interesting results. The ensemble range in projections for example suggest that total consecutive dry days could be a little as 13 days in a row, or as much as 21 days in a row (so the potential for prolonged dry conditions or drought exists).

Finally, **growing season** conditions consistently show an earlier start date (from May 14 on average, to May 1), and a later end date (from Oct. 24 to Oct. 31). Growing season length is projected to increase by an average of 21 days. **Agricultural parameters** all indicate increasing trends as well. Corn heat units, growing degree days, canola growing degree days, among others show increases of between 12 and 20% more from historical conditions. As a downside, as agricultural conditions improve, the risk of pests increases significantly. Degree days where there is risk of presence of pests is projected to rise about 33% more than historical conditions.

Durham Region's Climate in Medium Term (2050s)

Moving further into the future, the amount of emissions that are reduced becomes increasingly important for determining future climate conditions. The following summarizes results for the higher scenario, RCP8.5.

Mean **air temperatures** are projected to continue to rise to an average of 10.1C (or by 3℃). From a practical standpoint, this projected rise in temperature *exceeds* the targets currently being discussed by the IPCC and national governments around the world as they target temperature rises of 2℃, and ideally 1.5℃. Therefore, as adaptation initiatives are implemented across Durham Region, it is important to take a prudent (conservative approach) that accounts for a more extreme future to ensure risks are mitigated.

Describing temperature trends **geographically** across Durham Region, climate projections indicate that municipalities further south – namely Pickering, Ajax, Whitby, Oshawa and Clarington are all anticipated to warm faster and overall than their neighbours to the north (Uxbridge, Scugog and Brock). This trend is particularly pronounced for minimum and mean temperatures and continues across all future time periods – the short term, mid-century and by the end of century. Maximum temperatures behave a little differently as we examine the geography across the Region. As we move further out into the future (mid-Century and end of Century), increased warming is noticed first in the southwest portion of the Region – in Pickering, Ajax and in south Uxbridge. However, all municipalities are seeing increased rates of warming across all seasons, and all time periods. These geographic trends may be partially explained through the bias correction process used in this study. Climate models themselves do not explicitly capture ground surface temperature, but the behavior of observational records used to adjust climate model information may have propagated into the future.

By mid-century, it is anticipated that Durham Region will exceed historical thresholds of **extreme heat**. Days with air temperatures above 35℃ (excluding humidity or urban heat island influences) are projected to rise from basically 0 days per year to 4 days. Days above 30℃ are projected to increase from 7.6 to over almost a full month of the year being this hot. Examining **extreme cold** projections, it is projected that Durham will only have around 2 days where temperatures average below -20℃ over the day, and only one week of days below -15℃.

Total precipitation is projected to continue to increase by mid-Century as well. Compared to the historical baseline period, total precipitation is anticipated to increase by 17% to an average of 1118mm over the year, with the largest increases in the winter and spring seasons once again. **Extreme precipitation** parameters indicate that 1-day maximum and 3-day maximum precipitation are similarly increasing by 20% and 13% respectively, compared to historical conditions.

Geographically, precipitation patterns are dynamic and are not the same across the entire Region. In general, precipitation increases are occurring more rapidly in the north and eastern portions of Durham Region. This is particularly important for the agricultural centres in Durham Region including Brock, Scugog, and Clarington that may see higher percent increases by the 2050s and the 2080s. This does not mean that other municipalities across the Region are not (and will not) experience more intense storms – only that the rate of change appears faster in the north and eastern areas. This trend is particularly pronounced in by end of century where Brock and Scugog see increases of around 35 to 40% compared to areas further southwest that are slightly lower around 30% to 35%. This trend may in part be due to lake-effect conditions being captured in the ensemble of models, but it should be emphasized that these are ensemble averages, and so some RCMs would illustrate different spatial trends and potentially identify southern portions of the Region as being wetter by mid to late Century as well.

All other parameters described above (**dry conditions**, **growing season**, **agricultural conditions**) continue to illustrate the same trends through time described in the short-term time period. By mid-century, the growing season is expected to be 1 month longer in duration across the Region, starting as early as April 15 and ending as late as November 15th potentially. This further emphasizes the increased growing degree days and agricultural opportunities across Durham, but dramatically increases the risk of pests. As an example, by 2040, the risk of pests is projected to increase by about 30% on average, whereas by mid-Century that risk is around 85% higher compared to the historical presence of pests.

Durham Region's Climate in the Long Term (2080s)

As projections are used and interpreted for the end of the century, it is important to keep in mind that uncertainty grows as time goes on. This is because policies, conditions and decisions made across the Earth may influence the degree to which climate conditions may continue changing. The following describes notable changes by the end of century in Durham Region, with the full parameters summarized in Table 10 of this report.

By the 2080s, Durham Region is on track to warm by an additional 5℃, leading to an average annual **air temperature** around 12℃. This can by compared to the historical condition across the Region of 7℃. Minimum temperatures, and winter temperatures continue to rise the fastest compared to other seasons across the year. By this time, it is projected that the average air temperature in the winter season will be above freezing – at almost 2℃. This implies that there will be as many days with temperatures exceeding 2℃ than there would be below this threshold, and that snow and ice conditions will no longer dominate winter conditions as they do so today through freeze-thaw, salt use, snow clearing, etc. At this time in the future, summertime temperatures will be particularly warm. Maximum air temperatures in the summer, on average, are projected to be above 26℃. Currently, this summertime condition is around 21℃. It is anticipated that municipalities may have changed programs, thresholds associated with warnings and extreme heat and/or services to respond to the changing climate conditions at this time, since they differ significantly from our current seasons.

Notable **extreme temperature** conditions are summarized below:

- Over a week (11 days) where temperatures exceed 35℃, with multiple days likely exceeding 40℃.
- Over 1.5 months (47 days) where temperatures exceed 30℃ and where nighttime temperatures exceed 20℃
- Approximately zero (0) days where temperatures are below -20℃, compared to over a week now
- Only 2.5 days where temperatures are below -15℃, compared to the over 3 weeks now
- Almost two months (56 days) fewer days where temperatures are below freezing (0℃), indicating that Durham would experience about 3 months of the year with freezing conditions (historically, Region has experienced almost 5 months with freezing temperatures)

Total precipitation is projected to continue to increase out until end of Century. Compared to the historical baseline period, total precipitation is anticipated to increase by 29% to an average of over 1200mm in a given year, with the largest increase in the spring season once again. **Extreme precipitation** parameters indicate that 1-day maximum and 3-day maximum precipitation are projected to increase 30% and 23% by end of century, respectively (compared to historical conditions). Average annual precipitation intensity is projected to be 3.4mm/day (or 31% higher than historical conditions), with the highest projected increase in the spring (25%) followed by the summer season (24%)

All other parameters described above (**dry conditions**, **growing season**, **agricultural conditions**) continue to illustrate the same trends described for the short- and medium-term time horizon. By the end of the century, the growing season is expected to be over 1.5 months longer in duration across the Region, starting as early as April 2 and ending as late as November 30th potentially. This further emphasizes the increased growing degree days and agricultural opportunities across Durham, but dramatically increases the risk of pests. As an example, by the 2080s, the risk of pests is projected to increase over 100% on average compared to historical conditions.

Next Steps

A comparison between local municipalities across Durham Region, including summaries of all tailored all climate parameters can be found under Appendix F. The ensemble climate modeling completed for Durham Region will be a useful tool for years to come. It will serve as the foundational data set for many climate change adaptation projects and move implementation of the DCCAP forward. This report also sets the stage for future updates, providing the Region with the opportunity to incorporate advancements in climate science as new information becomes available. The following is a list of potential projects Durham Region may wish to undertake as part of future projects to advance climate change initiatives. These include:

- **The Creation of Future IDF Curves:** IDF curves, are used to plan for municipal infrastructure such as the sizing of culverts, stormwater ponds, roads, etc. This project may trigger the need to update existing IDF curves within Durham Region to account for future climate change and inform design and engineering standards.

- **Updating the Urban Heat Island and Floodplain Mapping:** While these new climate projections do not differ drastically from the SENES Study, the projections may trigger the need to update existing urban heat island mapping as well as floodplain mapping to account for the changes.

- **A User Interface:** The development of an online web application (e.g., R Shiny) would provide Durham Region with an easy-to-use interface for data handling. Those who may find the methods difficult to replicate would be able to use the web app and easily access the data.

- **Public Education:** These new climate projections will trigger a need for public engagement and a public version of this document. While the climate projections do not differ drastically from the SENES Study, the Region may wish to engage the public to showcase action on climate change science in the Region. A summary technical report that can be taken to Council and is easily understandable should also be developed.

- **Building Staff Capacity:** As noted above, the updated climate projections will help to inform future climate change projects. However, municipal and conservation authority staff will require training on the use and application of the modeling.

- **Quantitative Vulnerability Analysis:** The DCCAP Working Groups will be able to use these climate projections to identify and map out highly vulnerable areas are within the Region and target their adaptation efforts to those areas (e.g., a vulnerability assessment of natural systems)

- **Co-benefit projects:** The updated climate projections in this report may stimulate the creation of projects that have multiple cross sectoral benefits and that can address both adaptation and mitigation.

While this project focuses on Durham Region, the approach is transferable to other municipalities in Ontario. The following is a set of considerations for municipalities in Ontario to take into account when undertaking climate modeling exercises.

- Leverage existing data and tools, where possible (e.g., Regional or City data, online portals and tools, etc.). There are many climate data portals available and the landscape is evolving rapidly, making it easier for municipalities to access climate data.

- Seek input from experts to understand what is considered 'best' available climate data and where it is available.

- Involve broad stakeholders, practitioners and academic expertise where possible for validation and review.

- Acknowledge that gaps in science exist and certain parameters may not be accounted for.

- Build staff capacity through training on the use and application of climate modeling to understand the limitations or caveats of climate data use

1. Introduction

Changes to the Earth's climate system over the last few decades have resulted in unprecedented trends in global temperatures (IPCC, 2014). The Special Report put forth by the Intergovernmental Panel on Climate Change (IPCC) concludes with certainty that recent anthropogenic emissions of greenhouse gases such as carbon dioxide, are the main cause of recently observed global temperature increases (IPCC, 2019). These human influences have been associated with warmer atmospheric and ocean temperatures, changes to the global water cycle, reductions in snow and ice, increases in global mean sea level rise, as well as changes in extreme weather events. As demonstrated in the *Canada in a Changing Climate Report* (2019), Canada's annual average temperature over land has warmed by 1.7°C since 1948. Changes in climate will continue to significantly affect all of Canada's communities, both at the regional and local scale in the future.

In Ontario, these impacts are already being felt and will continue to influence communities across the province. Warming temperatures, increasing precipitation and more extreme weather events are all expected to increase throughout the end of the century (McDermid et al., 2015). In the Great Lakes Basin, it is projected that temperatures will increase between 1.5 to 7°C by the 2080s, with northern latitudes expected to experience the highest rate of warming (ibid). Winter precipitation in the Great Lakes Basin is also projected to increase as much as 16 cm, while summer conditions are expected to be drier, with up to 6 cm less precipitation as compared to historic levels (ibid).

The Great Lakes, as well as smaller lakes such as Lake Simcoe, play an important role in local weather patterns and climate processes, due to their vast sizes, depths, and degrees of thermal inertia. However, in recent decades, the Great Lakes Basin has felt the impacts of climate change, generally consisting of higher temperatures, increased precipitation, decreased annual lake ice coverage, reduced snow cover and lake-effect snow, increased wind speeds, fluctuating lake levels, changes in timing and quantity of precipitation events, and an increased number of extreme weather events (Wang et al., 2017). These changes in climate can cause many cascading impacts, including increased flooding events, erosion of shorelines and infrastructure, contamination of water, and/or the loss and alterations of habitats for a variety of aquatic species (Mortsch, 1998).

At the local scale, these climate change projections will have a significant impact on Durham Region. Through the *Durham Community Climate Adaptation Plan* (2016), the SENES model shows that Durham Region will be subjected to increased precipitation, more severe rainstorm events, increased average annual temperatures, and reduced snowfall (Durham Region, 2016). This will lead to significant changes across the Region, including more localized flooding, threats to human health and safety, as well as overall changes its ecosystems (Durham Region, 2016).

In recent years, confidence around future climate modeling projections has significantly increased. Since the IPCC released their second assessment report in 1995, the number of Global Circulation Models has grown to over 40 different models (Auld et al., 2016). Global Circulation Models (GCMs) have increasingly included more components of the Earth system and their coupled interactions (e.g., ocean, atmosphere and land interactions), and have also developed better resolution simultaneously over time. Regional Climate Models

(RCMs) have also increased their spatial resolution significantly (IPCC, 2014). This increase in the number of climate models has provided the opportunity for practitioners to analyze climate projections through an ensemble of models, reducing the overall uncertainty associated with climate projections.

In Ontario, the state of climate modeling around the Great Lakes has also enhanced significantly in the past few decades. Most climatological studies in the Great Lakes Basin now use Regional Climate Models (RCMs) which offer higher resolution, dynamically downscaled GCM output under a more regional climate context. This increased resolution allows for a more accurate representation of climatological variables across hydrological features, which are typically represented as land surfaces in GCMs. The use of climate modeling in Ontario municipalities as well as initiatives, including initiatives undertaken within Durham Region can be found under Appendix A.

Despite improvements to climate modeling in recent years, a consistent approach to undertaking climate modeling in Ontario does not currently exist. Many municipalities in Ontario have undertaken their own climate modeling, but much uncertainty around which climate models to use, how many models to use, and how to conduct the modeling itself still exists. Due to the limited institutional capacity around climate modeling, municipalities are often required to hire external contractors to develop climate projections, creating inconsistent climate change projections across closely situated municipalities. With rapid changes in climate science over the last few years, ensuring that communities use the most up-to-date climate information is essential to implementing appropriate adaptation strategies. By enhancing the way in which we examine current conditions and projected future climates, using a consistent approach across the Region and by communicating these findings within Durham Region, decision-makers and resource managers will have the necessary information to inform the implementation of adaptation strategies and to help residents in Durham Region withstand the negative impacts of climate change.

With this context, Durham Region has identified the need to update their climate projections to support the implementation of climate adaptation initiatives across the Region. The need for a guidance document was also identified to provide municipalities within Durham, as well as those within the Greenbelt with an opportunity to undertake their own climate modeling exercises, to improve consistency in this area across Ontarian municipalities. This guidance document provides Durham Region and municipalities within Ontario the opportunity to fill the existing knowledge gaps around climate modeling and encourage consistency amongst Ontario municipalities, by demonstrating the methodologies behind climate modeling in a way that is understandable and replicable. Therefore, this report will allow Ontario municipalities to reproduce the same methodologies taken in this study when undertaking their own climate change analyses.

1.1 Objectives of this Report

The purpose of this report is to provide guidance around the climate modeling methodology that the Region of Durham and other Greenbelt municipalities and Conservation Authorities can replicate, adapt, and built upon for use in their respective jurisdictions. It provides a step-by-step methodology for obtaining and analyzing climate data.

The following are the general objectives associated with this project:

- To create a clear and replicable approach for climate change analysis, which allows for a range of climate projections, for the short, mid and long term, including averages and extremes;
- To provide climate model output data (e.g., temperature, precipitation, etc.) that will inform or could be used as inputs for Durham Region's climate change adaptation planning efforts; and
- To provide a consistent approach across Durham Region that can be utilized by Regional staff, lower-tier municipalities, conservation authorities, and the broader community for decision-making and analysis.

2. Durham Region

2.1 Study Area: Durham Region

For the purposes of this report, climate projections for the Region of Durham are presented as a case study for other Ontario municipalities to use as an example of how to develop their own climatological studies.

Durham Region is a regional municipality located in southern Ontario and consists of eight local municipalities, including Ajax, Brock, Clarington, Oshawa, Pickering, Scugog, Uxbridge, and Whitby. The Region is situated within the Golden Horseshoe area of Ontario, located directly east of the City of Toronto and York Region, west of Northumberland County and the City of Kawartha Lakes, and is located directly north of Lake Ontario and south of Lake Simcoe (Figure 2).

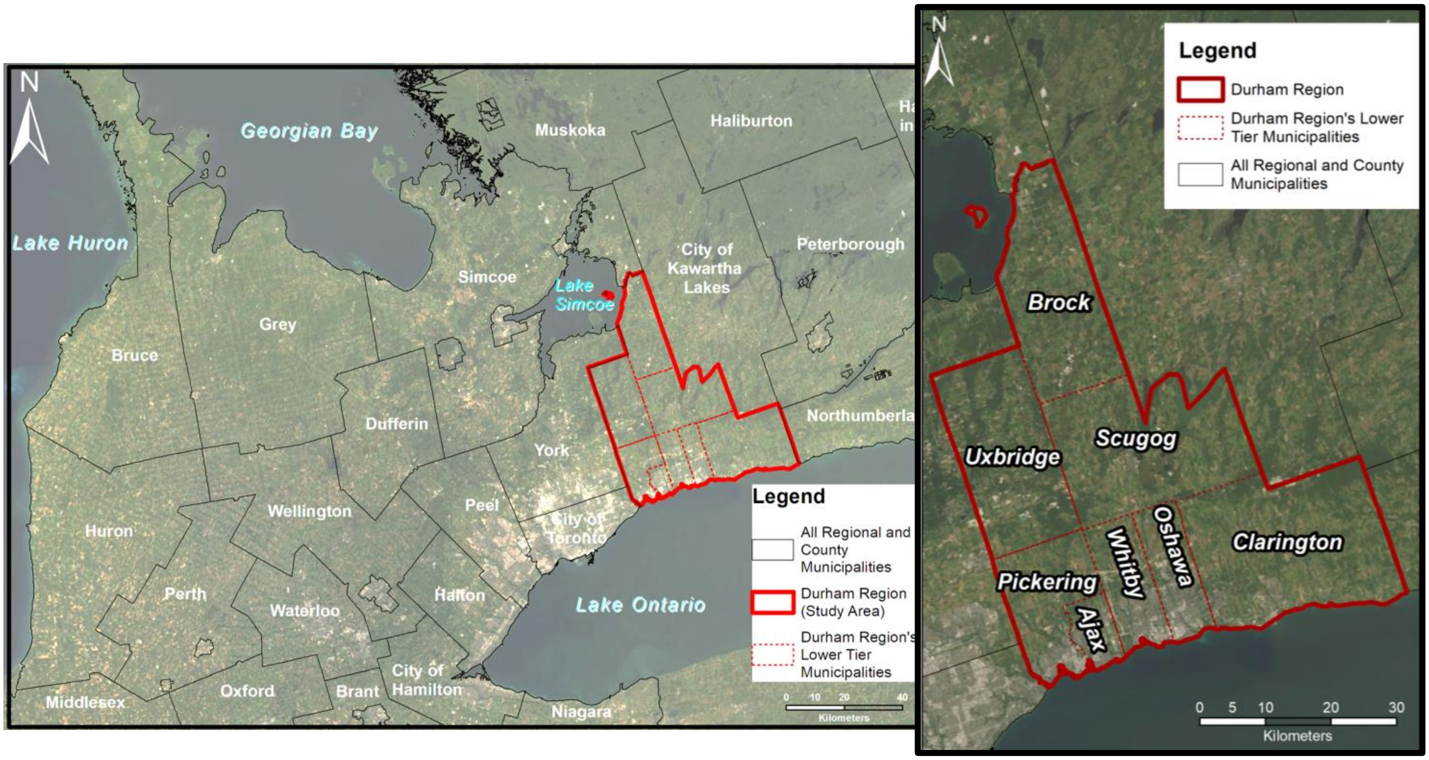


Figure 2: Durham Region and its surrounding regional governments, and its eight local municipalities in Southern Ontario.

Durham Region is composed of a mixture of rural, residential, and commercial land. North Durham is mostly rural, with a thriving agricultural sector, while South Durham is composed of lakeshore communities that offer urban development and a diverse employment base. The Oak Ridges Moraine is nestled in between, dividing both North and South Durham. Over 80% of Durham Region is located within the Greenbelt. The Region currently has a population of about 706,200 people; however, this is projected to increase to about 1.2 million people by 2041 (Durham Region, 2017).

Durham Region has a large area of about 2,500 square kilometers and has 17 different quaternary watersheds that intersect its municipal boundaries. As a result, Durham Region's water conservation, restoration, and management services are controlled by five different conservation authorities (CAs), including Central Lake Ontario CA (CLOCA), Ganaraska Region CA (GRCA), Kawartha Region CA (KRCA), Lake Simcoe Region CA (LSRCA), and Toronto and Region CA (TRCA), with Otonabee Region CA (ORCA) directly adjacent to Durham's CAs (Figure 2).

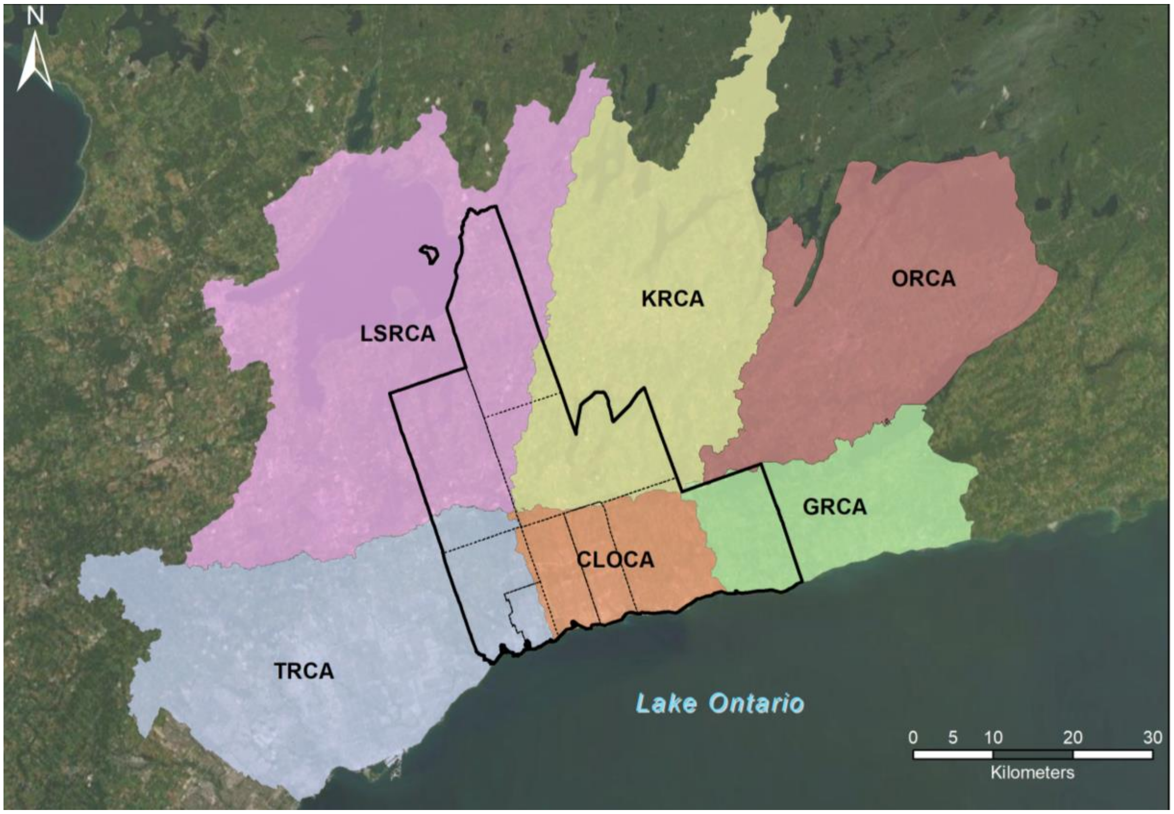


Figure 3: Durham Region and its six surrounding conservation authorities, five of which intersect its municipal boundaries.

With an increase in population of about 78% by 2041, and future impacts of climate change affecting the Region's water quantity and quality in the future, it is of most importance for the Region to continue to plan for these major changes in all sectors, in collaboration with all eight local municipalities and with five corresponding CAs. For the purposes of this study, climate change projections are summarized for the Region as a whole, then broken down into specific climate change projections for each local municipality, and each CA jurisdiction (Appendix F-I).

2.2 Overview of the Region of Durham's SENES Report and Purpose for Updating Climate Modeling in Durham Region

Between 2012 and 2014, the Region of Durham undertook a climate modeling exercise with SENES Consultants Ltd. to predict future climate in the Region for the 2040-2049 period. The study, known as the 'SENES Study' was one of the first steps towards the development of the *Durham Community Climate Adaptation Plan* (DCCAP). The report provides information on numerous climate indicators (e.g., temperature, precipitation, etc.) and uses available models and weather station data from 2000-2009 to compare to future climate projections (2040 to 2049). Through the study, it was determined that Durham Region will experience warmer, wetter and more extreme climate conditions in the decade 2040-2049 as compared to the 2000 to 2009 time period.

At the time, SENES selected the most credible climate emissions scenario (the A1B scenario of the IPCC) (see Section 3.4 for more information on climate emissions scenarios). These emissions scenarios are known as the Special Report on Emissions Scenario (SRES), which have since been replaced by more representative climate scenarios called Representative Concentration Pathways (RCPs). The A1B emission scenario was used in the SENES study, which is a climate scenario that represents a world of rapid economic growth, a global population that reaches 9 billion in 2050 and then gradually declines, a quick spread of new and efficient technologies, and extensive social and cultural interactions worldwide (IPCC, 2013). The A1B scenario was used to drive the Global Climate Model titled, the third version of the *Hadley Centre Coupled Model* (HadCM3), and the Regional Climate Model titled, *Providing Regional Climates for Impacts Studies* (PRECIS), along with the FReSH weather forecasting system in order to project relevant climate parameters for the 2040 to 2049 period. Since the release of the SENES study, significant developments in climate information have emerged, including updated climate emissions scenarios and climate models. The SRES scenarios have since been replaced with Representative Concentration Pathways (RCPs) to better account for the driving forces that influence greenhouse gas emissions (Charron, 2016). Four RCP scenarios have been developed including RCP 8.5 (business-as-usual), RCP 6.0 (stabilized), RCP 4.5 (stabilized) and RCP 2.6 (best case scenario).

In early 2018, the Region of Durham hired the Ontario Climate Consortium (OCC), in partnership with municipalities and CAs in and surrounding Durham Region, to develop a report examining how climate change considerations are being incorporated into natural environment-related policies and plans within the region. One of the recommendations that came out of the report was for the Region of Durham to undertake a climate modeling exercise to update the current SENES model as well as emissions scenarios to include both Global and Regional Climate Models through an ensemble approach to inform future updates to policies and plans. A comparison between the SENES study and the 2019 Durham Climate Modeling Project can be found under Appendix D. Funding for this work was received through the Greenbelt Foundation.

2.3 Region of Durham's Natural Environment and Climate Change Collaborative (NECCC)

The DCCAP was approved by Region of Durham council in 2016, with ongoing partnerships and coordination required to support the implementation of the DCCAP. As a recommendation of the DCCAP, the Natural Environment and Climate Change Collaborative (referred to as the NECCC) was formed to enable natural environment coordination amongst municipal and CA partners. The NECCC is comprised of representatives from each of the five conservation authorities in Durham Region, as well as all eight local municipalities and the Region.

The NECCC supports the implementation of the Natural Environment Sector Objectives and Programs as contained in the *Towards Resilience Durham Community Climate Adaptation Plan* (2016). The NECCC acts as a conduit for the exchange of knowledge between its members and helps to guide and coordinate activities and projects taking place between each member's respective organizations to help further the resilience of the natural environment in Durham Region. Through their work they identified gaps in climate data that was required to help scope and prioritize the actions required to achieve the objectives of the DCCAP.

In late 2018, the NECCC, the Region of Durham's Office of Sustainability, along with the Planning and Economic Development Department and the Ontario Climate Consortium received funding through the Greenbelt Foundation to update the Region's climate projections using an ensemble of climate models. The result of this project will be new climate projections for the Region of Durham and a guidance document intended to be a step-by-step process for municipal and CA staff looking to undertake their own climate modeling. It is also intended that other municipalities within the Greenbelt and beyond will be able to use the methodology presented within this report and adapt it to reflect their needs.

2.4 Collaboration, Engagement and Capacity Building

Collaboration and engagement were essential components in the development of the Durham Region's climate projections. Key stakeholders including the NECCC, Region of Durham, its 8 lower-tier municipalities as well as the 5 Conservation Authorities were involved throughout the process. The overall goal was to allow stakeholders an opportunity to provide input on the climate parameters of interest to Durham Region, as well as review the preliminary results.

To ensure the objectives for the 2019 Durham Climate Modeling Project were fulfilled, the Project Team undertook the following process:

- In 2019, the NECCC submitted a funding proposal to the Greenbelt Foundation, engaging the Ontario Climate Consortium (OCC) to lead the technical aspects of the project.

- The OCC prepared a list of potential climate parameters as well as climate models/data portals to be included as part of the selection process, determined the downscaling approach based on the climate models available and drafted a methodological approach which was taken to the NECCC Technical Subcommittee for feedback. The Project Team also engaged with the Region of Durham's Community Climate Adaptation Plan Agriculture Working Group and the Region of Durham's Planning Department.

- As a part of the climate model selection process, the Project Team also consulted with Provincial government staff to review the approach being used by the Province as well as the methodology to ensure alignment.

- In November 2019, the Project Team hosted a Preliminary Results meeting for the NECCC partners and Durham Community Climate Adaptation Plan working group chairs (i.e., building, electrical, flooding, roads, human health, agriculture, and food security). Participants were provided with an opportunity to provide comments on the preliminary results.

- In November 2019, representatives from the Project Team presented the Preliminary Results at the AD Latornell Symposium.
- Over the course of the Fall 2019, the Project Team engaged in discussions with Dr. Michael Notaro, Associate Director, Nelson Institute Centre for Climatic Research at the University of Wisconsin as a third-party reviewer of the process and documentation.
- In January 2020, the Project Team hosted a technical and non-technical webinar to present the findings to the NECCC, DCCAP working chairs, as well as municipalities and conservation authorities across the Greenbelt.

3. Background on Climate Models and Future Climate Data

It is important for all municipalities to have a common understanding of climate modeling and the specific terminology encompassed in this field of study. The following section provides a brief background on climate modeling and key terminologies used throughout this report. This section discusses the differences between Global Climate Models and Regional Climate Models, various downscaling methods, ensemble approaches, and the different climate change scenarios used in climate modeling.

3.1 Global Climate Models (GCMs) and Regional Climate Models (RCMs)

Global Climate Models (GCMs) are coupled atmosphere-ocean-land-sea ice models that project future changes in climate over the entire Earth surface under various GHG emissions scenarios (Charron, 2016; EBNFLO, 2010). These models develop climate projections with a resolution usually ranging between 110 – 500 km by 110 - 500 km, on continental scales (Wang et al., 2016) (see Figure 4) and are designed to characterize future climate on an annual, seasonal, and monthly basis (EBNFLO, 2010). In general, three different types of GCMs exist: Atmospheric General Models (AGCMs), Atmospheric-Ocean Global Climate Models (AOGCMs), and Earth System Models (ESMs) (Charron, 2016). ESMs are the latest generation of models and include biogeochemical interactions and cycles, as well as changes in land cover (e.g., vegetation types) (Charron, 2016). Since GCMs provide projections over larger spatial scales, there remain many limitations in climate data. Some of the most prominent limitations to GCMs are that GCMs cannot simulate smaller scale convective storms (i.e., thunderstorms), and as a result cannot account for some extreme events at the local scale (EBNFLO, 2010). GCMs are also known to misrepresent many local features such as lakes and cloud processes, and they usually dampen extreme weather conditions compared to observational data. Additionally, since GCMs simulate many physical processes at a large scale, there are many smaller-scale processes such as cloud activity that cannot be adequately modelled in a GCM (IPCC, n.d.). These processes must be averaged over a large

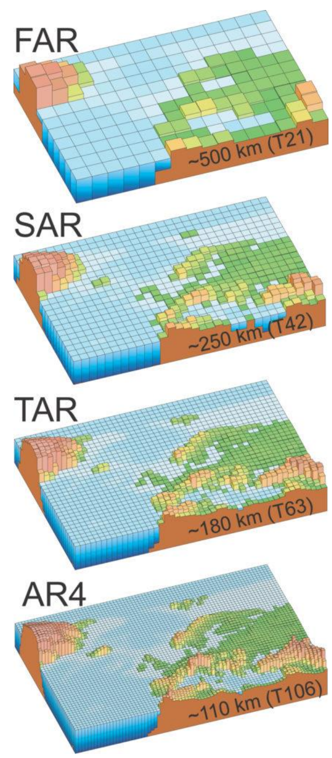


Figure 4: Ranges of GCM Spatial Resolution (Source, IPCC, 2007)

scale to be reflected in the GCM (ibid). As such, this creates a level of uncertainty in the GCM, as it may not accurately reflect the smaller-scale processes in the model.

Most GCMs were not designed with an emphasis on lake-land-atmosphere conditions, despite the Great Lakes' influence on regional climate. As previously mentioned, GCMs usually have a horizontal resolution between 110 to 500 km by 110 to 500 km, limiting the ability for GCMs to appropriately account for the Great Lakes to a certain extent. A study by the Great Lakes Integrated Impacts and Sciences Assessment group (GLISA) (currently in review) evaluates how all 55 GCMs within the Coupled Model Intercomparison Project Phase 5 (CMIP5) models (the models used in the latest IPCC report) incorporate the Great Lakes, if at all. Table 3 shows the findings of this study, where only 18 of the GCMs in CMIP5 simulate all five of the Great Lakes as dynamic lakes (i.e., they incorporate lake-atmosphere feedbacks).

RCMs have emerged as an increasingly valuable climate model. RCMs are high resolution models that are used to downscale the lower (or "coarser") resolution GCM outputs, providing a physically realistic simulation of climate projections over a smaller geographical area (ECCC, 2017; Charron, 2016). RCMs produce climate projections on a much finer scale than GCMs (ranging from 10 – 50 km, some even have resolutions of 4 km) and produce more regionally-relevant climate information (e.g., the effects of the Great Lakes). As a result, RCMs allow for a more precise representation of land features such as lakes and rivers and ensures that consistency is maintained among different climate variables (Charron, 2016). Unlike GCMs, RCMs can project smaller scale storms (e.g., finer resolution RCMs can project thunderstorms, lake-effect snowstorms, and snow bands), allowing the models to incorporate future storms and extreme events (EBNFLO, 2010). As a physical model, RCMs also provide the benefit of linking the interaction of GHG emissions with other components of the climate system (Charron, 2016).

Table 3: Summary of Great Lakes representation in each of the Global Circulation Models in the CMIP5 Ensemble (GLISA, in review)

Model Acronym	Atmospheric Component Spatial Resolution	All Five Great Lakes are Simulated (green = yes, red = no)
These models simulate all five Great Lakes as dynamic lakes (i.e., lake-atmosphere feedbacks are simulated). An accurate representation of lake surface temperatures and lake ice cover is necessary for those feedbacks to add value to the simulation, so additional evaluation should be conducted prior to use.		
BCC-CSM1-1m	1.12°x1.13°	yes
CCSM4	0.94°x1.25°	yes
CESM1-BGC	0.94°x1.25°	yes
CESM1-CAM5	0.94°x1.25°	yes
CESM1(WAC-CM)	1.88°x2.5°	yes
CESM1(fast- chem)	0.94°x1.25°	yes
CSIRO-Mk3.6.0	1.87°x1.88°	yes
FGOALS-g2	2.79°x2.81°	yes
GFDL-CM3	2.00°x2.50°	yes
GFDL-ESM2G	2.02°x2.50°	yes
GFDL-ESM2M	2.02°x2.5°	yes
GISS-E2-H	2.00°x2.50°	unknown
GISS-E2-H-CC	2°x2.5°	unknown
GISS-E2-R	2.00°x2.50°	unknown
MIROC5	1.40°x1.41°	unknown
MRI-CGCM3	1.12°x1.13°	unknown
NorESM1-M	1.89°x2.50°	yes
NorESM1-ME	1.89°x2.50°	yes
This model simulates the Great Lakes as oceans. An accurate representation of sea (lake) surface temperatures and sea (lake) ice cover is necessary to add value to the simulation, so additional evaluation should be conducted prior to use.		
MIROC4h	0.56°x0.56°	yes
These models treat lakes as a water surface, but the absence of interactive (i.e., dynamic) lakes is a limiting factor for accurately representing lake temperature and lake ice cover feedbacks. For this reason, use of these models is not recommended.		
ACCESS 1.0	1.25°x1.88°	unknown
BNU-ESM	2.79°x2.81°	unknown
HadGEM2 family	1.875°x1.25°	unknown

Model Acronym	Atmospheric Component Spatial Resolution	All Five Great Lakes are Simulated (green = yes, red = no)
Part of the Great Lakes are crudely (with limited spatial coverage and resolution) simulated as oceans in these models. These models may be able to offer useful information and simulate lake-atmosphere feedbacks at the regional scale, but site-specific or local analysis is not advised.		
HadCM3	2.5°x3.75°	no
IPSL-CM5A-LR	1.89°x3.75°	no
IPSL-CM5A-MR	1.27°x2.50°	no
IPSL- CM5B-LR	1.89°x3.75°	no
From the found documentation, it is not apparent that there is any form of lake representation in these models. These models are not recommended for the Great Lakes region.		
ACCESS 1.3	1.25°x1.88°	no
BCC-CSM1.1	2.79°x2.81°	no
GFDL-CM2.1	2.79°x2.81°	no
MIROC-ESM	2.79°x2.81°	no
In these models, there are conflicts over how the Great Lakes are geographically defined in the land and ocean components. Inspection of the land and ocean components revealed the case where 1) both components claim 100% responsibility for simulating surface states/fluxes over at least one Great Lake and/ or 2) neither component is responsible for simulations over at least one Great Lake. These conflicts indicate uncertainty in how fluxes between the land, ocean, and atmosphere components are coupled. These models are not recommended for the Great Lakes region.		
CMCC-CESM	3.44°x3.75°	no
CMCC-CM	0.75°x0.75°	no
CMCC-CMS	1.86°x1.88°	no
INM-CM4	1.50°x2.00°	no
CanESM2	2.79°x2.81°	no
NCEP-CFSv2	1°x1°	no
CNRM-CM5	1.40°x1.41°	no
EC-Earth	1.12°x1.13°	no
MPI-ESM-LR	1.86°x1.88°	no

3.2 Downscaling Methods

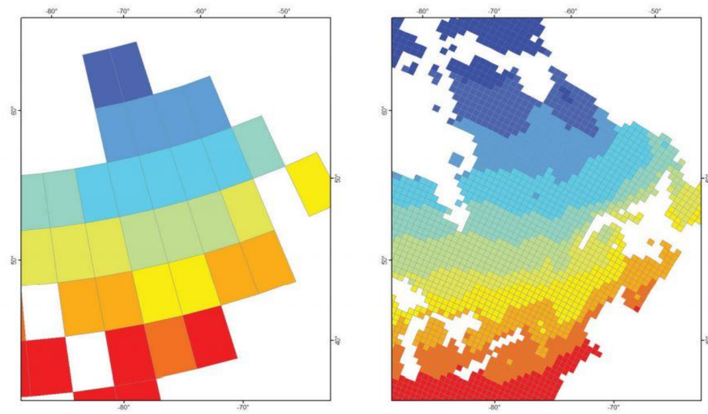


Figure 5: Downscaling from a GCM with 200km spatial resolution to a 45 km grid cell (Source: Logan, 2016).

Downscaling is the process of generating climate information from a GCM with coarse spatial resolution to a finer spatial resolution (Wilby et al., 2004; Flint and Flint, 2012) (see Figure 5). The two types of approaches, statistical downscaling and dynamical downscaling, have been established to achieve detailed regional and local atmospheric data (Castro et al., 2005).

Statistical downscaling is based on a statistical model that compares large-scale climate variables from GCMs to smaller scale regional or local climate variables (Wilby et al., 2004). It relies on historical relationships (also referred to as "stationary assumption") among climate variables at different scales (Auld et al., 2016). There are three types of statistically downscaled approaches that can be applied, including weather classification schemes, regression models, and weather generators (Wilby et al., 2004). As the impacts of climate change become more significant, using a stationary assumption (i.e. relying on historical radiative forcing conditions) will result in greater uncertainty among the statistically downscaled data, as important feedback cycles in the climate are not accounted for in these projections (e.g., the impact of warming temperatures and lake ice will exponentially increase the rate of lake effect snow and evaporation in some models, while other models that have been downscaled suggest rising temperatures will eventually reverse the positive trend in lake-effect snow to negative). Thus, using a stationary assumption is not a recommended approach to be taken to account for future changes in climate, particularly for extreme weather events, and processes that are dependent on other climate forces. The approach taken in statistical downscaling is therefore not physically verifiable (Wilby et al., 2004). Since statistical downscaling relies on historic relationships among climate variables at various scales, using a statistical relationship based on present-day conditions may not hold up under different RCP scenarios using future climate projections, where the principle of stationarity no longer applies (Wilby et al., 2004). In addition, it is commonly understood that most statistical downscaling methods underestimate observed extremes; however, there are benefits to considering both statistical and dynamical downscaling in climate modeling as both approaches consist of strengths and limitations. For example, there are some statistical techniques (e.g., the probability density function) that have been used (e.g., by the Wisconsin Initiative on Climate Change Impacts – WICCI) that reproduce observed extremes and allows for probabilistic assessments.

Dynamical downscaling is a downscaling approach which involves running a very high-resolution model once over the area of interest, driven by global climate model boundary conditions (so called 'dynamical downscaling'). These boundary conditions provide Regional Climate Models with information about conditions in neighbouring cells (e.g., when calculating rainfall, you need to understand how much moisture is entering the region) (Hannah, 2011). In the simplest of terms, one can either have 'many model runs at a coarse resolution' or 'few model runs at high resolution'. These high-resolution models are called 'Regional Climate Models' (RCMs).

Traditional dynamical downscaling incorporates GCM data to provide the initial conditions, lateral boundary conditions, sea surface temperatures, and initial land surface conditions (e.g., general topography, large bodies of water, etc.) (Xu and Yang, 2012). Once the GCMs provide the initial conditions, RCMs are integrated using the initial data and the boundary conditions from the GCM to develop the projections (Xu and Yang, 2012). To successfully downscale RCMs, GCM radiative forcing must be incorporated into the RCM formulation through the development of a buffer zone, whereby the GCM and RCM both maintain their consistency, allowing the RCM to produce its own smaller scale climate modeling (Liang and Kunkel, 2001). Depending on the purpose of the dynamic downscaling, RCMs can develop five types of downscaling including short-term weather simulations, seasonal predictions, regional weather simulations, seasonal predictions, and climate prediction.

Both statistical and dynamical downscaling techniques rely on GCMs to drive local-scale modeling and analysis, and ideally the uncertainty associated with GCMs should be transparent through the downscaling process (Wilby et al., 2004). A comparison between statistical and dynamical downscaling is demonstrated in Figure 6. A summary of the key advantages and disadvantages of both statistical and dynamical downscaling is also provided in Table 4.

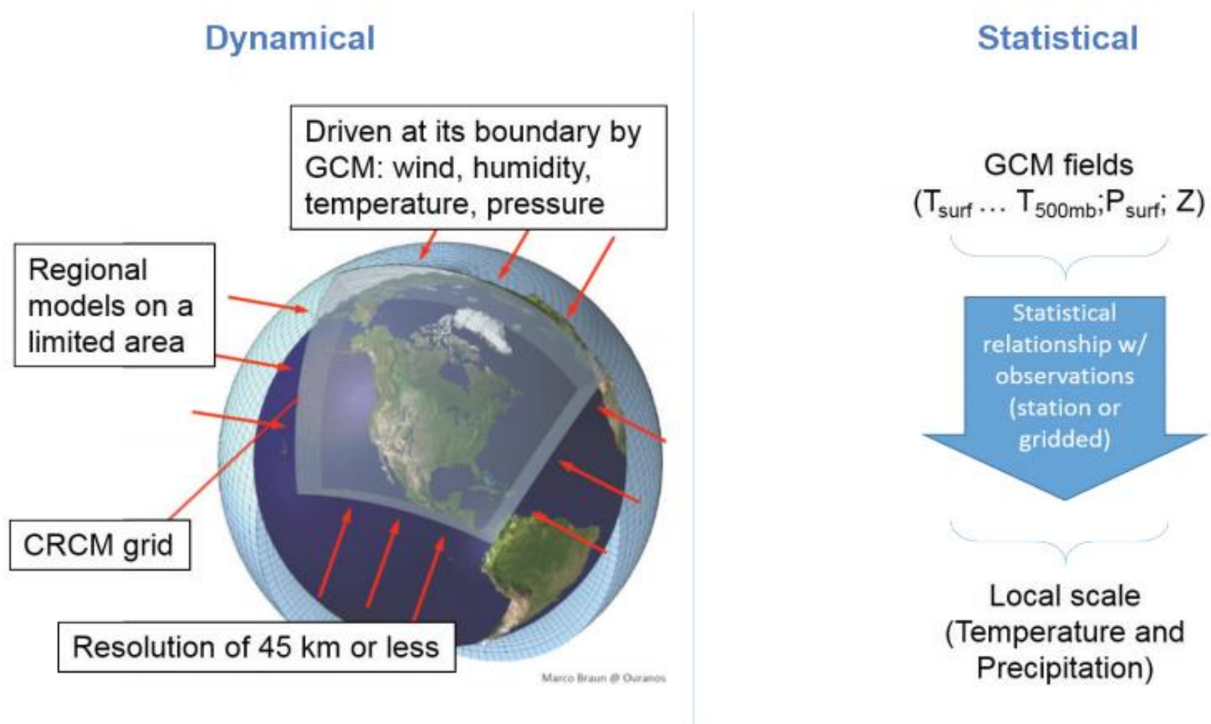


Figure 6: Comparison Between Dynamical and Statistical Downscaling. Source: Ouranos, 2016.

Table 4: Key advantages and disadvantages of downscaling techniques (adapted from Hostetler et al., 2011).

Statistical Downscaling	Dynamical Downscaling
+ Fast and computationally inexpensive (relatively)	+ More accurate simulation of high-resolution RCP scenarios and climate compared to statistical downscaling - Many RCMs and GCMs still lack the Great Lakes representation so it is important to carefully select the RCMs being used
+ High resolution (e.g., 4 km or less)	+ Large, internally consistent set of atmospheric and surface variables
+ Multiple GCMs for ensembles and different emissions scenarios	+ Avoids stationary assumption (i.e. uses trends into the future that differ from the historical rates of change, and incorporates feedback cycles)
- Limited ability to account for finer scale topography (reducing ability to account for features such as precipitation induced by mountain ranges, or evaporation over lakes)	- Time consuming. For example, requires more time to incorporate local influences (e.g., bias correcting (see section 4.3)).
- May not conserve mass and heat	- Limited number of GCMs used
- Uses stationary assumption (uses historical rates of change to model the future), and mostly only models for precipitation and temperature	- Greater number of uncertainties as the number of climate models increase

3.3 Using an Ensemble Approach

Previous research using AOGCMs to project future changes in climate has shown that no single model exists that can determine all possible future climates (Tebaldi et al., 2004). Research has shown that the use of a single model to project climate trends increases the number of errors within the climate modeling and can result in a misinterpretation of climate trends (Auld et al., 2016). Each individual model represents specific climatological processes and comes with its own set of biases (Sheffield et al., 2013).

