Historical and Future Climate Trends in York Region

Summary Report

January, 2016

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Recommended Citation

Fausto, E., Milner, G., Nikolic, V., Briley, L., Basile, S., Behan, K., and Trainor, E. 2015. *Historical and Future Climate Trends in York Region.* Ontario Climate Consortium: Toronto, ON: pp.48.

Table of Contents

1. INTRODUCTION

1.1 Purpose of this Report

The purpose of the climate trends described in this report is to support the development of a framework for risk and vulnerability assessment in York Region, and the completion of a case study in Vaughan on their stormwater system. These climate projections are also meant to be available for use in additional planning applications in York Region, and build on existing climate science research. This summary report describes climate trend results based on available datasets.

1.2 Climate Variables

The variables analysed in this report were identified to be of relevance to York Region by stakeholders part of the “Joint Municipal Climate Change Working Group” and “Project Steering Committee” consulted as part of the “Assessing and Mitigating Municipal Climate Risks and Vulnerabilities in York Region” project. The variables analysed represent a subset of all possible climate variables, and were selected by the stakeholders in light of the information elucidated by a literature review of historical climate events and impacts experienced in Southern Ontario (1985-2015) and their perceptions of York Region’s exposure to these climate event (See Appendix A). Input was received through the format of a webinar presentation and survey on June 25, 2015. Climate variables were developed with substantial support from the Great Lakes Integrated Sciences and Assessments (GLISA) group and were derived based on relevant climate trend analyses completed in and around York Region (e.g., Auld et al. 2015, Zhu et al. 2015), and in light of international literature based on the most recent climate change modeling conducted by the Intergovernmental Panel on Climate Change (IPCC) (e.g., Sillmann et al. 2013a, Sillmann et al. 2013b). Table 1 lists the variables included in this analysis and provides a brief description, as well as the units in which the variables are expressed.

Table 1: Variables selected for analysis and description.

Climate Driver	Variable	Units	Symbol	Description[1]
Temperature	Average Maximum Temperature	DegC	TX	Average maximum daily air temperature over a time period
	Average Minimum Temperature	DegC	TN	Average minimum daily air temperature over a time period
	Average Temperature	DegC	Tmean	Average daily air temperature over a time period
	Maximum Maximum Temperature	DegC	TX_x	Highest maximum ("day-time") daily air temperature reached over a time period
	Maximum Minimum Temperature	DegC	TX_N	Highest minimum ("night-time") daily air temperature reached over a time period
	Minimum Maximum Temperature	DegC	TN_X	Lowest maximum ("day-time") daily air temperature reached over a time period
	Minimum Minimum Temperature	DegC	TN_N	Lowest minimum ("night-time") daily air temperature reached over a time period
	Diurnal Temperature Range	DegC	DTR	Difference between Daily Maximum and Daily Minimum air Temperature over a time period
Precipitation	Total Precipitation	mm	PRCPTOT	Total amount of precipitation falling on wet days (where precipitation is greater than 1mm) over a time period
	Number of Wet Days	Days	R1mm	The total number of days where precipitation exceeds 1mm over a time period
	Consecutive Wet Days	Days	CWD	The number of days in a row where precipitation exceeds 1mm, averaged over a time period
Extreme Precipitation	1-Day Maximum Precipitation	mm	RX1day	Maximum precipitation in 1 day over a time period
	5-Day Maximum Precipitation	mm	RX5day	Maximum precipitation in 5 day over a time period
	Simple Daily Intensity Index	mm/day	SDII	Average intensity over a time period, calculated as total wet day precipitation divided by the total number of wet days
	Heavy Precipitation Days (>10mm)	Days	R10mm	The total number of days where precipitation exceeds 10mm over a time period
	Very Heavy Precipitation Days (>20mm)	Days	R20mm	The total number of days where precipitation exceeds 20mm over a time period
Ice Storms	Ice Days (Tmax<0)	Days	ID	The total number of days where maximum ("day-time") temperatures are below freezing over a time period
	Ice Potential	Events	IP	Total number of days where precipitation is greater than 1mm, maximum temperatures <2˚C and minimum temperatures are >-2˚C
Extreme Cold	Number of Days with Minimum Temperature < -5C	Days	TN-5	Total number of days with minimum temperatures below -5˚C over a time period
	Number of Days with Minimum Temperature < -15C	Days	TN-15	Total number of days with minimum temperatures below -15˚C over a time period

	Number of Days with Minimum Temperature < -20C	Days	TN-20	Total number of days with minimum temperatures below -20˚C over a time period
	Number of Days with Minimum Temperature < -25C	Days	TN-25	Total number of days with minimum temperatures below -25˚C over a time period
Extreme Heat	Number of Days with Maximum Temperature >25C (A.K.A. Summer Days)	Days	TX25 or SU	Total number of days with maximum temperatures above 25˚C over a time period
	Number of Days with Maximum Temperature >30C	Days	TX30	Total number of days with maximum temperatures above 30˚C over a time period
	Number of Days with Maximum Temperature >35C	Days	TX35	Total number of days with maximum temperatures above 35˚C over a time period
	Number of Days with Maximum Temperature > 38C	Days	TX38	Total number of days with maximum temperatures above 38˚C over a time period
	Number of Days with Maximum Temperature >40C	Days	TX40	Total number of days with maximum temperatures above 40˚C over a time period
	Tropical Nights (Tmin >20C)	Days	TN20 or TR	Total number of days with minimum temperatures above 20˚C over a time period
Growing Season	Growing Season Length	Days	GSL	Annual number of days after having 5 consecutive days above 5˚C and before having five consecutive days below 5˚C.
	Growing Season Start Date	Date	GS_Start	The first day after 5 days of consecutive temperatures above 5˚C.
	Growing Season End Date	Date	GS_End	The first day after 5 days of consecutive temperatures below 5˚C.
	Frost Days (Tmin <0)	Days	FD	The total number of days where minimum ("night-time") temperatures are below freezing over a time period
Drought	Consecutive Dry Days	Days	CDD	The average number of days in a row where precipitation does not exceed 1mm over a time