The ensemble, or multi-model approach, uses multiple models together to produce a full range of possible climate scenarios and represents those projections using statistical distribution (e.g., see Figure 7). Several ensemble approaches exist, including CMIP5, CORDEX (Coordinated Regional Climate Downscaling Experiment), NARCCAP (North American Regional Climate Change Assessment Program), and many others. Statistical distribution allows the users to interpret trends probabilistically and address the uncertainties associated with the climate modeling (Auld et al., 2016). Using a multi-model approach provides better predictions and compares more favorably to historical observations than a single model (Auld et al., 2016). With the ensemble approach, individual biases present in a single model tend to be reduced while the uncertainty associated with the overall process is maintained and can be disseminated through further analysis and local-scale modeling. Ensembles can consist of multiple GCMs coupled with a single or multiple RCMs, one GCM coupled with multiple RCMs, or simply running one single model with an ensemble of “runs” (e.g., running the model to multiple climate scenarios such as RCP8.5 and RCP4.5). An ensemble of RCMs requires that users first select the GCM(s) that they wish to use followed by the selection of RCMs that they would like to downscale the GCM data from (Evans et al., 2013). While there is no best future scenario that can be applied for any given situation, the use of an ensemble approach allows for a more plausible approach to capture what the future may represent (Charron, 2016).

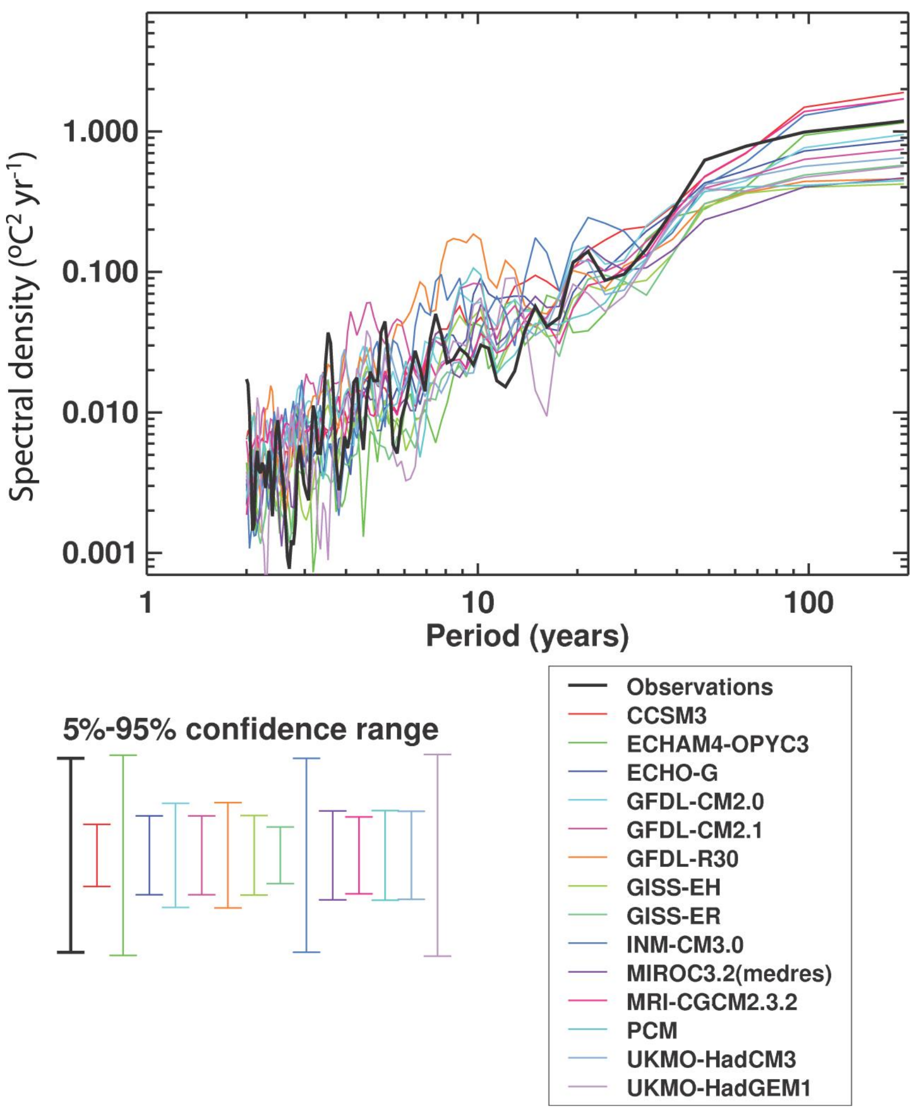


Figure 7: Example of an ensemble of climate models used to determine annual global mean temperature from an observed record. Source: IPCC, 2007.

3.4 Climate Change Scenarios

Another uncertainty associated with modeling and projecting climate is the future of human behaviour, technology, and of the amount of carbon in the atmosphere. Therefore, in climate modeling, there exists a series of plausible pathways, otherwise referred to as "scenarios", or targets that embody the relationships among human behaviour, emissions, GHG concentrations, and temperature change. The most recently produced climate change scenarios are called Representation Concentration Pathways (RCPs), which have been endorsed by the Intergovernmental Panel on Climate Change (IPCC). RCP scenarios consider the impacts of policies that may reduce GHG emissions significantly (e.g., RCP 2.6), as well as the impact of the continued heavy reliance on fossil fuels (e.g., RCP 8.5). Figure 8 demonstrates the four RCP scenario projections through time, for three different greenhouse gases including, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Both methane and nitrous oxide examine use the temperature gradient (Tg) to determine emission levels.

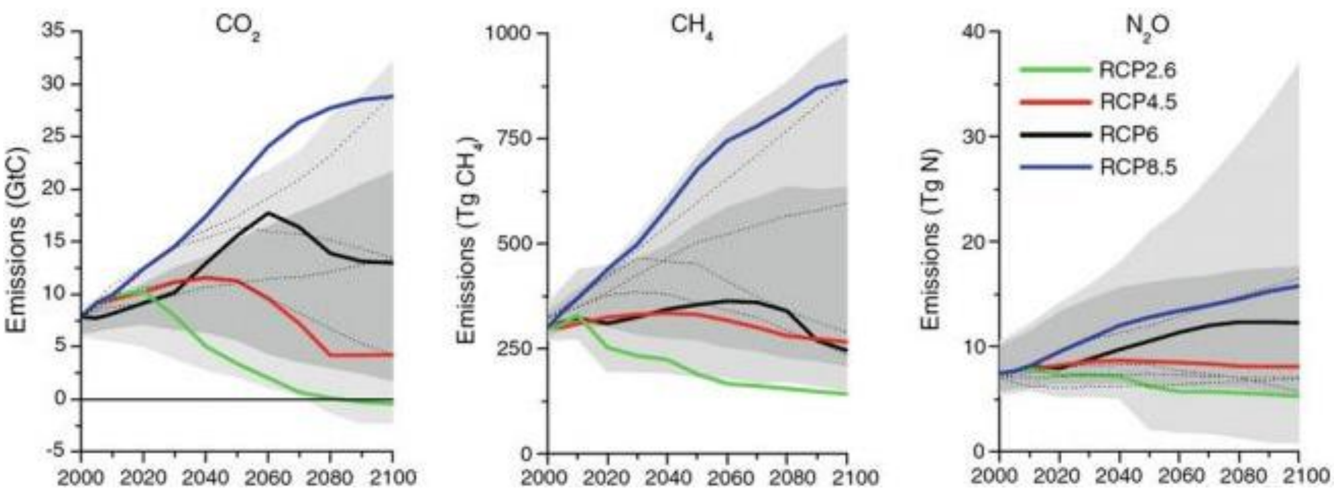


Figure 8: Graphs demonstrating annual emissions for the four Representative Concentration Pathways (RCPs) through time for carbon dioxide (CO2) methane (CH4), and nitrous oxide (N2O) (Van Vuuren et al., 2011).

Prior to the development of the RCP climate scenarios, climate modelers across the globe used (and some may still use) the SRES climate scenarios. These scenarios do not account for all of the different mitigative futures that are available in the RCP climate scenarios. One of the main differences between the RCP and SRES climate scenarios is that RCP scenarios consider GHG *concentrations*, while SRES scenarios consider GHG *emissions*; this is due to the fact that carbon concentration in the atmosphere is not solely reliant on human-induced emissions, as the carbon cycle is much more complex than this (e.g., the carbon storage of plants and soils, the amount of carbon absorbed by oceans, etc.). Therefore, RCP climate scenarios are now more commonly used as best practice, to account for the complexity of the carbon cycle into the climate models and the SRES scenarios are not generally used in the latest climate modeling exercises. Table 5 provides an overview of RCP concentration scenarios, with the comparative SRES emissions scenarios used in previous IPCC assessments for reference.

Table 5: The four Representative Concentration Pathways that have been used in the Fifth Intergovernmental Panel on Climate Change (IPCC) Assessment, with comparative SRES scenarios (IPCC, 2014).

Representative Concentration Pathway (RCP)	SRES Temperature Anomaly Equivalent	Definition
RCP 2.6	None	The lowest emission scenario, where peak radiative forcing is 3 Wm^{-2} and declines before 2100 (IPCC, 2014). This scenario would require all the main GHG emitting countries, including developing countries, to participate in climate change mitigation initiatives and policies.
RCP 4.5	SRES B1	The second lowest emission scenario, where stabilization without overshoot pathway to 4.5 Wm^{-2} and stabilization after 2100 (IPCC, 2014).
RCP 6.0	SRES B2	The second highest emission scenario, where stabilization without overshoot pathway to 6 Wm^{-2} and stabilization after 2100 (IPCC, 2014).
RCP 8.5	SRES A1F1	The highest emission scenario, where rising radiative forcing pathway leading to 8.5 Wm^{-2} in 2100 and continues to rise for some amount of time (IPCC, 2014). GHG concentrations are up to seven times higher than preindustrial levels.

3.5 Analyzing and Interpreting Climate Change Model Results

Ideally, climate change models that capture the best available science and considerations are used to assess potential risks and impacts, and plans reflect these data. However, practitioners and decision makers face several barriers in accessing the best available climate data (Environmental Commissioner of Ontario, 2015) for the following reasons:

- There is low awareness of what is considered “best” available climate data and where it is available as the state of climate science is rapidly evolving;
- There is a lack of collaboration between climate scientists and practitioners, and a lack of two-way dialogues around the strengths and weaknesses of different approaches and datasets, including their limitations;
- There is an inability to understand and incorporate climate data into decision making;
- There is a lack of translation of complex scientific information, which leads to less access and less usage of the best data;
- There is low capacity or expertise in climate science to understand the limitations or caveats of climate data use (e.g., users must be careful to not select the models with the lowest mean regional climate biases as this does not guarantee the model correctly captures key local climate drivers or sensitivity to GHGs); and

- There is inconsistency in data sources; for example, there are available historic data, but different sources provide different types of data, levels of precision as well as resolution.

Notably, a number of these barriers have been improved since the release of the ECO (2015) report, and this section explores the extent to which the latest climate data are accessed for applications and decision making. Through this project, Durham Region is working to address some of the barriers associated with analyzing and interpreting climate change model results. This guidance document will help to build capacity in undertaking climate modeling exercises across the region and will help to build consistency in climate data. Durham Region, in partnership with OCC and GLISA will also be involved in delivering training modules on climate data for use in natural environment-related applications, helping to build awareness and improving their understanding of what constitutes best practice.

4. Methodology for Climate Change Analysis in Durham Region

The following provides a high-level overview of the methodology as to how the project team undertook the climate modeling update for Durham Region. Appendix J provides detailed, step-by-step descriptions for each component of the methodology that was undertaken and provides rationale and advantages for each. Figure 9 provides an illustration of the overall process.

The first step taken in this approach involved conducting a literature review around best practices in climate modeling projections and determining the climate change data portal that would be used to derive specific climate indicators for Durham Region. The review of climate data portals demonstrated that there are numerous climate portals that provide data for Durham Region as well as across the Great Lakes basin.

Evaluation criteria and selection of the climate data portal were established through a combination of literature review around best practices in climate modeling projections and analyses, as well as through consultation with the NECCC group. Through the evaluation criteria, the project team narrowed down the selection of climate portals down to. Figure 10 demonstrates the steps that were taken to reach a confirmed approach.

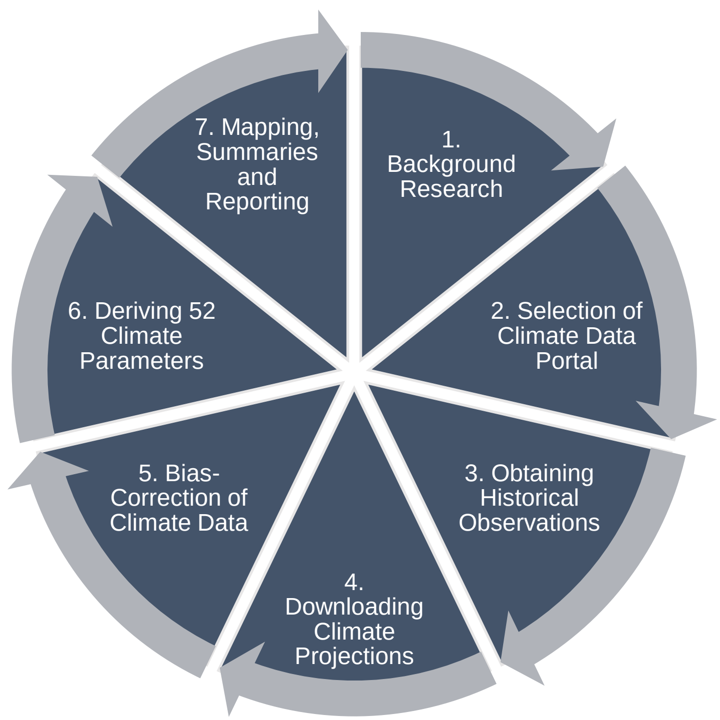


Figure 9: Overall Methodology for Conducting the Local Climate Change Analysis in Durham Region

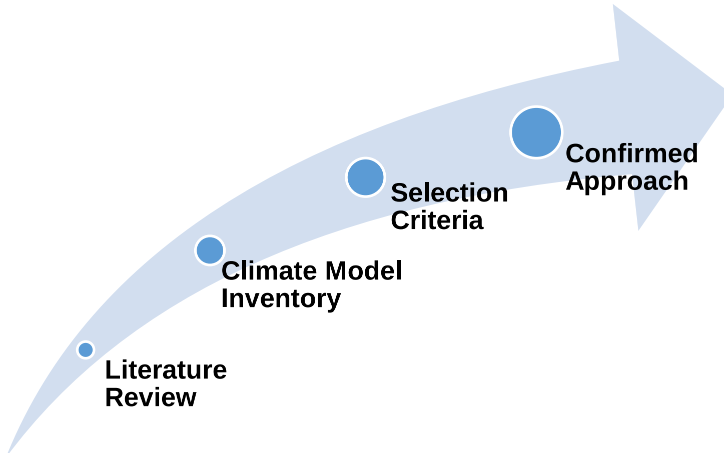


Figure 10: Process to reach consensus on the selected climate data portal for the Region's updated climate change analysis.

The following were the selection criteria used to inform the climate data portals of interest:

- The data had the ability to capture the influence of the Great Lakes (e.g., through the incorporation of a lake model into these models, or by spatially accounting for the lakes themselves in the models and treating them as water), since Lake Ontario has a great influence on Durham Region's weather and climate patterns (see Section 5.6 for more information on Lake Ontario's climate influence on Durham Region);
- The data was used in other peer-reviewed climatological publications in the Great Lakes Basin and in Ontario;
- The data was derived through dynamical downscaling, to capture the influence of the Great Lakes;
- The data was driven by multiple models and model runs (i.e. takes an ensemble approach) to ensure more robust results were generated;
- The data had a spatial resolution of 25 km by 25 km or finer;
- The data included projections for both climate change scenarios RCP 4.5 and 8.5, and was available up until 2100; and
- There were hourly data available (for the purpose of Durham Region creating their own IDF curves to account for climate change).

The four climate change portals that were identified to examine in further detail included:

- York University's Laboratory of Mathematical Parallel Systems (LAMPS) Climate Change Portal;
- University of Toronto's Peltier Climate Change Ensemble Data;
- University of Wisconsin's Notaro Climate Change Ensemble Data Portal; and
- The second phase of the North American Coordinated Regional Climate Downscaling Experiment (NA-CORDEX) Portal.

For a detailed summary of each of these portals, as well as advantages and limitations for use in this study, see Appendix J. Ultimately, the NA-CORDEX portal was selected to use as part of this analysis based on its ability to meet the majority of selection criteria identified.

The NA-CORDEX data portal was developed by the World Climate Research Programme (WCRP) and provides RCM outputs on historical data and future RCP climate scenarios running from 1950 to 2005 and 2006 to 2100, respectively (Lucas-Picher, Laprise, and Winger, 2017). Mean, maximum, and minimum temperatures as well as total precipitation were downloaded for this project as daily data, averaged over 30-year climate normal periods at a maximum spatial resolution of 0.22° (or 25 km by 25 km).

In addition, hourly precipitation data was also downloaded for Durham Region to be used by stakeholders in the development of Intense-Duration-Frequency (IDF) curves that account for future climates (see Appendix E for a brief summary of how to derive IDF curves). IDF curves are used to demonstrate the characteristics of shorter duration rainfall events and are often used to inform engineering design standards (Simonovic and Peck, 2009).

All climate models on the NA-CORDEX data portal are dynamically downscaled (see section 3.2 for the different downscaling methods). While debate exists around the realism of the RCP 8.5 from a socio-economic perspective (Smith, 2019), it should be noted that since the RCP 4.5 climate scenario is not as frequently used by climate modelers, or in as high of demand as RCP 8.5, there are less climate model runs available online for this climate scenario in the NA-CORDEX ensemble (see Appendix J for more detail around what specific models were used). This report summarizes the results of the RCP 8.5 climate scenario, and includes a summary table for the RCP 4.5 climate scenario in Appendix C. It should be noted that RCP 8.5 and RCP 4.5 should not be directly compared as the RCP 4.5 scenario is less frequently used (i.e., less model runs) and limited in both its access and availability.

To demonstrate exactly how the Great Lakes are represented in the NA-CORDEX portal, Table 6 identifies the seven RCMs used and how they account for or simulate the Great Lakes. As demonstrated, four of the seven RCMs have a one-dimensional lake model included, two use nearby sea surface temperatures (SSTs), and includes the Great Lakes at a higher resolution.

Table 6: The seven RCMs in the NA-CORDEX Climate Model Ensemble, and how they incorporate or simulate the Great Lakes.

RCM	CanRCM4	CRCM5 (OURANOS)	CRCM5 (UQUAM)	HIRHAM5	RCA4	RegCM4	WRF
How Great Lakes were Incorporated into RCM	Incorporated through derived GCM	Uses the one-dimensional FLake model	Uses the one-dimensional FLake model	No lake model; however, it interpolates lapse-rate corrected for SSTs for lakes > 0.5 gridbox	Uses the one-dimensional FLake model	Uses the one-dimensional Hostetler Lake model	Uses nearby ocean SSTs as lake surface temperatures

All data were collected and downloaded as NetCDF files (otherwise known as Network Common Data Form files), which are files able to store large datasets and many layers of data into one file that is easily downloadable. Figure 11 illustrates the spatial scale at which data were obtained. Each point illustrated below represents about 90 years of climate data and are spaced by 25 x 25km.

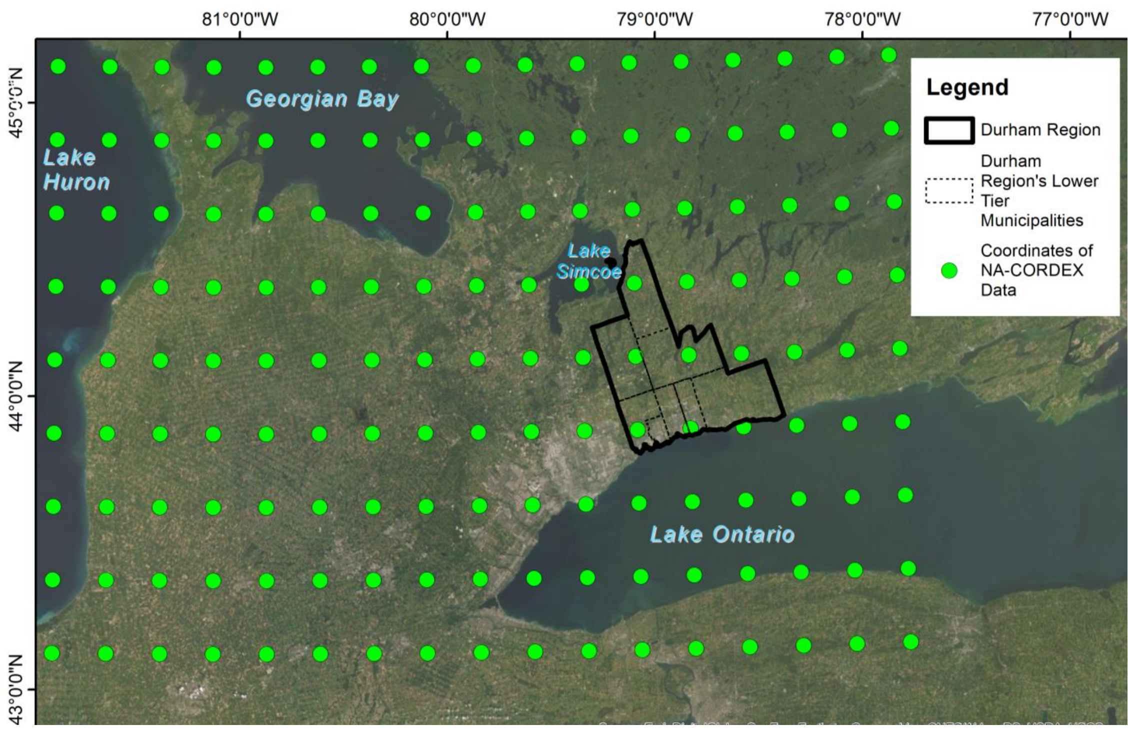


Figure 11: The coordinates (i.e. green dots) that were downloaded from the NA-CORDEX model ensemble, which are found at the bottom right corner of each grid cell.

All data was bias corrected to Durham Region to eliminate any biases or skewed data for variables like topography, surrounding vegetation, human error, and other geographic characteristics. To conduct a bias analysis, historical climate data was analyzed, and a reference period was established to identify climate trends from 1971-2000. Average values for the four main climate parameters (i.e., average temperature, maximum temperature, minimum temperature, and precipitation) were obtained from each climate station. These averages were then compared to the historical climate data developed through the climate models. The difference (or 'delta difference') between the observed values and the historical values from the climate models were then applied to the climate projections to account for the bias adjustment. As previously noted, the data used to complete the delta difference is based on daily climate data that is bias corrected using 30-year averages. The 1971-2000 reference period was chosen as this was encompassed by the NA-CORDEX portal and aligned with Environment and Climate Change Canada's (ECCC) climate normal data for comparison. A climate normal period is an average of the values obtained for specific climate parameters that represent the recent past climate for a given area (e.g., average mean temperature over a 30-year period). To reduce the effects of short-term variability created by weather conditions, a general best practice in climate modeling is to use a 30-year reference period (WMO, 2011). Analyzing a period less than 30 years may not provide enough time to determine the climatic conditions and can be more heavily influenced by short-term variability. While the bias correction process helps to reduce the uncertainty associated with the climate projections, there is no single climate model that can accurately capture all features. All climate models inherently contain limitations. For more information on the limitations of various climate model ensembles, including the NA-CORDEX portal, please refer to OCC's *The State of Climate Modeling in the Great Lakes Basin* (2019) report.

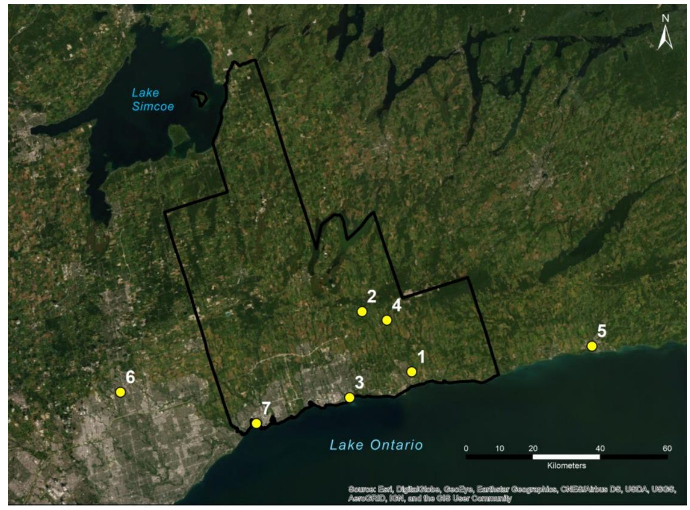


Figure 12: A map of the seven climate data stations that were used to bias correct the NA-CORDEX data to Durham Region's local climate influences.

For the purposes of this report, a total of 7 representative climate stations were used to examine historic climate data within Durham Region and its surrounding vicinity. The list of climate stations can be found in Table 7 below and they are mapped in Figure 12. The climate data from these stations were collected from ECCC's climate normal website, where data for annual mean, maximum, and minimum temperature and annual total precipitation were collected.

Table 7: List of Climate Stations used to observe the historical climate of Durham Region

Station Number	Station Name	Latitude	Longitude	Elevation above Sea Level (m)
1	Bowmanville Mostert	43.92˚N	78.67˚W	99.1
2	Burketon McLaughlin	44.03˚N	78.8˚W	312.4
3	Oshawa WPCP	43.87˚N	78.83˚W	83.8

4	Tyrone	44.02˚N	78.73˚W	205.7
5	Cobourg STP	43.97˚N	78.18˚W	79.2
6	Richmond Hill	43.88˚N	79.45˚W	240
7	Frenchman's Bay	43.82 ˚N	79.08˚W	76.2

It is extremely important to keep in mind that since values have only been bias-corrected to Durham Region for this report, when interpreting the maps, only values in Durham Region are considered to be bias-corrected. Municipalities outside of Durham Region have been included to demonstrate the variability in climate across the broader region, but the values for areas outside of the Region have not been bias-corrected and these areas have been marked with black dots (e.g., see Figure 17 in in Section 5). Appendix J provides additional step-by-step instructions on how bias correction was conducted, and the model performance results.

Following bias correction, climate parameters were identified and defined. A climate parameter is the measurement used to analyze how much a given climate condition (e.g., air temperature) has changed or will change in the future (Harris et al., 2016). For example, parameters for measuring air temperature may include the number of frost days, the number of summer days and tropical nights, growing season length, etc. Certain climate parameters can be derived through direct calculations (e.g., mean temperature), while others are derived through proxies (e.g., growing degree days). When determining the climate parameters that will be analyzed, it is important to involve stakeholders from across the organization(s) (e.g., agriculture, health, public works and engineering staff, etc.) to determine the most appropriate climate parameters.

The goal of this study is to provide valuable climate data within Durham Region under future climate change and a step-by-step methodology that can be replicated by other municipalities within Ontario's Greenbelt and across the province. Therefore, it is of utmost importance that any climate parameters provided for this study are clearly defined. However, it is of interest to determine sub-annual indices of climate, ones that capture seasonal changes and extremes of precipitation and temperature, which are not captured by annual measurements. Other parameters of interest, such as growing degree days (GDD), act as agricultural indicators where the minimum temperature values act as thresholds (e.g., the growth of canola (4°C) and forage crops (5°C), corn and beans (10°C) and for insect and pest risk (15°C)) (Climate Atlas of Canada, 2019).

A few climate parameters typically used in climate change analyses are provided below in Table 9.
Climate parameters were chosen for Durham Region based on engagement with the NECCC group, the previous SENES study, data availability, and the robustness of data. Certain parameters (e.g., snow, wind) were not included as a part of this analysis due to the limited data available and robustness. The full list of the climate parameters undertaken in this study and their technical definitions are provided under Appendix B, and a sample of results for a few climate parameters for the RCP 8.5 scenario are summarized in Table 8.

Table 8: Examples of Climate Parameters

Parameter	Definition	Why you should consider including this parameter in your study?
Mean Air Temperature	The mean temperature in degrees Celsius (°C) is defined as the average of the maximum and minimum temperature at a location for a specified time interval	The temperature range we expect within a season or year is a very important aspect of climate. Changes in average and extreme temperatures can dramatically affect our everyday lives (e.g., our health and our cooling needs) as well as a wide range of planning and policy decisions. The average highest temperature is an environmental indicator with many applications in agriculture, engineering, health, energy management, recreation, etc.
Total Precipitation	The total amount of precipitation in millimeters (mm) such as rain, drizzle, freezing rain, snow (in liquid equivalent), and hail, observed at the location during a specified time interval.	Precipitation patterns are critical for many important issues, including water availability and quality, crop production, electricity generation, wildfire suppression, snow accumulation, seasonal and flash-flooding, and short- and long-term drought risk.
Freeze-Thaw Cycles	A simple count of days when the air temperature fluctuates between freezing and non-freezing temperatures (i.e. minimum temperatures are equal to or below -1˚C and maximum temperatures are above 0˚C). Under these conditions, it is likely that some water at the surface is both liquid and ice at some point during the 24-hour period.	Freeze-thaw cycles can have major impacts on infrastructure. Water expands when it freezes, so the freezing, melting and re-freezing of water can over time cause significant damage to roadways, sidewalks, and other outdoor structures. Potholes that form during the spring, or during mid-winter melts, are good examples of the damage caused by this process.

Once all the climate parameters were produced, results were summarized in map forms, summary tables and in descriptions. Section 5 provides an overview of the results of this study.

5. Results: Climate Trends in Durham Region

The following section highlights the results of the climate analysis for Durham Region. Table 10 provides a summary of all the annual averages and climate model ensemble means for each climate parameter analyzed in this study for all climate periods for the RCP 8.5 climate scenario (refer to Appendix C for the RCP 4.5 summary table). Confidence levels for each of the groups of climate parameters have also been provided. The remaining subsections describe the patterns and trends in the NA-CORDEX data for the RCP 8.5 scenario and highlight some of the major implications Durham Region might face in the future. For a comparison between the SENES Study and the 2019 Durham Climate Modeling Project, as well as other studies (e.g., York Region Climate Trends Report), refer to Appendix D. The maps provided in Section 5.2 and 5.3 are bias corrected for Durham Region only but have incorporated surrounding areas to visualize the impacts of climate change on Durham Region and the variability in climate trends at a broader scale that would not otherwise be reflected if only Durham Region was displayed.

5.1 Confidence Levels

Climate projections are designed to demonstrate how the climate will respond to a selected RCP scenario over a longer period of time (e.g., over a 30-year climate normal period) (Climate Change in Australia, 2015). While projections cannot guarantee a particular outcome, it is expected that the climate projections will show a trend if a particular RCP scenario is followed (e.g., RCP 8.5). Therefore, because climate projections are not expected to provide exact predictions around future climate, confidence levels are used to determine the likelihood of change in climate that is expected under a given RCP scenario and it demonstrates the author's assessment of its reliability (ibid). Confidence levels can be based on several factors including a comparison between historical observations and future climate, the level of agreement between the different climate model simulations, as well as consideration for the physical processes that are driving the change in climate (ibid). Confidence language is provided by the IPCC and is characterized into terms such as 'very likely', 'likely', 'virtually certain'. As new IPCC reports are released, higher quality observations and improvements in models are made, allowing for better predictions. More robust climate change projections use multiple, consistent, independent sources of high-quality information (IPCC, 2012; OCC, 2016). The following table demonstrates the confidence terminology used by the IPCC (2014).

Table 9: IPCC Confidence Terminology. Source: IPCC, 2014 and OCC, 2016.

Term	Likelihood of the Outcome
Virtually certain	99 – 100% probability
Very likely	90 – 100% probability
Likely	66 – 100% probability
About as likely as not	33 – 66% probability
Unlikely	0 – 33% probability
Very unlikely	0 – 10% probability
Exceptionally unlikely	0 – 1% probability

Figure 13 demonstrates the relationship between the strength of evidence for a given climate parameter and the level of agreement within the scientific community. The confidence levels provided in Table 9 align with the confidence scale outlined below.

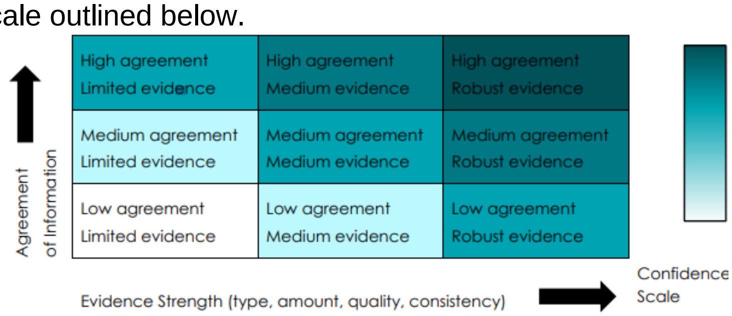


Figure 13: Relationship between strength of evidence and level of agreement to determine confidence levels. Source: OCC, 2016; IPCC,2014.

Table 10: A summary of all climate parameters for each climate period (i.e., 2020s, 2050s, and 2080s) analyzed in the study for the RCP 8.5 climate scenarios.

Climate Parameter	Definition	Baseline Value (1971-2000)	Short-Term (2020s) (2011-2040)			Medium Term (2050s) (2041-2070)			Long Term (2080s) (2071-2100)			Confidence Level
			10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	
Mean Temperature (˚C)												
Mean Annual Temperature	Average annual air temperature over a time period.	**7.1**	6.5	**8.6**	11.4	8.3	**10.1**	13.0	10.2	**12.08**	15.3	
Mean Winter Temperature	Average winter (D-J-F) air temperature over a time period.	**-3.0**	-4.4	**-1.4**	1.8	-3.1	**-0.0**	3.0	-1.4	**1.89**	4.7	
Mean Spring Temperature	Average spring (M-A-M) air temperature over a time period.	**3.7**	3.5	**4.9**	6.4	4.9	**6.2**	7.9	6.1	**7.86**	10.1	high evidence high agreement
Mean Summer Temperature	Average summer (J-J-A) air temperature over a time period.	**17.1**	15.9	**18.7**	21.7	17.2	**20.3**	23.6	18.6	**22.32**	26.2	
Mean Fall Temperature	Average fall (S-O-N) air temperature over a time period.	**10.1**	9.0	**11.6**	14.8	10.8	**13.1**	16.4	13.1	**15.02**	18.9	
Maximum Temperature (˚C)												
Annual Mean Maximum Daily Air Temperature	Average maximum annual air temperature over a time period.	**11.6**	10.8	**12.9**	16.1	12.5	**14.5**	17.6	14.1	**16.4**	19.9	
Winter Mean Maximum Daily Air Temperature	Average maximum winter (D-J-F) air temperature over a time period.	**2.1**	1.2	**3.4**	6.1	0.9	**4.4**	7.1	3.5	**6.3**	8.8	
Spring Mean Maximum Daily Air Temperature	Average spring (M-A-M) air temperature over a time period.	**8.3**	7.8	**9.5**	11.2	9.1	**10.6**	12.5	10.5	**12.3**	14.6	high evidence high agreement
Summer Mean Maximum Daily Air Temperature	Average maximum summer (J-J-A) air temperature over a time period.	**21.4**	19.5	**23.0**	25.8	20.9	**24.4**	27.7	22.2	**26.6**	30.2	
Fall Mean Maximum Daily Air Temperature	Average maximum fall (S-O-N) air temperature over a time period.	**14.5**	13.6	**16.0**	19.1	14.1	**17.2**	20.6	16.6	**19.3**	23.0	
Minimum Temperature (˚C)												
Annual Mean Minimum Daily Air Temperature	Average minimum annual air temperature over a time period.	**2.5**	1.8	**4.1**	6.7	3.7	**5.7**	8.4	5.9	**7.9**	10.8	
Winter Mean Minimum Daily Air Temperature	Average minimum winter (D-J-F) air temperature over a time period.	**-8.0**	-8.4	**-5.8**	-2.7	-7.1	**-4.5**	-0.7	-6.4	**-2.6**	0.5	high evidence high agreement
Spring Mean Minimum Daily Air Temperature	Average minimum (M-A-M) air temperature over a time period.	**-1.0**	-1.3	**0.4**	2.1	0.5	**2.0**	4.2	1.6	**3.5**	5.8	

Climate Parameter	Definition	Baseline Value (1971-2000)	Short-Term (2020s) (2011-2040)			Medium Term (2050s) (2041-2070)			Long Term (2080s) (2071-2100)			Confidence Level
			10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	
Summer Mean Minimum Daily Air Temperature	Average minimum summer (J-J-A) air temperature over a time period.	**12.8**	*11.9*	**14.1**	*16.6*	*13.4*	**16.1**	*19.0*	*14.8*	**18.0**	*21.3*	high evidence high agreement
Fall Mean Minimum Daily Air Temperature	Average minimum fall (S-O-N) air temperature over a time period.	**5.7**	*4.8*	**7.4**	*10.7*	*6.2*	**8.9**	*11.3*	*8.6*	**10.7**	*14.8*	
Extreme Heat (days per year)												
Days Above 35˚C	Total number of days of the year with maximum temperatures above 35˚C.	**0.2**	*0.0*	**1.2**	*3.3*	*0.1*	**4.0**	*12.3*	*0.2*	**10.8**	*32.2*	high evidence high agreement
Days Above 30˚C	Total number of days of the year with maximum temperatures above 30˚C.	**7.6**	*1.4*	**15.9**	*38.9*	*4.7*	**27.4**	*63.0*	*10.6*	**46.9**	*97.1*	
Days Above 25˚C	Total number of days of the year with maximum temperatures above 25˚C.	**42.1**	*23.9*	**59.2**	*100.6*	*39.1*	**78.2**	*120.4*	*61.0*	**100.3**	*144.0*	
Tropical Nights	Total number of days of the year with minimum temperatures above 20˚C.	**100.6**	*92.1*	**117.0**	*147.8*	*109.0*	**132.0**	*161.5*	*121.8*	**148.1**	*181.4*	
Extreme Cold (days per year)												
Days Below -20˚C	Total number of days of the year with minimum temperatures below -20˚C.	**8.6**	*0.3*	**4.2**	*4.0*	*0.0*	**2.3**	*2.2*	*0.0*	**0.5**	*0.3*	high evidence high agreement
Days Below -15˚C	Total number of days of the year with minimum temperatures below -15˚C.	**22.7**	*2.0*	**13.1**	*19.8*	*0.7*	**7.9**	*14.3*	*0.0*	**2.6**	*4.7*	
Days Below -10˚C	Total number of days of the year with minimum temperatures below -10˚C.	**49.0**	*11.9*	**34.4**	*53.2*	*6.6*	**23.5**	*43.8*	*0.7*	**11.3**	*25.4*	
Days Below -5˚C	Total number of days of the year with minimum temperatures below -5˚C.	**89.0**	*43.4*	**71.6**	*98.8*	*31.1*	**57.0**	*84.1*	*12.4*	**37.0**	*62.0*	
Days Below 0˚C (Freezing Days)	Total number of days of the year with minimum temperatures below 0˚C.	**146.8**	*100.2*	**129.1**	*152.9*	*84.3*	**114.0**	*136.6*	*58.4*	**91.1**	*118.4*	
Total Precipitation (mm per time period)												
Total Average Annual Precipitation (mm)	Total amount of precipitation throughout the year falling on wet days (where precipitation is greater than 0.2 mm).	**952.4**	*944.3*	**1075.0**	*1194.5*	*948.6*	**1117.5**	*1242.4*	*1052.5*	**1231.6**	*1419.5*	high evidence medium agreement
Total Average Winter Precipitation (mm)	Total amount of precipitation throughout the winter (D-J-F) falling on wet days (where precipitation is greater than 0.2 mm).	**228.3**	*191.3*	**250.1**	*300.3*	*209.9*	**252.4**	*298.9*	*232.1*	**276.6**	*331.4*	

Climate Parameter	Definition	Baseline Value (1971-2000)	Short-Term (2020s) (2011-2040)			Medium Term (2050s) (2041-2070)			Long Term (2080s) (2071-2100)			Confidence Level
			10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	
Total Average Spring Precipitation (mm)	Total amount of precipitation throughout the spring (M-A-M) falling on wet days (where precipitation is greater than 0.2 mm).	**217.3**	*187.0*	**233.0**	*269.2*	*211.5*	**251.2**	*293.4*	*247.0*	**277.6**	*309.9*	high evidence medium agreement
Total Average Summer Precipitation (mm)	Total amount of precipitation throughout the summer (J-J-A) falling on wet days (where precipitation is greater than 0.2 mm).	**231.0**	*193.0*	**239.7**	*274.9*	*177.2*	**247.4**	*291.7*	*159.7*	**282.4**	*308.8*	
Total Average Fall Precipitation (mm)	Total amount of precipitation throughout the fall (S-O-N) falling on wet days (where precipitation is greater than 0.2 mm).	**275.8**	*253.5*	**285.5**	*320.8*	*249.5*	**297.2**	*340.9*	*272.8*	**311.9**	*346.4*	
Extreme Precipitation												
Max Precipitation in 1 day (mm)	Annual 1-day maximum precipitation accumulation.	**33.8**	*34.7*	**37.9**	*40.8*	*36.4*	**40.4**	*43.9*	*40.8*	**44.0**	*46.5*	high evidence medium agreement
Max Precipitation in 3 day (mm)	Annual 3-day maximum precipitation accumulation.	**54.9**	*53.8*	**58.0**	*62.2*	*55.4*	**61.8**	*68.0*	*61.6*	**67.7**	*73.9*	
Extreme Precipitation Days (days/year)	The annual average amount of days where precipitation exceeds 25 mm.	**3.2**	*3.1*	**4.1**	*4.9*	*3.8*	**5.0**	*6.0*	*5.0*	**6.6**	*8.3*	
Annual Simple Daily Intensity Index (SDII) (mm/day)	The average amount of precipitation which occurs per wet day (more than 0.2 mm/day) on average in a year.	**2.6**	*2.6*	**2.9**	*3.3*	*2.6*	**3.1**	*3.4*	*2.9*	**3.4**	*3.9*	
Winter SDII (mm/day)	The average amount of precipitation which occurs per wet day (more than 0.2 mm/day) on average in a year.	**2.5**	*2.1*	**2.7**	*3.3*	*2.3*	**2.8**	*3.3*	*2.5*	**3.0**	*3.6*	
Spring SDII (mm/day)	The average amount of precipitation which occurs per wet day (more than 0.2 mm/day) on average in a year.	**2.4**	*2.1*	**2.6**	*3.0*	*2.3*	**2.8**	*3.2*	*2.7*	**3.0**	*3.4*	
Summer SDII (mm/day)	The average amount of precipitation which occurs per wet day (more than 0.2 mm/day) on average in a year.	**2.5**	*2.1*	**2.6**	*3.0*	*1.9*	**2.7**	*3.2*	*1.8*	**3.1**	*3.4*	
Fall SDII (mm/day)	The average amount of precipitation which occurs per wet day (more than 0.2 mm/day) on average in a year.	**3.0**	*2.8*	**3.1**	*3.5*	*2.7*	**3.3**	*3.7*	*3.0*	**3.4**	*3.8*	
95th Percentile Precipitation (mm)	The percent of the total annual precipitation when precipitation is greater or equal to the 95th percentile.	**36.1**	*34.1*	**36.2**	*38.4*	*35.0*	**37.0**	*39.7*	*34.2*	**37.2**	*40.2*	
99th Percentile Precipitation (mm)	The percent of the total annual precipitation when precipitation is greater or equal to the 99th percentile.	**11.2**	*10.4*	**11.1**	*11.7*	*10.6*	**11.3**	*12.2*	*10.2*	**11.4**	*12.7*	

Climate Parameter	Definition	Baseline Value (1971-2000)	Short-Term (2020s) (2011-2040)			Medium Term (2050s) (2041-2070)			Long Term (2080s) (2071-2100)			Confidence Level
			10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	
Dry Days (days per year)												
Total Annual (days)	Total annual number of days where precipitation was less than 0.2 mm.	**145.3**	113.4	140.4	155.8	*116.6*	**144.2**	*167.4*	*113.8*	**138.7**	*155*	low evidence high agreement
Maximum Total Consecutive Dry Days (days)	The number of consecutive days where annual total number of days where precipitation was less than 0.2 mm.	**18.2**	13	16.7	21	*13.5*	**18.3**	*23.5*	*13.5*	**17.8**	*21*	
Growing Season												
Growing Season Start Date (day of year)	The first day after 5 days of consecutive minimum temperatures above 5˚C was reached.	**14-May**	21-Apr	**1-May**	16-May	15-Apr	**30-Apr**	12-May	*2-Apr*	**19-Apr**	*4-May*	high evidence high agreement
Growing Season End Date (day of year)	The first day after 5 days of consecutive maximum temperatures below 5˚C was reached.	**24-Oct**	24-Oct	**31-Oct**	15-Nov	30-Oct	**9-Nov**	23-Nov	*9-Nov*	**18-Nov**	*30-Nov*	
Growing Season Length (days/year)	Annual number of days after having 5 consecutive days above 5˚C and before having five consecutive days below 5˚C.	**162 days**	162 days	**183 days**	208 days	176 days	**193 days**	220 days	*192 days*	**213 days**	*239 days*	
Cold Snap Events (years/climate normal period)	The number of years where there was more than one growing season (i.e. indicating a cold snap period).	**5.8 years**	3 years	**6.9 years**	11 years	4 years	**7.2 years**	14 years	*3.5 years*	**9 years**	*14 years*	
Agricultural Variables												
Corn Heat Units (CHUs)	Number of CHUs, indicating ideal climates for corn to fully mature (very generally, at least 2200 CHUs are required to mature most varieties of corn).	**3194**	*2959*	**3591**	*4516*	*3554*	**4196**	*5036*	*4007*	**4798**	*5847*	high evidence high agreement
Growing Degree Days (days/year)	Number of degree days > 0˚C per year.	**3198**	*3026*	**3579**	*4365*	*3471*	**4022**	*4850*	*3845*	**4495**	*5650*	
Canola Growing Degree Days (days/year)	Number of degree days > 4˚C per year.	**2236**	*2067*	**2547**	*3223*	*2439*	**2943**	*3652*	*2757*	**3403**	*4349*	
Forage Crops Growing Degree Days (days/ year)	Number of degree days > 5˚C per year.	**2024**	*1868*	**2319**	*2969*	*2205*	**2702**	*3383*	*2377*	**3084**	*4055*	

Climate Parameter	Definition	Baseline Value (1971-2000)	Short-Term (2020s) (2011-2040)			Medium Term (2050s) (2041-2070)			Long Term (2080s) (2071-2100)			Confidence Level
			10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	
Corn and Bean Growing Degree Days (days/year)	Number of degree days > 10˚C per year.	**1119**	*985*	**1338**	*1855*	*1200*	**1659**	*2230*	*1359*	**1974**	*2271*	high evidence high agreement
Days at Risk of Presence of Pests (days/year)	Number of degree days > 15˚C per year.	**463**	*320*	**617**	*992*	*488*	**858**	*1271*	*623*	**1078**	*1734*	
Freeze-Thaw Cycles and Ice Potential												
Freeze-Thaw Cycles (cycles/year)	Number of freeze thaw cycles, where the minimum temperature is equal to or below -1°C and the maximum temperature is above 0°C.	**80**	*62*	**78**	*84*	*53*	**68**	*81*	*43*	**59**	*76*	low evidence high agreement
Ice Potential (days/year)	Number of days where minimum temperature is greater than -2˚C and maximum temperature is under 2˚C.	**29**	*14*	**24**	*32*	*12*	**22**	*29*	*4*	**15**	*23*	

5.2 Temperature and Extreme Heat and Cold

Based on the maps below (Figures 14 and 15), **mean annual temperatures** within Durham Region are expected to increase every climate period up until the end of the century, for the RCP 8.5 climate scenario. Most of Durham Region will experience average annual temperatures increase from the 4-6°C historic climate period temperatures to about 12-14°C by 2100. This will result in a 2°C increase in average annual temperature for each climate period. The most significant impact will be for communities along the shores of Lake Ontario, where average annual temperatures are expected to rise even further to 14-16°C by 2100.

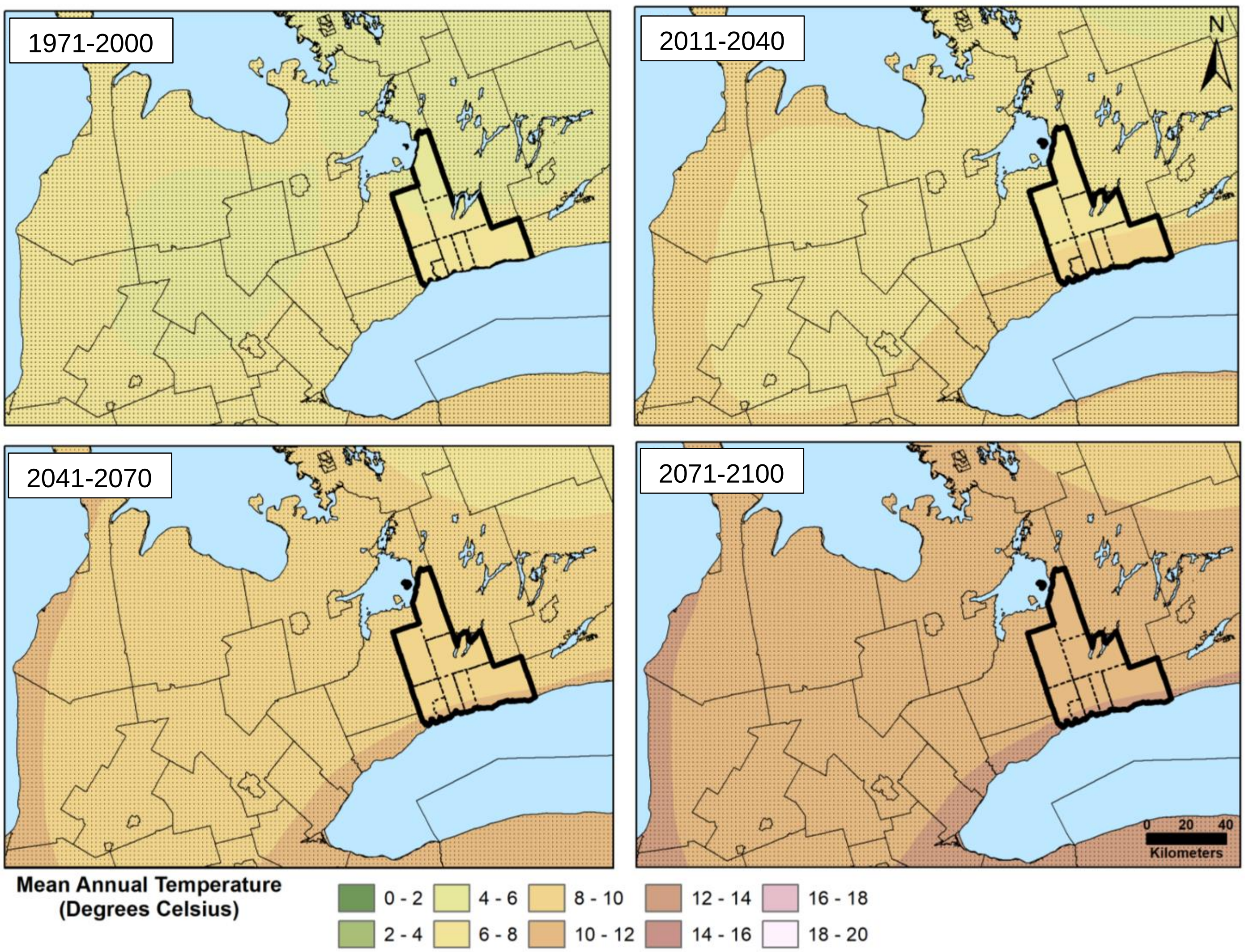


Figure 14: Mean Annual Temperature for a) 1971-2000, b) 2011-2040, c) 2041-2070, and d) 2071-2100 for the RCP 8.5 climate scenario.

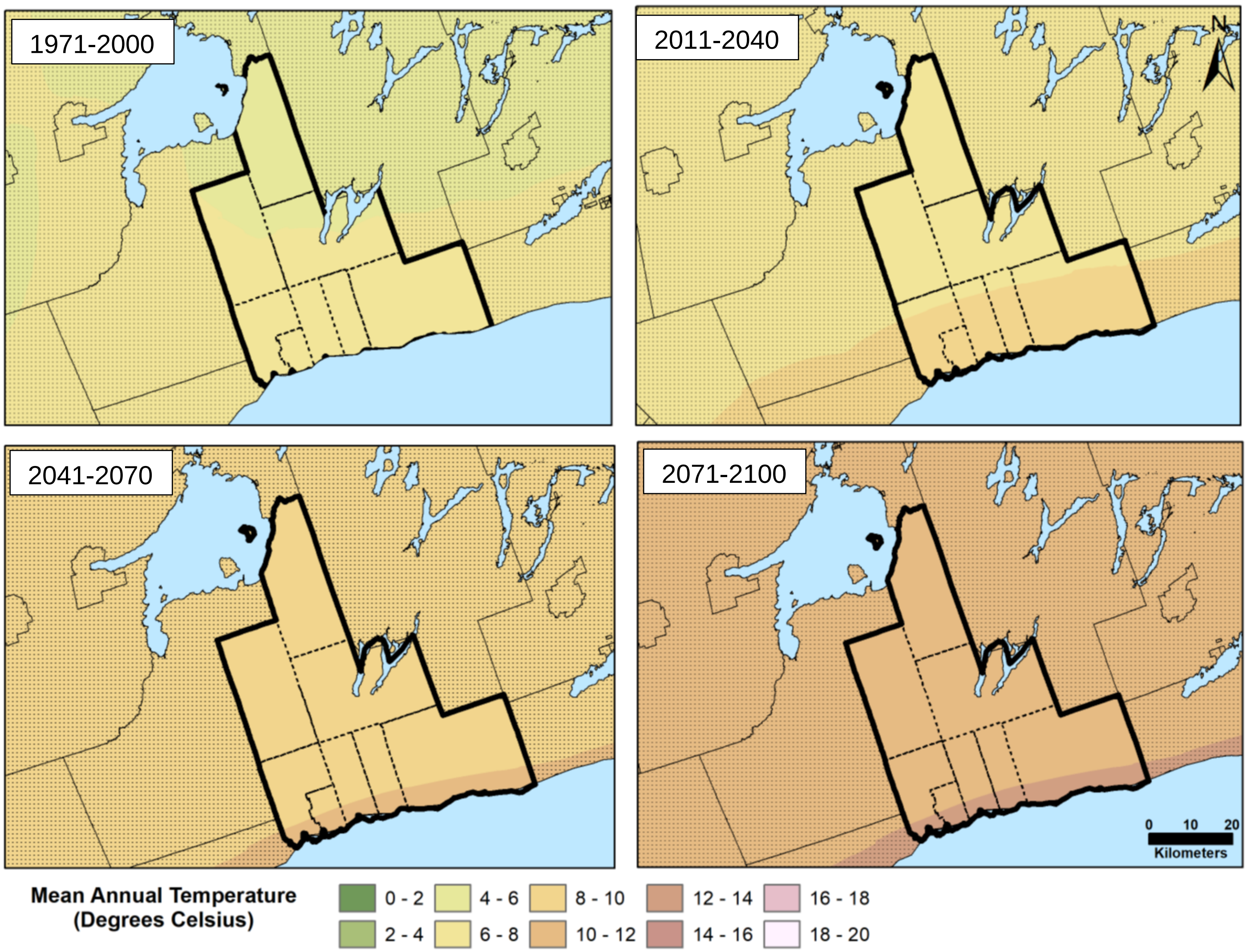


Figure 15: A closer look at the Mean Annual Temperature for a) 1971-2000, b) 2011-2040, c) 2041-2070, and d) 2071-2100 for the RCP 8.5 climate scenario.

Maximum annual temperatures are expected to increase throughout Durham to varying degrees in the RCP 8.5 climate scenario (Figures 16 and 17). Maximum annual temperatures in most parts of Durham will reach 12-14°C by 2040, with a portion of the north showing an increase of 10-12°C. The 2041-2070 climate period demonstrates that most of Durham Region (including the northern portion) will see maximum annual temperatures between 12-14°C, while parts of western Durham will experience higher maximum annual temperatures between 14-16°C. For the 2071-2100 climate period, most of Durham Region will see maximum annual temperatures between 14-16°C, with the small western portion of Durham seeing maximum annual temperatures between 16-18°C.

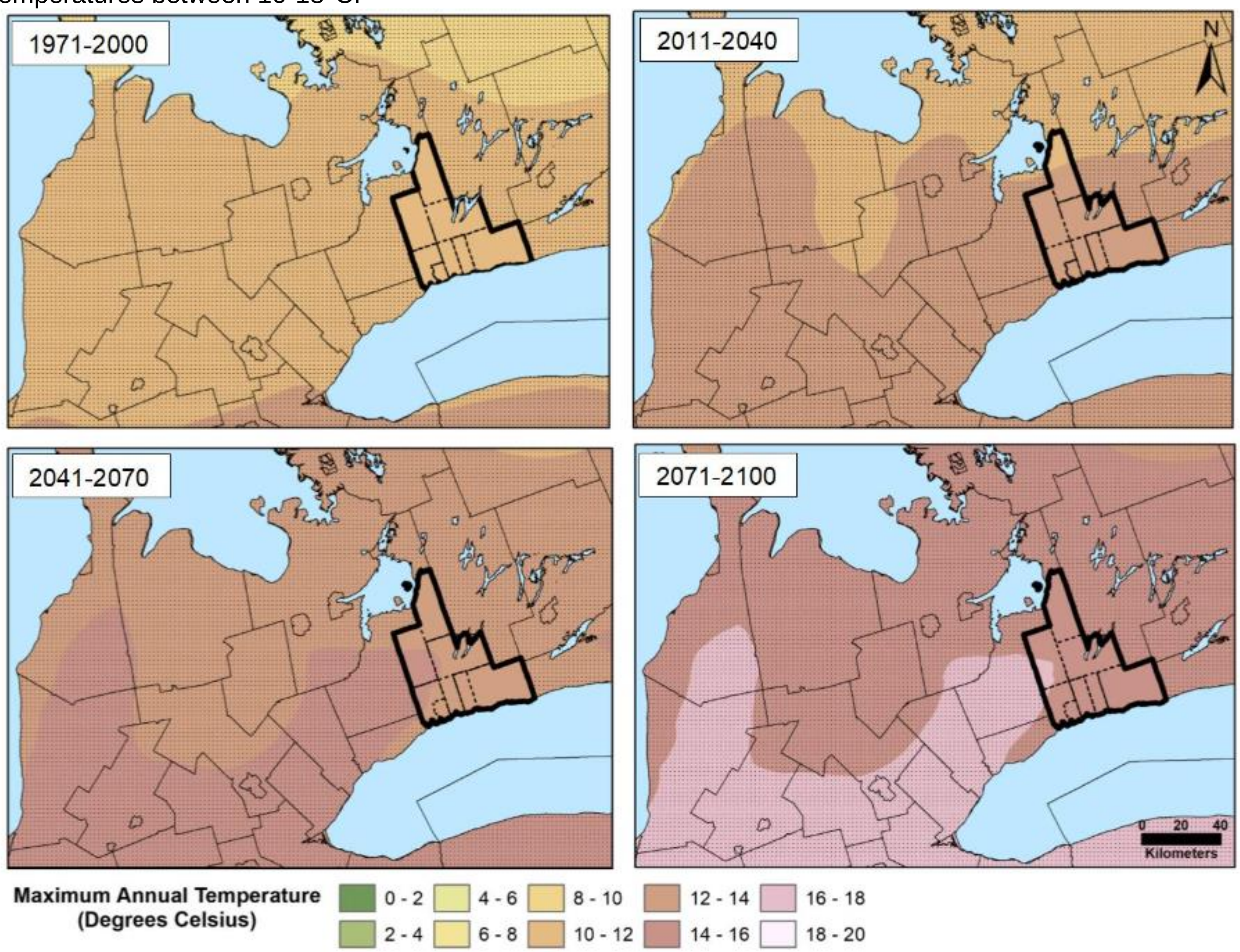


Figure 16: Maximum Annual Temperature for a) 1971-2000, b) 2011-2040, c) 2041-2070, and d) 2071-2100 for the RCP 8.5 climate scenario.

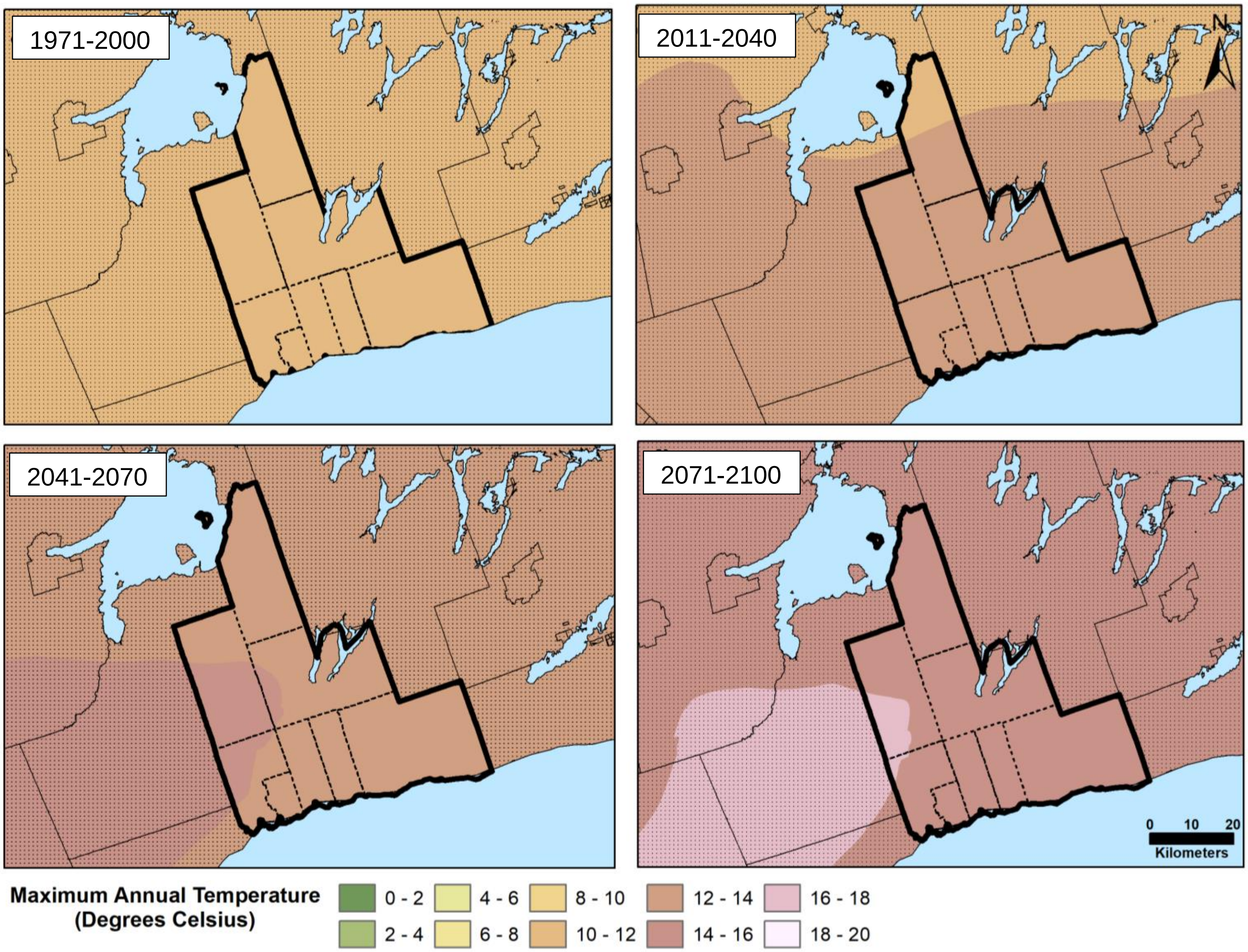


Figure 17: A closer look at Maximum Annual Temperature for a) 1971-2000, b) 2011-2040, c) 2041-2070, and d) 2071-2100 for the RCP 8.5 climate scenario.

Minimum annual daily temperatures will also increase from the historic climate period in the RCP 8.5 climate scenario (Figures 18 and 18). It is projected that annual mean minimum daily air temperatures will increase from 0-2°C from 1971-2000, to 2-4°C by 2040. The minimum annual temperatures for the southern portion of Durham will also increase to 4-6°C. By 2070, all of Durham Region is projected to see minimum annual temperatures around 6-8°C, with communities along Lake Ontario showing slightly higher temperatures. This distinction is further depicted in the 2071-2100 climate period where the northern portion of Durham shows minimum annual temperatures around 6-8°C and the southern portion of Durham along the lake shows minimum annual temperatures around 8-10°C.

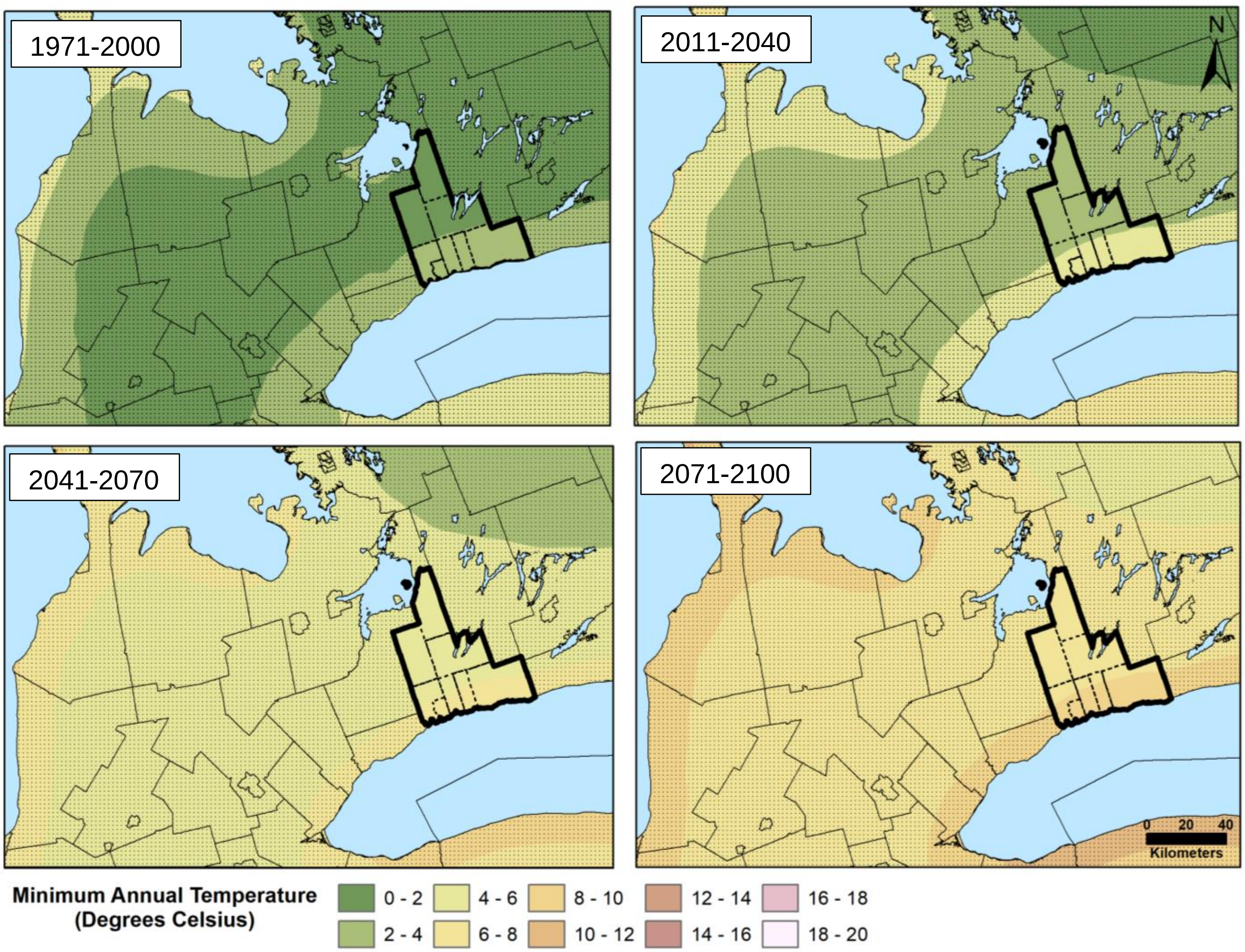


Figure 18: Minimum Annual Temperature for a) 1971-2000, b) 2011-2040, c) 2041-2070, and d) 2071-2100 for the RCP 8.5 climate scenario.

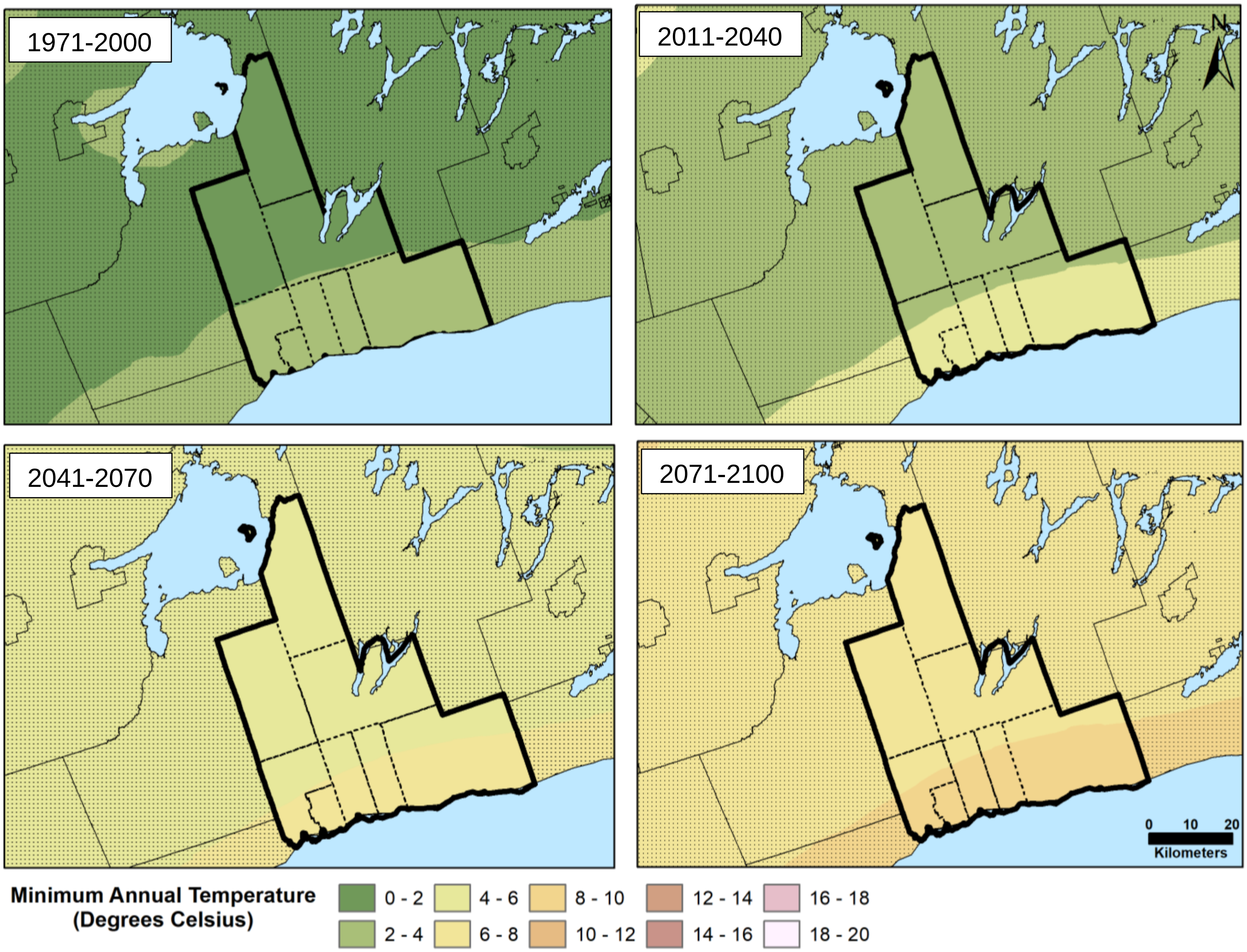


Figure 19: A closer look at Minimum Annual Temperature for a) 1971-2000, b) 2011-2040, c) 2041-2070, and d) 2071-2100 for the RCP 8.5 climate scenario.

5.3 Precipitation and Extreme Precipitation

5.3.1. Total Annual Precipitation

The following three images (Figure 20) depict the **percent change in precipitation** from the historic climate period (1971-2000). By 2011-2040, the west of Durham Region is projected to see a change in precipitation between 10-15% from the historic climate period, and the east will experience about a 15-20% increase. By 2041-2070, the west of Durham Region is expected to see about an 20-25% increase in precipitation from the baseline, and the east will likely experience a 25-30% increase. By the end of 2100, the southern portion of Durham will see a 30-35% increase in precipitation from the historic climate period, compared to the rest of the northern portion of Durham, which will see a 35-40% increase in precipitation.

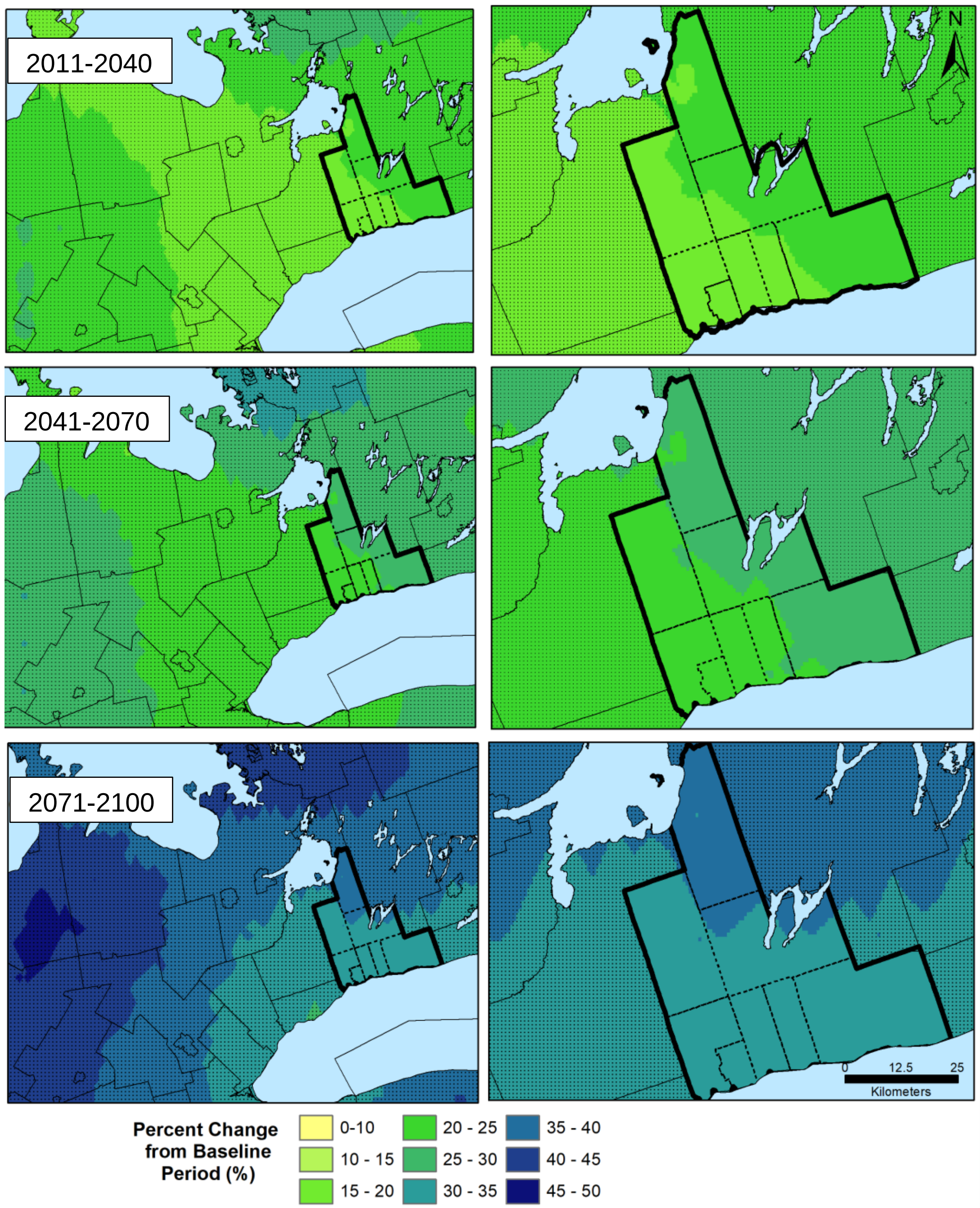


Figure 20: Percent Change in Precipitation from the Baseline Period (1971-2000) for a) 2011-2040, b) 2041-2070, and around c) 2071-2100 for the RCP 8.5 climate scenario.

5.3.2. Extreme Precipitation

In Figure 21, it is evident that in the RCP 8.5 climate scenario, extreme precipitation is expected to increase in Durham Region in the future. The maximum amount of precipitation falling in one day is expected to increase by about 30% (from about 34 mm to 44 mm), while the maximum amount of precipitation falling in three days is expected to increase by 23% (from 55 mm to 68 mm). It is also expected that Durham Region will experience about twice as more extreme precipitation days (i.e., days where precipitation is greater than 25 mm in one day) by the end of the century (e.g., the historical baseline experienced about 3 days while the end of the century will have about 6 days). These great amounts of precipitation falling in a short period of time can pose threats to Durham Region's infrastructure (e.g., flooding of roads and buildings), and can pose threats to its residents (e.g., through the negative impact on water quality, flooding of basements, etc.).

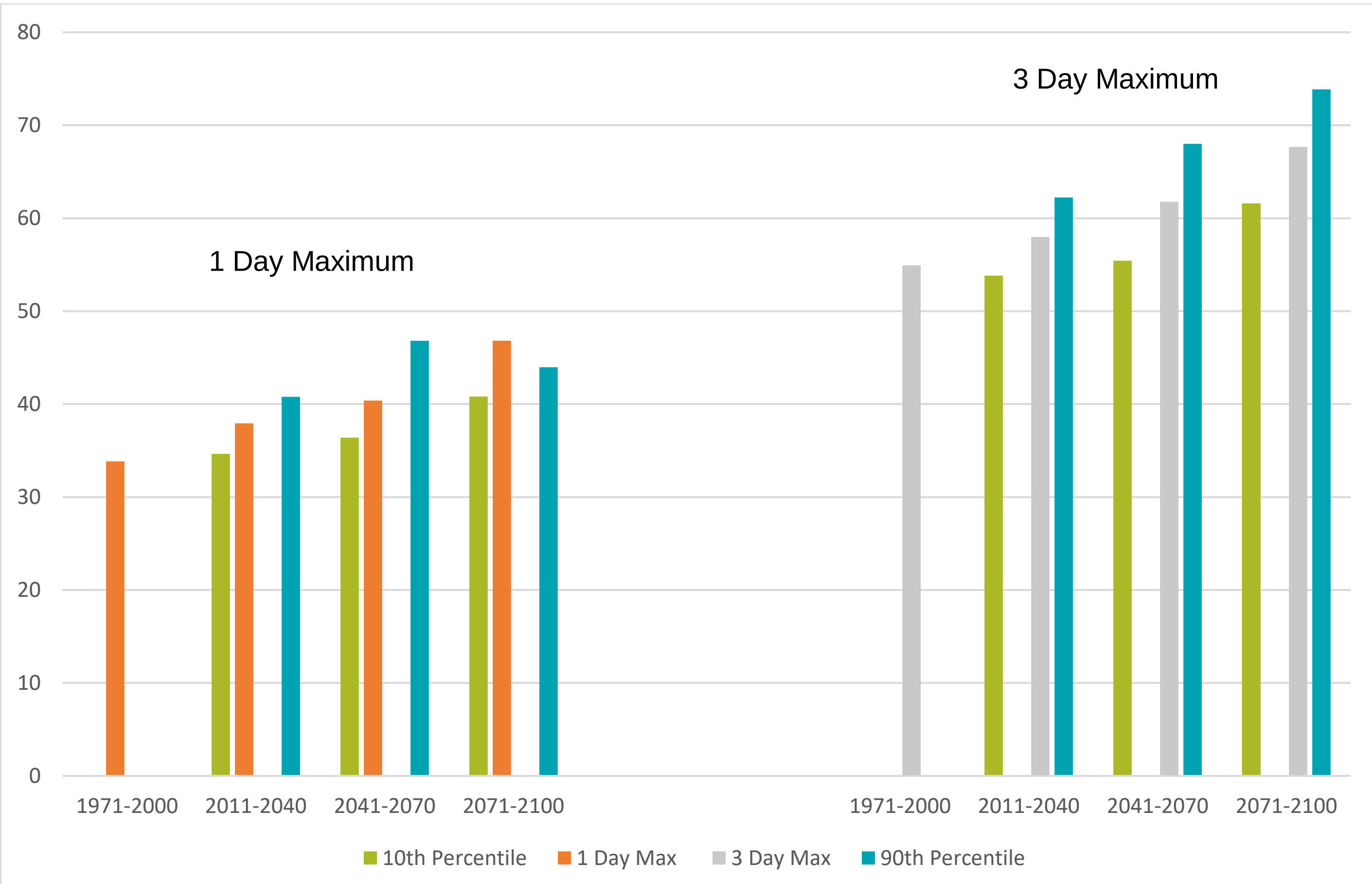


Figure 21: The annual maximum amount of precipitation falling in one (orange) and three (turquoise) days for each climate period under the RCP 8.5 climate scenario. Values are also displayed for the 10th and 90th Percentiles.

While extreme precipitation is expected to occur, it is also expected that Durham Region will also experience more precipitation per day in every season (Figure 22), with spring expected to increase the most, by 27% by the end of the century for the RCP 8.5 climate scenario. All other seasons will also expect to see an increase, with winter expected to increase by 21%, the summer will increase by 22%, and the fall will increase by 13%. Due to the increase in air temperatures as well as the increase in precipitation, it can be expected that winters in Durham Region will experience more rain and more groundwater recharge throughout the year.

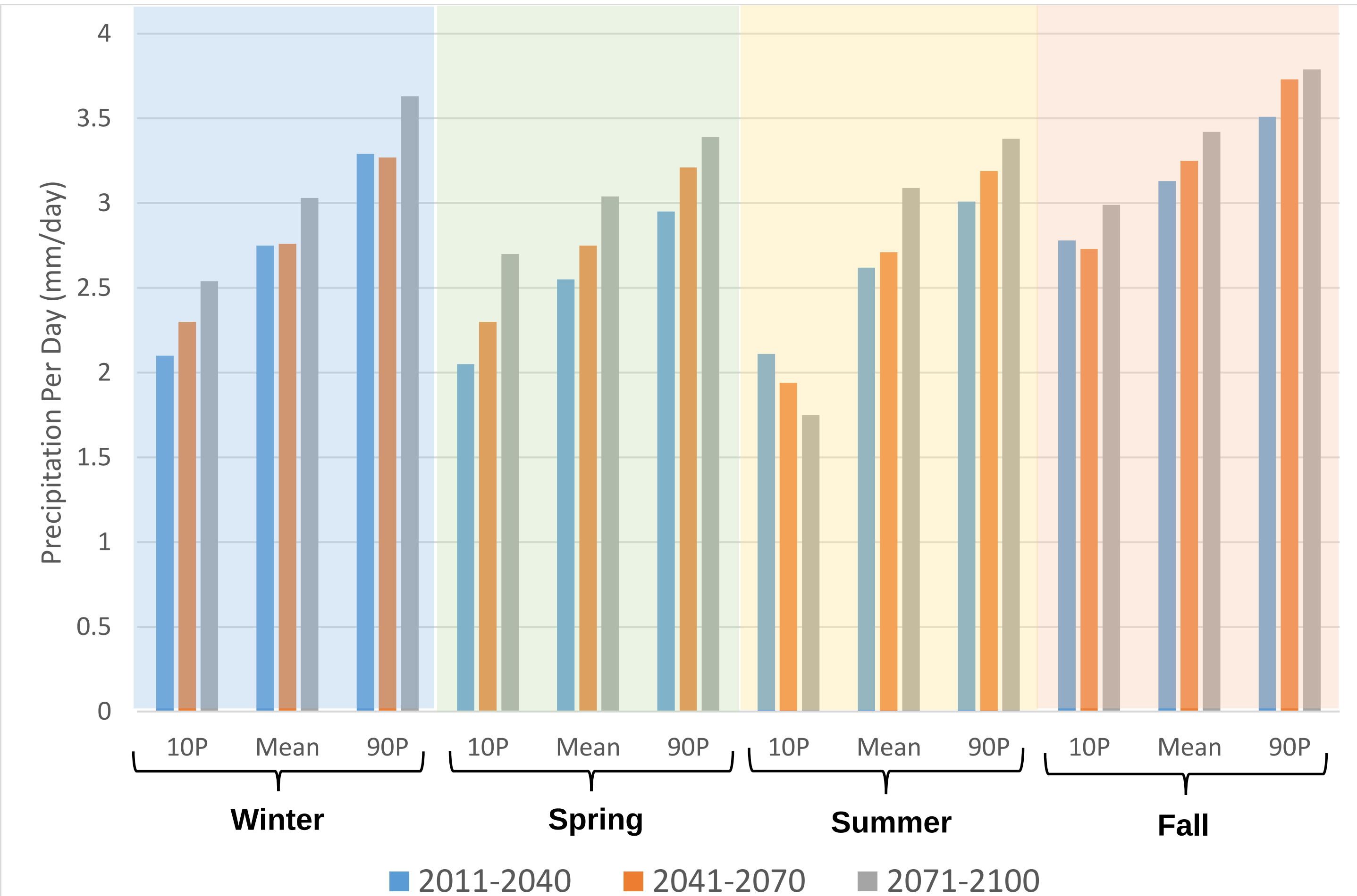


Figure 22: The average winter, spring, summer, and fall simple daily intensity indexes (SDII) (total amount of precipitation in millimeters per wet day) for each climate period under the RCP 8.5 climate scenario. Values are displayed for the 10th and 90th Percentiles (10P and 90P, respectively), and for the ensemble means.

5.4 Agricultural Parameters

5.4.1. Dry Conditions

It is expected that dry conditions will become more variable over time across Durham Region. If we look at the total annual amount of dry days, this number is expected to decrease overall from the baseline period to the end of the century. It is expected that the amount of dry days will decrease by 6 days by the end of the century (decreasing from about 145 days to 139 days). However, this decrease is not linear, as the near term (2011-2040) will experience about 4 days less of dry days, whereas the medium term (2041-2070) is expected to only experience one day less of dry days than the baseline period. Similarly, the maximum number of consecutive dry days is expected to fluctuate throughout the century. Durham Region has recently experienced a maximum of 18 consecutive dry days, and by the end of the century, it is expected that this number will remain relatively the same.

From a seasonal perspective, it is anticipated that increased heat in the summer season, coupled with similar conditions that are already being experienced, will result in drier conditions. For instance, if another prolonged dry period of 18 days occurs in the mid-century, conditions and impacts may be worse than historically experienced across ecosystems in Durham Region. This is because there may be increased evaporation of moisture, and dry conditions be exacerbated by cascading climate conditions (e.g., a hotter summer, with similar prolonged consecutive dry period could reduce flows through evaporation faster thereby impacting aquatic species through habitat loss and/or agricultural production due to heat stress).

5.4.2. Growing Season

The results from this analysis showed that the total increase from 1971-2000 to 2071-2100 in the growing season in Durham Region will be of about seven weeks (51 days) in the RCP 8.5. The growing season will likely begin in mid-April (~April 19th) by the end of the century and will likely end in mid-November (~November 18th), compared to the historical average start date of May 14th and end date of October 24th. However, due to the increased temperatures in the winter seasons in the future, there may be more chances for plant mortality when there are periods of frost once the growing season has occurred. In this study, the end date for the growing seasons was queried to be past September 1st. However, the models demonstrated growing season start and end dates between January and April; therefore, these indicate cold snaps, which can have significant impacts to crops in the future. As temperature continues to warm in the future, Durham Region can expect more cold snap events (i.e., the number of years where there was more than one growing season), about 3 more years with cold snap periods, which may be difficult to plan for, and may cause significant economic damage.

5.4.3. Corn Heat Units (CHUs) and Growing Degree Days (GDDs)

The amount of Corn Heat Units and Growing Degree Days is expected to increase over time, for each variable analyzed (i.e., canola, forage crop, corn and bean, and pests) (Figure 22). CHUs are expected to increase by 50% by the end of century, GDDs above 0°C are expected to increase by 40%, GDDs for canola and for forage crops are expected to increase by 52% and corn and bean GDDs are expected to increase by 76% by the end of the century. This is due to the increases in air temperature that were summarized in the previous section. Therefore, by the end of the century, Durham Region can expect to have more ideal days for growing corn, canola, forage crops, and beans. However, with an increase in temperature comes the risk of having more pests. The amount of GDDs for pest occurrence is expected to increase two-fold by the end of the century. Climate change introduces uncertainty in the spread of pests and pathogen risk from its marginal ranges through changes in temperature and moisture regimes Expected higher temperatures would result in less cold stress and longer growing seasons for more temperate climate pests and conversely more heat stress from more northerly species. Moisture also affects pest risk with drought risk expected to increase plant stresses, suppressing host defense responses. Conversely increased precipitation may reduce the occurrence of certain pests or pathogens which require water or humidity for development (Sutherst et al., 2011). In addition, the CO_2 fertilization effect, whereby increasing levels of carbon dioxide lead to increased rates of photosynthesis, can also impact the growth of agriculture under climate change (Terrer et al., 2016).

While these figures demonstrate opportunities for the agricultural sector in Durham Region, it is important to realize that there are temperature and precipitation thresholds for these crops, where they will not be able to survive under certain climate conditions. For example, the North Dakota Agricultural Weather Network has determined the upper temperature threshold for corn is about 30°C. Therefore, with the predicted 47-day increase in the amount of days above 30°C, there could be a significant impact to corn crops in the future (see Figure 23). It is also important to recognize the increased potential for cold snap periods, with earlier growing seasons, there is more risk for a cold snap to cause plant mortality.

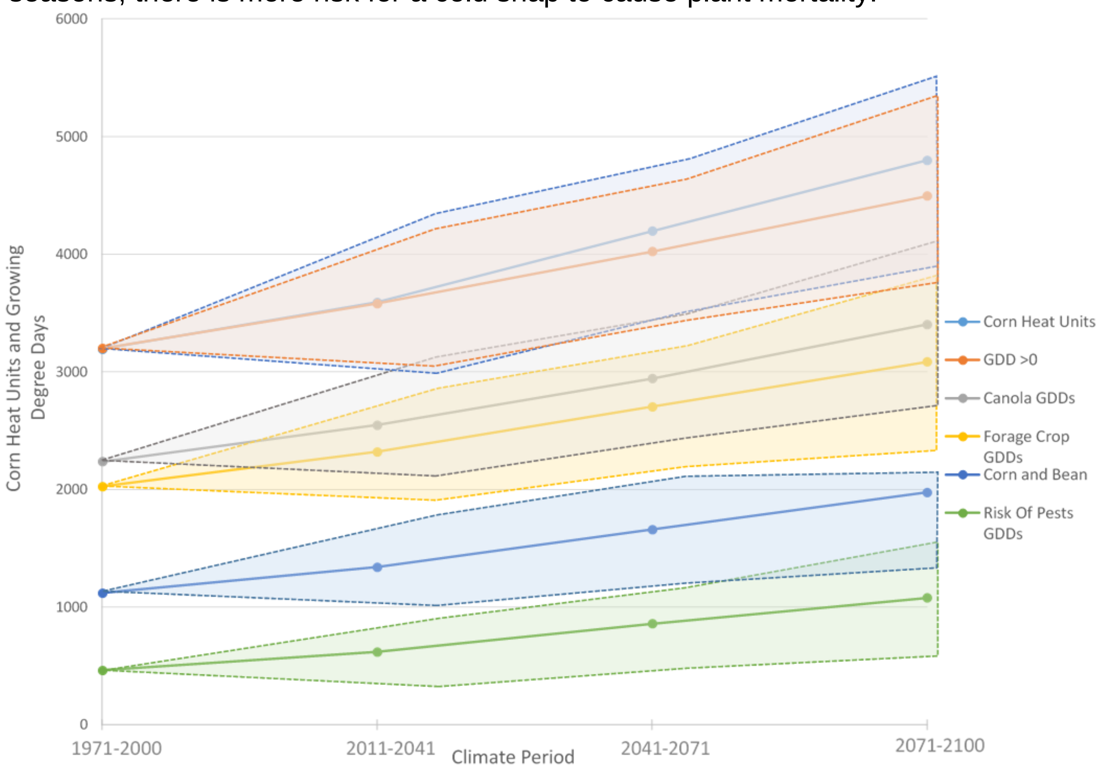


Figure 23: The projected number of Corn Heat Units and Growing Degree Days for various crops for each climate period under the RCP 8.5 climate scenario. Dotted lines demonstrate the 10th and 90th percentiles, shading between the dotted lines represent the range in climate model results, and solid lines demonstrate the ensemble means.

For example, in some areas in the Great Lakes Basin in 2012, a mild winter and spring was followed by a frost in April that destroyed many fruit trees in the area. For a full list of climate parameters examined, see Table 10.

5.5 Ice and Freeze-Thaw Cycles

As expected, with increase temperatures in Durham Region, it is expected that there will be less freeze-thaw cycles and less occurrence of ice. The number of freeze-thaw cycles is expected to gradually decrease from the baseline period to the near term (2011-2040), which can be expected, as the winter temperatures will likely fall between 0 and -1°C, in the short term. Then, as temperatures will continue to rise, freeze-thaw cycles are expected to decline rapidly in the medium and long term in the RCP 8.5 climate scenario (Figure 24). It should be noted that freeze-thaw cycles are based purely on air temperature and does not take into account soil temperature. For example, in November, if the air temperature falls below 0°C, then you are not likely to have a freeze-thaw event.

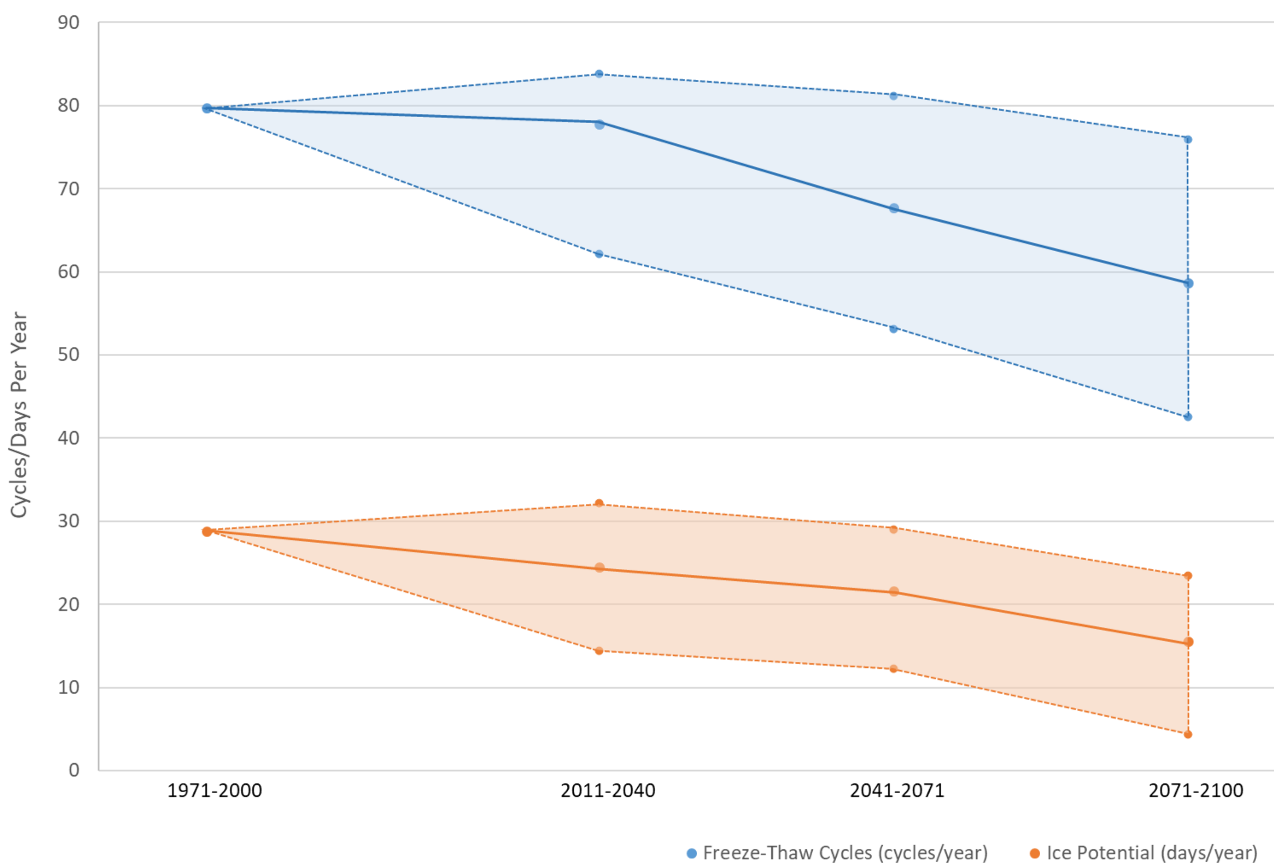


Figure 24: Projected number of freeze-thaw cycles per year and ice potential days per year for each climate period up until 2100 in the RCP 8.5 climate scenario. Dotted lines demonstrate the 10th and 90th percentiles, shading between the dotted lines represent the range in climate model results, and solid lines demonstrate the ensemble means.

5.6 Local Climate Considerations

There are many local influences that may not fully be captured by the climate modeling that has been conducted, as regional climate models cannot incorporate all local features that may influence climate. This section discusses some of the local influences from Lake Simcoe, the Oak Ridges Moraine, as well as the physical-dynamic influences of Lake Ontario, and their impacts on Durham Region's climate.

5.6.1 Lake Ontario

The Great Lakes play a major role in influencing regional climate. They modify air masses passing over them by altering moisture and heat content in the atmosphere (Changnon and Jones, 1972). The Great Lakes also retain a great amount of heat, which supplies the lower atmosphere with moisture through evaporation (when the lakes are not frozen). This in turn influences the air temperatures and the amount of precipitation around the Great Lakes in all seasons. For example, in late autumn to early winter, evaporation from the Great Lakes enhances cloud cover and precipitation over and downwind of the Lakes, while in the summer months, there is greater atmospheric stability leading to diminished cloud cover and rainfall (Scott and Huff, 1997).

During winter, lake-effects depend greatly on the role of ice cover. Over the last several decades, ice cover on the Great Lakes has declined significantly (Mason et al, 2016). For Lake Ontario, a shift to fewer days per year with ice cover *on average* occurred in the mid-1980s. Reduced winter ice cover leads to increased lake evaporation (i.e., more moisture is transported to the atmosphere) and increased lake-effect precipitation. Historically, winter lake-effect precipitation has fallen in the form of snow. However, as air temperatures continue to rise due to climate change, there will be a transition to more lake-effect rain in the future.

Durham Region, located on the northern shore of Lake Ontario, is outside of the major lake-effect zones, but it can receive lake-effect precipitation from Lake Ontario when winds are from the south or when lake-effects from Lake Huron extend into the area. Historically, Durham Region has experienced intense and high-impact lake-effect weather events that have created challenges for communities such as major winter snow and ice storms. In addition to lake-effect weather, Great Lakes coastal communities like those in Durham Region face unique coastal challenges such as extreme ice cover, lake level conditions, storm surge events, and coastal erosion.

When it comes to planning for the future, practitioners need to know how lake effects, lake levels, and other regional climate conditions (e.g., air temperatures, precipitation patterns, etc.) are projected to change. Climate models vary greatly in their simulation quality of the Great Lakes and lake-land-atmosphere interactions. Many of the NA-CORDEX models used in this report employ simple 1-dimensional (1D) lake models (Table 6). Although these 1D lake models have helped to improve research across the Great Lakes Basin, many limitations still remain including the inability to capture all components of the Great Lakes accurately (e.g., lake surface temperature, ice coverage, and thermal stratification) (Delaney and Milner, 2019; Xue et al., 2017). Work is actively being undertaken by climate modelers to research and refine lake models, including the development of 3D lake models. Ultimately, however, no model is perfect and so it is important that when reviewing climate projections, more focus should be placed on the overall climate trends, rather than exact values in time.

Practitioners needing lake level information face additional challenges because a second set of simulations (using hydrological models and high-quality future projections of precipitation as input, among other variables) are required to simulate future lake levels. Future lake level simulations vary greatly – some models suggest lake level declines, while others suggest rises. This is in part due to differences in future precipitation projections. Practitioners should consider multiple scenarios of future lake levels including both highs and lows as well as more severe extremes and greater variability.

5.6.2 Lake Simcoe

In Southern Ontario, Lake Simcoe is considered one of the largest inland lakes (North et al., 2013). The watershed is roughly 3,400 km^2 in size and supports approximately 8,620km of watercourses (LSRCA, 2020). Parts of Durham Region fall within the Lake Simcoe watershed, including Uxbridge, Brock and Scugog. Over the years, the Lake Simcoe watershed has experienced rapid population growth, with a current population of slightly more than 400,000 people (a 50% increase from the 1980's) (ibid). During most winters, Lake Simcoe freezes over completely, with mixing occurring in the spring and fall (Stainsby et al., 2011). Due to the size of Lake Simcoe, lake-effect precipitation is also experienced in and around the area, including Durham Region.

Over the last several decades, Lake Simcoe has experienced significant changes, including the timing of its thermal stratification and increase in lake temperatures (LSRCA, 2020). Through ice record data, ice cover on Lake Simcoe has also been decreasing and in recent years, open water has been maintained throughout the year (ibid). This in turn leads to increased evaporation that fuels increased cloud cover and precipitation. As described in the *LSRCA Climate Change Adaptation Strategy* (2020), warmer winters will result in greater lake-effect precipitation during the winter than is already experienced. With climate change models projecting an increase in temperatures, it is expected that an increase in lake-effect precipitation will occur during the winter, with a larger portion of that precipitation falling as rain or freezing rain (LSRCA, 2020; Notaro et al., 2015).

Additionally, future climate change impacts on Lake Simcoe itself can further exacerbate the impacts of climate change on Durham Region. For example, changes to water quality and quantity in Lake Simcoe due to climate change will have impacts on natural systems and shorelines. As demonstrated through the Lake Simcoe Climate Change Adaptation Strategy (2017), the watershed has experienced a 1.6˚C rise in annual air temperatures between 1980 and 2012, leading to increases in water temperature, which in turn have led to impacts on surrounding areas such as ecosystem degradation (ibid). For example, these impacts can be seen over the last few decades with the rise in phosphorous loading in the Lake.

In order to support informed and science-based decision-making, practitioners will need to understand how lake-effect precipitation, lake temperatures, lake levels and other regional climate conditions (e.g., air temperature, precipitation patterns, etc.) are expected to change. Although Lake Simcoe is one of the largest inland lakes in Ontario, climate models (including RCMs used in this study) have difficulty capturing Lake Simcoe's regional impacts to climate with the Lake being represented as a land surface. When inland lakes are isolated as land surfaces, climate models do not capture how they modify atmospheric conditions (e.g., lake-effect precipitation, energy exchanges between lakes and lower atmospheric boundaries, evaporation, convective storms, etc.) (Delaney and Milner, 2019). Other lakes such as Lake Scugog are also not captured within climate models (including RCMs used in this study). Therefore, while Lake Simcoe is captured within the climate projections, limitations exist around the extent of its influence on local climate.

5.6.3 Oak Ridges Moraine

The Oak Ridges Moraine (ORM) is one of Ontario's most significant landforms. It is located north of and parallel to Lake Ontario and is approximately 160km in length, extending from the Trent River in the east to the Niagara Escarpment in the west (Ontario, 2017). It spans across the middle of Durham Region, covering most of Durham Region's local municipalities. The ORM divides the watersheds draining south into western Lake Ontario from those draining north into Georgian Bay, Lake Simcoe and the Trent River system (ibid). It is also the headwaters to more than 30 rivers and is known for its rolling hills, forests, meadows, wetlands, ponds, river valleys and lakes, which provide important habitat for many plants and animals (City of Richmond Hill, 2020). The ORM also stores a large volume of groundwater that serves as an important source of drinking water for many people in Ontario and contributes to both local and regional groundwater flows (ibid).

Within Durham Region, the elevated topography of the ORM makes it one of the dominant local-scale drivers of spatial variations in weather and climate, along with Lake Ontario and Lake Simcoe (OCC, 2016). For example, the elevated topography of the ORM in the northern portion of Durham results in cooler temperatures in and around the area. Meanwhile, areas in the south, which feature higher rates of urbanization combined with the urban heat island effect (UHI), generally experience warmer temperatures (OCC, 2016).

Additionally, future climate change impacts on the ORM itself can further exacerbate the impacts of climate change on Durham Region. Example impacts of climate change on the ORM include effects on surface water quality and stream temperature increases (CAMC, 2015). It is expected that changes to water resources, and plant and animal habitat within the ORM due to climate change will inherently influence the landscape in Durham Region. For example, areas with cooler water may feature marginal habitats, resulting in an increased risk to species due to climate change and land use changes (CAMC, 2015). Protecting and enhancing the ORM through adaptive strategies (e.g., creating ecological linkages with surrounding areas) will play a significant role in ensuring that the impacts of climate change are not further exacerbated.

For practitioners, it is important to note that the ORM is also captured as a homogeneous landform in most climate models. Therefore, certain features within the ORM (e.g., streams) are not simulated by climate models due to their fine geographic scale. However, the impact of these features *on* local climate is small, so their omission from climate models does not significantly alter future projections of temperature and precipitation. If information about how climate change may impact these features in the future is desired, the use of additional models may be helpful. For example, ecosystem models and hydrological models can incorporate more intricate features within ORM to project how stream temperatures or wetlands may respond to climate changes in the future.

5.6.4 Strategies for Overcoming Limitations Related to Lake Ontario, Lake Simcoe, Oak Ridges Moraine, and other Features

The following is a list of recommendations for practitioners on ways to overcome the limitations associated with the three features, and potentially others, as discussed above:

- Integrate climate projection information with other sources of information, such as historical climate trends, expert guidance, and local experiences. This hybrid model-experience integration process can be used to develop possible future scenarios that lend themselves well for community planning where future weather and climate impacts are examined
- Connect with climate change experts and translators to better understand what is considered 'best' available climate data and where they are available
- Work with climate change experts and translators to build capacity among staff and stakeholders to improve understanding of the limitations or caveats of climate data, and how climate data and information can be applied
- Undertake additional modeling (e.g., hydrological modeling) to better understand the impacts of climate change on features such as Lake Simcoe and ORM
- Acknowledge that all climate models are imperfect. No model can capture real-world processes perfectly; assumptions and biases are inherently a part of the climate modeling process

6 Conclusion and Next Steps

This report was intended to provide Durham Region with a summary of the climate change trends that have been observed historically and will likely be observed in the future, and to provide municipalities within Ontario's Greenbelt with the necessary data and guidance to undertake their own climate modeling analyses. This guidance document is also intended to increase consistency around climate modeling within Ontario, to bridge the gap between cross-jurisdictional modeling and planning.

This climate analysis uses data from the NA-CORDEX ensemble model and bias correcting this to thirty years of historical data in Durham Region. This ensemble is composed of 16 RCM model runs, which incorporates the feedback from the Great Lakes into its projections. The raw data was then bias corrected to best represent the local climate influences of Durham Region.

This analysis demonstrates that Durham Region will likely experience a wetter and warmer climate, with a longer growing season of about seven weeks, and with substantial increases in growing degree days for specific crops by the end of the century. However, these conditions are also favourable to the presence of pests invading the Region and its crops in the future. The Region is also expected to experience more extreme weather and will experience higher intensity storms with greater amounts of precipitation in all seasons. This may impose threats to the health of communities within the Region, it's natural systems, infrastructure, agriculture, economy and services.

While these impacts can be helpful for municipal planning practices, it is important to realize that all climate modeling comes with varying degrees of uncertainty. Uncertainty is caused by variation in the climate between locations from year-to-year, by downscaling GCMs to RCMs, by projecting further and further into the future, and by the uncertainty associated with future emissions scenarios and future available technologies.

The ensemble climate modeling will be a useful tool in Durham Region for years to come. It will serve as the foundational data set for many climate change adaptation projects and serve to move the DCCAP implementation forward. The following is a list of possible projects Durham Region may wish to undertake as part of future projects to advance climate change initiatives. These include:

- **The Creation of IDF Curves:** IDF curves, are used to plan for municipal infrastructure such as the sizing of culverts, stormwater ponds, roads, etc. Additional information will be required to determine what additional projected storm information should be used for designing storm structures. As a critical next step, the DCCAP Flooding Working Group should be consulted in the development of new IDF curves using the updated climate modeling projections.

- **Updating the Urban Heat Island and Floodplain Mapping:** While these new climate projections do not differ drastically from the SENES Study, the projections may trigger the need to update existing urban heat island mapping as well as floodplain mapping to account for the changes.

- **A User Interface:** The development of an online web application (e.g., R Shiny) would provide Durham Region with an easy-to-use interface for data handling. Those who may find the methods difficult to replicate would be able to use the web app and easily access the data.

- **Public Education:** These new climate projections may trigger a need for public engagement and a public version of this document. While the climate projections do not differ drastically from the SENES Study, the Region may wish to engage the public to showcase action on climate change science in the Region. A summary technical report that can be taken to Council and is easily understandable may also be developed.

- **Building Staff Capacity:** As noted above, the updated climate projections will help to inform future climate change projects. However, municipal and conservation authority staff will require training on the use and application of the modeling. At the time of this report, the DCCAP Natural Environment Working Group secured funding for the development of a 3-module training project, focused on natural environment applications. Further education and training for other DCCAP Working Groups may require a day-long event or individualized training sessions at each of the municipalities and conservation authorities.

- **Quantitative Vulnerability Analysis:** The DCCAP Working Groups will be able to use these climate projections to identify and map out highly vulnerable areas are within the Region and target their adaptation efforts to those areas (e.g., a vulnerability assessment of natural systems)

- **Co-benefit projects:** The updated climate projections in this report may stimulate the creation of projects that have multiple cross sectoral benefits and that can address both adaptation and mitigation.

While this project focuses on Durham Region, the approach is transferable to other municipalities in Ontario. The following is a set of considerations for municipalities in Ontario to consider when undertaking climate modeling exercises.

- Leverage existing data and tools, where possible (e.g., Regional or City data, online portals and tools, etc.). There are many climate data portals available and the landscape is evolving rapidly, making it easier for municipalities to access climate data.

- Seek input from experts to understand what is considered ‘best’ available climate data and where it is available.

- Involve broad stakeholders, practitioners and academic expertise where possible for validation and review.

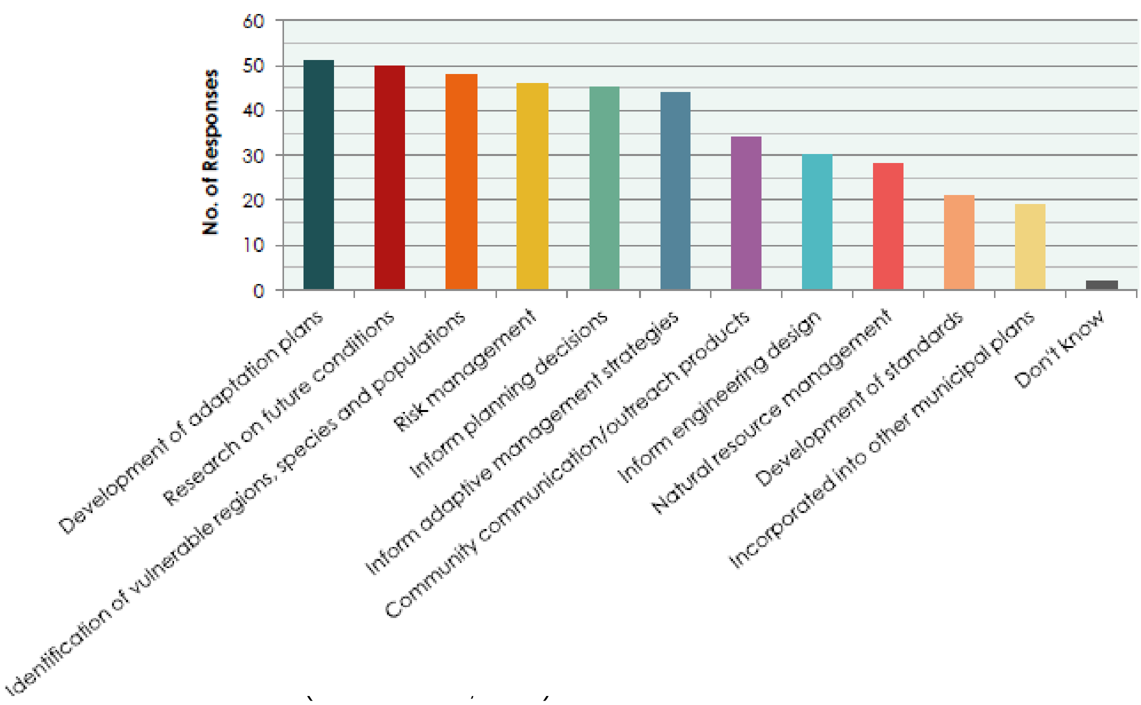
- Acknowledge that gaps in science exist and certain parameters may not be accounted for.

- Build staff capacity through training on the use and application of climate modeling to understand the limitations or caveats of climate data use.

Appendix A: Use of Climate Change Modeling in Ontario and Durham Region

As previously noted, a consistent approach to undertaking climate modeling in Ontario does not currently exist; however, the recognition of climate change as a risk to the environment as well as economy, human health, infrastructure, etc. is increasingly on the rise. Many municipalities use qualitative information or climate models statistically derived from a global climate models (e.g., Climate Atlas or Canadian Centre for Climate Services) to help inform their policies and plans. Other municipalities have also developed local climate trends reports (e.g., *Climate Trends and Future Projections in Peel Region*), to incorporate more localized information into their planning processes.

The level of understanding related to climate modeling and climate modeling varies and will depend on the user. There are numerous types of users who typically access or require the provision of climate data. These can range from individuals interested in basic summaries of trends to those requiring advanced decision support tools for specific sectoral-based studies or applications. It is important to note as well, that these users are affiliated across a range of different types of organizations, such as government agencies, academic institutions, non-profits, private sector consultants, industry and watershed management agencies. A survey conducted in 2015 across the Province of Ontario and across a broader network of climate adaptation practitioners (a total of 114 respondents) provides some insight into the types of these users, where they access climate information in Ontario, and what this information is being used for (Morand et al., 2015). Figure A1 illustrates the applications for which users are most interested in accessing future climate projections.



ents) in

As illustrated above, the practical uses of climate information are diverse. Morand et al. (2015) identifies that the three most common purposes tend to be related to (1) the development of adaptation-related plans, (2) research projects related to future conditions, and (3) identifying vulnerable populations, species and regions. These types of initiatives and projects frequently involve collaboration between those requiring the climate data and those developing and producing the climate data. The following section provides detailed information on municipal initiatives in Ontario that have stemmed from climate modeling.

- **Modeling Exercises:** Modeling exercises are typically used to examine climate projections for a specific area and further influence other work such as climate change adaptation plans. For example, York Region's *Historical and Future Climate Trends in York Region*, City of Toronto's SENES Study, and the Region of Waterloo's *Localized Climate Projections for Waterloo Region*.

- **Adaptation Plans:** Adaptation plans in Ontario have been in existence since the early 2000's. The local modeling projection data helps to identify specific areas and/or actions that are needed. Examples of adaptation plans include: City of Toronto *Resiliency Strategy*, Waterloo Region *Community Climate Adaptation Plan*, and the Thunder Bay *Climate Adaptation Strategy*.

- **Research:** Many ministries and provincial associations have analyzed climate projection data to accompany climate change research. These include resources for policy makers and planners, infrastructure, health, and more. For example, Infrastructure Canada's *Climate Resilient Buildings and Core Public Infrastructure Initiative*.

- **Provincial Programming:** Several provincial ministries have also included climate modeling or climate change policies within their programming, including the ministries of: Transportation, Environment, Conservation and Parks, Natural Resources and Forestry, Health and Long-Term Care, and Metrolinx. For example, the Ministry of Natural Resources and Forestry's *Climate Change Projections for Ontario***.**

In addition, Durham Region has also been a leader in undertaking initiatives to reduce the impacts of climate change. Table A1 summarizes all the initiatives Durham Region has already undertaken thus far to plan for climate change.

Table A1: Summary of initiatives that have been undertaken in Durham Region to plan for the anticipated impacts of climate change.

Organization	Date	Initiative
Region of Durham	2016	Durham Community Climate Adaptation Plan
Region of Durham	2019	Envision Durham – Climate Change and Sustainability Discussion Paper
Region of Durham	2018	Integrating Climate Change Considerations into Plans and Policies in Durham Region
Region of Durham	2019	Agriculture Sector Climate Adaptation Strategy
Region of Durham	2018	Keeping Our Cool: Managing Urban Heat Islands in Durham Region

Organization	Date	Initiative
Town of Ajax	2019	Ajax Climate Risk and Resiliency Plan
Town of Ajax	2017	Great Lakes Climate Adaptation Project
Municipality of Clarington	2019	Corporate Climate Change Risk Assessment
Municipality of Clarington	In development	Climate Change Action Plan
Town of Whitby	In development	Urban Flooding Study
City of Oshawa	In development	Municipal Natural Assets Initiative – Oshawa Creek Pilot
Toronto and Region Conservation Authority	2007	Meeting the Challenge of Climate Change TRCA Action Plan for The Living City
Town of Ajax	2010	Urban Forest Management Plan
Kawartha Conservation	2014	Changing Climate – a Challenge and an Opportunity Background Paper
Lake Simcoe Region Conservation Authority	2018	Adapting Forestry Programs for Climate Change
Lake Simcoe Region Conservation Authority	In development	Lake Simcoe Climate Change Adaptation Strategy
Lake Simcoe Region Conservation Authority	In development	Lake Simcoe Climate Change Mitigation Strategy
Ganaraska Region Conservation Authority	2014	Climate Change Strategy

Appendix B: List of Climate Parameters

Climate Parameter	Definition	Why Consider Including Parameter in Study
Temperature Parameters		
Mean Air Temperature (°C)	The mean temperature in degrees Celsius (°C) is defined as the average of the maximum and minimum temperature at a location for a specified time interval	The temperature range we expect within a season or year is a very important aspect of climate. Changes in average and extreme temperatures can dramatically affect our everyday lives as well as a wide range of planning and policy decisions. The average highest temperature is an environmental indicator with many applications in agriculture, engineering, health, energy management, recreation, and more
Mean Maximum Air Temperature (°C)	The average of the maximum temperature in degrees Celsius (°C) observed at the location for that month	
Mean Minimum Air Temperature (°C)	The average of the minimum temperature in degrees Celsius (°C) observed at the location for that month	
Maximum Temperature (°C)	The highest temperature in degrees Celsius (°C) observed at a location for a specified time interval	
Minimum Temperature (°C)	The lowest temperature in degrees Celsius (°C) observed at a location for a specified time interval	
Extreme Maximum Air Temperature (°C)	The highest daily maximum temperature in degrees Celsius reached at a specific location for that month	
Extreme Minimum Air Temperature (°C)	The lowest daily minimum temperature in degrees Celsius reached at a specific location for that month	
Extreme Heat Parameters		
Days Above 35˚C	The sum of days in a given period of time when the temperature rises to at least 35˚C	High temperatures determine if plants and animals can thrive, they limit or enable outdoor activities, define how we design our buildings and vehicles, and shape our transportation and energy use. It is useful to know how high summer temperatures are likely to become in the future, to make sure that our cooling and air-conditioning systems can reliably deal with these extremes. When temperatures are very hot, people - especially the elderly - are much more likely to suffer from heat exhaustion and heat stroke. Many outdoor activities become dangerous or impossible in very high temperatures. In general, Canadians are not used to extremely hot summers, and further warming will bring new and unusual risks as well as a very different experience of the summer season. High, persistent temperatures increase the risk of drought, which can severely impact food production and increases the risk of wildfire. High temperatures can also lead to more thunderstorms, which means increased risks of flash flooding, lightning, hail and perhaps even tornadoes
Days Above 30˚C	The sum of days in a given period of time when the temperature rises to at least 30˚C	
Days Above 25˚C	The sum of days in a given period of time when the temperature rises to at least 25˚C	
Tropical Nights	A tropical night occurs when the lowest temperature of the day does not go below 20˚C	
Extreme Cold Parameters		
Days Below -20˚C	The sum of days in a given period of time when the temperature drops to at least -20˚C	Cold weather is an important aspect of life in Canada, and many places in Canada are well adapted to very cold winters. It is especially important to know how our winters will change in the future, because cold temperatures affect our health and safety, determine what plants and animals can live in the area, limit or enable outdoor activities, define how we design our buildings and vehicles, and shape our transportation and energy use
Days Below -10˚C	The sum of days in a given period of time when the temperature drops to at least -10˚C	
Days Below -5˚C	The sum of days in a given period of time when the temperature drops to at least -5˚C	
Days Below 0˚C (Frost Days)	The sum of days in a given period of time when the coldest temperature of the day is lower than 0˚C. Under these conditions, frost might form at ground level or on cold surfaces	The number of frost days is an indicator of the length and severity of the winter season. A location with a large number of frost days is also likely to have a short growing season, since frost is harmful to many plants
Precipitation Parameters		
Total Annual Precipitation (mm/year)	The sum of the total rainfall and the water equivalent of the total snowfall in millimeters (mm), observed at the location during a specified time interval[1]. Winter is defined as DJF, spring as MAM, summer as JJA, and fall as SON.	Precipitation patterns are critical for many important issues, including water availability, crop production, electricity generation, wildfire suppression, snow accumulation, seasonal and flash-flooding, and short- and long-term drought risk
Total Winter Precipitation (mm/season)		
Total Spring Precipitation (mm/season)		
Total Summer Precipitation (mm/season)		
Total Fall Precipitation (mm/season)		
Extreme Precipitation Parameters		
Maximum Precipitation in one day (mm)	The maximum amount of precipitation (mm) in one day over a given period of time	Precipitation patterns are critical for many important issues, including water availability, crop production, electricity generation, wildfire suppression, snow accumulation, seasonal and flash-flooding, and short- and long-term drought risk

Climate Parameter	Definition	Why Consider Including Parameter in Study
Extreme Precipitation Days (days with more than 25 mm)	The sum of days in a given period of time when at least a total of 25 mm of rain or frozen precipitation falls. Frozen precipitation is measured according to its liquid equivalent: 10 cm of snow is usually about 10 mm of precipitation	Heavy rainfall events can create many challenges. In cities and towns, heavy rainfalls can overwhelm storm drains and cause flash flooding. They can also cause problems in rural areas by drowning crops, eroding topsoil, and damaging roads. Heavy snowfall events can disrupt ground transportation, and very heavy snowfall events can cause damage to buildings if their roofs become overburdened.
Annual Simple Daily Intensity Index (SDII) (mm/day)	Average intensity (mm/day) over a given period of time, calculated as total wet day precipitation divided by the total number of wet days	
Winter SDII (mm/day)		
Spring SDII (mm/day)		
Summer SDII (mm/day)		
Fall SDII (mm/day)		
Number of Heavy Precipitation Days (days with more than 25 mm)	A Heavy Precipitation Day (HPD) is a day on which at least a total of 25 mm of rain or frozen precipitation falls. Frozen precipitation is measured according to its liquid equivalent: 25 cm of snow is usually about 25 mm of precipitation	
95th Percentile Precipitation (mm)	The percent of the total precipitation when precipitation is greater or equal to the 95th percentile.	
99th Percentile Precipitation (mm)	The percent of the total precipitation when precipitation is greater or equal to the 99th percentile.	
Drought Parameters		
Total Annual Dry Days	Total annual number of days where precipitation was less than 0.2 mm.	Total annual dry days and the maximum consecutive dry days are useful indicators for predicting drought in the future. This is useful for municipalities who have a large agricultural sector, such as Durham Region.
Maximum Total Consecutive Dry Days	The number of consecutive days where annual total number of days where precipitation was less than 0.2 mm.	
Agricultural Parameters		
Growing Degree Days (Base 0°C)	Growing Degree Days (GDD) provide an index of the amount of heat available for the growth and maturation of plants and insects. Different base temperatures (0, 4, 5, 10, 15°C) are used to capture results for organisms that demand different amounts of heat	GDDs accumulate whenever the daily mean temperature is above a specified threshold temperature. Generally, 5°C GDDs are used for assessing the growth of canola and forage crops; 10 °C GDDs are more appropriate for assessing the growth of corn and beans; and 15°C GDDs are used to assess the growth and development of insects and pests
Growing Degree Days (Base 4°C)		
Growing Degree Days (Base 5°C)		
Growing Degree Days (Base 10°C)		
Growing Degree Days (Base 15°C)		
Growing Season Length (also referred to as Frost Free Days)	Number of frost-free days is calculated based on the last occurrence of frost in spring and the first occurrence of frost in autumn.	The average length of the growing season (and its year-to-year variability) is an important consideration when selecting or predicting what plants might grow well in a region. A longer frost-free season means plants and crops have a longer window to grow and mature. This is an especially important parameter for agriculture, because the variability in the number of frost-free days is crucial for many agricultural activities such as planting and harvesting.
Growing Season Start Date	The first day after 5 consecutive minimum temperatures above 5°C	Changes in the length and timing of the frost-free season affect plant and animal life, but also our social, psychological, and physical experience of the changing seasons. The growth of most plants and crops is limited by the temperature of the air and soil. Since crops and plants need time to mature, the later in the fall they experience freezing temperatures, the more likely it is that they will be able to mature to their full potential. The time available for growth, maturity and productivity of these plants is determined by the Growing Season Start and End date, which together determine the length of the frost-free season.
Growing Season End Date	The first day after 5 consecutive maximum temperatures below 5°C	
Corn Heat Unit	Corn Heath Units (CHU) is a temperature-based index often used by farmers and agricultural researchers to estimate whether the climate is warm enough (but not too hot) to grow corn. Corn typically requires a minimum of a daily temperature of 10˚C, and of a nightly temperature of 4.4˚C. Generally, at least 2200 CHUs are required to mature most varieties of corn in a region.	The CHUs expected in a region's growing season are used to assess whether corn, or a particular variety of corn, is likely to fully mature in that region. It is important to note that this index is only based on temperature and does not consider the availability of water to grow the crop.
Ice Parameters		
Freeze-Thaw Cycles	A simple count of days when the air temperature fluctuates between freezing and non-freezing temperatures. Under these conditions, it is likely that some water at the surface was both liquid and ice at some point during the 24-hour period.	Freeze-thaw cycles can have major impacts on infrastructure. Water expands when it freezes, so the freezing, melting and re-freezing of water can over time cause significant damage to roadways, sidewalks, and other outdoor structures. Potholes that form during the spring, or during mid-winter melts, are good examples of the damage caused by this process.
Ice Potential	Number of days where minimum temperature is greater than -2˚C and maximum temperature is under 2˚C.	Number of days in which air temperature does not rise above freezing is a good indicator of the length and severity of the winter season. It is especially important to know how our winters will change in the future, because cold temperatures affect our health and safety, determine what plants and animals can live in the area, limit or enable outdoor activities, define how we design our buildings and vehicles, and shape our transportation and energy use.

Appendix C: Climate Change in Durham Region Based on the RCP 4.5 (Low Emissions) Scenario

Disclaimer: Since the RCP 4.5 climate change scenario is used less frequently by planners and practitioners than the RCP 8.5 scenario (a more likely scenario), there was much less available data available online for RCP 4.5 (e.g., the NA-CORDEX portal had three model runs for the RCP 4.5 scenario, while RCP 8.5 had 16 model runs) and therefore these results should not be directly compared with those of RCP 8.5.

Table C-1: A summary of all climate parameters for each climate period analyzed in the study for the RCP 4.5 climate scenario.

Climate Parameter	Definition	Baseline Value (1971-2000)	Short-Term (2020s) (2011-2040)			Medium Term (2050s) (2041-2070)			Long Term (2080s) (2071-2100)			Confidence Levels
			10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	
Mean Temperature (˚C)												
Mean Annual Temperature	Average annual air temperature over a time period.	**7.1**	7.6	**9.7**	11.3	8.6	**10.9**	12.6	8.8	**11.3**	13.2	high evidence high agreement
Mean Winter Temperature	Average winter (D-J-F) air temperature over a time period.	**-3.0**	-1.7	**0.3**	1.8	-0.1	**1.8**	3.3	0.2	**2.0**	3.7	
Mean Spring Temperature	Average spring (M-A-M) air temperature over a time period.	**3.7**	2.6	**4.7**	6.2	3.4	**5.9**	7.6	3.7	**6.3**	8.2	
Mean Summer Temperature	Average summer (J-J-A) air temperature over a time period.	**17.1**	16.4	**18.5**	20.8	17.6	**19.8**	22.2	17.8	**20.3**	22.8	
Mean Fall Temperature	Average fall (S-O-N) air temperature over a time period.	**10.1**	11.5	**13.3**	14.8	12.4	**14.4**	16.0	12.4	**14.8**	16.7	
Maximum Temperature (˚C)												
Maximum Annual Temperature	Average maximum annual air temperature over a time period.	**11.6**	13.1	**14.3**	17.0	14.0	**15.5**	18.3	14.2	**15.9**	18.9	high evidence high agreement
Maximum Winter Temperature	Average maximum winter (D-J-F) air temperature over a time period.	**2.1**	2.9	**4.6**	5.9	2.1	**5.1**	7.2	4.1	**6.0**	7.5	
Maximum Spring Temperature	Average spring (M-A-M) air temperature over a time period.	**8.3**	7.1	**9.2**	10.8	5.7	**9.5**	12.3	8.0	**10.8**	12.9	
Maximum Summer Temperature	Average maximum summer (J-J-A) air temperature over a time period.	**21.4**	20.7	**22.8**	25.0	19.7	**23.2**	26.4	22.0	**24.6**	27.0	
Maximum Fall Temperature	Average maximum fall (S-O-N) air temperature over a time period.	**14.5**	15.8	**17.6**	19.1	14.6	**17.8**	20.3	16.6	**19.1**	21.0	
Minimum Temperature (˚C)												
Minimum Annual Temperature	Average minimum annual air temperature over a time period.	**2.5**	2.6	**5.1**	6.3	3.7	**6.4**	7.8	3.9	**6.8**	8.3	high evidence high agreement

Climate Parameter	Definition	Baseline Value (1971-2000)	Short-Term (2020s) (2011-2040)			Medium Term (2050s) (2041-2070)			Long Term (2080s) (2071-2100)			Confidence Levels
			10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	
Minimum Winter Temperature	Average minimum winter (D-J-F) air temperature over a time period.	**-8.0**	*-6.2*	**-4.0**	*-2.2*	*-2.0*	**-1.3**	*-0.5*	*-4.6*	**-2.1**	*-0.1*	high evidence high agreement
Minimum Spring Temperature	Average minimum (M-A-M) air temperature over a time period.	**-1.0**	*-1.7*	**0.4**	*2.0*	*1.6*	**2.6**	*3.4*	*-0.5*	**2.1**	*4.0*	
Minimum Summer Temperature	Average minimum summer (J-J-A) air temperature over a time period.	**12.8**	*12.2*	**14.3**	*16.5*	*15.2*	**16.6**	*18.1*	*13.6*	**16.0**	*18.6*	
Minimum Fall Temperature	Average minimum fall (S-O-N) air temperature over a time period.	**5.7**	*7.3*	**9.2**	*10.6*	*10.7*	**11.3**	*11.7*	*8.2*	**10.7**	*12.5*	
Extreme Heat (days per year)												
Days Above 35˚C	Total number of days of the year with maximum temperatures above 35˚C.	**0.2**	*0.5*	**2.7**	*5.1*	*1.1*	**5.3**	*9.5*	*1.7*	**7.9**	*13.8*	high evidence high agreement
Days Above 30˚C	Total number of days of the year with maximum temperatures above 30˚C.	**7.6**	*8.4*	**25.3**	*39.7*	*11.0*	**35.1**	*54.4*	*15.9*	**42.7**	*64.1*	
Days Above 25˚C	Total number of days of the year with maximum temperatures above 25˚C.	**42.1**	*47.0*	**77.2**	*98.9*	*48.6*	**85.2**	*111.9*	*60.1*	**95.2**	*121.0*	
Tropical Nights	Total number of days of the year with minimum temperatures above 20˚C.	**100.6**	*106.1*	**129.4**	*146.9*	*105.6*	**134.7**	*155.6*	*116.5*	**142.3**	*161.1*	
Extreme Cold (days per year)												
Days Below -20˚C	Total number of days of the year with minimum temperatures below -20˚C.	**8.6**	*0.1*	**1.3**	*3.0*	*0.0*	**0.3**	*0.7*	*0.0*	**0.3**	*0.7*	high evidence high agreement
Days Below -15˚C	Total number of days of the year with minimum temperatures below -15˚C.	**22.7**	*1.8*	**6.9**	*14.0*	*0.4*	**2.6**	*5.7*	*0.2*	**3.2**	*7.4*	
Days Below -10˚C	Total number of days of the year with minimum temperatures below -10˚C.	**49.0**	*11.7*	**23.9**	*40.8*	*4.2*	**13.2**	*25.3*	*3.3*	**13.7**	*28.1*	
Days Below -5˚C	Total number of days of the year with minimum temperatures below -5˚C.	**89.0**	*41.4*	**59.6**	*83.8*	*21.8*	**41.9**	*67.7*	*19.1*	**41.6**	*70.0*	
Days Below 0˚C (Freezing Days)	Total number of days of the year with minimum temperatures below 0˚C.	**146.8**	*101.4*	**118.7**	*141.9*	*79.4*	**100.5**	*127.9*	*74.0*	**99.1**	*131.2*	
Total Precipitation (mm per time period)												

Climate Parameter	Definition	Baseline Value (1971-2000)	Short-Term (2020s) (2011-2040)			Medium Term (2050s) (2041-2070)			Long Term (2080s) (2071-2100)			Confidence Levels
			10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	
Total Average Annual Precipitation (mm)	Total amount of precipitation throughout the year falling on wet days (where precipitation is greater than 0.2 mm).	**952.4**	861.7	**943.3**	943.3	873.7	**960.3**	1039.5	870.4	**1009.3**	1133.8	
Total Average Winter Precipitation (mm)	Total amount of precipitation throughout the winter (D-J-F) falling on wet days (where precipitation is greater than 0.2 mm).	**228.3**	212.6	**235.3**	260.1	252.1	**265.5**	277.9	216.9	**234.1**	251.8	
Total Average Spring Precipitation (mm)	Total amount of precipitation throughout the spring (M-A-M) falling on wet days (where precipitation is greater than 0.2 mm).	**217.3**	188.1	**212.1**	231.2	170.2	**200.3**	236.5	198.4	**226.5**	250.0	high evidence medium agreement
Total Average Summer Precipitation (mm)	Total amount of precipitation throughout the summer (J-J-A) falling on wet days (where precipitation is greater than 0.2 mm).	**231.0**	160.6	**181.8**	208.6	187.1	**199.1**	211.0	167.7	**191.3**	213.8	
Total Average Fall Precipitation (mm)	Total amount of precipitation throughout the fall (S-O-N) falling on wet days (where precipitation is greater than 0.2 mm).	**275.8**	253.2	**295.0**	335.4	297.1	**319.2**	340.9	241.2	**281.8**	312.3	
Extreme Precipitation												
Max Precipitation in 1 day (mm)	Annual 1-day maximum precipitation accumulation.	**33.8**	34.8	**35.0**	35.4	44.9	**60.7**	74.4	37.6	**38.1**	38.5	
Max Precipitation in 3 day (mm)	Annual 3-day maximum precipitation accumulation.	**54.9**	54.6	**55.2**	56.2	54.8	**57.4**	60.3	55.3	**58.0**	60.5	
Extreme Precipitation Days (days/year)	The annual average amount of days where precipitation exceeds 25 mm.	**3.2**	3.2	**3.4**	3.6	3.4	**3.9**	4.4	3.3	**4.2**	5.0	high evidence medium agreement
Annual Simple Daily Intensity Index (SDII) (mm/day)	The average amount of precipitation which occurs per day on average in a year.	**2.6**	2.4	**2.6**	2.8	2.4	**2.6**	2.8	2.4	**2.6**	3.1	
Winter SDII (mm/day)	The average amount of precipitation which occurs per day on average in a year.	**2.5**	2.3	**2.6**	2.9	2.8	**2.9**	3.0	2.4	**2.6**	2.8	

Climate Parameter	Definition	Baseline Value (1971-2000)	Short-Term (2020s) (2011-2040)			Medium Term (2050s) (2041-2070)			Long Term (2080s) (2071-2100)			Confidence Levels
			10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	
Spring SDII (mm/day)	The average amount of precipitation which occurs per day on average in a year.	**2.4**	*2.1*	**2.3**	*2.5*	*1.9*	**2.2**	*2.6*	*2.2*	**2.5**	*2.7*	
Summer SDII (mm/day)	The average amount of precipitation which occurs per day on average in a year.	**2.5**	*1.8*	**2.0**	*2.3*	*2.1*	**2.2**	*2.3*	*1.8*	**2.1**	*2.3*	
Fall SDII (mm/day)	The average amount of precipitation which occurs per day on average in a year.	**3.0**	*2.8*	**3.2**	*3.7*	*3.3*	**3.5**	*3.7*	*2.6*	**3.1**	*3.4*	high evidence medium agreement
95th Percentile Precipitation (mm)	The percent of the total precipitation when precipitation is greater or equal to the 95th percentile.	**36.1**	*37.2*	**38.9**	*41.0*	*35.4*	**37.1**	*38.5*	*38.9*	**40.4**	*42.4*	
99th Percentile Precipitation (mm)	The percent of the total precipitation when precipitation is greater or equal to the 99th percentile.	**11.2**	*11.5*	**12.3**	*13.2*	*10.9*	**11.5**	*12.0*	*11.7*	**12.5**	*13.6*	
Dry Days												
Total Annual (days)	Total annual number of days where precipitation was less than 0.2 mm.	**145.3**	153.7	**161.1**	170.1	*126.1*	**144.0**	*157.5*	*155.0*	**163.7**	*174.2*	low evidence high agreement
Maximum Total Consecutive Dry Days (days)	The number of consecutive days where annual total number of days where precipitation was less than 0.2 mm.	**18.2**	15.4	**17.0**	18.6	*16.2*	**17.7**	*19.4*	*20.4*	**22.0**	*23.6*	
Growing Season												
Growing Season Start Date (day of year)	The first day after 5 days of consecutive minimum temperatures above 5˚C was reached.	**12-May**	28-Apr	**30-Apr**	3-May	20-Apr	**2-May**	15-May	*13-Apr*	**25-Apr**	*11-May*	
Growing Season End Date (day of year)	The first day after 5 days of consecutive maximum temperatures below 5˚C was reached.	**5-Nov**	31-Oct	**8-Nov**	15-Nov	7-Nov	**15-Nov**	22-Nov	*3-Nov*	**16-Nov**	*25-Nov*	high evidence high agreement
Growing Season Length (days/year)	Annual number of days after having 5 consecutive days above 5˚C and before having five consecutive days below 5˚C.	**177 days**	181 days	**192 days**	201 days	176 days	**197 days**	216 days	*176 days*	**205 days**	*226 days*	
Agricultural Variables												

Climate Parameter	Definition	Baseline Value (1971-2000)	Short-Term (2020s) (2011-2040)			Medium Term (2050s) (2041-2070)			Long Term (2080s) (2071-2100)			Confidence Levels
			10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	10th Percentile	Ensemble Mean	90th Percentile	
Corn Heat Units (CHUs)	Number of CHUs, indicating ideal climates for corn to fully mature (very generally, at least 2200 CHUs are required to mature most varieties of corn).	**3194**	*3259*	**3936**	*4505*	*3516*	**4293**	*4921*	*3619*	**4479**	*5159*	
Growing Degree Days (days/year)	Number of days > 0˚C.	**3198**	*3277*	**3861**	*4317*	*3462*	**4177**	*4715*	*3580*	**4346**	*4910*	
Canola Growing Degree Days (days/year)	Number of days > 4˚C.	**2236**	*2297*	**2792**	*3182*	*2452*	**3052**	*3508*	*2556*	**3207**	*3692*	high evidence high agreement
Forage Crops Growing Degree Days (days/ year)	Number of days > 5˚C.	**2024**	*2080*	**2555**	*2928*	*2229*	**2807**	*3238*	*2330*	**2952**	*3417*	
Corn and Bean Growing Degree Days (days/year)	Number of days > 10˚C.	**1119**	*1162*	**1533**	*1829*	*1277*	**1720**	*2061*	*1360*	**1845**	*2213*	
Days at Risk of Presence of Pests (days/year)	Number of days > 15˚C.	**463**	*500*	**764**	*976*	*574*	**900**	*1153*	*642*	**998**	*1269*	
Freeze-Thaw Cycles and Ice Potential												
Freeze-Thaw Cycles (cycles/year)	Number of freeze thaw cycles, where the minimum temperature is equal to or below -1°C and the maximum temperature is above 0°C.	**80**	*66*	**73**	*80*	*54*	**61**	*67*	*51*	**64**	*77*	low evidence high agreement
Ice Potential (days/year)	Number of days where minimum temperature is greater than -2˚C and maximum temperature is under 2˚C.	**29**	*11*	**18**	*27*	*9*	**21**	*38*	*6*	**14**	*24*	

Appendix D: Comparison of the SENES Study with the 2019 Durham Climate Modeling Project and other Climate Studies

This report provides updated climate projections and emission scenarios for Durham Region that integrates both Global and Regional Climate Models through an ensemble approach. Prior to this report, *Durham Region's Future Climate (2040-2049)* developed by SENES was developed to examine future climate projections. Below is a concise comparison of the methodological differences between the SENES Study and the 2019 Durham Climate Modeling Project.

Table D-1: Differences between the SENES Study and the 2019 Climate Modeling Project

Factors	Durham SENES Study	Durham Climate Modeling Project
Climate Models	1 GCM (HadCM3 Model) 1 RCM (Hadley PRECIS Model) 1 Weather Forecasting Model (WRF)	8 different GCMs 5 different RCMs
Emissions Scenarios	Older SRES Scenario A1B	Newer RCP 8.5 and RCP 4.5
Time Period	2040-2049	2020's, 2050's, and 2080's
Baseline	2000-2009	1971-2000
Regional Averages	Used Whitby as proxy station for all of Durham	Uses all climate stations in Durham Region to develop averages
Climate Parameters	Extreme precipitation, extreme rain, extreme snowfall, extreme heat, extreme cold, wind chill, degree days, extreme wind, humidex, potential for violent storms	Mean temperatures, maximum temperature, minimum temperature, extreme heat, extreme cold, total precipitation, extreme precipitation, dry days, growing season, agriculture variables, freeze-thaw cycles and ice potential

The 2019 Durham Climate Modeling Project incorporates 8 different GCMs and 5 different RCMs for three different time periods (2020's, 2050's, and 2080's) as a part of the analysis. The use of an ensemble approach allows for more robust predictions and compares more favorably to historical observations than a single model. Individual biases that may be present in a single model tend to be reduced in an ensemble approach, as the average from each of the climate models are used to determine the values (Auld et al., 2016). When a single climate model is used, greater variability exists. The SENES study uses a single GCM (HadCM3), a single RCM (Hadley PRECIS model) as well as a weather forecasting model (WRF). Based on the GLISA review of climate models (see Table 2), the HadCM3 model used in the SENES study projects the Great Lakes as oceans rather than dynamic lakes in the model. GLISA advises to avoid using this model for any site-specific, local analyses. In addition, Weather Forecasting Models use current observational data to forecast future climate (NOAA, n.d.). As demonstrated in section 3.2, weather forecasting models rely on statistical analyses, using historical relationships to project future climate data. Therefore, using a statistically downscaled approach may provide different results than that of dynamically downscaled RCM climate projections.

Another important factor was the use of a 30-year climate normal period compared to the 10-year baseline used for the SENES Study. A 30-year climate normal period is typically used to smooth out extremes, and ensure that particularly wet, dry, hot or cold years do not dominate the climate conditions overall (which may occur if only a subset of years are used as a normal period). For example, the 1-day Maximum Precipitation in Table D-2 depicts much lower values than that of the SENES Study. Since the SENES Study had a much shorter climate normal period (2000-2009) and only uses single climate models, this allowed for greater variability, providing the opportunity for extremes to dominate (e.g., see Table D-3 Summer Total Precipitation values). As the 2019 Durham Climate Modeling Project uses a 30-year climate normal period and an ensemble of climate models, there is greater opportunity to smooth out the extremes that would otherwise be present in a shorter climate period. This allows for a more robust picture of the expected future climate. As shown in tables D-2 and D-3, this project uses the baseline period of 1971-2000 as the NA-CORDEX data portal provides historical data from for the period of 1951-2005. Other climate portals may have a different historical baseline period (e.g., York Region and Peel Region used the 1981-2010 historical baseline), depending on where the historical data was obtained and the availability of data.

Another notable difference between the SENES study and this project is the way in which Regional averages are calculated. In the SENES Study, Whitby is used as the proxy climate station to determine regional climate. This approach may not account for differences across the Region. The 2019 Durham Climate Modeling Project takes all the climate stations in Durham Region and averages them out, providing a greater range in values and a more accurate picture of the averages in the Region. Additionally, this project provides updated emission scenarios (i.e., RCPs) to reflect developments in climate science. These RCP scenarios consider GHG concentrations rather than emissions under the previous SRES scenarios.

It can be noted that several of the climate parameters used in the SENES study (e.g., extreme wind, extreme snowfall, humidex, etc.) were not included as a part of this project. These climate parameters are highly variable and require good quality data to provide accurate projections. Since the 2019 Durham Climate Modeling Project integrates several climate models, certain models may have limited data available for specific parameters. As such, climate parameters that were determined to be highly variable and lacked good quality data were excluded from the project to provide a robust and more accurate picture of Durham Region's future climate.

The following tables (Table D-2 and D-3) provide a comparison in temperature indicators and precipitation indicators between the 2019 Durham Climate Modeling Project, the SENES Study, as well as Peel Region and York Region's climate projections. Since this comparison examines local scale climate projections initiatives, portals such as Climatedata.ca and Climate Atlas, were not included as a part of this comparison. In addition, each study had slightly different time periods, but for the purposes of this report, similar time periods were attempted to be used for the comparison (e.g., 2050s). It should also be noted that while York Region and Peel Region's climate projections have been included as a part of this comparison, the values provided under the climate parameters may differ due to the spatial variability in climate across the GTA.

Table D-2: Summary of Temperature Parameters in the RCP 8.5 Scenario.

Time Period	2019 Durham Climate Modeling Baseline (°C) 1971-2000	2019 Durham Climate Modeling (°C) 2041-2070	SENES Future Baseline (°C) 2000-2009	SENES Future (°C) 2040-2049	Peel Climate Trends Report Baseline (°C) 1981-2010	Peel Climate Trends Report 2041-2070	York Region Baseline (°C) 1981-2010	York Region CNRM-CM5 Model (°C) 2031-2058	York Region MIROC5 Model (°C) 2031-2058
	Mean	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**
Average Maximum Temperature									
Annual	11.6	**14.5**	12.1	**16.3**	12.3	**14.2**	12.1	**14.2**	**14.7**
Winter	2.1	**4.4**	-0.8	**5.0**	-1.0	**0.9**	-1.3	**0**	**1.1**
Spring	8.3	**10.6**	10.7	**14.6**	11.3	**13.2**	11.2	**13.2**	**18**
Summer	23.4	**24.4**	24.2	**27.3**	25.1	**27.1**	25.0	**27.6**	**25.1**
Fall	14.5	**17.2**	14.2	**18.3**	13.7	**15.7**	13.6	**15.4**	**12.5**
Average Minimum Temperature									
Annual	2.5	**5.7**	4.3	**8.4**	2.5	**4.5**	2.4	**4.7**	**5.3**
Winter	-8.0	**-4.5**	-6.6	**-0.5**	-8.7	**-6.1**	-9.3	**-6.8**	**-5.8**
Spring	-1.0	**2.0**	1.9	**5.9**	0.8	**2.6**	0.8	**2.8**	**6.7**
Summer	12.8	**16.1**	15.2	**17.8**	13.5	**15.5**	13.7	**15.7**	**14.2**
Fall	5.7	**8.9**	6.8	**25.6**	4.4	**6.3**	4.5	**6.4**	**4.1**
Average Temperature									
Annual	7.1	**10.1**	8.1	**12.1**	7.4	**9.1**	7.3	**9.4**	**10**
Winter	-3.0	**-0.0**	-3.9	**1.9**	-4.8	**-2.8**	-5.3	**-3.4**	**-2.4**
Spring	3.7	**6.2**	6.1	**5.9**	6.1	**7.7**	6.0	**7.9**	**12.2**
Summer	17.1	**20.3**	19.7	**17.8**	19.3	**20.9**	19.4	**21.7**	**19.7**
Fall	10.1	**13.1**	10.3	**10.6**	9.1	**10.7**	9.0	**10.8**	**8.3**

Table D-3: Summary of Precipitation Indicators in the RCP 8.5 Scenario.

Time Period	2019 Durham Climate Modeling Baseline (mm) 1971-2000	2019 Durham Climate Modeling 2041-2070	SENES Future Baseline (mm) 2000-2009	SENES Future 2040-2049	Peel Climate Trends Report Baseline (mm) 1981-2010	Peel Climate Trends Report 2041-2070	York Region Baseline (mm) 1981-2010	York Region CNRM-CM5 Model 2031-2058	York Region MIROC5 Model 2031-2058
	Mean	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**
Total Precipitation [mm]									
Annual	952.4	**1117.5**	869	**1004.0**	852	**926.0**	853.5	**936.6**	**841.2**
Winter	228.3	**252.4**	191	**182.0**	183	**213.0**	187	**194**	**184.3**
Spring	217.3	**251.2**	213	**197.0**	204	**234.0**	202.3	**207.2**	**203.9**
Summer	231.0	**247.4**	251	**402.0**	231	**234.0**	228.7	**234.8**	**226.2**
Fall	275.8	**297.2**	213	**223.0**	231	**246.0**	235.4	**242.6**	**225.5**

Appendix E: Using Climate Projections to Derive IDF Curves

As previously mentioned, IDF curves describe the relationship between rainfall intensity, rainfall duration, and return period. IDF curves are used in many applications including stormwater and watershed planning, flooding and erosion risk management, drainage design, and for infrastructure operations (Coulibaly et al., 2016). Typically, practitioners have used historical observations to calculate IDF curves (ibid). Recently observed and projected trends in North America's climate has shown that using historical observations may not fully account for the magnitude and frequency of extreme events in the future (ibid). These trends are well documented in scientific studies (Sillman et al., 2014; King et al., 2012; Peck et al., 2012; Cheng et al., 2011, 2010) and climate model outputs (Wang et al., 2014; Wang and Huang, 2014; SENES 2011), which suggests that the intensity and frequency of extreme precipitation events are increasing and will continue to increase in southern Ontario (Lemmen et al., 2008). Given the anticipated impacts of climate change on extreme rainfall, there is a great deal of interest by municipalities, CAs, provincial agencies, infrastructure proponents, and risk managers in developing rainfall IDF statistics that reflect anticipated future climate conditions, so that these can be reflected in design and operation of water management systems.

In 2016, the Ontario Climate Consortium, in partnership with TRCA and the Essex Region Conservation Authority (ERCA), developed a report on the Comparison of Future IDF Curves for Southern Ontario (2016). This report was used to provide TRCA, ERCA and their partners with IDF statistics, curve plots and equations in a form similar to Environment and Climate Change Canada's official plots. The overall goal of the study was to understand the limitations and applicability of different techniques for updating IDF statistics in light of climate change for two local study sites in southern Ontario: Windsor-Essex Region and the Greater Toronto Area (GTA). The flowchart in Figure E-1 demonstrates a summary of the study methodology.

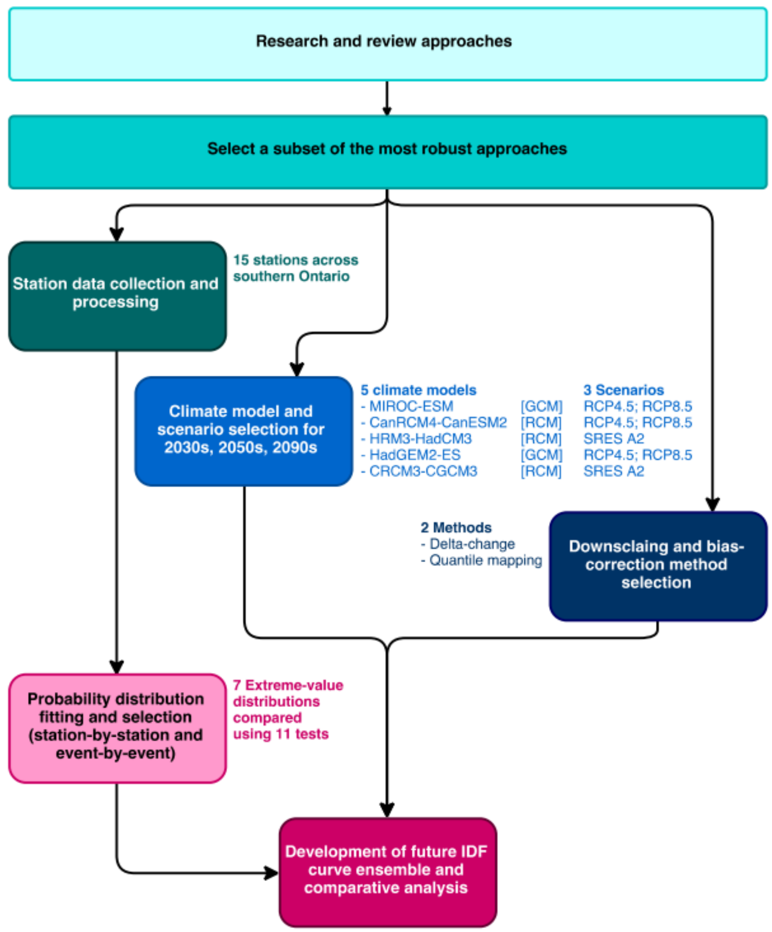


Figure E-1: Summary of overall study methodology (Coulibaly et al., 2016)

Based on this study, it was determined that no single method can be deemed as the 'best' approach for developing future IDF curves. The study also showed that there are a number of challenges involved in developing future extreme rainfall statistics. One of the most prominent challenges is the lack of a 'universal' or 'well-established methodology' for updating IDF curves based on future climate change scenarios. There is also a significant number of future climate projections from various climate modeling experiments that can be used to represent future local climate. For example, due to the highly localized nature of many of the atmospheric processes, downscaled datasets are necessary to account for the local processes that are part of extreme rainfall events. Therefore, a wide range of climate models can be used to represent future climate.

While there is no single approach for developing IDF curves, the study focuses on evaluating the different techniques for updating IDF curves. As such, the project began by undertaking a literature review of the various techniques to update IDF curves using future climate projections. Based on the literature review, the delta change approach and bias correction methods were selected based on their use in previous studies. Over the years, there has been development in several online portals such as the IDF CC Tool, as well as the dynamically downscaled approach that is used in the Ontario Climate Change Data Portal for developing IDF curves that can also be considered. Their use and limitations are further outlined in the report.

Once the downscaling and bias-correction methods were selected, historical precipitation data was gathered and analyzed from different stations across Windsor-Essex Region as well as the GTA. Several of the short duration rainfall recording stations were screened for data quality and length, which included selection criteria such as stations with a minimum 20-years of data, stations with the least gaps in precipitation records, and an adequate geographic coverage across each study area. For maximum rainfall data collection, different storm durations were considered including the 15 minute and 30-minute storms as well as the 1, 2, 3, 6, 12, and 24-hour. The observed data was pre-processed and analyzed for trend detection using the Mann-Kendall (MK) trend test to determine if there's an upward or downward trend in precipitation over time.

Following this, the project team examined and evaluated various distribution functions that can be used in the development of IDF curves. Through this work, the Gumbel distribution used by Environment and Climate Change Canada was identified as the appropriate distribution function for the selected study areas. This distribution function was selected based on its use by Environment and Climate Change Canada across Canada. While the Gumbel distribution has been used for this project, it has been shown that the most appropriate distribution function will depend on the area being examined. This can be done by fitting different distributions to each station observed data and then determining how they ranked based on different goodness of fit criteria.

The final component prior to developing the IDF curves involved the integration of future precipitation datasets. Due to the range in future precipitation datasets available, a subset of datasets from climate model outputs were used. Criteria for selecting the most appropriate models included the performance of the climate models, the temporal resolution of the data, as well as the availability of data. As such, five different climate models and two RCP scenarios (RCP 4.5 and RCP 8.5) were selected as part of the ensemble. More information on the models and RCP scenarios can be found in the report.

Below is an example of a few of the IDF curves that were developed for the GTA. These IDF curves are based on Pearson Airport, using the 2050s time period and compares historical observations with the future climate data for the 2-year storm event and the 100-year storm event. The 10th and 90th percentile ranges have also been included for each of the graphs.

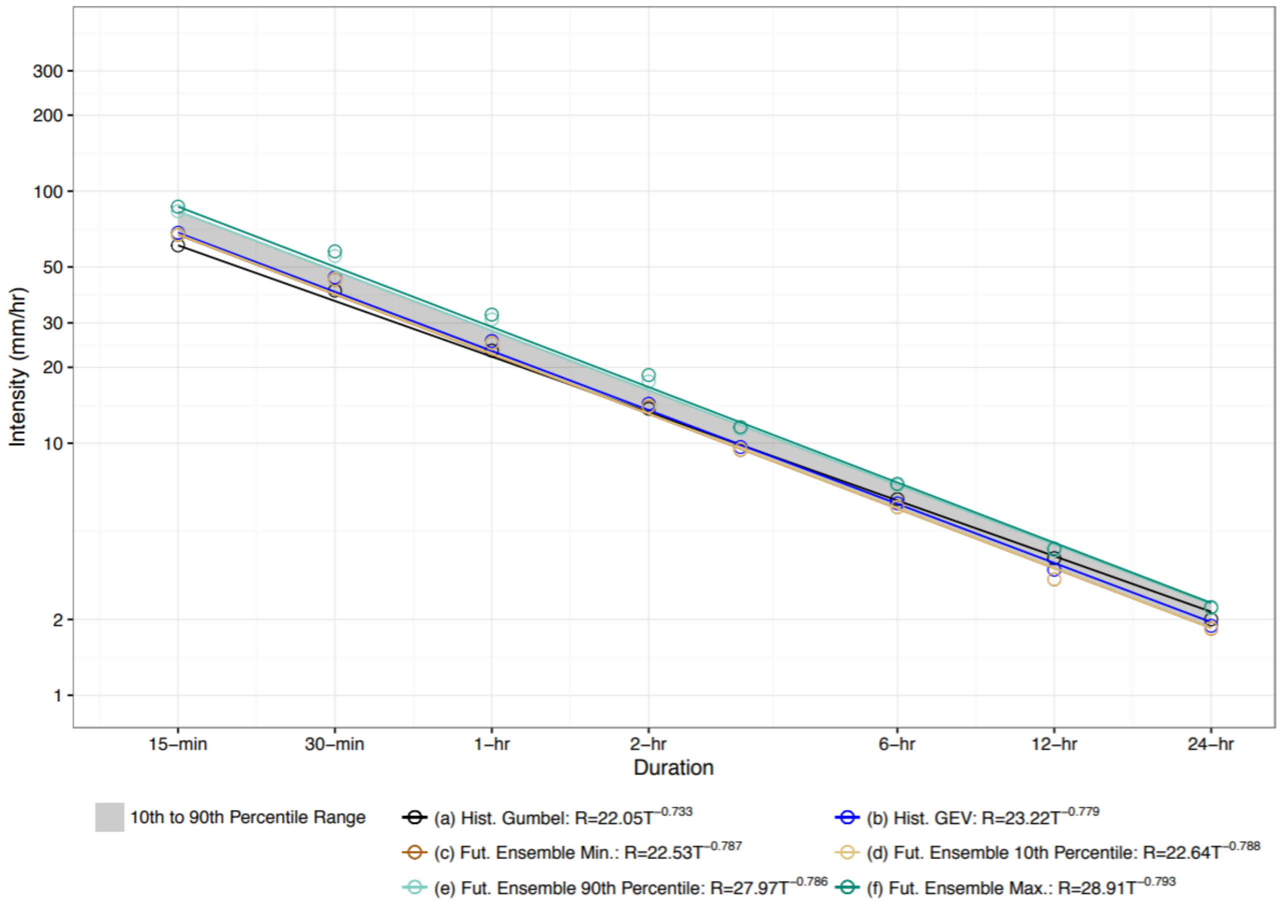


Figure E-2: IDF Curve Comparison for Pearson Airport, 2050s 2-year Return Period Event (10th-90th Percentile)

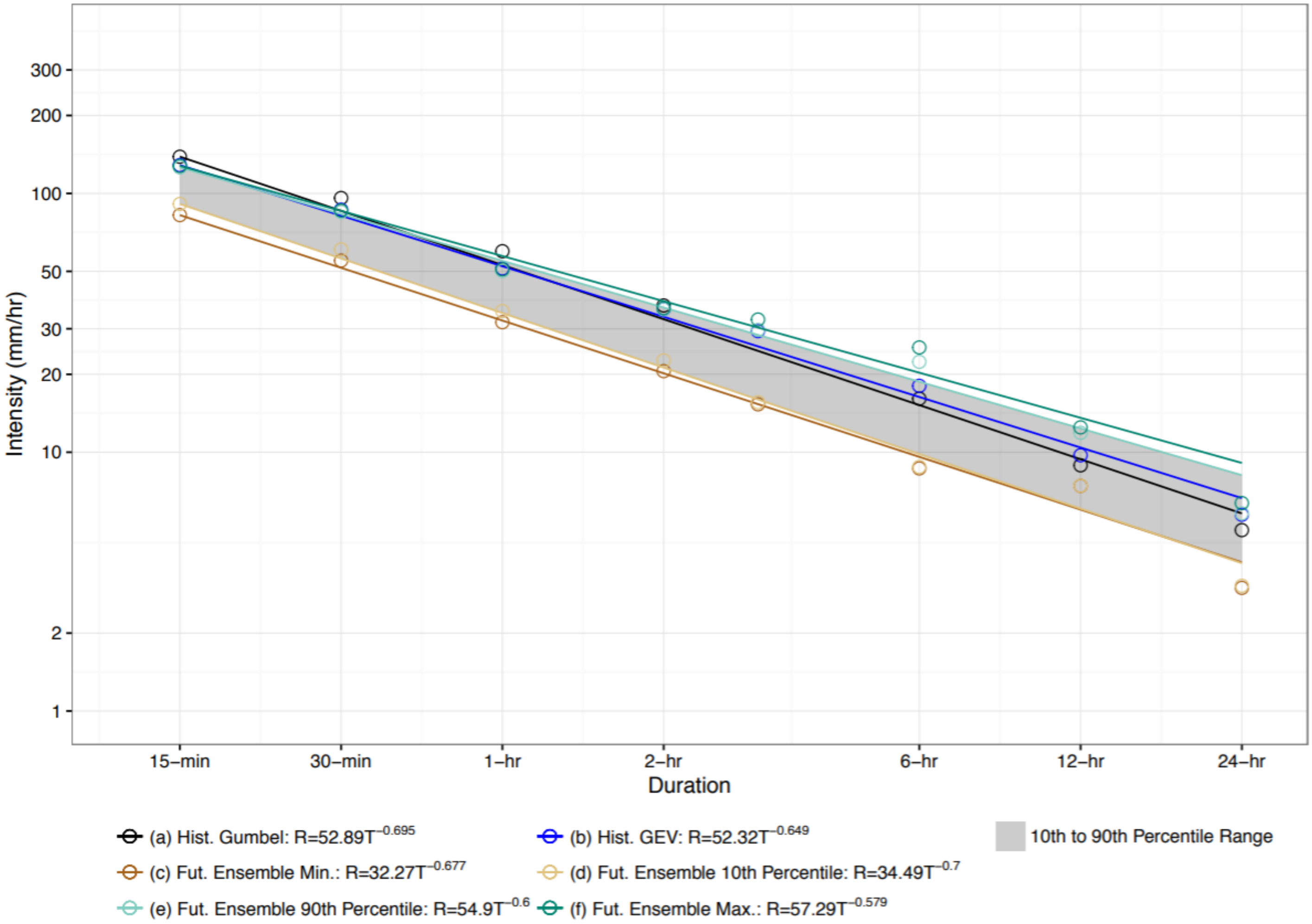


Figure E-3: IDF Curve Comparison for Pearson Airport, 2050s 100-year Return Period Event (10th and 90th Percentile)

Appendix F: Climate Summary Tables for Each Local Municipality within Durham Region under the RCP 8.5 Scenario

Municipal Comparisons and Narrative

As described throughout this guidance document and in the Executive Summary, the climate conditions across Durham Region is not the same. Local municipalities do exhibit changing conditions as a function of geography, local features, and based on historical observed conditions. The following provides a comparison across all 8 local municipalities in Durham Region, and provides an “indexing” or “ranking” based which municipality exhibits the highest to lowest temperature, precipitation to understand relative changes. The narrative described in the Executive Summary also describes geographic differences in temperatures (mean, minimum and maximum) and total precipitation across the local municipalities in Durham Region.

Mean Air Temperature
Examining trends in average air temperature across Durham Region, the rate of increase across the entire varies by local municipality. Across Durham’s 8 local municipalities, Oshawa, Scugog and Clarington have been identified to be warming the fastest. While all are warming, the following illustrates their ranking from fastest rate of warming (on average moving into to future) to lowest rate of warming. Notably, these results are consistent with the geographic trends described in this guidance document – namely, that warming is occurring everywhere and over every time period, but fastest in the north (Brock, Scugog) and east (Clarington, Oshawa):

1. Oshawa (+5.8℃)
2. Brock (+5.3℃)
3. Scugog (+5.2℃)
4. Clarington (+5.2℃)
5. Pickering (+5.2℃)
6. Ajax (+5.1℃)
7. Uxbridge (+5.1℃)
8. Whitby (+4.8℃)

Extreme Hot Temperatures
Changing climate conditions are not necessarily uniform, and so while the characterization above describes average annual air temperature, it is important to also capture how extreme temperatures may behave across the Region’s local municipalities moving into the future. For extreme heat temperatures, there is strong evidence that the Region’s northern municipalities (Scugog, Uxbridge and Brock) all are expected to have higher numbers of extreme heat days (likely across the summer season). The contrast between the north (around a 16-day increase) compared to southern Durham (between 6- and 13-day increases) by end of century is striking. This implies that there may be a need for the Region to consider how extreme heat warnings are established and/or how to support local municipalities in addressing the demand for cooling and shade

moving into the future. The following provides the ranking from highest (where projections show the most extreme heat) to lowest (where projections show lesser extreme heat, but still significant increases):

1. Scugog (+16.6 days)
2. Uxbridge (+16.5 days)
3. Brock (+16 days)
4. Whitby (+13 days)
5. Pickering (+8.3 days)
6. Ajax (+7.1 days)
7. Clarington (+7 days)
8. Oshawa (+6.6 days)

Extreme Cold Temperatures

Expressed in another way, extreme temperatures can also be examined across the Region's local municipalities. The number of days where temperatures are below -20C is indicative of how fast warming may occur, or in other words how many fewer cold days may occur by end of the century - particularly in the winter season. In this case, all reductions are substantial, where at least a month fewer extreme cold days are projected. However, it is clear that in this case, local municipalities in the south end of Durham (e.g., Oshawa, Pickering, Ajax and Clarington) are projected to lose more extreme cold days than those in the north (Uxbridge, Scugog, and Brock). This result is also consistent with the study findings that warming is occurring more quickly along the southern shoreline municipalities across Durham (e.g., see section 5). The following provides the ranking from highest (where projections show a faster reduction in extreme cold days) to lowest (where projections indicate a slower reduction in extreme cold days, but still significant reductions):

1. Oshawa (-37.4 days)
2. Pickering (-37.4 days)
3. Ajax (-37.1 days)
4. Clarington (-36.8 days)
5. Whitby (-35 days)
6. Uxbridge (-33.8 days)
7. Scugog (-33.3 days)
8. Brock (-33.8 days)

Total Precipitation

Total amounts of precipitation are less certain across Durham Region in comparison than temperatures. Historical conditions in and of themselves differ as it relates to observational records. However, the list below indicates municipalities that are projected to have the largest change in precipitation by end of century across the Region. Again, this does not necessarily imply they already receive the most precipitation on an annual basis. Results summarized are ensemble averages and it is expected that variability is critical when factoring in planning (e.g., see table 10 in this report). It should be noted that all these increases in total precipitation are significant, where historical conditions are around 950mm over the year:

1. Oshawa (+31%)

2. Clarington (+31%)
3. Brock (+31%)
4. Pickering (+27%)
5. Ajax (+27%)
6. Whitby (+27%)
7. Uxbridge (+27%)
8. Scugog (+27%)

Extreme Precipitation
Finally, it is important to consider how extreme precipitation may behave across the Region's local municipalities. While less certain than the parameters described above, all trends indicate an increase in 1-day maximum precipitation. Generally, it appears that the increase in extreme precipitation events may increase more among the southern municipalities (Ajax, Whitby, Clarington and Oshawa) than those in the north (Uxbridge and Brock) – though Scugog (ranked second highest) is a large exception. The following provides a ranking from the municipalities projected to have the highest increase in extreme 1-day precipitation (ranked #1) to the lowest (#8).

1. Ajax (+29mm in 1 day)
2. Scugog (+29mm in 1 day)
3. Whitby (+28mm in 1 day)
4. Clarington (+28mm in 1 day)
5. Oshawa (+27mm in 1 day)
6. Pickering (+26mm in 1 day)
7. Uxbridge (+25mm in 1 day)
8. Brock (+23mm in 1 day)

The following summarizes each local municipality in detail, for the climate parameters derived as part of this study. Each summary table provides annual and seasonal conditions where available along with the trend and ensemble averages for near term (2011-2040), medium term (2041-2070) and long term (2071-2100) projections.

City of Pickering

Table F-1: Climate Change Trends for the City of Pickering under the RCP 8.5 scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	8.5	10.1	12.2	↑
	Winter	-3.0	-4.3	-2.5	-0.2	↓
	Spring	3.6	6.8	8.3	10.1	↑
	Summer	17.1	21.0	22.8	24.8	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Fall	10.1	10.3	11.9	14.0	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	13.0	14.5	16.5	↑
	Max Winter Temperature	2.1	-0.2	1.0	3.1	↑
	Max Spring Temperature	8.3	11.6	13.0	14.7	↑
	Max Summer Temperature	21.4	26.4	28.1	30.0	↑
	Max Fall Temperature	14.5	14.3	16.0	18.0	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	4.1	5.7	8.0	↑
	Min Winter Temperature	-8.0	-8.3	-6.4	-3.5	↓
	Min Spring Temperature	-1.0	2.1	3.6	5.6	↑
	Min Summer Temperature	12.7	15.9	17.5	19.6	↑
	Min Fall Temperature	5.7	6.6	8.2	10.4	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	0.8	2.8	8.5	↑
	Days Above 30°C	7.6	12.5	23.1	42.0	↑
	Days Above 25°C	42.1	53.0	73.6	94.4	↑
	Days Above 20°C (Tropical Nights)	100.6	112.2	129.2	145.6	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	6.0	3.0	0.8	↓
	Days Below -10°C	49.0	33.0	22.2	11.6	↓
	Days Below 0°C (freezing days)	146.8	128.9	111.6	89.1	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	1059.2	1132.3	1205.3	↑
	Winter (mm/season)	228.3	219.2	237.4	264.8	↑
	Spring (mm/season)	219.2	273.9	292.2	319.6	↑
	Summer (mm/season)	228.3	301.3	310.5	328.7	↑
	Fall (mm/season)	273.9	273.9	283.1	292.2	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	50.3	55.0	59.6	↑
	Max Precipitation in 3 days (mm)	54.9	71.3	76.7	83.9	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.9	3.1	3.3	↑
	95th Percentile Precipitation (mm)	36.1	44.5	45.3	45.3	↑
	99th Percentile Precipitation (mm)	11.2	14.7	15.1	15.1	↑
Dry Days (days/year)	Total Annual	145.3	195.0	195.5	190.6	↓

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Total Annual Consecutive Dry Days	18.2	21.4	21.9	22.1	↑
Growing Season	Growing Season Start Date (day of year)	May 14	May 7	May 1	April 18	↑
	Growing Season End Date (day of year)	Oct 24	Oct 31	Nov. 9	Nov. 19	↑
	Growing Season Length (days/year)	163	178	193	215	↑
Agricultural Variables	Corn Heat Units	3193.9	3614.7	4152.5	4770.0	↑
	Growing Degree Days (Base 0°C)	3197.9	3563.4	4000.5	4546.9	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2523.0	2903.4	3375.0	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2294.1	2660.5	3112.9	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1315.9	1613.6	1978.3	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	597.7	819.2	1100.8	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	78.4	69.7	60.3	↓
	Ice Potential (days per year)	28.8	15.6	12.7	8.5	↓

Town of Ajax

Table F-2: Climate Change Trends for the Town of Ajax under the RCP 8.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	8.5	10.1	12.1	↑
	Winter	-3.0	-3.4	-1.8	0.4	↓
	Spring	3.6	6.4	7.8	9.6	↑
	Summer	17.1	20.4	22.1	24.1	↑
	Fall	10.1	10.6	12.2	14.2	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	13.0	14.4	16.4	↑
	Max Winter Temperature	2.1	0.9	2.0	3.8	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Max Spring Temperature	8.3	10.9	12.4	14.1	↑
	Max Summer Temperature	21.4	25.2	27.1	29.2	↑
	Max Fall Temperature	14.5	14.8	16.2	18.3	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	4.1	5.8	7.8	↑
	Min Winter Temperature	-8.0	-7.6	-5.8	-3.3	↓
	Min Spring Temperature	-1.0	1.6	3.3	5.1	↑
	Min Summer Temperature	12.7	15.4	17.1	19.1	↑
	Min Fall Temperature	5.7	6.8	8.4	10.3	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	0.7	2.0	7.3	↑
	Days Above 30°C	7.6	10.4	19.7	38.9	↑
	Days Above 25°C	42.1	49.9	68.0	90.0	↑
	Days Above 20°C (Tropical Nights)	100.6	108.1	125.0	143.3	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	6.4	3.2	1.0	↓
	Days Below -10°C	49.0	32.1	21.1	11.9	↓
	Days Below 0°C (freezing days)	146.8	128.1	110.0	87.3	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	1059.2	273.9	301.3	↑
	Winter (mm/season)	228.3	237.4	246.5	273.9	↑
	Spring (mm/season)	219.2	273.9	292.2	328.7	↑
	Summer (mm/season)	228.3	273.9	292.2	319.6	↑
	Fall (mm/season)	273.9	264.8	273.9	292.2	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	51.8	57.6	62.6	↑
	Max Precipitation in 3 days (mm)	54.9	72.9	79.7	87.4	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.9	3.0	3.3	↑
	95th Percentile Precipitation (mm)	36.1	45.7	46.9	46.8	↑
	99th Percentile Precipitation (mm)	11.2	15.3	15.8	15.8	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Dry Days (days/year)	Total Annual	136.9	202.8	207.5	202.6	↓
	Total Annual Consecutive Dry Days	17.0	22.4	23.1	23.1	↑
Growing Season	Growing Season Start Date (day of year)	May 14	May 9	May 2	April 20	↑
	Growing Season End Date (day of year)	Oct 24	Oct. 31	Nov. 10	Nov 19	↑
	Growing Season Length (days/year)	163	176	193	214	↑
Agricultural Variables	Corn Heat Units	3193.9	3555.7	4095.4	4722.8	↑
	Growing Degree Days (Base 0°C)	3197.9	3536.1	3975.3	4521.8	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2484.0	2860.6	3337.3	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2253.9	2614.8	3072.7	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1276.9	1565.2	1934.8	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	567.1	778.6	1062.7	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	81.0	72.1	60.0	↓
	Ice Potential (days per year)	28.8	14.2	10.5	7.4	↓

Town of Whitby

Table F-3: Climate Change Trends for the Town of Whitby under the RCP 8.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	8.4	9.8	11.8	↑
	Winter	-3.0	-4.0	-2.6	-0.2	↓
	Spring	3.6	6.6	7.6	9.4	↑
	Summer	17.1	20.6	22.2	24.1	↑
	Fall	10.1	10.2	11.8	13.8	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	13.0	14.5	16.5	↑
	Max Winter Temperature	2.1	-0.2	1.0	3.1	↑
	Max Spring Temperature	8.3	11.6	13.0	14.7	↑
	Max Summer Temperature	21.4	26.4	28.1	30.0	↑
	Max Fall Temperature	14.5	14.3	15.9	18.0	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	4.1	5.7	8.0	↑
	Min Winter Temperature	-8.0	-8.3	-6.4	-3.5	↓
	Min Spring Temperature	-1.0	2.1	3.6	5.6	↑
	Min Summer Temperature	12.7	15.9	17.5	19.6	↑
	Min Fall Temperature	5.7	6.6	8.2	10.4	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	2.4	5.7	13.2	↑
	Days Above 30°C	7.6	18.3	30.3	49.5	↑
	Days Above 25°C	42.1	61.8	81.0	102.0	↑
	Days Above 20°C (Tropical Nights)	100.6	118.6	133.3	149.0	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	7.6	3.9	0.9	↓
	Days Below -10°C	49.0	39.0	27.2	14.0	↓
	Days Below 0°C (freezing days)	146.8	127.8	112.2	89.5	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	1059.2	1132.3	1205.3	↑
	Winter (mm/season)	228.3	219.2	237.4	264.8	↑
	Spring (mm/season)	219.2	273.9	292.2	319.6	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Summer (mm/season)	228.3	301.3	310.5	328.7	↑
	Fall (mm/season)	273.9	264.8	283.1	292.2	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	51.3	56.6	61.8	↑
	Max Precipitation in 3 days (mm)	54.9	73.3	78.3	86.6	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.9	3.1	3.3	↑
	95th Percentile Precipitation (mm)	36.1	45.1	45.6	45.6	↑
	99th Percentile Precipitation (mm)	11.2	14.9	15.2	15.3	↑
Dry Days (days/year)	Total Annual	145.3	204.3	203.7	198.4	↓
	Total Annual Consecutive Dry Days	18.2	23.2	23.7	23.4	↑
Growing Season	Growing Season Start Date (day of year)	May 14	May 2	Apr 27	Apr 16	↑
	Growing Season End Date (day of year)	Oct 24	Oct 30	Nov 8	Nov 18	↑
	Growing Season Length (days/year)	163	182	196	217	↑
Agricultural Variables	Corn Heat Units	3193.9	3748.6	4253.4	4876.3	↑
	Growing Degree Days (Base 0°C)	3197.9	3656.7	4079.0	4636.4	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2632.2	3000.2	3485.0	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2404.3	2759.1	3225.9	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1418.5	1708.3	2091.0	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	679.6	899.3	1200.1	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	68.8	63.6	54.7	↓
	Ice Potential (days per year)	28.8	17.9	15.2	10.7	↑

City of Oshawa

Table F-3: Climate Change Trends for the City of Oshawa under the RCP 8.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	8.9	10.7	12.8	↑
	Winter	-3.0	-4.2	-2.7	-0.2	↓
	Spring	3.6	6.8	8.7	10.6	↑
	Summer	17.1	21.3	24.0	26.0	↑
	Fall	10.1	11.6	12.7	14.9	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	12.9	14.5	16.4	↑
	Max Winter Temperature	2.1	0.2	1.2	3.2	↑
	Max Spring Temperature	8.3	10.9	12.9	14.6	↑
	Max Summer Temperature	21.4	25.4	27.9	29.9	↑
	Max Fall Temperature	14.5	15.1	15.9	18.0	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	4.0	5.8	8.1	↑
	Min Winter Temperature	-8.0	-8.3	-6.3	-3.4	↓
	Min Spring Temperature	-1.0	2.0	3.6	5.6	↑
	Min Summer Temperature	12.7	15.1	17.5	19.6	↑
	Min Fall Temperature	5.7	7.2	8.2	10.4	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	4.2	1.9	6.8	↑
	Days Above 30°C	7.6	17.1	19.7	38.6	↑
	Days Above 25°C	42.1	52.7	68.5	91.4	↑
	Days Above 20°C (Tropical Nights)	100.6	105.0	126.3	144.4	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Extreme Cold (days/year)	Days Below -20°C	8.6	6.6	3.2	1.0	↓
	Days Below -10°C	49.0	31.0	21.5	11.6	↓
	Days Below 0°C (freezing days)	146.8	121.9	110.1	87.3	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	1388.0	1132.3	1241.9	↓
	Winter (mm/season)	228.3	465.7	255.7	283.1	↓
	Spring (mm/season)	219.2	337.9	292.2	328.7	↓
	Summer (mm/season)	228.3	292.2	301.3	319.6	↑
	Fall (mm/season)	273.9	273.9	283.1	301.3	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	51.6	55.9	60.9	↑
	Max Precipitation in 3 days (mm)	54.9	102.5	78.1	85.5	↓
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	3.8	3.1	3.4	↓
	95th Percentile Precipitation (mm)	36.1	46.9	45.8	45.9	↓
	99th Percentile Precipitation (mm)	11.2	14.6	15.3	15.4	↑
Dry Days (days/year)	Total Annual	145.3	200.1	200.1	196.0	↓
	Total Annual Consecutive Dry Days	18.2	22.8	21.9	21.9	↓
Growing Season	Growing Season Start Date (day of year)	May 14	May 9	May 2	April 20	↑
	Growing Season End Date (day of year)	Oct 24	Nov 1	Nov 10	Nov 19	↑
	Growing Season Length (days/year)	163	177	193	214	↑
Agricultural Variables	Corn Heat Units	3193.9	3568.1	4111.8	4742.5	↑
	Growing Degree Days (Base 0°C)	3197.9	3541.4	3981.7	4530.6	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2488.8	2868.9	3345.9	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2258.4	2623.2	3081.2	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1280.1	1572.7	1942.0	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	569.5	784.3	1067.7	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	80.4	71.2	60.2	↓
	Ice Potential (days per year)	28.8	14.5	11.3	7.6	↓

Municipality of Clarington

Table F-5: Climate Change Trends in the Municipality of Clarington under the RCP 8.5 scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	8.6	10.1	12.2	↑
	Winter	-3.0	-4.0	-2.5	-0.1	↓
	Spring	3.6	6.8	8.3	10.1	↑
	Summer	17.1	21.0	22.7	24.7	↑
	Fall	10.1	10.4	11.9	14.0	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	13.1	14.5	16.4	↑
	Max Winter Temperature	2.1	-0.1	1.2	3.2	↑
	Max Spring Temperature	8.3	11.6	12.9	14.6	↑
	Max Summer Temperature	21.4	26.3	27.9	29.9	↑
	Max Fall Temperature	14.5	14.4	15.9	18.0	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	4.1	5.8	8.1	↑
	Min Winter Temperature	-8.0	-8.3	-6.3	-3.4	↓
	Min Spring Temperature	-1.0	2.0	3.6	5.6	↑
	Min Summer Temperature	12.7	15.9	17.5	19.6	↑
	Min Fall Temperature	5.7	6.6	8.2	10.4	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	0.6	2.1	7.2	↑
	Days Above 30°C	7.6	10.9	20.8	40.3	↑
	Days Above 25°C	42.1	51.1	70.5	93.4	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Days Above 20°C (Tropical Nights)	100.6	111.3	127.9	145.4	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	6.6	3.3	1.0	↓
	Days Below -10°C	49.0	33.8	22.9	12.2	↓
	Days Below 0°C (freezing days)	146.8	127.7	110.3	87.6	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	1059.2	1132.3	1241.9	↑
	Winter (mm/season)	228.3	228.3	255.7	283.1	↑
	Spring (mm/season)	219.2	273.9	292.2	328.7	↑
	Summer (mm/season)	228.3	292.2	301.3	319.6	↑
	Fall (mm/season)	273.9	273.9	283.1	301.3	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	51.7	56.1	61.3	↑
	Max Precipitation in 3 days (mm)	54.9	73.1	78.4	86.0	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.9	3.1	3.4	↑
	95^{th} Percentile Precipitation (mm)	36.1	45.4	45.9	61.3	↑
	99^{th} Percentile Precipitation (mm)	11.2	15.0	15.2	86.0	↑
Dry Days (days/year)	Total Annual	145.3	199.4	199.6	195.7	↓
	Total Annual Consecutive Dry Days	18.2	22.3	22.3	22.3	-
Growing Season	Growing Season Start Date (day of year)	May 14	May 8	May 1	Apr 18	↑
	Growing Season End Date (day of year)	Oct 24	Oct. 31	Nov 9	Nov 18	↑
	Growing Season Length (days/year)	163	178	194	215	↑
Agricultural Variables	Corn Heat Units	3193.9	3610.2	4147.6	4779.9	↑
	Growing Degree Days (Base 0°C)	3197.9	3563.7	4000.4	4552.4	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2515.4	2892.9	3372.9	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2285.2	2647.7	3109.0	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1304.2	1595.9	1969.0	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	587.6	803.0	1090.6	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	78.6	70.1	59.6	↓
	Ice Potential (days per year)	28.8	15.0	12.0	8.0	↓

Township of Uxbridge

Table F-6: Climate Change Trends for the Township of Uxbridge under the RCP 8.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	8.5	10.1	12.1	↑
	Winter	-3.0	-3.9	-2.3	0.1	↑
	Spring	3.6	6.5	7.9	9.7	↑
	Summer	17.1	20.8	22.5	24.4	↑
	Fall	10.1	10.7	12.2	14.3	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	13.0	14.4	16.4	↑
	Max Winter Temperature	2.1	0.4	1.6	3.5	↑
	Max Spring Temperature	8.3	11.2	12.4	14.2	↑
	Max Summer Temperature	21.4	25.8	27.4	29.4	↑
	Max Fall Temperature	14.5	14.7	16.1	18.3	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	4.1	5.7	7.9	↑
	Min Winter Temperature	-8.0	-8.3	-6.4	-3.6	↓
	Min Spring Temperature	-1.0	1.8	3.4	5.3	↑
	Min Summer Temperature	12.7	15.9	17.5	19.5	↑
	Min Fall Temperature	5.7	6.8	8.4	10.5	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Extreme Heat (days/year)	Days Above 35°C	0.2	4.0	8.3	16.7	↑
	Days Above 30°C	7.6	22.5	34.7	53.8	↑
	Days Above 25°C	42.1	67.2	85.3	105.4	↑
	Days Above 20°C (Tropical Nights)	100.6	121.1	135.2	150.4	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	8.5	4.4	1.1	↓
	Days Below -10°C	49.0	41.7	29.2	15.2	↓
	Days Below 0°C (freezing days)	146.8	128.6	113.9	90.1	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	1022.7	1095.8	1205.3	↑
	Winter (mm/season)	228.3	210.0	237.4	264.8	↑
	Spring (mm/season)	219.2	255.7	273.9	310.5	↑
	Summer (mm/season)	228.3	292.2	292.2	319.6	↑
	Fall (mm/season)	273.9	273.9	283.1	301.3	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	47.8	52.7	58.4	↑
	Max Precipitation in 3 days (mm)	54.9	70.0	74.4	82.4	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.8	3.0	3.3	↑
	95th Percentile Precipitation (mm)	36.1	43.3	43.3	43.7	↑
	99th Percentile Precipitation (mm)	11.2	14.3	14.3	14.6	↑
Dry Days (days/year)	Total Annual	145.3	196.1	191.9	189.8	↓
	Total Annual Consecutive Dry Days	18.2	23.3	21.6	22.9	↓
Growing Season	Growing Season Start Date (day of year)	May 14	May 1	Apr 27	Apr 15	↑
	Growing Season End Date (day of year)	Oct 24	Oct 29	Nov 7	Nov 17	↑
	Growing Season Length (days/year)	163	183	195	217	↑
Agricultural Variables	Corn Heat Units	3193.9	3807.5	4279.0	4907.1	↑
	Growing Degree Days (Base 0°C)	3197.9	3702.2	4107.6	4674.2	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2688.8	3042.5	3535.0	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2462.4	2803.8	3278.4	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1477.4	1758.0	2148.7	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	730.3	945.3	1254.1	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	65.8	61.5	52.8	↓
	Ice Potential (days per year)	28.8	21.1	19.1	13.4	↓

Township of Scugog

Table F-7: Climate Change Trends for the Township of Scugog under the RCP 8.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	9.1	10.7	12.2	↑
	Winter	-3.0	-4.5	-2.8	-0.2	↓
	Spring	3.6	7.2	8.8	10.1	↑
	Summer	17.1	22.4	24.1	24.8	↑
	Fall	10.1	11.1	12.7	14.1	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	13.0	14.5	16.5	↑
	Max Winter Temperature	2.1	-0.2	1.0	3.1	↑
	Max Spring Temperature	8.3	11.6	13.0	14.7	↑
	Max Summer Temperature	21.4	26.4	28.1	30.0	↑
	Max Fall Temperature	14.5	14.3	15.9	18.0	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	4.1	5.7	8.0	↑
	Min Winter Temperature	-8.0	-8.3	-6.4	-3.5	↓

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Min Spring Temperature	-1.0	2.1	3.6	5.6	↑
	Min Summer Temperature	12.7	16.0	17.5	19.6	↑
	Min Fall Temperature	5.7	6.6	8.2	10.4	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	3.8	8.4	16.8	↑
	Days Above 30°C	7.6	22.5	35.3	54.9	↑
	Days Above 25°C	42.1	68.7	86.8	106.6	↑
	Days Above 20°C (Tropical Nights)	100.6	122.0	136.2	151.0	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	8.9	4.6	1.1	↓
	Days Below -10°C	49.0	42.1	30.1	15.7	↓
	Days Below 0°C (freezing days)	146.8	128.0	113.3	90.1	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	1059.2	1132.3	1205.3	↑
	Winter (mm/season)	228.3	219.2	237.4	264.8	↑
	Spring (mm/season)	219.2	273.9	292.2	319.6	↑
	Summer (mm/season)	228.3	301.3	310.5	328.7	↑
	Fall (mm/season)	273.9	264.8	283.1	292.2	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	51.5	57.2	62.4	↑
	Max Precipitation in 3 days (mm)	54.9	73.9	79.0	86.7	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.9	3.1	3.3	↑
	95th Percentile Precipitation (mm)	36.1	45.1	45.4	45.4	↑
	99th Percentile Precipitation (mm)	11.2	14.9	15.1	15.3	↑
Dry Days (days/year)	Total Annual	145.3	207.2	206.4	201.1	↓
	Total Annual Consecutive Dry Days	18.2	23.9	23.1	24.9	↑
Growing Season	Growing Season Start Date (day of year)	May 14	Apr 29	Apr 25	Apr 13	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Growing Season End Date (day of year)	Oct 24	Oct 29	Nov 7	Nov 17	↑
	Growing Season Length (days/year)	163	185	197	219	↑
Agricultural Variables	Corn Heat Units	3193.9	3816.4	4302.5	4924.1	↑
	Growing Degree Days (Base 0°C)	3197.9	3715.0	4129.1	4690.2	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2699.8	3063.0	3551.5	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2472.7	2823.4	3294.5	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1484.2	1772.9	2160.8	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	734.8	956.1	1263.1	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	62.8	59.0	50.8	↓
	Ice Potential (days per year)	28.8	196	17.0	12.1	↓

Township of Brock

Table F-8: Climate Change Trends for the Township of Brock under the RCP 8.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	6.0	10.0	12.3	↑
	Winter	-3.0	-4.2	-2.6	0.1	↓
	Spring	3.6	6.7	8.1	10.0	↑
	Summer	17.1	21.0	22.6	24.7	↑
	Fall	10.1	10.6	12.0	14.3	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	13.0	14.4	16.4	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Max Winter Temperature	2.1	0.0	1.3	3.3	↑
	Max Spring Temperature	8.3	11.4	12.7	14.4	↑
	Max Summer Temperature	21.4	26.1	27.7	29.8	↑
	Max Fall Temperature	14.5	14.5	16.0	18.1	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	4.1	5.7	8.0	↑
	Min Winter Temperature	-8.0	-8.5	-6.4	-3.5	↓
	Min Spring Temperature	-1.0	1.9	3.4	5.5	↑
	Min Summer Temperature	12.7	16.0	17.4	19.6	↑
	Min Fall Temperature	5.7	6.8	8.4	10.5	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	3.6	7.9	16.2	↑
	Days Above 30°C	7.6	21.9	34.2	53.9	↑
	Days Above 25°C	42.1	67.8	85.6	106.0	↑
	Days Above 20°C (Tropical Nights)	100.6	121.6	135.6	150.7	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	9.2	4.8	1.1	↓
	Days Below -10°C	49.0	42.7	30.5	15.7	↓
	Days Below 0°C (freezing days)	146.8	127.7	112.9	89.2	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	1095.8	1132.3	1241.9	↑
	Winter (mm/season)	228.3	228.3	255.7	292.2	↑
	Spring (mm/season)	219.2	255.7	273.9	310.5	↑
	Summer (mm/season)	228.3	301.3	301.3	319.6	↑
	Fall (mm/season)	273.9	301.3	310.5	319.6	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	55.2	52.3	56.9	↑
	Max Precipitation in 3 days (mm)	54.9	67.6	74.1	80.8	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	3.0	3.1	3.4	↑
	95th Percentile Precipitation (mm)	36.1	42.3	42.9	42.7	↓
	99th Percentile Precipitation (mm)	11.2	13.8	14.0	14.1	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Dry Days (days/year)	Total Annual	145.3	179.2	191.6	183.6	↑
	Total Annual Consecutive Dry Days	18.2	21.3	22.5	22.1	↑
Growing Season	Growing Season Start Date (day of year)	May 14	Apr 30	Apr 30	Apr 15	↑
	Growing Season End Date (day of year)	Oct 24	Oct 30	Nov 7	Nov 17	↑
	Growing Season Length (days/year)	163	183	191	216	↑
Agricultural Variables	Corn Heat Units	3193.9	3827.6	4304.4	4928.1	↑
	Growing Degree Days (Base 0°C)	3197.9	3713.8	4121.0	4685.7	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2698.3	3054.2	3544.8	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2471.4	2814.9	3287.7	↓
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1483.8	1766.6	2155.3	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	734.2	951.5	1258.4	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	64.8	60.6	51.9	↓
	Ice Potential (days per year)	28.8	21.9	18.9	13.9	↓

Appendix G: Climate Summary Tables for Each Local Municipality within Durham Region under the RCP 4.5 Scenario

City of Pickering

Table G-1: Climate change trends for the City of Pickering under the RCP 4.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	9.9	11.1	11.5	↑
	Winter	-3.0	-2.5	-0.7	-0.7	↓
	Spring	3.6	8.1	9.1	9.7	↑
	Summer	17.1	22.2	23.2	23.7	↑
	Fall	10.1	11.8	12.9	13.3	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	14.7	15.8	16.3	↑
	Max Winter Temperature	2.1	1.1	2.7	2.7	↑
	Max Spring Temperature	8.3	13.1	14.0	14.7	↑
	Max Summer Temperature	21.4	28.2	29.3	29.8	↑
	Max Fall Temperature	14.5	16.2	17.2	17.8	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	5.2	6.6	7.0	↑
	Min Winter Temperature	-8.0	-6.5	-4.2	-4.1	↓
	Min Spring Temperature	-1.0	3.1	4.2	4.8	↑
	Min Summer Temperature	12.7	16.2	17.3	17.8	↑
	Min Fall Temperature	5.7	7.8	8.9	9.3	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	1.2	4.3	4.3	↑
	Days Above 30°C	7.6	16.5	31.1	31.1	↑
	Days Above 25°C	42.1	65.4	85.2	85.2	↑
	Days Above 20°C (Tropical Nights)	100.6	123.4	137.7	137.7	↑
	Days Below -20°C	8.6	1.0	0.2	0.2	↓
	Days Below -10°C	49.0	19.2	11.2	11.2	↓

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Extreme Cold (days/year)	Days Below 0°C (freezing days)	146.8	116.9	95.2	95.2	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	949.7	986.2	1059.2	↑
	Winter (mm/season)	228.3	219.2	228.3	237.4	↑
	Spring (mm/season)	219.2	246.5	255.7	264.8	↑
	Summer (mm/season)	228.3	228.3	237.4	264.8	↑
	Fall (mm/season)	273.9	255.7	264.8	273.9	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	32.6	83.8	53.8	↑
	Max Precipitation in 3 days (mm)	54.9	66.8	72.4	73.0	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.6	2.7	2.9	↑
	95^{th} Percentile Precipitation (mm)	36.1	47.6	48.8	48.7	↑
	99^{th} Percentile Precipitation (mm)	11.2	15.9	16.4	16.6	↑
Dry Days (days/year)	Total Annual	145.3	214.2	215.2	203.2	↓
	Total Annual Consecutive Dry Days	18.2	24.7	21.7	22.3	↓
Growing Season	Growing Season Start Date (day of year)	May 14	May 10	May 2	Apr 28	↑
	Growing Season End Date (day of year)	Oct 24	Nov 4	Nov 18	Nov 18	↑
	Growing Season Length (days/year)	163	179	200	205	↑
Agricultural Variables	Corn Heat Units	3193.9	3840.6	4235.2	4412.2	↑
	Growing Degree Days (Base 0°C)	3197.9	3780.2	4131.6	4275.9	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2694.1	2980.1	3115.4	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2455.6	2726.3	2858.4	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1438.7	1639.0	1752.3	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	684.3	826.6	914.1	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	76.6	66.7	63.0	↓
	Ice Potential (days per year)	28.8	9.2	6.9	8.7	↓

Town of Ajax

Table G-2: Climate Change Trends for the Town of Ajax under the RCP 4.5 scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	9.6	10.9	11.2	↑
	Winter	-3.0	-2.0	-0.2	-0.2	-
	Spring	3.6	7.1	8.2	8.7	↑
	Summer	17.1	21.1	22.2	22.8	↑
	Fall	10.1	12.1	13.2	13.6	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	14.3	15.5	15.9	↑
	Max Winter Temperature	2.1	1.9	3.3	3.4	↑
	Max Spring Temperature	8.3	12.1	13.1	13.7	↑
	Max Summer Temperature	21.4	26.8	27.9	28.5	↑
	Max Fall Temperature	14.5	16.5	17.6	18.0	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	4.9	6.3	6.7	↑
	Min Winter Temperature	-8.0	-6.1	-4.0	-3.9	↓
	Min Spring Temperature	-1.0	2.2	3.4	3.9	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Min Summer Temperature	12.7	15.5	16.6	17.2	↑
	Min Fall Temperature	5.7	7.9	9.1	9.4	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	0.4	1.2	2.1	↑
	Days Above 30°C	7.6	11.5	18.6	23.8	↑
	Days Above 25°C	42.1	56.8	70.2	77.9	↑
	Days Above 20°C (Tropical Nights)	100.6	118.9	128.7	134.8	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	0.7	0.1	0.1	↓
	Days Below -10°C	49.0	16.0	9.4	9.5	↓
	Days Below 0°C (freezing days)	146.8	116.0	96.6	93.3	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	949.7	986.2	1022.7	↑
	Winter (mm/season)	228.3	228.3	237.4	246.5	↑
	Spring (mm/season)	219.2	237.4	246.5	255.7	↑
	Summer (mm/season)	228.3	219.2	228.3	246.5	↑
	Fall (mm/season)	273.9	246.5	255.7	255.7	↓
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	34.2	89.5	56.7	↑
	Max Precipitation in 3 days (mm)	54.9	69.0	74.7	75.3	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.6	2.7	2.8	↑
	95th Percentile Precipitation (mm)	36.1	49.2	50.6	50.6	↑
	99th Percentile Precipitation (mm)	11.2	16.6	17.2	17.6	↑
Dry Days (days/year)	Total Annual	136.9	226.1	227.8	215.3	↓
	Total Annual Consecutive Dry Days	17.0	29.0	24.7	23.7	↓
Growing Season	Growing Season Start Date (day of year)	May 14	May 13	May 5	May 3	↑
	Growing Season End Date (day of year)	Oct 24	Nov 5	Nov 19	Nov 19	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Growing Season Length (days/year)	163	154	199	200	↑
Agricultural Variables	Corn Heat Units	3193.9	3770.73	4180.8	4363.3	↑
	Growing Degree Days (Base 0°C)	3197.9	3727.7	4088.0	4231.0	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2628.4	2919.2	3052.6	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2389.2	2663.6	2793.9	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1375.9	1576.5	1688.6	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	631.9	773.4	857.7	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	79.5	67.4	63.3	↓
	Ice Potential (days per year)	28.8	7.4	5.1	7.0	↓

Town of Whitby

Table G-3: Climate change trends for the Town of Whitby under the RCP 4.5 scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	9.3	11.1	11.5	↑
	Winter	-3.0	-3.0	-0.7	-0.7	↓
	Spring	3.6	7.1	9.1	9.7	↑
	Summer	17.1	21.5	23.2	23.7	↑
	Fall	10.1	11.4	12.9	13.3	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	13.9	15.8	16.3	↑
	Max Winter Temperature	2.1	1.0	2.7	2.7	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Max Spring Temperature	8.3	12.1	14.0	14.7	↑
	Max Summer Temperature	21.4	26.8	29.3	29.8	↑
	Max Fall Temperature	14.5	15.6	17.2	17.8	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	4.6	6.6	7.0	↑
	Min Winter Temperature	-8.0	-7.2	-4.2	-4.1	↓
	Min Spring Temperature	-1.0	2.0	4.2	4.8	↑
	Min Summer Temperature	12.7	16.0	17.3	17.8	↑
	Min Fall Temperature	5.7	7.5	8.9	9.3	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	2.4	9.0	11.8	↑
	Days Above 30°C	7.6	19.2	40.0	46.6	↑
	Days Above 25°C	42.1	68.4	90.3	96.9	↑
	Days Above 20°C (Tropical Nights)	100.6	123.7	139.4	143.7	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	3.6	0.9	1.1	↓
	Days Below -10°C	49.0	32.4	16.7	16.1	↓
	Days Below 0°C (freezing days)	146.8	124.8	98.5	96.0	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	986.2	986.2	1059.2	↑
	Winter (mm/season)	228.3	219.2	228.3	237.4	↑
	Spring (mm/season)	219.2	237.4	255.7	264.8	↑
	Summer (mm/season)	228.3	237.4	237.4	264.8	↑
	Fall (mm/season)	273.9	292.2	264.8	273.9	-
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	34.4	91.3	56.3	↑
	Max Precipitation in 3 days (mm)	54.9	68.7	75.6	77.0	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.7	2.7	2.9	↑
	95th Percentile Precipitation (mm)	36.1	46.0	49.2	48.6	↑
	99th Percentile Precipitation (mm)	11.2	15.0	16.9	16.8	↑
Dry Days (days/year)	Total Annual	145.3	218.2	223.1	207.5	↓

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Total Annual Consecutive Dry Days	18.2	24.0	22.3	23.0	↓
Growing Season	Growing Season Start Date (day of year)	May 14	May 7	Apr 30	Apr 28	↑
	Growing Season End Date (day of year)	Oct 24	Oct 20	Nov 12	Nov 11	↑
	Growing Season Length (days/year)	163	168	197	198	↑
Agricultural Variables	Corn Heat Units	3193.9	3866.1	4373.6	4542.2	↑
	Growing Degree Days (Base 0°C)	3197.9	3766.2	4274.9	4419.0	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2719.9	3142.9	3279.1	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2486.4	2889.5	3023.2	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1485.9	1794.3	1908.7	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	734.1	958.8	1050.8	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	75.1	61.5	58.9	↓
	Ice Potential (days per year)	28.8	13.1	8.6	10.8	↓

City of Oshawa

Table G-4: Climate change trends for the City of Oshawa under the RCP 4.5 scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	10.5	5.9	7.0	↓
	Winter	-3.0	-2.7	-5.2	-4.1	↓
	Spring	3.6	8.5	3.0	4.8	↓
	Summer	17.1	23.4	17.0	17.8	↓
	Fall	10.1	12.6	8.7	9.3	↓
Maximum Temperature (°C)	Max Annual Temperature	11.6	14.6	14.8	16.2	↑
	Max Winter Temperature	2.1	1.2	2.5	2.8	↑
	Max Spring Temperature	8.3	13.0	12.6	14.6	↑
	Max Summer Temperature	21.4	28.0	27.6	29.7	↑
	Max Fall Temperature	14.5	16.1	16.6	17.7	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	5.2	14.8	16.2	↑
	Min Winter Temperature	-8.0	-6.5	2.5	2.8	↑
	Min Spring Temperature	-1.0	3.1	12.6	14.6	↑
	Min Summer Temperature	12.7	16.2	27.6	29.7	↑
	Min Fall Temperature	5.7	7.8	16.6	17.7	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	0.5	0.7	2.2	↑
	Days Above 30°C	7.6	11.8	15.3	24.4	↑
	Days Above 25°C	42.1	57.9	62.8	78.9	↑
	Days Above 20°C (Tropical Nights)	100.6	114	122.2	134.9	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	0.5	0.2	0.1	↑
	Days Below -10°C	49.0	15.5	13.1	8.5	↓
	Days Below 0°C (freezing days)	146.8	114	107.6	90.9	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	986.2	1059.2	1059.2	↑
	Winter (mm/season)	228.3	228.3	246.5	246.5	↑
	Spring (mm/season)	219.2	246.5	255.7	264.8	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Summer (mm/season)	228.3	228.3	237.4	255.7	↑
	Fall (mm/season)	273.9	273.9	319.6	273.9	-
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	33.3	83.6	54.5	↑
	Max Precipitation in 3 days (mm)	54.9	69.1	71.7	73.0	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.7	2.9	2.9	↑
	95th Percentile Precipitation (mm)	36.1	48.1	46.6	49.1	↑
	99th Percentile Precipitation (mm)	11.2	16.0	15.3	16.9	↑
Dry Days (days/year)	Total Annual	145.3	218.1	213.0	207.5	↓
	Total Annual Consecutive Dry Days	18.2	21.3	21.0	23.0	↑
Growing Season	Growing Season Start Date (day of year)	May 14	May 14	May 6	May 6	↑
	Growing Season End Date (day of year)	Oct 24	Nov 8	Nov 17	Nov 16	↑
	Growing Season Length (days/year)	163	178	195	194	↑
Agricultural Variables	Corn Heat Units	3193.9	3810.3	4102.1	4399.6	↑
	Growing Degree Days (Base 0°C)	3197.9	3757.0	3968.8	4259.8	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2653.6	2838.5	3076.8	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2413.1	2590.2	2816.7	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1393.6	1535.9	1704.9	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	645.0	754.6	869.3	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	77.0	76.1	61.2	↓
	Ice Potential (days per year)	28.8	8.3	7.7	7.7	↓

Municipality of Clarington

Table G-5: Climate change trends for the Municipality of Clarington under the RCP 4.5 scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	9.9	11.5	7.0	↓
	Winter	-3.0	-2.5	-0.3	-4.1	↓
	Spring	3.6	8.0	9.4	4.8	↓
	Summer	17.1	22.1	23.5	17.8	↓
	Fall	10.1	11.8	13.3	9.3	↓
Maximum Temperature (°C)	Max Annual Temperature	11.6	14.6	15.8	16.2	↑
	Max Winter Temperature	2.1	1.2	2.8	2.8	↑
	Max Spring Temperature	8.3	13.0	13.9	14.6	↑
	Max Summer Temperature	21.4	28.0	29.1	29.7	↑
	Max Fall Temperature	14.5	16.1	17.2	17.7	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	5.2	6.6	11.5	↑
	Min Winter Temperature	-8.0	-6.5	-4.2	-0.6	↓
	Min Spring Temperature	-1.0	3.1	4.2	9.6	↑
	Min Summer Temperature	12.7	16.2	17.3	23.7	↑
	Min Fall Temperature	5.7	7.8	9.0	13.3	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	0.6	1.4	2.6	↑
	Days Above 30°C	7.6	13.1	21.2	26.8	↑
	Days Above 25°C	42.1	60.9	74.6	81.5	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Days Above 20°C (Tropical Nights)	100.6	121.4	130.9	135.9	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	0.7	0.2	0.1	↓
	Days Below -10°C	49.0	17.3	9.9	10.0	↑
	Days Below 0°C (freezing days)	146.8	112.9	94.0	90.5	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	986.2	986.2	1059.2	↑
	Winter (mm/season)	228.3	228.3	237.4	246.5	↑
	Spring (mm/season)	219.2	246.5	255.7	264.8	↑
	Summer (mm/season)	228.3	228.3	228.3	255.7	↑
	Fall (mm/season)	273.9	273.9	273.9	273.9	-
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	33.1	83.5	54.9	↑
	Max Precipitation in 3 days (mm)	54.9	69.9	72.3	74.0	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.7	2.7	2.9	↑
	95th Percentile Precipitation (mm)	36.1	48.2	49.4	49.1	↑
	99th Percentile Precipitation (mm)	11.2	16.0	16.5	16.8	↑
Dry Days (days/year)	Total Annual	145.3	217.4	218.9	207.0	↓
	Total Annual Consecutive Dry Days	18.2	21.7	22.3	22.3	↑
Growing Season	Growing Season Start Date (day of year)	May 14	May 9	May 2	Apr 29	↑
	Growing Season End Date (day of year)	Oct 24	Nov 7	Nov 20	Nov 21	↑
	Growing Season Length (days/year)	163	183	203	207	↑
Agricultural Variables	Corn Heat Units	3193.9	3863.7	4268.5	4444.5	↑
	Growing Degree Days (Base 0°C)	3197.9	3794.3	4151.8	4290.7	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Canola Growing Degree Days (Base 4°C)	2236.3	2692.9	2983.7	3112.3	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2451.7	2726.5	2852.1	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1426.8	1629.3	1736.4	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	671.3	814.4	895.9	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	74.4	64.3	60.3	↓
	Ice Potential (days per year)	28.8	9.1	6.5	8.3	↓

Township of Uxbridge

Table G-6: Climate change trends for the Township of Uxbridge under the RCP 4.5 scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	9.8	11.1	11.5	↑
	Winter	-3.0	-2.5	-0.6	-0.5	↓
	Spring	3.6	7.5	8.5	9.1	↑
	Summer	17.1	22.0	23.1	23.5	↑
	Fall	10.1	12.1	13.2	13.7	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	14.5	15.6	16.0	↑
	Max Winter Temperature	2.1	1.5	2.9	3.0	↑
	Max Spring Temperature	8.3	12.3	13.3	13.9	↑
	Max Summer Temperature	21.4	27.6	28.7	29.1	↑
	Max Fall Temperature	14.5	16.4	17.4	17.9	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Minimum Temperature (°C)	Min Annual Temperature	2.4	5.2	6.6	7.0	↑
	Min Winter Temperature	-8.0	-6.6	-4.3	-4.2	↓
	Min Spring Temperature	-1.0	2.8	4.0	4.5	↑
	Min Summer Temperature	12.7	16.4	17.5	18.0	↑
	Min Fall Temperature	5.7	8.1	9.2	9.6	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	10.7	15.7	18.7	↑
	Days Above 30°C	7.6	38.9	48.9	54.8	↑
	Days Above 25°C	42.1	87.3	96.4	103.1	↑
	Days Above 20°C (Tropical Nights)	100.6	134.3	142.7	146.4	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	3.4	1.3	1.3	↓
	Days Below -10°C	49.0	29.7	18.4	17.7	↓
	Days Below 0°C (freezing days)	146.8	116.2	100.4	97.7	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	913.1	949.7	986.2	↑
	Winter (mm/season)	228.3	210.0	219.2	228.3	↑
	Spring (mm/season)	219.2	228.3	237.4	246.5	↑
	Summer (mm/season)	228.3	219.2	219.2	246.5	↑
	Fall (mm/season)	273.9	255.7	264.8	264.8	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	36.2	87.4	56.4	↑
	Max Precipitation in 3 days (mm)	54.9	70.0	72.9	77.5	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.5	2.6	2.7	↑
	95th Percentile Precipitation (mm)	36.1	46.9	47.2	46.9	-
	99th Percentile Precipitation (mm)	11.2	16.4	16.4	16.2	↓
Dry Days (days/year)	Total Annual	145.3	215.7	215.1	201.2	↓
	Total Annual Consecutive Dry Days	18.2	23.3	23.0	23.0	-

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Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Growing Season	Growing Season Start Date (day of year)	May 14	Apr 26	Apr 21	Apr 18	↑
	Growing Season End Date (day of year)	Oct 24	Nov 3	Nov 13	Nov 13	↑
	Growing Season Length (days/year)	163	192	207	210	↑
Agricultural Variables	Corn Heat Units	3193.9	4085.5	4434.3	4594.2	↑
	Growing Degree Days (Base 0°C)	3197.9	4027.4	4358.9	4502.6	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2967.1	3240.7	3376.6	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2729.2	2989.6	3122.5	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1696.0	1895.4	2008.1	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	902.8	1049.6	1140.2	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	66.1	60.3	57.4	↓
	Ice Potential (days per year)	28.8	13.5	10.7	13.2	↓

Township of Scugog

Table G-7: Climate change trends for the Township of Scugog under the RCP 4.5 scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	10.6	11.2	11.6	↑
	Winter	-3.0	-2.9	-0.8	-0.7	↓
	Spring	3.6	8.6	9.1	9.7	↑
	Summer	17.1	23.7	23.3	23.8	↑
	Fall	10.1	12.8	13.1	13.5	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Maximum Temperature (°C)	Max Annual Temperature	11.6	14.7	15.8	16.3	↑
	Max Winter Temperature	2.1	1.1	2.7	2.7	↑
	Max Spring Temperature	8.3	13.1	14.0	14.7	↑
	Max Summer Temperature	21.4	28.2	29.3	29.8	↑
	Max Fall Temperature	14.5	16.2	17.2	17.8	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	5.2	6.6	7.0	↑
	Min Winter Temperature	-8.0	-6.5	-4.2	-4.1	↓
	Min Spring Temperature	-1.0	3.1	4.2	4.8	↑
	Min Summer Temperature	12.7	16.2	17.3	17.8	↑
	Min Fall Temperature	5.7	7.8	8.9	9.3	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	9.8	14.5	18.2	↑
	Days Above 30°C	7.6	38.5	49.0	55.0	↑
	Days Above 25°C	42.1	87.6	96.9	103.1	↑
	Days Above 20°C (Tropical Nights)	100.6	134.4	142.7	146.5	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	3.8	1.6	1.7	↓
	Days Below -10°C	49.0	30.0	19.4	18.6	↓
	Days Below 0°C (freezing days)	146.8	115.3	99.2	96.5	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	949.7	986.2	1059.2	↑
	Winter (mm/season)	228.3	219.2	228.3	237.4	↑
	Spring (mm/season)	219.2	246.5	255.7	264.8	↑
	Summer (mm/season)	228.3	228.3	237.4	264.8	↑
	Fall (mm/season)	273.9	255.7	264.8	273.9	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	38.0	103.8	57.7	↑
	Max Precipitation in 3 days (mm)	54.9	74.1	77.7	79.0	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.6	2.7	2.9	↑
	95^{th} Percentile Precipitation (mm)	36.1	48.4	49.2	48.3	↓

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	99th Percentile Precipitation (mm)	11.2	16.6	17.0	16.7	↑
Dry Days (days/year)	Total Annual	145.3	226.3	225.5	208.2	↓
	Total Annual Consecutive Dry Days	18.2	28.0	22.7	23.0	↓
Growing Season	Growing Season Start Date (day of year)	May 14	May 1	Apr 28	Apr 26	↑
	Growing Season End Date (day of year)	Oct 24	Oct 29	Nov 10	Nov 11	↑
	Growing Season Length (days/year)	163	182	198	213	↑
Agricultural Variables	Corn Heat Units	3193.9	4087.6	4446.2	4608.7	↑
	Growing Degree Days (Base 0°C)	3197.9	4031.8	4367.4	4510.7	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2967.1	3245.1	3381.3	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2728.1	2992.6	3126.0	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1690.8	1893.2	2007.5	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	896.8	1045.1	1137.7	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	63.8	58.2	55.2	↓
	Ice Potential (days per year)	28.8	12.6	9.5	12.4	↓

Township of Brock

Table G-8: Climate change trends for the Township of Brock under the RCP 4.5 scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	9.9	11.2	11.6	↑
	Winter	-3.0	-2.4	-0.5	-0.4	↓
	Spring	3.6	8.0	8.9	9.5	↑
	Summer	17.1	22.0	23.1	23.5	↑
	Fall	10.1	12.1	13.2	13.6	↑
Maximum Temperature (°C)	Max Annual Temperature	11.6	14.5	15.6	16.0	↑
	Max Winter Temperature	2.1	1.5	2.9	3.0	↑
	Max Spring Temperature	8.3	12.6	13.5	14.2	↑
	Max Summer Temperature	21.4	27.6	28.8	29.1	↑
	Max Fall Temperature	14.5	16.2	17.2	17.7	↑
Minimum Temperature (°C)	Min Annual Temperature	2.4	5.3	6.7	7.2	↑
	Min Winter Temperature	-8.0	-6.4	-4.1	-3.9	↓
	Min Spring Temperature	-1.0	3.1	4.2	4.9	↑
	Min Summer Temperature	12.7	16.4	17.4	17.9	↑
	Min Fall Temperature	5.7	8.2	9.3	9.7	↑
Extreme Heat (days/year)	Days Above 35°C	0.2	10.1	15.1	18.0	↑
	Days Above 30°C	7.6	38.1	48.3	54.2	↑
	Days Above 25°C	42.1	86.9	96.0	102.4	↑
	Days Above 20°C (Tropical Nights)	100.6	133.8	142.4	146.0	↑
Extreme Cold (days/year)	Days Below -20°C	8.6	3.6	1.4	1.4	↓
	Days Below -10°C	49.0	30.2	19.0	18.0	↓
	Days Below 0°C (freezing days)	146.8	114.7	99.1	95.8	↓
Total Precipitation (mm)	Annual (mm/year)	949.7	949.7	949.7	1022.7	↑
	Winter (mm/season)	228.3	228.3	228.3	246.5	↑
	Spring (mm/season)	219.2	228.3	237.4	255.7	↑
	Summer (mm/season)	228.3	210.0	210.0	237.4	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Fall (mm/season)	273.9	283.1	283.1	292.2	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.8	36.7	84.7	54.3	↑
	Max Precipitation in 3 days (mm)	54.9	70.5	71.7	75.2	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.6	2.6	2.6	2.8	↑
	95th Percentile Precipitation (mm)	36.1	46.2	46.5	46.1	↓
	99th Percentile Precipitation (mm)	11.2	16.0	16.0	15.6	↓
Dry Days (days/year)	Total Annual	145.3	211.0	210.6	197.2	↓
	Total Annual Consecutive Dry Days	18.2	23.7	20.0	23.3	↓
Growing Season	Growing Season Start Date (day of year)	May 14	Apr 26	Apr 20	Apr 18	↑
	Growing Season End Date (day of year)	Oct 24	Nov 3	Nov 13	Nov 13	↑
	Growing Season Length (days/year)	163	192	208	210	↑
Agricultural Variables	Corn Heat Units	3193.9	4107.3	4459.0	4618.6	↑
	Growing Degree Days (Base 0°C)	3197.9	4037.1	4371.3	4513.2	↑
	Canola Growing Degree Days (Base 4°C)	2236.3	2972.7	3248.5	3382.5	↑
	Forage Crops Growing Degree Days (Base 5°C)	2024.5	2733.8	2996.3	3127.1	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1119.2	1696.4	1897.4	2008.3	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	462.5	901.2	1049.3	1138.2	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	79.6	65.3	59.5	56.6	↓
	Ice Potential (days per year)	28.8	13.8	10.8	13.5	↓

Appendix H: Climate Summary Tables for Each Conservation Authority within Durham Region under the RCP 8.5 Scenario

Please note that these summary tables have been bias-corrected to the individual regions.

Toronto and Region Conservation Authority (TRCA)

Table H-1: Climate Trends for the TRCA under the RCP 8.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.3	8.8	10.4	12.4	↑
	Winter	-4.9	-3.2	-1.6	0.5	↑
	Spring	5.4	6.6	8.1	9.8	↑
	Summer	19.3	20.7	22.5	24.4	↑
	Fall	9.3	10.8	12.4	14.4	↑
Maximum Temperature (°C)	Max Annual Temperature	12.0	12.9	14.7	16.7	↑
	Max Winter Temperature	-0.7	2.5	2.1	3.7	↑
	Max Spring Temperature	10.5	11.6	12.8	14.6	↑
	Max Summer Temperature	24.8	25.9	27.7	29.8	↑
	Max Fall Temperature	13.3	15.0	16.6	18.5	↑
Minimum Temperature (°C)	Min Annual Temperature	2.7	3.7	6.1	8.2	↑
	Min Winter Temperature	-9.5	-6.7	-5.5	-3.1	↓
	Min Spring Temperature	0.6	2.8	3.5	5.4	↑
	Min Summer Temperature	14.5	15.1	17.4	19.5	↑
	Min Fall Temperature	5.3	6.6	8.6	10.5	↑
Extreme Heat (days/year)	Days Above 35°C	0.9	2.7	6.7	14.4	↑
	Days Above 30°C	11.3	20.3	33.2	52.0	↑
	Days Above 25°C	48.1	65.2	84.7	104.8	↑
	Days Above 20°C (Tropical Nights)	106.0	121.4	136.3	150.7	↑
	Days Below -20°C	9.6	5.5	2.7	0.6	↓

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Extreme Cold (days/year)	Days Below -10°C	48.1	35.3	23.6	11.9	↓
	Days Below 0°C (freezing days)	142.8	126.2	109.6	87.0	↓
Total Precipitation (mm)	Annual (mm/year)	986.2	1022.7	1095.8	1168.8	↑
	Winter (mm/season)	191.8	210.0	237.4	255.7	↑
	Spring (mm/season)	237.4	246.6	264.8	292.2	↑
	Summer (mm/season)	283.1	283.1	292.2	310.5	↑
	Fall (mm/season)	264.8	274.0	283.1	283.1	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	29.4	45.9	49.3	53.7	↑
	Max Precipitation in 3 days (mm)	63.7	65.9	69.9	77.3	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.7	2.8	3.0	3.2	↑
	95th Percentile Precipitation (mm)	42.3	41.8	42.2	43.0	↑
	99th Percentile Precipitation (mm)	13.8	13.6	13.8	14.1	↑
Dry Days (days/year)	Total Annual	180.5	178.3	176.3	174.5	↓
	Total Annual Consecutive Dry Days	21.4	20.8	19.8	21.4	-
Growing Season	Growing Season Start Date (day of year)	May 12	May 2	Apr. 26	Apr. 17	↑
	Growing Season End Date (day of year)	Oct. 23	Nov. 1	Nov. 9	Nov. 19	↑
	Growing Season Length (days/year)	166	184	198	217	↑
Agricultural Variables	Corn Heat Units	3318.2	3805.4	4319.5	4902.7	↑
	Growing Degree Days (Base 0°C)	3309.2	3711.1	4145.1	4669.9	↑
	Canola Growing Degree Days (Base 4°C)	2334.0	2676.9	3055.0	3513.3	↑
	Forage Crops Growing Degree Days (Base 5°C)	2118.5	2447.1	2811.5	3253.3	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1195.8	1452.1	1750.7	2115.3	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	518.6	704.2	931.7	1220.4	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	76.2	70.2	64.6	54.8	↓
	Ice Potential (days per year)	21.2	18.3	15.0	10.5	↓

Ganaraska Region Conservation Authority (GRCA)

Table H-2: Climate Trends for the GRCA under the RCP 8.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	6.5	8.0	9.6	11.7	↑
	Winter	-5.9	-4.2	-2.5	-0.2	↑
	Spring	4.6	5.9	7.3	9.1	↑
	Summer	18.5	20.0	21.7	23.7	↑
	Fall	8.5	10.1	11.7	13.7	↑
Maximum Temperature (°C)	Max Annual Temperature	11.4	12.7	14.3	16.1	↑
	Max Winter Temperature	-2.0	2.0	1.7	2.8	↑
	Max Spring Temperature	10.2	11.0	12.2	14.4	↑
	Max Summer Temperature	24.7	25.3	27.0	29.7	↑
	Max Fall Temperature	12.5	14.5	16.0	17.7	↑
Minimum Temperature (°C)	Min Annual Temperature	1.7	2.5	5.0	7.2	↑
	Min Winter Temperature	-11.3	-8.1	-6.8	-4.3	↑
	Min Spring Temperature	0.0	1.8	2.6	4.9	↑
	Min Summer Temperature	14.0	14.2	16.4	18.9	↑
	Min Fall Temperature	4.4	5.7	7.6	9.6	↑
Extreme Heat (days/year)	Days Above 35°C	0.5	1.5	4.2	10.2	↑
	Days Above 30°C	7.7	15.2	26.9	44.8	↑
	Days Above 25°C	40.6	57.1	77.0	98.0	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Days Above 20°C (Tropical Nights)	99.2	114.8	130.6	145.9	↑
Extreme Cold (days/year)	Days Below -20°C	14.3	9.2	4.8	1.3	↓
	Days Below -10°C	56.3	43.7	31.2	17.2	↓
	Days Below 0°C (freezing days)	153.2	137.3	121.9	99.7	↓
Total Precipitation (mm)	Annual (mm/year)	1022.7	1059.2	1132.3	1241.9	↑
	Winter (mm/season)	210.0	228.3	246.5	273.9	↑
	Spring (mm/season)	255.7	273.9	292.2	319.6	↑
	Summer (mm/season)	292.2	301.3	301.3	328.7	↑
	Fall (mm/season)	273.9	273.9	283.1	301.3	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.5	52.7	56.3	62.3	↑
	Max Precipitation in 3 days (mm)	70.9	73.9	78.6	87.4	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.8	2.9	3.1	3.4	↑
	95th Percentile Precipitation (mm)	44.5	45.1	45.3	45.8	↑
	99th Percentile Precipitation (mm)	14.7	15.0	15.0	15.3	↑
Dry Days (days/year)	Total Annual	201.4	201.5	200.5	198.2	↓
	Total Annual Consecutive Dry Days	24.1	23.6	22.5	23.2	↓
Growing Season	Growing Season Start Date (day of year)	May 16	May 6	May 1	Apr. 20	↑
	Growing Season End Date (day of year)	Oct. 19	Oct. 25	Nov. 4	Nov. 12	↑
	Growing Season Length (days/year)	158	174	188	207	↑
Agricultural Variables	Corn Heat Units	3080.2	3547.8	4054.2	4659.8	↑
	Growing Degree Days (Base 0°C)	3124.4	3503.2	3923.3	4456.0	↑
	Canola Growing Degree Days (Base 4°C)	2176.4	2498.3	2863.4	3325.1	↑
	Forage Crops Growing Degree Days (Base 5°C)	1967.7	2275.5	2627.1	3071.6	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Corn and Bean Growing Degree Days (Base 10°C)	1078.2	1315.9	1601.5	1963.6	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	438.5	605.9	818.5	1099.7	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	82.9	77.3	72.5	63.7	↓
	Ice Potential (days per year)	22.0	18.9	15.7	11.2	↓

Lake Simcoe Region Conservation Authority (LSRCA)

Table H-3: Climate Trends for the LSRCA under the RCP 8.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	6.7	8.0	9.8	11.8	↑
	Winter	-5.7	-3.4	-2.3	-0.1	↑
	Spring	4.7	5.9	7.4	9.1	↑
	Summer	18.7	19.2	21.8	23.7	↑
	Fall	8.8	10.1	11.9	13.9	↑
Maximum Temperature (°C)	Max Annual Temperature	11.8	13.1	14.6	16.4	↑
	Max Winter Temperature	1.3	0.7	2.0	5.4	↑
	Max Spring Temperature	9.3	11.2	12.5	13.1	↑
	Max Summer Temperature	22.4	25.5	27.2	27.3	↑
	Max Fall Temperature	14.2	14.8	16.4	19.0	↑
Minimum Temperature (°C)	Min Annual Temperature	1.8	3.4	5.1	7.3	↑
	Min Winter Temperature	-9.9	-8.6	-6.7	-3.5	↑
	Min Spring Temperature	-1.3	0.9	2.5	3.7	↑
	Min Summer Temperature	12.4	14.9	16.5	17.8	↑
	Min Fall Temperature	4.6	6.1	7.7	10.0	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Extreme Heat (days/year)	Days Above 35°C	0.6	1.9	5.4	11.9	↑
	Days Above 30°C	10.4	18.3	30.4	48.0	↑
	Days Above 25°C	45.5	60.9	79.9	100.1	↑
	Days Above 20°C (Tropical Nights)	102.4	117.6	133.3	148.2	↑
Extreme Cold (days/year)	Days Below -20°C	12.8	7.7	3.8	0.9	↓
	Days Below -10°C	56.3	43.1	30.1	15.5	↓
	Days Below 0°C (freezing days)	152.9	137.4	121.8	98.6	↓
Total Precipitation (mm)	Annual (mm/year)	1022.7	1022.7	1095.8	1205.3	↑
	Winter (mm/season)	237.4	246.5	264.8	283.1	↑
	Spring (mm/season)	228.3	228.3	255.7	273.9	↑
	Summer (mm/season)	264.8	264.8	283.1	310.5	↑
	Fall (mm/season)	310.5	301.3	319.6	328.7	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	31.0	46.3	48.6	53.8	↑
	Max Precipitation in 3 days (mm)	64.2	67.4	70.0	78.4	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.8	2.8	3.0	3.3	↑
	95th Percentile Precipitation (mm)	40.0	41.7	41.0	42.2	↑
	99th Percentile Precipitation (mm)	13.2	13.7	13.3	13.9	↑
Dry Days (days/year)	Total Annual	181.0	187.6	183.7	183.8	↑
	Total Annual Consecutive Dry Days	23.3	22.3	21.6	23.6	↑
Growing Season	Growing Season Start Date (day of year)	May 16	May 7	May 3	Apr. 22	↑
	Growing Season End Date (day of year)	Oct. 20	Oct. 27	Nov 4	Nov. 15	↑
	Growing Season Length (days/year)	158	174	187	208	↑
Agricultural Variables	Corn Heat Units	3143.0	3499.7	4095.8	4695.8	↑
	Growing Degree Days (Base 0°C)	3177.7	3475.6	3971.1	4498.5	↑
	Canola Growing Degree Days (Base 4°C)	2226.0	2479.1	2906.8	3362.7	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Forage Crops Growing Degree Days (Base 5°C)	2016.1	2258.5	2669.7	3108.5	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1118.0	1306.1	1637.2	1996.2	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	466.2	603.3	845.3	1124.9	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	86.1	80.4	75.7	65.4	↓
	Ice Potential (days per year)	27.2	24.2	19.5	13.9	↓

Central Lake Ontario Conservation Authority (CLOCA)

Table H-4: Climate Trends for the CLOCA under the RCP 8.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	8.5	10.1	12.1	↑
	Winter	-5.4	-3.6	-2.0	0.2	↑
	Spring	5.1	6.4	7.8	9.6	↑
	Summer	18.9	20.4	22.1	24.1	↑
	Fall	8.9	10.5	12.1	14.1	↑
Maximum Temperature (°C)	Max Annual Temperature	11.9	13.2	14.8	16.6	↑
	Max Winter Temperature	-1.5	2.4	2.1	3.2	↑
	Max Spring Temperature	10.6	11.5	12.7	14.8	↑
	Max Summer Temperature	25.1	25.7	27.4	30.2	↑
	Max Fall Temperature	12.9	14.9	16.5	18.2	↑
Minimum Temperature (°C)	Min Annual Temperature	2.1	3.0	5.4	7.6	↑
	Min Winter Temperature	-10.7	-7.5	-6.3	-3.8	↑
	Min Spring Temperature	0.4	2.2	3.0	5.3	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Min Summer Temperature	14.3	14.5	16.8	19.3	↑
	Min Fall Temperature	4.8	6.1	8.0	10.0	↑
Extreme Heat (days/year)	Days Above 35°C	0.8	2.2	5.6	12.6	↑
	Days Above 30°C	9.7	18.3	30.7	49.6	↑
	Days Above 25°C	45.5	62.7	82.5	102.9	↑
	Days Above 20°C (Tropical Nights)	104.4	119.9	135.1	150.2	↑
Extreme Cold (days/year)	Days Below -20°C	12.8	8.0	4.2	1.0	↓
	Days Below -10°C	53.0	40.4	28.3	15.0	↓
	Days Below 0°C (freezing days)	148.3	132.2	116.5	93.8	↓
Total Precipitation (mm)	Annual (mm/year)	986.2	1022.7	1095.8	1168.8	↑
	Winter (mm/season)	200.9	210.0	237.4	255.7	↑
	Spring (mm/season)	255.7	255.7	283.1	310.5	↑
	Summer (mm/season)	292.2	292.2	301.3	319.6	↑
	Fall (mm/season)	255.7	255.7	273.9	292.2	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.7	52.6	56.6	61.0	↑
	Max Precipitation in 3 days (mm)	70.1	73.1	78.3	85.6	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.7	2.8	3.0	3.2	↑
	95^{th} Percentile Precipitation (mm)	45.1	46.9	46.7	46.4	↑
	99^{th} Percentile Precipitation (mm)	15.0	15.6	15.6	15.6	↑
Dry Days (days/year)	Total Annual	211.5	212.6	210.5	205.8	↓
	Total Annual Consecutive Dry Days	25.1	24.1	24.2	24.7	↓
Growing Season	Growing Season Start Date (day of year)	May 14	May 5	Apr. 29	Apr. 19	↑
	Growing Season End Date (day of year)	Oct. 21	Oct. 30	Nov. 6	Nov. 17	↑
	Growing Season Length (days/year)	162	179.0	192	213	↑
Agricultural Variables	Corn Heat Units	3206.0	3684.2	4193.6	4807.4	↑
	Growing Degree Days (Base 0°C)	3234.3	3625.6	4054.1	4597.9	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Canola Growing Degree Days (Base 4°C)	2267.2	2600.5	2973.5	3446.5	↑
	Forage Crops Growing Degree Days (Base 5°C)	2053.9	2372.8	2732.3	3187.7	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1142.9	1390.3	1683.2	2056.0	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	480.9	657.4	878.3	1170.4	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	81.7	76.1	70.7	60.7	↓
	Ice Potential (days per year)	18.6	15.3	13.1	9.2	↓

Kawartha Conservation (KRCA)

Table H-5: Climate Trends for the KRCA under the RCP 8.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	8.3	10.1	12.2	↑
	Winter	-5.6	-3.2	-2.2	0.2	↑
	Spring	5.2	6.4	7.9	9.7	↑
	Summer	19.2	19.7	22.3	24.3	↑
	Fall	9.0	10.3	12.1	14.2	↑
Maximum Temperature (°C)	Max Annual Temperature	11.9	13.3	14.8	16.7	↑
	Max Winter Temperature	-1.2	0.7	2.0	3.4	↑
	Max Spring Temperature	10.6	11.5	12.8	14.7	↑
	Max Summer Temperature	25.0	25.9	27.7	30.0	↑
	Max Fall Temperature	13.2	14.9	16.4	18.3	↑
Minimum Temperature (°C)	Min Annual Temperature	2.3	3.9	5.6	7.8	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Min Winter Temperature	-10.8	-8.3	-6.3	-3.8	↑
	Min Spring Temperature	0.4	1.6	3.2	5.3	↑
	Min Summer Temperature	14.5	15.4	17.1	19.5	↑
	Min Fall Temperature	5.1	6.5	8.1	10.3	↑
Extreme Heat (days/year)	Days Above 35°C	1.0	2.5	6.4	13.7	↑
	Days Above 30°C	10.9	19.6	32.6	51.5	↑
	Days Above 25°C	48.0	65.2	84.9	104.8	↑
	Days Above 20°C (Tropical Nights)	106.3	121.4	136.5	151.1	↑
Extreme Cold (days/year)	Days Below -20°C	13.1	8.3	4.3	1.1	↓
	Days Below -10°C	53.7	41.3	29.1	15.4	↓
	Days Below 0°C (freezing days)	145.9	130.2	114.9	92.2	↓
Total Precipitation (mm)	Annual (mm/year)	986.2	1022.7	1095.8	1168.8	↑
	Winter (mm/season)	191.8	210.0	228.3	255.7	↑
	Spring (mm/season)	237.4	255.7	264.8	301.3	↑
	Summer (mm/season)	283.1	292.2	292.2	310.5	↑
	Fall (mm/season)	264.8	273.9	273.9	292.2	↑
Extreme Precipitation	Max Precipitation in 1 day (mm)	32.2	50.2	54.2	59.4	↑
	Max Precipitation in 3 days (mm)	67.9	70.8	75.5	83.3	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.7	2.8	3.0	3.2	↑
	95th Percentile Precipitation (mm)	44.2	44.8	45.8	46.3	↑
	99th Percentile Precipitation (mm)	14.6	14.7	15.1	15.4	↑
Dry Days (days/year)	Total Annual	204.5	204.8	204.0	201.5	↓
	Total Annual Consecutive Dry Days	24.6	23.4	22.9	24.0	↓
Growing Season	Growing Season Start Date (day of year)	May 12	May 3	Apr. 27	Apr. 18	↑
	Growing Season End Date (day of year)	Oct. 22	Oct. 30	Nov. 7	Nov. 17	↑
	Growing Season Length (days/year)	164	181	194.4	215	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Agricultural Variables	Corn Heat Units	3281.5	3656.5	4254.4	4863.7	↑
	Growing Degree Days (Base 0°C)	3284.3	3598.1	4097.5	4640.5	↑
	Canola Growing Degree Days (Base 4°C)	2315.6	2584.6	3017.4	3489.8	↑
	Forage Crops Growing Degree Days (Base 5°C)	2101.3	2359.2	2775.8	3230.8	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1183.5	1384.9	1722.6	2095.7	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	510.8	658.7	910.5	1203.9	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	78.2	72.9	68.2	58.4	↓
	Ice Potential (days per year)	19.1	17.4	13.7	9.6	↓

Appendix I: Climate Summary Tables for Each Conservation Authority within Durham Region under the RCP 4.5 Scenario

Please note that these summary tables have been bias-corrected to the individual regions.

Toronto and Region Conservation Authority (TRCA)

Table H-1: Climate Trends for the TRCA under the RCP 4.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.3	10.0	11.2	11.6	↑
	Winter	-4.9	-1.6	0.1	0.2	↑
	Spring	5.4	7.5	8.5	9.1	↑
	Summer	19.3	21.5	22.6	23.1	↑
	Fall	9.3	12.4	13.5	13.9	↑
Maximum Temperature (°C)	Max Annual Temperature	12.0	14.7	15.8	16.2	↑
	Max Winter Temperature	-0.7	2.1	3.5	3.2	↑
	Max Spring Temperature	10.5	12.4	13.3	14.2	↑
	Max Summer Temperature	24.8	27.2	28.3	29.0	↑
	Max Fall Temperature	13.3	16.7	17.8	18.1	↑
Minimum Temperature (°C)	Min Annual Temperature	2.7	5.4	6.7	7.1	↑
	Min Winter Temperature	-9.5	-5.6	-3.5	-3.9	↑
	Min Spring Temperature	0.6	2.7	3.8	4.2	↑
	Min Summer Temperature	14.5	15.9	17.0	17.5	↑
	Min Fall Temperature	5.3	8.3	9.4	9.5	↑
Extreme Heat (days/year)	Days Above 35°C	0.9	5.3	9.4	12.2	↑
	Days Above 30°C	11.3	31.0	42.0	48.4	↑
	Days Above 25°C	48.1	82.5	92.6	99.3	↑
	Days Above 20°C (Tropical Nights)	106.0	132.8	141.4	145.9	↑
	Days Below -20°C	9.6	1.6	0.4	0.4	↓
	Days Below -10°C	48.1	23.4	14.0	13.6	↓

Possibility grows here.

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Extreme Cold (days/year)	Days Below 0°C (freezing days)	142.8	113.8	97.3	94.6	↓
Total Precipitation (mm)	Annual (mm/year)	986.2	913.1	913.1	949.7	↓
	Winter (mm/season)	191.8	210.0	210.0	219.2	↑
	Spring (mm/season)	237.4	210.0	228.3	237.4	-
	Summer (mm/season)	283.1	210.0	210.0	228.3	↓
	Fall (mm/season)	264.8	264.8	255.7	255.7	↓
Extreme Precipitation	Max Precipitation in 1 day (mm)	29.4	45.6	47.8	49.2	↑
	Max Precipitation in 3 days (mm)	63.7	63.3	66.8	69.0	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.7	2.5	2.5	2.6	↓
	95th Percentile Precipitation (mm)	42.3	45.0	47.4	46.7	↑
	99th Percentile Precipitation (mm)	13.8	15.1	15.7	15.6	↑
Dry Days (days/year)	Total Annual	180.5	193.7	198.6	196.1	↑
	Total Annual Consecutive Dry Days	21.4	17.7	19.0	22.0	↑
Growing Season	Growing Season Start Date (day of year)	May 12	May 2	Apr. 24	Apr. 22	↑
	Growing Season End Date (day of year)	Oct. 23	Nov 8	Nov. 15	Nov. 17	↑
	Growing Season Length (days/year)	166	191	205	210	↑
Agricultural Variables	Corn Heat Units	3318.2	4047.6	4417.1	4588.6	↑
	Growing Degree Days (Base 0°C)	3309.2	3974.6	4316.4	4462.8	↑
	Canola Growing Degree Days (Base 4°C)	2334.0	2895.1	3176.9	3315.5	↑
	Forage Crops Growing Degree Days (Base 5°C)	2118.5	2654.7	2922.5	3058.3	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1195.8	1617.6	1820.9	1937.0	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	518.6	831.5	979.1	1072.0	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	76.2	68.5	61.6	58.9	↓
	Ice Potential (days per year)	21.2	12.1	9.3	9.5	↓

Ganaraska Region Conservation Authority (GRCA)

Table H-2: Climate Trends for the GRCA under the RCP 4.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	6.5	9.3	9.9	11.0	↑
	Winter	-5.9	-2.2	-1.1	-0.4	↑
	Spring	4.6	6.8	6.8	8.4	↑
	Summer	18.5	20.8	21.3	22.4	↑
	Fall	8.5	11.7	12.5	13.3	↑
Maximum Temperature (°C)	Max Annual Temperature	11.4	14.1	14.3	15.6	↑
	Max Winter Temperature	-2.0	1.8	2.8	2.5	↑
	Max Spring Temperature	10.2	11.7	11.4	14.3	↑
	Max Summer Temperature	24.7	26.3	26.2	29.3	↑
	Max Fall Temperature	12.5	16.1	16.6	17.4	↑
Minimum Temperature (°C)	Min Annual Temperature	1.7	4.6	5.5	6.4	↑
	Min Winter Temperature	-11.3	-6.4	-5.3	-4.8	↑
	Min Spring Temperature	0.0	2.0	2.1	4.2	↑
	Min Summer Temperature	14.0	15.2	16.2	17.2	↑
	Min Fall Temperature	4.4	7.6	8.5	8.7	↑
Extreme Heat (days/year)	Days Above 35°C	0.5	2.8	2.0	7.6	↑
	Days Above 30°C	7.7	22.5	21.4	39.1	↑
	Days Above 25°C	40.6	72.9	70.8	90.6	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Days Above 20°C (Tropical Nights)	99.2	126.0	125.7	139.1	↑
Extreme Cold (days/year)	Days Below -20°C	14.3	2.6	1.2	1.0	↓
	Days Below -10°C	56.3	28.6	23.6	17.0	↓
	Days Below 0°C (freezing days)	153.2	123.0	115.7	103.3	↓
Total Precipitation (mm)	Annual (mm/year)	1022.7	913.1	1059.2	949.7	↓
	Winter (mm/season)	210.0	228.3	246.5	228.3	↑
	Spring (mm/season)	255.7	228.3	246.5	246.5	↓
	Summer (mm/season)	292.2	210.0	219.2	228.3	↓
	Fall (mm/season)	273.9	264.8	319.6	264.8	↓
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.5	52.1	55.3	53.9	↑
	Max Precipitation in 3 days (mm)	70.9	71.2	74.5	73.2	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.8	2.5	2.9	2.6	↓
	95^{th} Percentile Precipitation (mm)	44.5	49.4	46.6	51.2	↑
	99^{th} Percentile Precipitation (mm)	14.7	16.4	15.4	17.3	↑
Dry Days (days/year)	Total Annual	201.4	216.5	208.9	219.1	↑
	Total Annual Consecutive Dry Days	24.1	21.0	21.0	25.3	↑
Growing Season	Growing Season Start Date (day of year)	May 16	May 6	May 4	Apr. 27	↑
	Growing Season End Date (day of year)	Oct. 19	Nov. 3	Nov 11	Nov. 14	↑
	Growing Season Length (days/year)	158	182	199	201	↑
Agricultural Variables	Corn Heat Units	3080.2	3825.8	4040.9	4364.1	↑
	Growing Degree Days (Base 0°C)	3124.4	3776.2	3912.0	4251.7	↑
	Canola Growing Degree Days (Base 4°C)	2176.4	2719.1	2828.3	3124.8	↑
	Forage Crops Growing Degree Days (Base 5°C)	1967.7	2484.6	2587.0	2872.7	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Corn and Bean Growing Degree Days (Base 10°C)	1078.2	1477.8	1551.3	1781.0	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	438.5	724.5	773.9	949.9	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	82.9	76.6	74.7	66.8	↓
	Ice Potential (days per year)	22.0	13.0	12.1	9.5	↓

Lake Simcoe Region Conservation Authority (LSRCA)

Table H-3: Climate Trends for the LSRCA under the RCP 4.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	6.7	9.4	9.9	11.0	↑
	Winter	-5.7	-2.3	-1.4	-0.4	↑
	Spring	4.7	6.7	6.8	8.4	↑
	Summer	18.7	20.8	21.6	22.4	↑
	Fall	8.8	11.9	12.5	13.4	↑
Maximum Temperature (°C)	Max Annual Temperature	11.8	14.3	14.7	15.8	↑
	Max Winter Temperature	1.3	2.0	2.8	5.1	↑
	Max Spring Temperature	9.3	12.0	11.8	12.1	↑
	Max Summer Temperature	22.4	26.5	26.9	25.7	↑
	Max Fall Temperature	14.2	16.5	16.9	18.8	↑
Minimum Temperature (°C)	Min Annual Temperature	1.8	5.9	5.2	6.3	↑
	Min Winter Temperature	-9.9	-6.7	-5.6	-3.5	↑
	Min Spring Temperature	-1.3	1.7	1.8	2.3	↑
	Min Summer Temperature	12.4	15.2	16.2	15.9	↑
	Min Fall Temperature	4.6	7.6	8.3	9.7	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Extreme Heat (days/year)	Days Above 35°C	0.6	2.9	3.6	7.6	↑
	Days Above 30°C	10.4	25.6	27.9	42.4	↑
	Days Above 25°C	45.5	77.3	79.1	95.1	↑
	Days Above 20°C (Tropical Nights)	102.4	129.3	131.5	142.1	↑
Extreme Cold (days/year)	Days Below -20°C	12.8	3.1	1.8	1.2	↓
	Days Below -10°C	56.3	29.8	25.7	18.0	↓
	Days Below 0°C (freezing days)	152.9	125.5	120.9	105.6	↓
Total Precipitation (mm)	Annual (mm/year)	1022.7	876.6	949.7	949.7	↓
	Winter (mm/season)	237.4	246.5	264.8	255.7	↑
	Spring (mm/season)	228.3	200.9	200.9	228.3	-
	Summer (mm/season)	264.8	173.5	191.8	210.0	↓
	Fall (mm/season)	310.5	301.3	319.6	301.3	↓
Extreme Precipitation	Max Precipitation in 1 day (mm)	31.0	49.9	43.8	51.2	↑
	Max Precipitation in 3 days (mm)	64.2	67.0	65.7	71.3	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.8	2.4	2.6	2.6	↓
	95^{th} Percentile Precipitation (mm)	40.0	47.5	44.3	45.2	↑
	99^{th} Percentile Precipitation (mm)	13.2	16.4	14.2	15.4	↑
Dry Days (days/year)	Total Annual	181.0	203.4	198.0	200.6	↑
	Total Annual Consecutive Dry Days	23.3	23.0	22.5	24.7	↑
Growing Season	Growing Season Start Date (day of year)	May 16	May 8	Apr. 20	Apr. 26	↑
	Growing Season End Date (day of year)	Oct. 20	Nov. 5	Nov. 20	Nov. 11	↑
	Growing Season Length (days/year)	158	182	196	200	↑
Agricultural Variables	Corn Heat Units	3143.0	3844.3	4059.3	4381.9	↑
	Growing Degree Days (Base 0°C)	3177.7	3799.6	3947.6	4276.9	↑
	Canola Growing Degree Days (Base 4°C)	2226.0	2745.9	2876.2	3151.7	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Forage Crops Growing Degree Days (Base 5°C)	2016.1	2511.2	2637.5	2899.8	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1118.0	1501.6	1604.3	1805.8	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	466.2	742.7	820.1	968.5	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	86.1	78.7	78.7	68.9	↓
	Ice Potential (days per year)	27.2	17.7	18.0	13.8	↓

Central Lake Ontario Conservation Authority (CLOCA)

Table H-4: Climate Trends for the CLOCA under the RCP 4.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	9.7	11.0	11.3	↑
	Winter	-5.4	-1.8	-0.1	0.0	↑
	Spring	5.1	7.2	8.2	8.8	↑
	Summer	18.9	21.1	22.2	22.7	↑
	Fall	8.9	12.1	13.2	13.6	↑
Maximum Temperature (°C)	Max Annual Temperature	11.9	14.5	15.7	16.1	↑
	Max Winter Temperature	-1.5	2.2	3.6	2.8	↑
	Max Spring Temperature	10.6	12.2	13.2	14.8	↑
	Max Summer Temperature	25.1	26.8	27.9	30.0	↑
	Max Fall Temperature	12.9	16.6	17.7	17.9	↑
Minimum Temperature (°C)	Min Annual Temperature	2.1	5.0	6.3	6.7	↑
	Min Winter Temperature	-10.7	-6.0	-3.9	-4.5	↑
	Min Spring Temperature	0.4	2.3	3.4	4.5	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Min Summer Temperature	14.3	15.5	16.6	17.4	↑
	Min Fall Temperature	4.8	7.9	9.1	8.9	↑
Extreme Heat (days/year)	Days Above 35°C	0.8	3.9	7.2	9.7	↑
	Days Above 30°C	9.7	26.1	37.5	43.8	↑
	Days Above 25°C	45.5	78.3	89.0	95.3	↑
	Days Above 20°C (Tropical Nights)	104.4	130.1	139.0	143.6	↑
Extreme Cold (days/year)	Days Below -20°C	12.8	2.3	0.7	0.9	↓
	Days Below -10°C	53.0	26.3	16.7	15.9	↓
	Days Below 0°C (freezing days)	148.3	118.6	101.5	98.7	↓
Total Precipitation (mm)	Annual (mm/year)	986.2	949.7	986.2	986.2	-
	Winter (mm/season)	200.9	219.2	228.3	219.2	↑
	Spring (mm/season)	255.7	246.5	246.5	255.7	-
	Summer (mm/season)	292.2	228.3	237.4	255.7	↓
	Fall (mm/season)	255.7	255.7	264.8	255.7	-
Extreme Precipitation	Max Precipitation in 1 day (mm)	33.7	52.9	56.6	55.8	↑
	Max Precipitation in 3 days (mm)	70.1	71.2	75.3	75.5	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.7	2.6	2.7	2.7	-
	95th Percentile Precipitation (mm)	45.1	48.6	49.6	50.4	↑
	99th Percentile Precipitation (mm)	15.0	16.3	16.9	17.3	↑
Dry Days (days/year)	Total Annual	211.5	224.2	223.8	224.9	↑
	Total Annual Consecutive Dry Days	25.1	24.0	22.3	28.0	↑
Growing Season	Growing Season Start Date (day of year)	May 14	May 5	Apr. 26	Apr. 24	↑
	Growing Season End Date (day of year)	Oct. 21	Nov. 5	Nov. 14	Nov. 15	↑
	Growing Season Length (days/year)	162	186	203	205	↑
Agricultural Variables	Corn Heat Units	3206.0	3938.6	4318.1	4486.9	↑
	Growing Degree Days (Base 0°C)	3234.3	3887.0	4231.4	4373.7	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Canola Growing Degree Days (Base 4°C)	2267.2	2812.0	3095.1	3229.2	↑
	Forage Crops Growing Degree Days (Base 5°C)	2053.9	2572.9	2841.5	2972.8	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1142.9	1545.6	1747.8	1859.9	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	480.9	773.6	918.6	1008.0	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	81.7	73.9	66.6	63.7	↓
	Ice Potential (days per year)	18.6	10.0	7.8	7.8	↓

Kawartha Conservation (KRCA)

Table H-5: Climate Trends for the KRCA under the RCP 4.5 Scenario

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Mean Temperature (°C)	Annual	7.0	9.9	10.4	11.5	↑
	Winter	-5.6	-1.9	-0.8	-0.1	↑
	Spring	5.2	7.5	7.5	9.1	↑
	Summer	19.2	21.5	22.0	23.1	↑
	Fall	9.0	12.2	12.9	13.7	↑
Maximum Temperature (°C)	Max Annual Temperature	11.9	14.6	14.9	16.2	↑
	Max Winter Temperature	-1.2	2.0	3.1	3.1	↑
	Max Spring Temperature	10.6	12.5	12.2	14.6	↑
	Max Summer Temperature	25.0	27.2	27.1	29.7	↑
	Max Fall Temperature	13.2	16.5	17.0	18.1	↑
Minimum Temperature (°C)	Min Annual Temperature	2.3	5.1	5.9	6.9	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
	Min Winter Temperature	-10.8	-6.1	-5.0	-4.2	↑
	Min Spring Temperature	0.4	2.6	2.6	4.7	↑
	Min Summer Temperature	14.5	15.8	16.7	17.8	↑
	Min Fall Temperature	5.1	8.0	8.9	9.4	↑
Extreme Heat (days/year)	Days Above 35°C	1.0	5.0	3.9	11.6	↑
	Days Above 30°C	10.9	30.1	28.8	47.6	↑
	Days Above 25°C	48.0	82.2	79.4	98.6	↑
	Days Above 20°C (Tropical Nights)	106.3	132.0	132.5	145.3	↑
Extreme Cold (days/year)	Days Below -20°C	13.1	2.6	1.3	1.2	↓
	Days Below -10°C	53.7	27.6	22.6	16.6	↓
	Days Below 0°C (freezing days)	145.9	116.5	111.0	97.2	↓
Total Precipitation (mm)	Annual (mm/year)	986.2	949.7	1022.7	949.7	↓
	Winter (mm/season)	191.8	210.0	219.2	219.2	↑
	Spring (mm/season)	237.4	228.3	228.3	237.4	-
	Summer (mm/season)	283.1	219.2	219.2	237.4	↓
	Fall (mm/season)	264.8	264.8	301.3	255.7	↓
Extreme Precipitation	Max Precipitation in 1 day (mm)	32.2	51.5	54.1	52.7	↑
	Max Precipitation in 3 days (mm)	67.9	69.4	73.1	72.7	↑
	Simple Daily Intensity Index (SDII) (mm/day)	2.7	2.6	2.8	2.6	↓
	95th Percentile Precipitation (mm)	44.2	47.8	46.5	49.4	↑
	99th Percentile Precipitation (mm)	14.6	16.0	15.4	16.7	↑
Dry Days (days/year)	Total Annual	204.5	217.4	211.7	218.2	↑
	Total Annual Consecutive Dry Days	24.6	23.7	20.5	23.7	↓
Growing Season	Growing Season Start Date (day of year)	May 12	May 2	Apr. 29	Apr. 21	↑
	Growing Season End Date (day of year)	Oct. 22	Nov. 6	Nov 13	Nov. 15	↑
	Growing Season Length (days/year)	164	189	206	209	↑

Climate Parameter	Detailed Parameter	1971-2000	2011-2040	2041-2070	2071-2100	Trend
Agricultural Variables	Corn Heat Units	3281.5	4015.6	4223.5	4553.8	↑
	Growing Degree Days (Base 0°C)	3284.3	3950.4	4077.7	4434.9	↑
	Canola Growing Degree Days (Base 4°C)	2315.6	2874.8	2978.0	3290.7	↑
	Forage Crops Growing Degree Days (Base 5°C)	2101.3	2634.8	2731.6	3033.7	↑
	Corn and Bean Growing Degree Days (Base 10°C)	1183.5	1600.2	1668.4	1914.4	↑
	Growing Degree Days - Risk of Presence of Pests (Base 15°C)	510.8	817.5	861.9	1053.3	↑
Ice and Snow	Freeze-Thaw Cycles (cycles per year)	78.2	71.7	71.9	61.7	↓
	Ice Potential (days per year)	19.1	10.7	10.3	8.0	↓

Appendix J: Step-by-Step Methodology for Climate Change Analysis

The following appendix provides technical details as to how the project team undertook the climate change modeling update for Durham Region. This appendix provides descriptions of each step that was undertaken in the process and provides rationale and advantages for each. For further inquiries of specific methodologies conducted, please contact occ@trca.ca.

Step 1: Choosing a Climate Data Portal

The first step taken in this process involved conducting a literature review around best practices in climate modeling projections and determining the climate change data portal that would be used to derive specific climate indicators for Durham Region. The review of climate data portals demonstrated that there are many climate portals that provide data for Durham Region as well as for Ontario. Once the review of climate portals was complete, the project team worked to establish evaluation criteria for selecting the most appropriate data for this study.

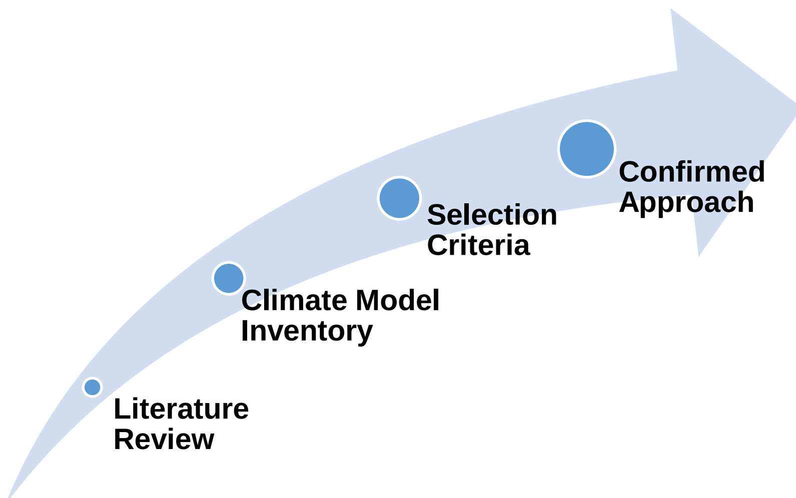


Figure H-1: Process to reach consensus on the climate change portal for the Region's updated climate change analysis.

The evaluation criteria were established through a combination of literature review around best practices in climate modeling projections and analyses, as well as through consultation with the NECCC group. Through the evaluation criteria, the project team narrowed down the selection of climate portals down to four climate data portals (see Table H-1), which were then presented to the NECCC including a recommended approach. This process allowed the project team to confirm the approach used in this study. Figure H-1 demonstrates the steps that were taken to reach a confirmed approach.

The OCC first reviewed and took stock of all the climate data portals that were accessible and had climate information for Durham Region. Certain projections are not available through online portals due to the size of RCM data and as such was noted as a limitation. There was a total of 24 climate change data portals available for Durham Region; however, OCC narrowed this list down to four portals based on a series of criteria. Although there are other sources of climate modeling that can be found offline, through direct contact with climate modelers, OCC wanted to find the best available information available online to the public, for other municipalities within the Greenbelt and beyond to be able to easily replicate this process.

The following were the criteria chosen by OCC and the NECCC to move forward with choosing a climate data source:

- The data had the ability to capture the influence of the Great Lakes (e.g., through the incorporation of a lake model into these models, or by spatially accounting for the lakes themselves in the models and treating them as water), since Lake Ontario has a great influence on Durham Region's weather and climate patterns (see Section 5.6 for more information on Lake Ontario's climate influence on Durham Region);
- The data was used in other peer-reviewed climatological publications in the Great Lakes Basin and in Ontario;
- The data was derived through dynamical downscaling, to capture the influence of the Great Lakes;
- The data was driven by multiple models and model runs (i.e. takes an ensemble approach) to ensure more robust results were generated;
- The data had a spatial resolution of 25 km by 25 km or finer;
- The data was easily accessible online;
- The data included projections for both climate change scenarios RCP 4.5 and 8.5, and was available up until 2100; and
- There were hourly data available (for the purpose of Durham Region creating their own IDF curves to account for climate change).

The four climate change portals that OCC narrowed the total of 24 portals to include the following:

- York University's Laboratory of Mathematical Parallel Systems (LAMPS) Climate Change Portal;
- University of Toronto's Peltier Climate Change Ensemble Data;
- University of Wisconsin's Notaro Climate Change Ensemble Data Portal; and
- The second phase of the North American Coordinated Regional Climate Downscaling Experiment (NA-CORDEX) Portal.

The following table (Table H-1) demonstrates the advantages and disadvantages for each of the four climate change portals, which allowed OCC and the NECCC group to make its final decision of choosing the NA-CORDEX portal for the climate change analysis.

Table H-1: A summary of the advantages and limitations with all four climate data portals that were evaluated for the use of updating Durham Region's climate change projections.

Portal	Description	Advantages	Limitations
LAMPS York University Portal	This data portal was developed in collaboration with York University and the Provincial Government of Ontario. The portal contains a "super ensemble" of 209 climate members derived from both GCMs and RCMs (47 of which have been dynamically downscaled, and 197 members have been statistically downscaled).	• Ensemble of 209 model runs • Spatial resolution of 10 km^2 • Data portal is free and easily accessible • Data downloaded from this portal are in forms of .csv files, which can be opened in Microsoft Excel, a program most practitioners are familiar with • Data is available up to the year 2100 • Data is provided for both climate scenarios RCP 4.5 and 8.5	• Most models used in the data portal are statistically downscaled data, which do not represent local influences, such as the Great Lakes • Due to large number of models and model runs, there is a large range in projections (e.g., precipitation trends can range from -2 mm/day to +20 mm/day) • Does not have hourly data available online
University of Wisconsin-Madison Center for Climate Research Ensemble	Six global climate models (GCMs) from CMIP5 have been dynamically downscaled to 25-km grid spacing according to the RCP 8.5 scenario using the International Centre for Theoretical Physics (ICTP) Regional Climate Model Version Four (RegCM4). The ensemble uses the validated and tuned one dimensional Hostetler Lake Model	• Spatial resolution of 25 km^2 • Ensemble of six GCMs run for one RCM • GCMs and RCMs used in ensemble account for the Great Lakes • Freely accessible data and easy-to-use portal, and uses interactive mapping • Data projections are available up to 2100 • Data has been dynamically downscaled • Has about 30 specific climate parameters available online	• Longer downloading time (e.g., each variable for each timeframe is about 670 NetCDF files in total), which can take a significant amount of storage and time • Projections are offered in 20-year time periods online, not 30-year climate normals • Only has climate scenario RCP 8.5 • Does not have hourly data available online
University of Toronto Ensemble	This ensemble was initiated out of the University of Toronto. The ensemble is composed of physics-based mini ensemble of five different physics configurations, using the U.S. Weather Research and Forecasting (WRF) Model	• Incorporates the Great Lakes, using a Freshwater Lakes model (FLake) • Is an ensemble of mini-ensembles of the Weather	• Uses outdated Community Earth System Model (CCSM) model • Only uses one RCM and one GCM to drive climate projections

	simulations dynamically downscaled from the National Center for Atmospheric Research (NCAR) Community Earth System Model, version 1 (CESM1) GCM. The ensemble also uses the freshwater lake model (FLake) (section 3.1.3 provides additional details on this model). The spatial resolution of this ensemble is of 10-km grids, and all model runs are for the RCP 8.5 climate scenario.	Research and Forecasting (WRF) Model • Data projections are available up to 2100 • Spatial resolution of 10 km^2	• Data is not available online as a standalone ensemble • Does not use 30-year climate normal • Only uses climate scenario RCP 8.5 • The portal does not have hourly data
NA-CORDEX Ensemble	The NA-CORDEX data contains output from regional climate models (RCMs) run over a domain that covers most of North America using boundary conditions from global climate model (GCM) simulations in the CMIP5 archive. These simulations run from 1950–2100 with a spatial resolution of 0.22°/25 km or 0.44°/50 km. Data is available for impacts-relevant variables at daily and longer frequencies in CF-compliant NetCDF format.	• Is an ensemble of six dynamically downscaled RCMs, run by six different GCMs • Spatial resolution is of 25 km^2 • All RCMs are dynamically downscaled • Freely accessible data portal • Has both RCP 4.5 and 8.5 climate scenarios • Incorporates the Great Lakes into models (e.g., includes one dimensional lake models in RCMs, including a Fresh-water Lake model (Flake)[1] and the Hostetler lake model[2]) • Has daily data available online and hourly data for certain climate parameters	• Some data are not yet available for download • Data comes in NetCDF files, which can be difficult for practitioners to easily use

As Table H-1 demonstrates, the NA-CORDEX portal checked most of the evaluation criteria that were established by the OCC and NECCC, and therefore, this was the portal that was chosen to undertake the climate modeling.

[1] The FLake Model was developed by Mironov et al., 2010.
[2] The Hostetler Lake Model was developed by Hostetler et al., 1993.

Step 2: Downloading Climate Change Data from the NA-CORDEX Portal

The NA-CORDEX model ensemble was developed by the World Climate Research Programme (WCRP) and provides RCM outputs on historical data and future RCP climate scenarios running from 1950 to 2005 and 2006 to 2100, respectively (Lucas-Picher, Laprise, and Winger, 2017). Mean, maximum, and minimum temperatures as well as total precipitation were downloaded for this project as daily data, averaged over 30-year climate normal periods at a maximum spatial resolution of 0.22° (or 25 km by 25 km). In addition, hourly precipitation data was also downloaded for Durham Region to be used by stakeholders in the development of Intense-Duration-Frequency (IDF) curves that account for future climates, which can be provided at request, but was not included as a part of this analysis as hourly data was not available for all of the climate parameters (see Appendix E for a brief summary of how to derive IDF curves). IDF curves are used to demonstrate the characteristics of shorter duration rainfall events and are often used to inform engineering design standards (Simonovic and Peck, 2009).

For both RCP climate scenarios 4.5 and 8.5, data was accessed and collected for the following 16 model runs shown in Table H-2, displaying both the driving GCM and corresponding RCM. This subset of climate models has been dynamically downscaled (see section 3.2 for the different downscaling methods). While debate exists around the realism of the RCP8.5 from a socio-economic perspective (Smith, 2019), it should be noted that since the RCP 4.5 climate scenario is not as frequently used by climate modelers, or in as high of demand as RCP 8.5, there are less climate model runs available online for this climate scenario in the NA-CORDEX ensemble (as shown in Table H-2). For a more detailed description of RCP4.5 and RCP8.5, refer to Table 4. Therefore, the projections and analysis demonstrated in this report focus on the RCP8.5 scenario. RCP4.5 has been included under Appendix C but it has not been included as part of this analysis and should not be compared to that of RCP8.5. According to current climate trends, the climate trajectory provided by an RCP 8.5 scenario would be more reflective of a future climate. Therefore, the RCP 4.5 scenario is less frequently used and limited in both its access and availability. This report summarizes the results of the RCP 8.5 climate scenario, and includes a summary table for the RCP 4.5 climate scenario in Appendix C.

Table H-2: CORDEX Climate Model Runs for the RCP 8.5 Climate Scenario. See Acronyms at beginning of document to see what each model acronym stands for.

Driving Global Climate Model	Regional Climate Model	RCPs Model Runs are available for
CanESM2	CRCM5-UQAM	RCP 8.5
CNRM-CM5	CRCM5-OUR	RCP 8.5
GFDL-ESM2M	CRCM5-OUR	RCP 8.5, RCP 4.5
MPI-ESM-LR	CRCM5-OUR	RCP 8.5
GEMatm-Can	CRCM5-UQAM	RCP 8.5
GEMatm-MPI	CRCM5-UQAM	RCP 8.5
MPI-ESM-LR	CRCM5-UQAM	RCP 8.5
CanESM2	CanRCM4	RCP 8.5, RCP 4.5
GFDL-ESM2M	RegCM4	RCP 8.5
HadGEM2-ES	RegCM4	RCP 8.5

MPI-ESM-LR	RegCM4	RCP 8.5
GFDL-ESM2M	WRF	RCP 8.5
HadGEM2-ES	WRF	RCP 8.5
MPI-ESM-LR	WRF	RCP 8.5
MPI-ESM-MR	CRCM5-UQAM	RCP 8.5
CanESM2	CRCM5-OUR	RCP 8.5, RCP 4.5

To demonstrate exactly how the Great Lakes are represented in the NA-CORDEX portal, Table H-3 summarizes how each of the seven RCMs in the ensemble account for or simulate the Great Lakes. As demonstrated, four of the seven RCMs have a one-dimensional lake model included, two use nearby sea surface temperatures (SSTs), and includes the Great Lakes at a higher resolution.

Table H-3: The seven RCMs in the NA-CORDEX Climate Model Ensemble, and how they incorporate or simulate the Great Lakes.

RCM	CanRCM4	CRCM5 (OURANOS)	CRCM5 (UQUAM)	HIRHAM5	RCA4	RegCM4	WRF
How Great Lakes were Incorporated into RCM	Incorporated through derived GCM	Uses the one-dimensional FLake model	Uses the one-dimensional FLake model	No lake model; however, it interpolates lapse-rate corrected for SSTs for lakes > 0.5 gridbox	Uses the one-dimensional FLake model	Uses the one-dimensional Hostetler Lake model	Uses nearby ocean SSTs as lake surface temperatures

All the data was collected and downloaded as NetCDF files (otherwise known as Network Common Data Form files), which are files able to store large datasets and many layers of data into one file that is easily downloadable. The NetCDF files contained temperature and precipitation data at points at every 25 km^2 grid cell, as shown in Figure H-2, which were then further examined to generate an additional 52 climate parameters (e.g., extreme precipitation, threshold-based parameters, freeze-thaw cycles, etc.). This data was bias-corrected to Durham Region to eliminate any biases or skewed data for variables like topography, surrounding vegetation, human error, and other geographic characteristics.

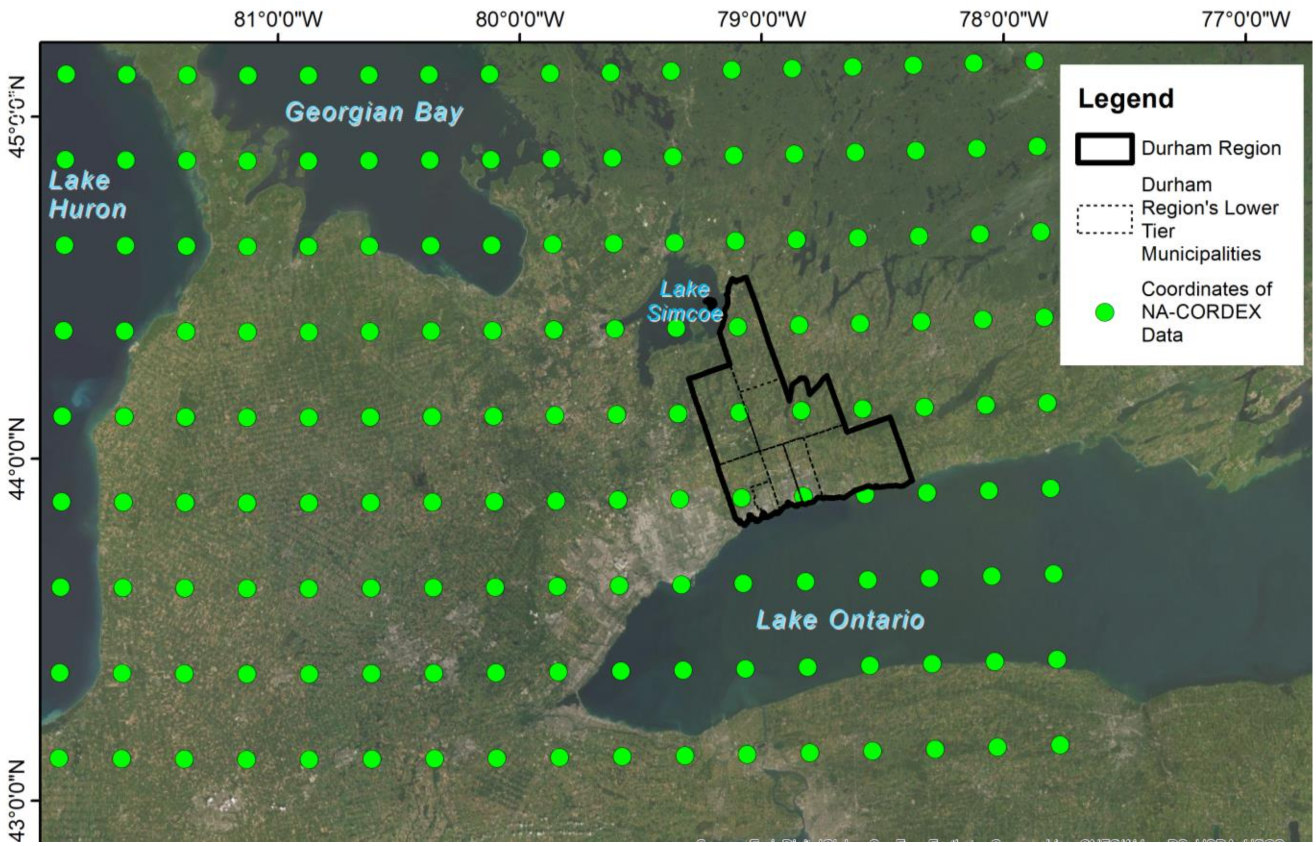


Figure H-2: The coordinates (i.e. green dots) that were downloaded from the NA-CORDEX model ensemble, which are found at the bottom right corner of each grid cell. Each point represents about 90 years of climate data. Each grid is spaced by 25 by 25 km.

These files can be difficult to work with, as such, the following section describes the methods undertaken for using the NetCDF files for this project. The outputs of the model runs were obtained through the North American domain of the CORDEX website, accessed through the Climate Data Gateway. The data downloaded includes the NA-CORDEX model ensemble outputs for daily mean, maximum, and minimum temperature and total precipitation, in 30-year increments, including the historical baseline (1971-2000), and future climate periods of 2011-2040, 2041-2070, and 2071-2100 timelines. The outputs were downloaded for the geographic extent of Durham Region and its neighbouring areas (between 45˚ to 43˚N to 80˚W to 78˚W latitude/longitude, see Figure H-2) for the RCP 4.5 and RCP 8.5 climate scenarios as well as for the historical baseline. Hourly precipitation was also downloaded for the same geographic area and for the same climate periods, for the RCP 8.5 scenario.

When using the Climate Data Gateway, users will need to select the appropriate dataset to gather daily data for the climate period and geographic extent of choice. Figures H-3 and H-4 demonstrate the features users will need to select to obtain the correct data. Once the user has selected the appropriate dataset, as seen in Figure H-3, click "Subset" (red box) to download the data. It should be noted that "raw" data was chosen to bias correct for Durham Region specifically, rather than obtaining the bias corrected data from the NA-CORDEX portal as OCC performed their own bias correction for Durham Region specifically.

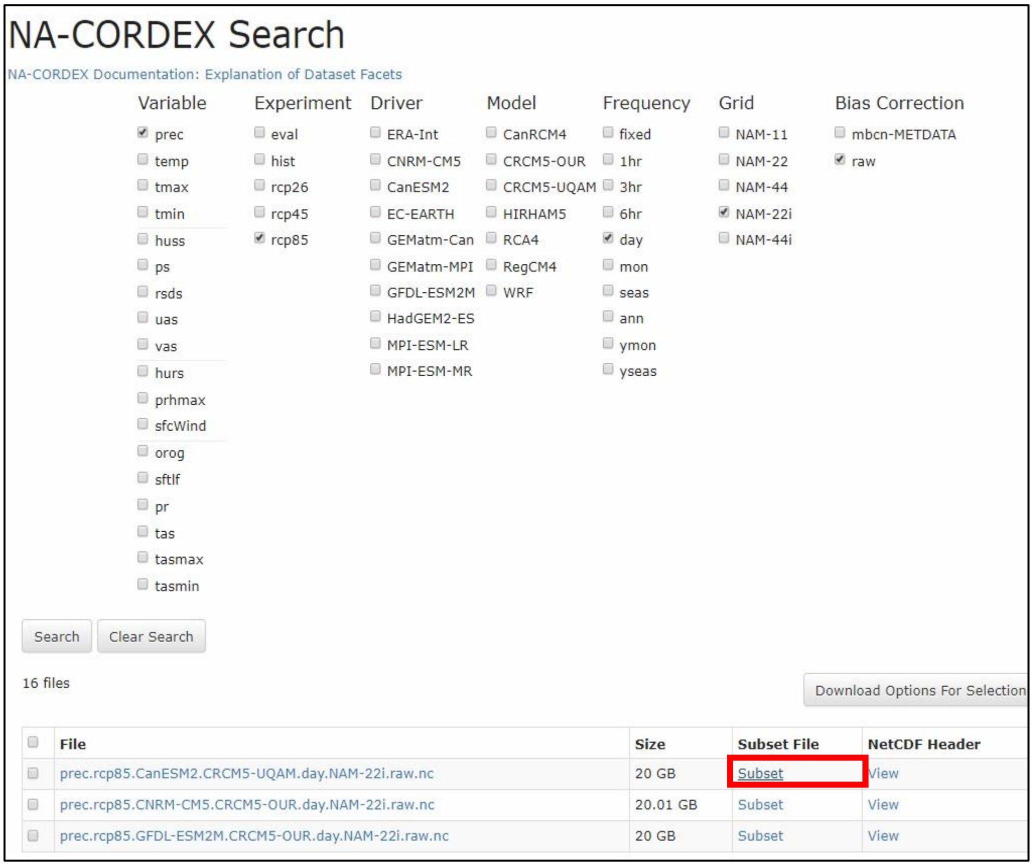


Figure H-3: A screenshot of the checked boxes of the NA-CORDEX (Climate Data Gateway) portal to obtain daily precipitation data for all model runs for the RCP 8.5 climate change scenario. Click here to see what all variables in the portals are.

Figure H-4 further demonstrates the criteria needed to be input to the website to allow for subsets of data, and specific climate periods of data to be collected. If this is not specified, the NetCDF file downloaded from the website may be too large to open, or alternatively, the NetCDF file will only display data for one day. The website will ask for specific latitudes and longitudes of the desired subset area (in this case, OCC used the points that apply to the study area, as shown in Figure H-2). It is therefore suggested to obtain an area of data that is much larger than the desired area, in order to provide more robust results. This selection of data was used for each climate normal period (1971-2000, 2011-2040, 2041-2070, and 2071-2100).

Converting NetCDF files to Comma Separated Values (CSV) Spreadsheet files

As previously mentioned, NetCDF files are interfaced, array-based dataframes used to make large amounts of data available to use in various platforms (e.g., C, Fortran, C++, Java, ArcMap, etc.). These NetCDF files are often used to store large volumes of climate data such as those within the NA-CORDEX climate portal. However, without specialized software, NetCDF packages can be difficult to interpret. To create accessible data from NetCDF files for the purpose of this project, (e.g., having climate variables for each grid cell within the area of study), the vector based NetCDF files (e.g., points) were transformed into raster data (e.g., grid cells) using the statistical programming software R. The NetCDF files (.nc) were transformed into rasters (i.e. images with pixels) by using the raster library in R to organize the data into date, climate variable, and its corresponding latitude and longitude coordinates. A sample of the code used to transform the file is shown on the following page (please note that the bolded values are simply instructions, and are not actually code):

```
#Loading the raster package into R:
library(raster)
nc.brick <- brick(file.choose())

#Reading the NetCDF files as raster files (creating grid cell data)
nc.brick
dim(nc.brick)

#Showing the dimensions of your dataframe (e.g., grid number,
latitude and longitude, date)
n = dim(nc.brick)[3]
nc.df <- as.data.frame(nc.brick[[1:n]], xy=T)

#Obtaining the netcdf dataframe to its full dimensions
write.csv(nc.df, file.choose())

#Once the CSV is written, save the dataframe as a comma separated
value to read in Microsoft Excel spreadsheets
```

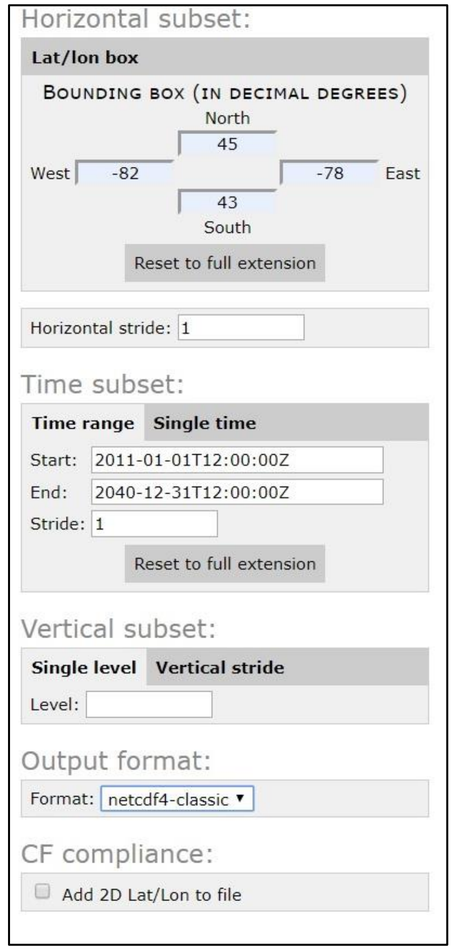
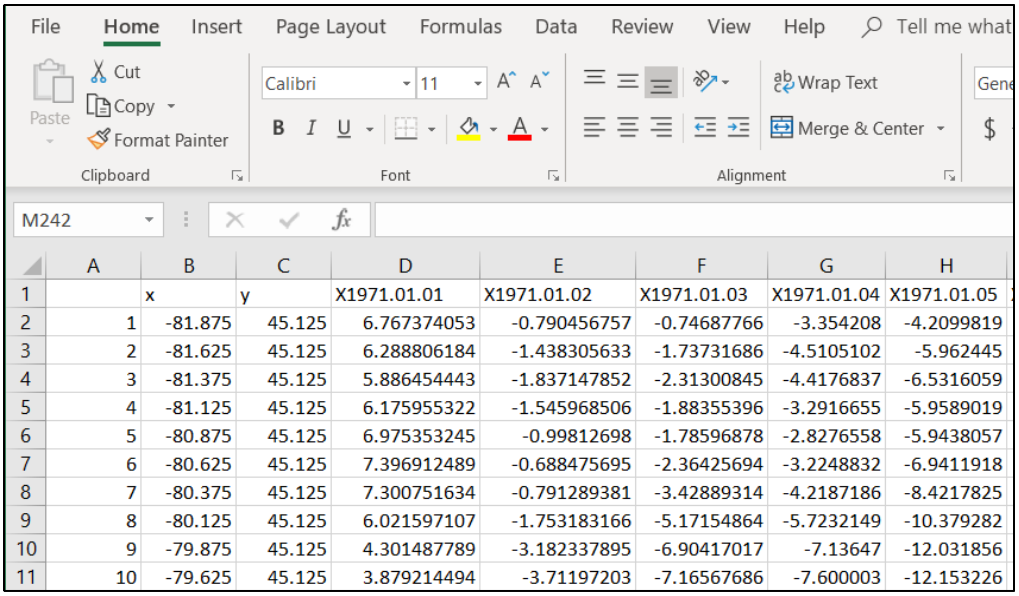


Figure H-4: A screenshot of the checked boxes of the NA-CORDEX (Climate Data Gateway) portal to obtain specific subsets of daily climate data for all model runs for the RCP 8.5 climate change scenario for precipitation, for the 2011-2040 climate normal period.

Once this was conducted, when opening the CSV file in Microsoft Excel, the output looked similar to Figure H-5. Longitude data is found under the “X” column, and latitudes are under the “Y” column. The following columns are titled by their dates. For example, “X1971.01.01” represents January 1st of 1971. Each CSV file represents a specific climate parameter and a climate model run (out of the 16 model runs in the NA-CORDEX ensemble) and has daily data for each grid cell.



	A	B	C	D	E	F	G	H
1		x	y	X1971.01.01	X1971.01.02	X1971.01.03	X1971.01.04	X1971.01.05
2	1	-81.875	45.125	6.767374053	-0.790456757	-0.74687766	-3.354208	-4.2099819
3	2	-81.625	45.125	6.288806184	-1.438305633	-1.73731686	-4.5105102	-5.962445
4	3	-81.375	45.125	5.886454443	-1.837147852	-2.31300845	-4.4176837	-6.5316059
5	4	-81.125	45.125	6.175955322	-1.545968506	-1.88355396	-3.2916655	-5.9589019
6	5	-80.875	45.125	6.975353245	-0.99812698	-1.78596878	-2.8276558	-5.9438057
7	6	-80.625	45.125	7.396912489	-0.688475695	-2.36425694	-3.2248832	-6.9411918
8	7	-80.375	45.125	7.300751634	-0.791289381	-3.42889314	-4.2187186	-8.4217825
9	8	-80.125	45.125	6.021597107	-1.753183166	-5.17154864	-5.7232149	-10.379282
10	9	-79.875	45.125	4.301487789	-3.182337895	-6.90417017	-7.13647	-12.031856
11	10	-79.625	45.125	3.879214494	-3.71197203	-7.16567686	-7.600003	-12.153226

Figure H-5: A screenshot of raw daily temperature data outputs of the NA-CORDEX portal.

Step 3: Conducting Historical Bias Correction on the NA-CORDEX Data

To analyze historical climate data, a reference period was established to identify climate trends of 1971-2000. This reference period was chosen as this was encompassed by the NA-CORDEX portal and aligned with Environment and Climate Change Canada's (ECCC) climate normal data for comparison. A climate normal period is an average of the values obtained for specific climate parameters that represent the recent past climate for a given area (e.g., average mean temperature over a 30-year period). Climate normals are generally used for two purposes, the first involves benchmarking current observations to allow for comparison (WHO, 2011), while the second allows for users to develop predictions for the climate impacts that are expected to be experienced within the jurisdiction. To reduce the effects of short-term variability created by weather conditions, a general best practice in climate modeling is to use a 30-year reference period (WMO, 2011). Analyzing a period less than 30 years may not provide enough time to determine the climatic conditions and can be more heavily influenced by short-term variability. Therefore, using a 30-year climate normal period would more accurately provide a representation of the changes in climate for particular climate variables. Historical climate information is typically obtained through observations from weather stations or climate models (Charron, 2016). For the purposes of this report, a total of 7 representative climate stations were used to examine historic climate data within Durham Region and its surrounding vicinity. The list of climate stations can be found in Table H-4 below and they are mapped in Figure H-6. The climate data from these stations were collected from ECCC's climate normal website, where data for annual mean, maximum, and minimum temperature and annual total precipitation were collected.

Table H-4: List of Climate Stations used to observe the historical climate of Durham Region (see Figure H-6 for a map of these climate stations in relation to Durham Region).

Station Number	Station Name	Latitude	Longitude	Elevation above Sea Level (m)
1	Bowmanville Mostert	43.92˚N	78.67˚W	99.1
2	Burketon McLaughlin	44.03˚N	78.8˚W	312.4
3	Oshawa WPCP	43.87˚N	78.83˚W	83.8
4	Tyrone	44.02˚N	78.73˚W	205.7
5	Cobourg STP	43.97˚N	78.18˚W	79.2
6	Richmond Hill	43.88˚N	79.45˚W	240
7	Frenchman's Bay	43.82 ˚N	79.08˚W	76.2

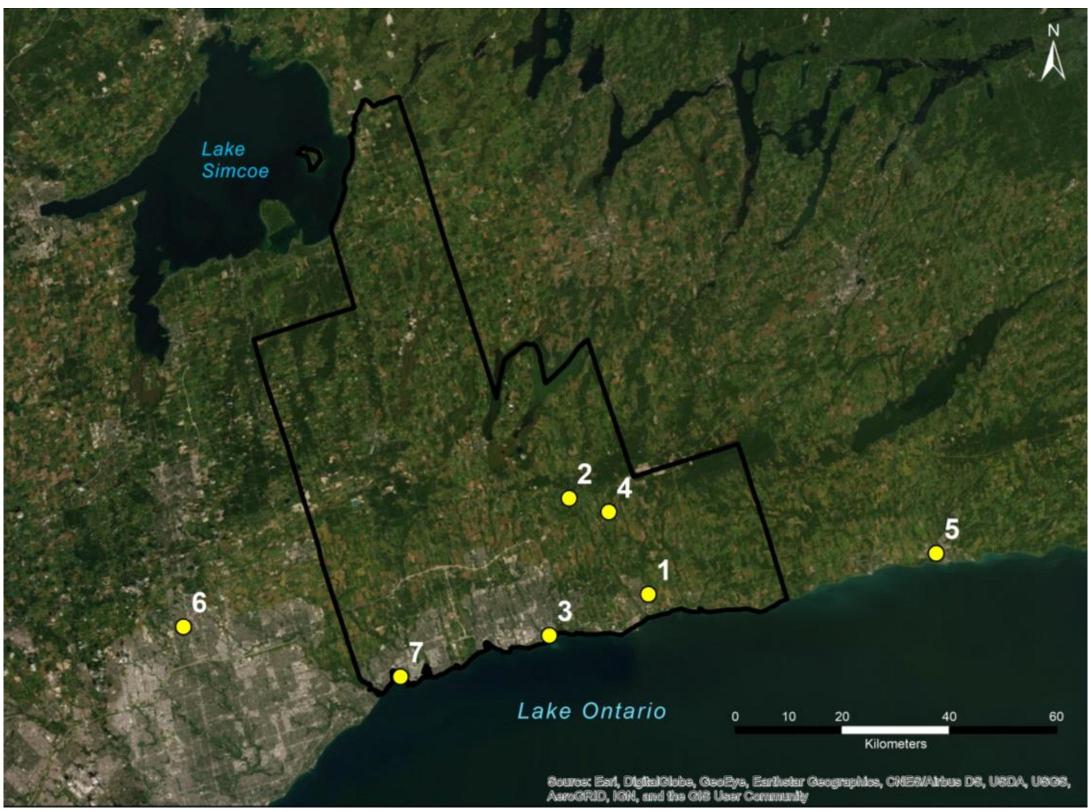


Figure H-6: A map of the seven climate data stations that were used to bias correct the NA-CORDEX data to Durham Region's local climate influences. Refer to Table 8 for associated climate station numbers.

To create relevant reference historical climate data for mean, maximum, and minimum temperature (degrees Celsius) and annual precipitation (millimeters per day), all stations in Table 8 were averaged together to provide a single representative coverage of observation values for Durham Region as a whole. Based on best practice, it was agreed upon that taking the average of these climate stations would eliminate any biases or skewed data for variables like topography, surrounding vegetation, human error, and other geographic characteristics. Taking the average values of these stations makes the historical baseline period for Durham more robust. Therefore, the annual average maximum and minimum temperatures were calculated, as well as the mean annual temperatures and mean annual precipitation from the weather stations within Durham Region.

Once the climate averages for each climate parameter were calculated from ECCC's climate normals, the projected historical data (i.e. the climate models' projected historical conditions) from the NA-CORDEX model ensemble were compared against the observed averages over Durham Region for the 30-year period of 1971-2000. The subtracted differences between the projected historical values and the actual observed values were then calculated. By knowing this difference, the same difference can be added/subtracted onto future projections to ensure that the projections are as accurate as possible and represent the local features that may not have been captured in the models themselves. In other words, the future climate change projections from the NA-CORDEX portal were bias corrected for Durham Region. Below is an example of how future climate change projections were bias corrected for observed temperature (T_{OBS}):

Averaged Observed Temperature in Durham Region	**Modeled Historical Temperature**	**Difference between modeled and observed values:**
$T_{OBS} = 5.5^{\circ}C$	$T_{RCM\ for\ Baseline} = 8.5^{\circ}C$	$\Delta T = T_{OBS} - T_{RCM\ for\ Baseline}$ $\Delta T = -3.0^{\circ}C$

Knowing this, OCC then took the difference between modeled and observed values (ΔT), and added this to the future climate change projection data, as shown below:

Modeled Future Temperature Data for the RCP 8.5 Scenario for 2041-2070	**Bias-Corrected Value for the Modeled Future Temperature value**
$T_{RCM\ RCP\ 8.5} = 15.5^{\circ}C$	$T_{BIAS} = T_{RCM\ RCP\ 8.5} + \Delta T$ $T_{BIAS} = (15.5\ ^{\circ}C) + (-3^{\circ}C)$ $T_{BIAS} = 12.5^{\circ}C$

This was applied to all parameters (mean, maximum, and minimum temperature and mean precipitation) for all grid point data of the NA-CORDEX modeled data, for all model runs, for all future timeframes (2011-2040, 2041-2070, and 2071-2100) for both RCP 4.5 and 8.5 climate scenarios. The model ensemble mean and 10th and 90th percentiles were then calculated, using the bias corrected data of each grid cell. The 10th and 90th percentiles were important to calculate, in order to demonstrate the variance in the model results. The nth percentile demonstrates the value below which n% of the data, when sorted, fall. For example, while the mean temperature for a grid cell could be 9˚C, the 10th percentile could be 7˚C and the 90th percentile could be 12˚C, demonstrating the range in model values (i.e. even though the mean is 9˚C, the models demonstrate that 90% of the runs predict the temperature to be under 12˚C and 90% predict higher temperatures than 7˚C). Once all the basic climate variables were bias corrected, specific climate variables were derived from these data, which are highlighted in the following section.

Step 4: Choosing Climate Parameters to Derive from the NA-CORDEX Data

A climate parameter is the measurement used to analyze how much a given climate condition (e.g., air temperature) has changed or will change in the future (Harris et al., 2016). For example, parameters for measuring air temperature may include the number of frost days, the number of summer days and tropical nights, growing season length, etc. Each component of the climate system has measurable parameters, and it is up to the municipality or CA undertaking the climate analysis to define which parameters are of most significance and should be evaluated further. Selecting the appropriate climate parameters will depend on the availability of data, quality of data, as well as stakeholder engagement (e.g., Table 9). When determining the climate parameters that will be analyzed, it is important to involve stakeholders from across the organization(s) (e.g., agriculture, health, public works and engineering staff, etc.) to determine the most appropriate climate parameters.

The goal of this study is to provide valuable climate data within Durham Region under future climate change and a step-by-step methodology that can be replicated by other municipalities within Ontario's Greenbelt and across the province. Therefore, it is of utmost importance that any climate parameters provided for this study are clearly defined. At the most basic level, climate parameters include measures of precipitation and temperature, including total annual precipitation and the annual mean, maximum and minimum temperature. However, it is of interest to determine sub-annual indices of climate, ones that capture seasonal changes and extremes of precipitation and temperature, which are not captured by annual measurements. Other parameters of interest, such as growing degree days (GDD), act as agricultural indicators where the minimum temperature values act as thresholds (e.g., the growth of canola (4°C) and forage crops (5°C), corn and beans (10°C) and for insect and pest risk (15°C)) (Climate Atlas of Canada, 2019).

A few climate parameters typically used in climate change analyses are provided below in Table 9.
Climate parameters were chosen for Durham Region based on engagement with the NECCC group, the previous SENES study, data availability, and the robustness of data. The full list of the climate parameters undertaken in this study and their technical definitions are provided under Appendix B, and a sample of results for a few climate parameters for the RCP 8.5 scenario are summarized in Table H-5.

Table H-5: Examples of Climate Parameters

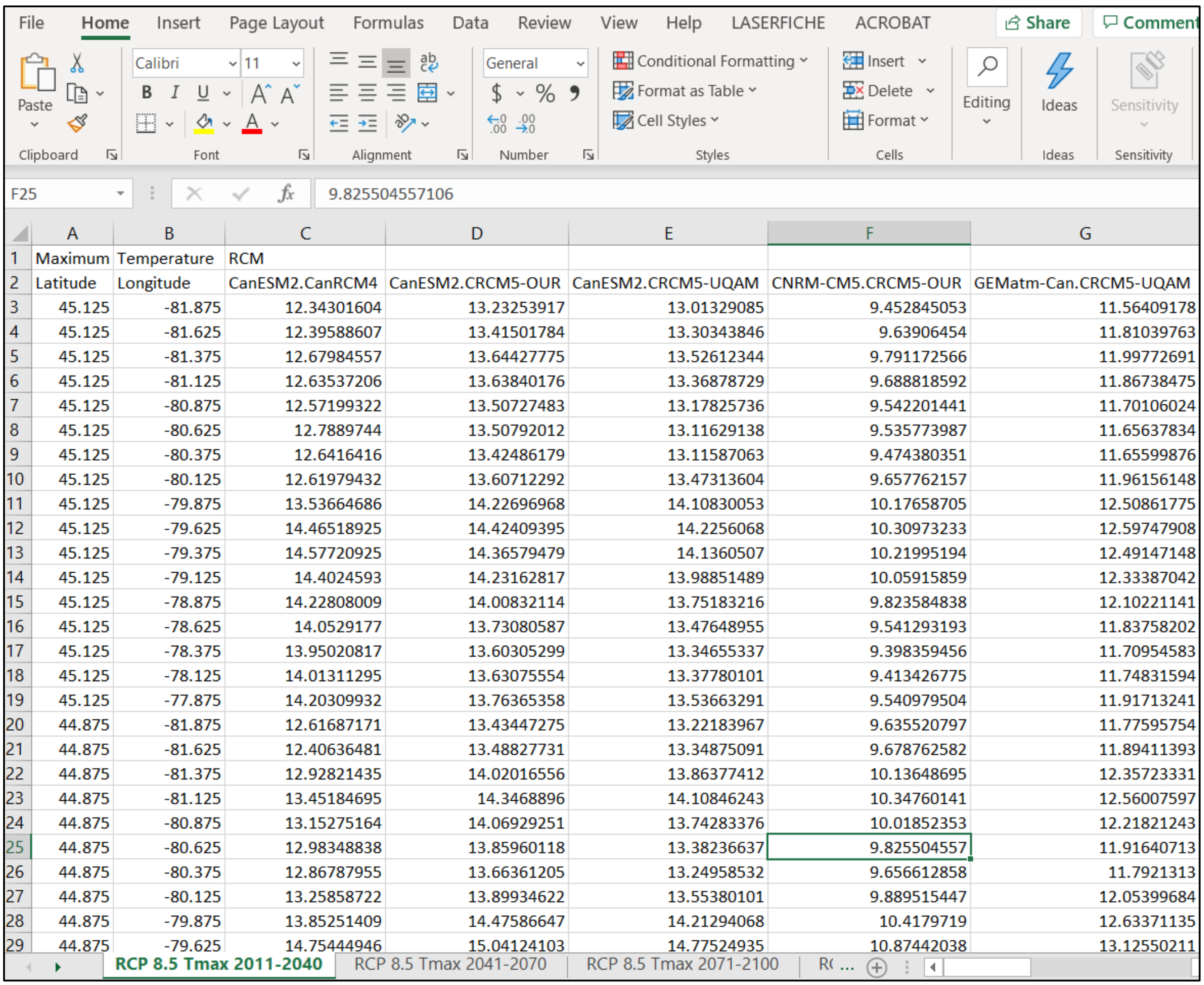
Parameter	Definition	Why you should consider including this parameter in your study?
Mean Air Temperature	The mean temperature in degrees Celsius (°C) is defined as the average of the maximum and minimum temperature at a location for a specified time interval	The temperature range we expect within a season or year is a very important aspect of climate. Changes in average and extreme temperatures can dramatically affect our everyday lives (e.g., our health and our cooling needs) as well as a wide range of planning and policy decisions. The average highest temperature is an environmental indicator with many applications in agriculture, engineering, health, energy management, recreation, etc.
Total Precipitation	The total amount of precipitation in millimeters (mm) such as rain, drizzle, freezing rain, snow (in liquid equivalent), and hail, observed at the location during a specified time interval.	Precipitation patterns are critical for many important issues, including water availability and quality, crop production, electricity generation, wildfire suppression, snow accumulation, seasonal and flash-flooding, and short- and long-term drought risk.
Freeze-Thaw Cycles	A simple count of days when the air temperature fluctuates between freezing and non-freezing temperatures (i.e. minimum temperatures are equal to or below -1˚C and maximum temperatures are above 0˚C). Under these conditions, it is likely that some water at the surface is both liquid and ice at some point during the 24-hour period.	Freeze-thaw cycles can have major impacts on infrastructure. Water expands when it freezes, so the freezing, melting and re-freezing of water can over time cause significant damage to roadways, sidewalks, and other outdoor structures. Potholes that form during the spring, or during mid-winter melts, are good examples of the damage caused by this process.

Step 5: How to Derive Climate Parameters from the NA-CORDEX Climate Data

As the previous sections explained, once all of the NA-CORDEX data was bias corrected to Durham Region specifically, additional climate parameters were able to be calculated from the basic climate parameters (e.g., daily mean, maximum, and minimum air temperatures and total precipitation). The derived climate parameters (listed in Appendix B) were obtained by developing query-based indices from the bias-corrected model outputs.

The first step in deriving all the climate parameters was to aggregate the data into a number of more manageable spreadsheets. As Figure H-3 indicated (in Step 2), the data gathered from the NA-CORDEX portal came as daily values for each grid cell for each climate model. Therefore, from the criteria that were put input into NA-CORDEX website, there were 64 spreadsheets gathered in total (e.g., 16 spreadsheets for each of the four climate periods).

To combine these spreadsheets to make them more manageable, OCC calculated the annual averages of all daily data for each model for each grid cell and combined these into a spreadsheet for each RCP climate scenario. For example, for the CanESM2-Can RCM4 model run at the RCP 8.5 climate scenario, the annual average maximum temperature for the grid cell located at 45.125, -81.875 was calculated to be 12.34˚C. This number was then input into the larger Excel Spreadsheet, with all other values for each grid cell. This was conducted 16 times, until the spreadsheet looked like Figure H-7.



	A	B	C	D	E	F	G
1	Maximum	Temperature	RCM				
2	Latitude	Longitude	CanESM2.CanRCM4	CanESM2.CRCM5-OUR	CanESM2.CRCM5-UQAM	CNRM-CM5.CRCM5-OUR	GEMatm-Can.CRCM5-UQAM
3	45.125	-81.875	12.34301604	13.23253917	13.01329085	9.452845053	11.56409178
4	45.125	-81.625	12.39588607	13.41501784	13.30343846	9.63906454	11.81039763
5	45.125	-81.375	12.67984557	13.64427775	13.52612344	9.791172566	11.99772691
6	45.125	-81.125	12.63537206	13.63840176	13.36878729	9.688818592	11.86738475
7	45.125	-80.875	12.57199322	13.50727483	13.17825736	9.542201441	11.70106024
8	45.125	-80.625	12.7889744	13.50792012	13.11629138	9.535773987	11.65637834
9	45.125	-80.375	12.6416416	13.42486179	13.11587063	9.474380351	11.65599876
10	45.125	-80.125	12.61979432	13.60712292	13.47313604	9.657762157	11.96156148
11	45.125	-79.875	13.53664686	14.22696968	14.10830053	10.17658705	12.50861775
12	45.125	-79.625	14.46518925	14.42409395	14.2256068	10.30973233	12.59747908
13	45.125	-79.375	14.57720925	14.36579479	14.1360507	10.21995194	12.49147148
14	45.125	-79.125	14.4024593	14.23162817	13.98851489	10.05915859	12.33387042
15	45.125	-78.875	14.22808009	14.00832114	13.75183216	9.823584838	12.10221141
16	45.125	-78.625	14.0529177	13.73080587	13.47648955	9.541293193	11.83758202
17	45.125	-78.375	13.95020817	13.60305299	13.34655337	9.398359456	11.70954583
18	45.125	-78.125	14.01311295	13.63075554	13.37780101	9.413426775	11.74831594
19	45.125	-77.875	14.20309932	13.76365358	13.53663291	9.540979504	11.91713241
20	44.875	-81.875	12.61687171	13.43447275	13.22183967	9.635520797	11.77595754
21	44.875	-81.625	12.40636481	13.48827731	13.34875091	9.678762582	11.89411393
22	44.875	-81.375	12.92821435	14.02016556	13.86377412	10.13648695	12.35723331
23	44.875	-81.125	13.45184695	14.3468896	14.10846243	10.34760141	12.56007597
24	44.875	-80.875	13.15275164	14.06929251	13.74283376	10.01852353	12.21821243
25	44.875	-80.625	12.98348838	13.85960118	13.38236637	9.825504557	11.91640713
26	44.875	-80.375	12.86787955	13.66361205	13.24958532	9.656612858	11.7921313
27	44.875	-80.125	13.25858722	13.89934622	13.55380101	9.889515447	12.05399684
28	44.875	-79.875	13.85251409	14.47586647	14.21294068	10.4179719	12.63371135
29	44.875	-79.625	14.75444946	15.04124103	14.77524935	10.87442038	13.12550211

Figure H-7: A screenshot of how the NA-CORDEX data was organized into more manageable spreadsheets. Each column represents annual averages of maximum temperature (˚C) for each grid cell, for each of the model runs (full spreadsheet includes the 16 model runs).

Once this was conducted for each of the climate scenarios, climate parameters were derived from query and search functions in Microsoft Excel. The queries that were used to derive the parameters were then used to match text-based filters that were applied based on conditional statements, which included but were not limited to: *DATEDIF, COUNTIF, INDIRECT*, *ISNUMBER*, *MATCH*, *OFFSET* functions for array-based model outputs.

The following subsections walk through how each climate variable in this study was calculated.

Step 5.1 Mean, Maximum, and Minimum Annual and Seasonal Temperatures

Since the NA-CORDEX data that was downloaded already included mean, maximum, and minimum temperatures, calculating the annual and seasonal averages for future climate periods was quite straightforward.

As Figure H-7 illustrates, all climate period averages and 10^{th} and 90^{th} percentiles of maximum, minimum, and mean temperatures for all grid cells were calculated for each climate period, climate scenario and model run. Therefore, to obtain the average annual numbers and the percentiles for each of the temperature parameters (mean, maximum, and minimum), OCC took the average of all 16-climate model (bias corrected) runs for each of the grid cells, as an ensemble of all climate data for each grid point. Then, an average of all the ensemble averages of each grid cell was calculated to obtain the final annual average mean, maximum, and minimum temperatures for Durham Region as a whole.

For example, for one grid cell (1), the following equations were applied (using the same climate scenario and climate period as shown in H-7) (BC indicates "Bias Corrected" and T_1 indicates the daily air temperature at a specific grid cell, 1):

$$T_{1\ MEAN} = \frac{T_{1\ CanESM2.CanRCM4\ BC} + T_{1\ CanESM2.CRCM5OUR\ BC} + \ldots + T_{1\ MPI\text{-}ESM\text{-}MR.CRM5UQUAM\ BC}}{16}$$

$$T_{1\ MEAN} = \frac{[(T_{1CanESM2.CanRCM4} + \Delta T_1) + (T_{1\ CanESM2.CRCM5OUR} + \Delta T_1) \ldots + (T_{1\ MPI\text{-}ESM\text{-}MR.CRM5UQUAM} + \Delta T_1)]}{16}$$

$$T_{1\ MEAN} = (12.34^{\circ}C + 2.58^{\circ}C)\ (13.23^{\circ}C + 2.58^{\circ}C) \ldots + (10.04^{\circ}C + 2.58^{\circ}C) / 16$$

$$T_{1\ MEAN} = 14.96^{\circ}C + 15.73^{\circ}C + 12.62^{\circ}C + \ldots + /16$$

$$T_{1\ MEAN} = 12.88\ ^{\circ}C$$

Then, to calculate the annual average over the entire area (i.e., for all grid cells, "n"), the average of all grid cell averages was calculated, for example:

$$T_{Annual\ Average} = \frac{T_{1\ MEAN} + T_{2\ MEAN} + T_{3\ MEAN} + \ldots + T_{n\ MEAN}}{n}$$

These numbers were then added to the final results summary tables (see section 5).

A similar process was undertaken to calculate the 10th and 90th percentiles for all of the model runs for each grid cell, using the *PERCENTILE* function in Excel. To calculate the percentiles, Excel asks the user to input (array, k). Therefore, to calculate the 10th percentile, OCC input the array as the row of bias corrected climate model run results for each grid cell, and “0.1” for the 10th percentile, and did the same for the 90th percentile, but input “0.9” as the k value.

Step 5.2 Extreme Heat and Extreme Cold Days

Extreme heat and cold parameters were also calculated quite simply, as these parameters are threshold-based climate parameters (e.g., days above 30˚C, days below -20˚C).

The raw excel files of daily temperature data from the NA-CORDEX portal were used for these queries. For each climate model, OCC calculated the number of days where maximum temperatures were above 35˚C, 30˚C, 25˚C, and where the minimum temperature was higher than 20˚C for tropical nights. Similarly, for cold temperatures, the minimum daily temperatures were used to calculate the number of days below -20˚C, -15˚C, -10˚C, -5 ˚C, and 0 ˚C.

OCC used the “Count If” function statements in Excel to query the number of days that exceeded each of these thresholds. For example, to calculate for days above 30˚C, the following was typed into Microsoft Excel:

= COUNTIF (range, “>30”)
= COUNTIF (C2:C18, “>30”)

Once this was conducted for each of the climate models, OCC calculated the average of all the model outputs to find the average annual amount of days for each grid cell. This process was repeated for all threshold-based parameters assessed in this study.

Step 5.3 Total Precipitation

Since the raw data that was collected from the NA-CORDEX included daily amounts of precipitation for each climate period (mm/day), a similar process was conducted to calculate the annual and seasonal amounts of precipitation.

Annual amounts of precipitation were calculated by taking the average amount of daily precipitation for all days in the climate normal period and multiplying this by 365.25 days (the ¼ of a day represents the extra day of the year for leap years) for each grid cell.

Similarly, the **seasonal amounts of precipitation** were calculated by taking the average amount of daily precipitation for the respective months that represent each season. For example,

- Winter represents December, January, and February (D-J-F),

- Spring represents March, April, and May (M-A-M),
- Summer includes June, July, and august (J-J-A), and
- Fall includes September, October, and November (S-O-N).

Once average daily precipitation amounts were calculated for each of the seasons for each grid cell, these numbers were multiplied by 91.31 days (365.25/4). This process was repeated for all climate models and climate scenarios.

Step 5.4 Extreme Precipitation

To calculate extreme precipitation in Durham Region, OCC calculated the maximum amount of precipitation falling in one and three days, the amount of "extreme precipitation days", where daily values of precipitation exceeded 25 mm, the annual and seasonal simple daily intensity index (SDII), and the 95th and 99th percentiles of precipitation.

To calculate the **maximum amount of precipitation falling in one day**, OCC used the "MAX" function in Microsoft Excel. Therefore, for each year of data, the maximum amount of precipitation was recorded. From here, the average maximum value of precipitation was calculated for the entire climate period, for each climate model and scenario, for each grid cell.

To calculate the **maximum precipitation falling in three days**, a rolling sum was applied in Excel. Therefore, for each three days of the year, a value was produced to provide a total amount of precipitation (see example below). This was done by using the "SUM" formula and specifying the ranges. For example, in the table below, the formula = SUM(B2:$D2) was applied to get the running three-day total from January 1st to 3rd (7.3 mm), this formula repeats itself for every day in the data.

	A	B	C	D	E	F
1		**Precipitation January 1, 2040**	**Precipitation January 2, 2040**	**Precipitation January 3, 2040**	**Precipitation January 4, 2040**	**Precipitation January 5, 2040**
2		2.1	2.5	2.7	3.9	5.2
3	**Running 3-Day Sum**			7.3	9.1	11.8

Once the running three-day totals were calculated for a year at a time, the maximum value for each year was derived using the "MAX" function in Excel. From here, the annual maximum three-day precipitation amounts were averaged for the entire climate normal period for all climate models and scenarios.

To calculate the **extreme precipitation days**, OCC conducted a similar process to how the temperature threshold-based parameters were calculated. Therefore, the "Count If" function in Microsoft Excel was used to count the number of days where precipitation exceeded 25 mm of rain for each grid cell and each model.

Averages of the 16 models were then calculated for the final number of extreme precipitation days for each climate normal period.

The **annual and seasonal simple daily intensity index (SDII)** is a measurement of how much precipitation occurs in one day. The raw NA-CORDEX data provides SDII for each day of the year; therefore, this calculation was quite simple. Annual averages of SDII was calculated for each climate period and model. Seasonal averages were also calculated based on the months defined earlier (e.g., D-J-F, M-A-M, J-J-A, and S-O-N).

The **95th and 99th percentiles of precipitation** are defined as the amount of annual precipitation for events (e.g., any day that had more than 0.2 mm) in the top 5% and 1% of precipitation events during a period compared to the baseline, respectively. Therefore the 95th and 99th percentiles represent the fraction of all precipitation events in millimetres above the 95th and 99th percentiles in the baseline period of 1971-2000. As an example, the total amount of precipitation for the baseline period was 952.4 mm, and the top daily 5% of events (i.e. the 95th percentile) produced about 36.11 mm of the total amount of precipitation. To calculate this, there is a function in Excel, “Percentil.Exc” that was used. Therefore, the following formula was used:

=PERCENTILE.EXC(A1:AX,k)

where "X" is the last row in the column and "A" is where you have entered data, and "k" is the desired percentile value. It should be noted that the percentile value must be between zero and one, therefore, to find the 95th percentile, you would use "0.95" as your percentile value.

Step 5.5 Dry Days, Growing Degree Days, and Agricultural Parameters

To examine the drought and agricultural conditions in Durham Region, the total annual number of dry days, the annual maximum total amount of consecutive dry days, the growing season start and end dates, the growing season lengths, as well as the annual average corn heat units (CHUs) and growing degree days (GDDs) for four different variables were calculated.

Dry days are defined as days where daily precipitation values are less than 0.2 mm. As with most models, there was a problem with drizzle; therefore, all values that were under 0.2 mm were zeroed to debias the problem. To calculate the **total annual amount of dry days** in a year, OCC used the “Count If” function in Excel to count the number of days where precipitation was less than 0.2 mm. This number was then averaged for each climate normal period and for each climate scenario.

The **maximum total number of consecutive dry days** is the amount of days were precipitation is consistently under 0.2 mm. To calculate this, OCC used the “IF” statement in Excel, to note the number “1” under the precipitation value if it was less than 0.2 mm. From here, OCC calculated the rolling sum of the “1”s for each year. From here, the “MAX” function was used to gather the maximum dry periods of each year. This was then averaged with all other climate models for each climate period and scenario.

The **start date of the growing season** is defined as the first day where the previous 5 days each had a minimum temperature above 5˚C, whereas the **end date of the growing season** is defined as the first day after 5 days of consecutive maximum temperatures above 5˚C was reached. To calculate the start date of the growing season, OCC conducted a similar process to the maximum number of consecutive dry days. Therefore, OCC used the “IF” statement to note when temperature was above 5˚C with a “1” in the row under the temperature value. Then, we calculated a running sum of all days with a count of one. Therefore, the first day within a year that was equal to 5 denoted the start of the growing season. The following equation was used to calculate the start of the growing season:

=IF(SUM(CCH206:CCL206)=5,"START","")

Similarly, to calculate the end of the growing season, the same methodology was applied, but the equation changed to denote a “1” where temperature was below 5˚C, and where the growing season had already begun. Then a rolling sum was calculated to determine the end date of the growing season (when the rolling sum reach 5). The following equation was used to calculate the end date of the growing season:

=IF(AND(CCM207="START",SUM(CCN206:CCR206)<1),"END","")

According to the above formula, it is not unlikely that a growing season may end shortly after a growing season has begun. This phenomenon may be observed when warm periods suddenly occur during cooler seasons which may trigger an early growing season or conversely when a “cold snap” event where temperatures drop sharply during warmer periods. Therefore, to calculate the actual length of the growing season, the adjusted growing season was assumed to end no earlier than September. This would assume that the end date of a growing season would take place after a growing season start date and would occur after the month of August. To calculate the adjusted growing season, a row was created to count the number of days from the beginning of the climate normal where a growing season has started and that the value for the end date exceeds that of the growing season. A query was then used to filter out the results which would occur after the month of August, which would be noted by text filter “SECONDEND”. In the case, where an early end of the growing season is observed, the text filter “END” would note such an outcome.

Corn Heat Units (CHUs) represent the ideal climate for corn to fully mature (e.g., at least 2200 CHUs are required to mature most varieties of corn every year). CHUs are a function of daytime and nighttime temperatures. The following equation represents how CHUs are calculated:

$$CHU = \frac{CHU_{night\,time} + CHU_{day\,time}}{2}$$

$$CHU_{night\,time} = 1.8T_{min} + 4.4$$
$$CHU_{day\,time} = 3.3(T_{max} - 10) - 0.084(T_{max} - 10)^2$$

$$s.t.\; if\; CHU_{night\,time} \leq 0\,;\; CHU_{night\,time} \leq 0\,,\; then\; CHU = 0$$

This equation was typed into Excel as a linear equation as such:

CHU = CHU:[1.8(daily min temp + 4.4) + 3.3(daily max temp – 10) – 0.084(daily max temp) -10)^2]/2

The total number of CHUs were summed for each year. Once CHUs were calculated for each year for the climate normal periods, the average of these were taken to represent the average CHUs for each climate period.

Growing Degree Days (GDDs) are similar to CHUs and the threshold parameters. A GDD is defined as the number of days where a certain crop can grow. For the purposes of this study, GDDs were calculated for days above 0˚C, 4 ˚C (where canola can grow), 5˚C (where forage crops can grow), 10˚C (where corn and beans can grow), and 15˚C (where there is a risk of pests). The following equation represents how GDDs are calculated (base temperatures were replaced with the temperature thresholds for the specific types of crops listed earlier):

GDD = GDD [(max daily temp + min daily temp)/2] – base temp

The total number of GDDs was summed for each year for each temperature threshold. Once GDDs were calculated for each year for the climate normal periods, the average of these were taken to represent the average GDDs for each climate period.

Step 5.6 Ice and Snow

To analyze the presence of freeze-thaw cycles and ice on the ground in the future, query-based calculations were made to the NA-CORDEX data.

Freeze-thaw cycles are defined as the number of days where the daily minimum temperature is equal to or below -1˚C and the maximum temperature is above 0˚C. Therefore, OCC used the “IF” function in Excel, to note a “1” when maximum temperature above or below -1˚C and used another “IF” statement to determine the minimum temperatures above 0. When there were two “1s” for both criteria, an equation was created to note a “FREEZE” cycle. Then the sum of the number of “FREEZE”s was taken to determine the annual amount of freeze-thaw cycles. This was calculated for each year, and then the average was taken for all 30 years of each climate normal period.

A very similar calculation was taken to determine the number of ice potential days. This number of **ice potential days** (e.g., days where we can expect to see rain freezing to ice on the ground) is defined by the number of days where minimum temperature is greater than -2˚C and maximum temperature is under 2˚C.

Step 6: Displaying the Data in ArcMap

Once all the climate parameters were derived, it was important to be able to display the data in the form of maps to visualize how climate change might impact Durham Region in the future. Since all the CSV files were composed of point data (e.g., climate information for each latitude and longitude), an interpolation method was used in ArcMap 10.4, using the Spatial Analyst Extension.

First, the CSV file of interest was imported into ArcMap by clicking “Import as XY data”. When this button is selected, a pop-up window appears and will prompt you to choose which fields of data you would like to display for the X, Y, and Z vectors. Be sure that X represents longitude and Y represents latitude. For the Z value, select parameter of interest (e.g., annual mean temperature). You will also be asked what type of file you would like this table to be saved as, select “feature class”; this will save your CSV file as a shapefile. After you click “Okay”, you will need to import the shapefile into ArcMap.

Once imported, the data will display as points (similar to Figure H-2). To interpolate the data between the points, OCC used a method called “kriging”. This is a geostatistical way of interpolating surfaces, which are based on statistical models that include autocorrelation (i.e. the statistical relationships between the measured points). Therefore, this technique not only produces a smooth surface interpolation between points, but it also provides some measure of certainty or accuracy of the predictions it makes. Kriging assumes that the distance between points reflects a spatial correlation that can be used to explain variation in the surface. For more information on kriging and the specific equations associated with it, click here.

It is extremely important to keep in mind that since values have only been bias-corrected to Durham Region for this report, when interpreting the maps, only values in Durham Region are considered to be bias-corrected. Municipalities outside of Durham Region have been included to demonstrate the variability in climate across the broader region, but the values for areas outside of the Region have not been bias-corrected and these areas have been marked with black dots (e.g., see Figure 17 in section 5.2 for an example).

Acronyms

AGCM	Atmospheric Global Climate Model
AHCCD	Adjusted and Homogenized Canadian Climate Data (AHCCD)
AOGCM	Atmosphere-Ocean Global Climate Model
CanESM2	Second Generation Canadian Center for Climate Modeling and Analysis Earth System Model
CanRCM4	Canadian Regional Climate Model 4
CHU	Corn Heat Units
CMIP5	Fifth Coupled Model Intercomparison Project
CNRM-CM5	Centre National de Recherches Météorologiques
CORDEX	Coordinated Regional Climate Downscaling Experiment
CRCM5-OUR	Canadian Regional Climate Model 5 (OURANOS) (RCM)
CRCM5-UQAM	Canadian Regional Climate Model 5 (Université du Québec à Montréal) (RCM)
CSV	Comma-Separated Values
CTVB	Climate Trends and Variations Bulletin
ECCC	Environment and Climate Change Canada
ESM	Earth Systems Model
GCM	Global Climate Model
GDD	Growing Degree Days
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory Earth System Model Version 2M
GHG	Greenhouse Gases
GRCA	Ganaraska Region Conservation Authority
HadGEM2-ES	U.K. Met Office Hadley Centre Earth System Model
HIRHAM5	Based on a subset of HIRLAM (High Resolution Limited Area Model) RCM and the ECHAM (European Centre developed at Hamburg)
IDF	Intensity Duration Frequency
IPCC	Intergovernmental Panel on Climate Change
KRCA	Kawartha Region Conservation Authority
LBC	Lateral Boundary Conditions
LSRCA	Lake Simcoe Region Conservation Authority
LST	Lake Surface Temperature
MPI-ESM-LR	Max Planck Institute for Meteorology Earth System Model LR
MPI-ESM-MR	Max Planck Institute for Meteorology Earth System Model MR
NARCCAP	North American Regional Climate Change Assessment
NECCC	Natural Environment and Climate Change Collaborative
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
ORCA	Otonabee Region Conservation Authority
OCC	Ontario Climate Consortium
RCA4	Rossby Centre Regional Atmospheric Model 4
RCM	Regional Climate Model
RCP	Representative Concentration Pathway

RegCM4	Regional Climate Model 4 (RCM)
SDII	Simple Daily Intensity Index
SST	Sea Surface Temperature
TRCA	Toronto and Region Conservation Authority
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting Model (RCM)

Glossary

Climate: Climate is defined as an area's long-term weather patterns. The simplest way to describe climate is to look at average conditions (e.g., temperature, precipitation, etc.) over time. Other useful elements for describing climate include the type and the timing of precipitation, amount of sunshine, average wind speeds and directions, number of days above freezing, and/or weather extremes (IPCC 2012a, IPCC 2012b).

Climate Anomaly: The difference between the baseline and the long-term average of a climate variable (e.g., temperature) (NOAA, 2019). For example, a positive climate anomaly in temperature indicates that observed temperatures is warmer than the baseline while a negative anomaly indicates that temperatures are cooler than the baseline (NOAA, 2019).

Climate Change: Refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the statistical properties (e.g., mean and/or the variability) in weather and atmospheric conditions that persists for an extended period, typically decades or longer (IPCC 2007, IPCC 2012a)

Climate Change Scenario: "A climate change scenario is a description of a possible future climate based on assumptions of how the earth's climate operates, future world population levels, economic activity and greenhouse gas emissions" (NRCan, 2018). There are four main climate scenarios that are referenced in the IPCC reports called, Representative Concentration Pathways (RCPs): RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5.

Climate Condition(s): A representation or measurement of a climate driver (e.g., total daily precipitation, minimum daily temperature, 1-day maximum precipitation). In this assessment, climate variables refer to those that have been modeled using a suite of Global Climate Models (GCMs) that are then used to infer trends in changing climate.

Climate Normal: "Refer to arithmetic calculations based on observed climate values for a given location over a specified time period and are used to describe the climatic characteristics of that location. Real-time values, such as daily temperature, are compared to the 'climate normal' to determine how unusual or how great the departure from 'average' they are" (Environment and Climate Change Canada, 2018). A 30-year period is typically used to smooth out extremes, and ensure that particularly wet, dry, hot or cold years do not dominate the climate conditions overall (which may occur if only a subset of years are used as a normal period). Typically, the middle decade is used to name the climate normal, such as 2041-2070 referred to as the 2050s, 1981-2010 referred to as the 1990s (or baseline period).

Climate Projection: The term "projection" is used in two ways in climate change literature. In its general usage, a projection can be regarded as any description of the future and the pathway leading to it (e.g., WMO 2007). However, a more specific interpretation has been attached to the term "climate projection" by the IPCC when referring to model-derived estimates of future climate (IPCC 2012a, IPCC 2012b).

(Climate Change) Impacts: Consequences of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts:

- **Potential impacts**: All impacts that may occur given a projected change in climate, without considering adaptation." (IPCC, 2014). This is the product of climate exposure and sensitivity.
- **Residual impacts:** The impacts of climate change that would occur after adaptation" (IPCC, 2014).

Degree Days: Degree-days for a given day represent the number of Celsius degrees that the mean temperature is above or below a given base temperature. For example, heating degree-days are the number of degrees below 18 °C. If the daily mean temperature is equal to or greater than 18 °C, then the number will be zero. Values above or below the base of 18°C are used primarily to estimate the heating and cooling requirements of buildings. Values above 5°C are frequently called growing degree-days and are used in agriculture as an index of crop growth.

Downscaling: The process of generating climate information from a Global Climate Model (GCM) with coarse spatial resolution to a finer spatial resolution. There are two types of downscaling, statistical and dynamical downscaling. Dynamical downscaling also adds value by incorporating additional physics of the Earth's atmosphere (e.g., wind).

Dynamical Downscaling: A downscaling approach which involves running a very high-resolution model once over the area of interest, driven by global climate model boundary conditions. These boundary conditions provide Regional Climate Models with information about conditions in neighbouring cells (e.g., to calculate rainfall, you need to understand how much moisture is entering the region) (Hannah, 2011). In the simplest of terms one can either have 'many model runs at a coarse resolution' or 'few model runs at high resolution'. These high-resolution models are called 'Regional Climate Models' (RCMs).

Global Climate Model (GCM): GCMs provide projected changes in climate over the entire Earth's surface (Charron, 2014). GCMs use mathematical equations to show how energy and matter interact among the ocean, land and atmosphere (NOAA, n.d.). These climate models divide the surface into 3-D grid cells where the results in each cell are passed to neighbouring cells to show how the exchange of energy and matter has changed over time (ibid). GCMs typically have a large spatial resolution (e.g., typically 200 km by 200 km). Therefore, the smaller the grid cell, the more detailed the information will be.

Intensity-Duration-Frequency (IDF) Curve: "IDF curves describe the relationship between rainfall intensity, rainfall duration, and return period. [They] are commonly used in the design of hydrologic, hydraulic, and water resource systems, and are obtained through frequency analysis of rainfall observations" (Colorado State University, *n.d.*).

Radiative Forcing: The change in the net, downward minus upward, radiative energy (expressed in Watts per square metre) at the tropopause (the boundary in the Earth's atmosphere between the troposphere and the stratosphere) due to a change in an external driver of climate (e.g., a change in concentration of carbon dioxide or the output energy coming from the sun) (Charron, 2016).

Raster: A raster graphics (also referred to a bitmap image) is a dot matrix data structure that represents a generally rectangular grid of pixels (points of color). Example of raster images include satellite images, aerial photographs, digital elevation models, etc.

Regional Climate Model (RCM): A dynamically downscaled model, derived and reanalyzed from a Global Climate Model (GCM) that produces climate projections on a much finer scale (Charron, 2016). Compared to GCMs, RCMs have a much smaller resolution (e.g., 25km x 25km).

Representative Concentration Pathways (RCPs): There are four RCPs that represent future total radiative forcing, a cumulative measure of human emissions of GHGs from all sources expressed in Watts per square meter pathway and level by 2100 (IPCC, 2014). Each RCP represents a different combination of economic, technological, demographic, policy, and institutional futures.

RCP 2.6: The lowest emission scenario, where peak radiative forcing is ~3W/m^2 and declines before 2100 (IPCC, 2014). This scenario would require all the main GHG emitting countries, including developing countries, to participate in climate change mitigation initiatives and policies.

RCP 4.5: The second lowest emission scenario, where stabilization without overshoot pathway to 4.5 W/m^2 and stabilization after 2100 (IPCC, 2014).

RCP 6.0: The second highest emission scenario, where stabilization without overshoot pathway to 6 W/m^2 and stabilization after 2100 (IPCC, 2014).

RCP 8.5: The highest emission scenario, where rising radiative forcing pathway leading to 8.5 W/m^2 in 2100 (IPCC, 2014). GHG emissions are up to seven times higher than preindustrial levels.

Seasonality: A characteristic of a time series in which the data experiences regular and predictable changes which recur every calendar year. Any predictable change or pattern in a time series that recurs or repeats over a one-year period can be said to be seasonal (e.g., summer, fall, winter, and spring).

Statistical downscaling: An approach that relies on historical observed relationships among climate parameters of various scales and develops mathematical equations to predict future conditions. Statistical downscaling uses observations to develop these relationships between the large-scale conditions and local-scale conditions and then applies these observed relationships to simulated large-scale patterns. Notably, there is uncertainty as to whether these relationships will hold under evolving conditions (e.g., feedback loops, tipping points) associated with climate change (e.g., changing lake temperatures and ice cover, changing soil moisture, changing snowpack).

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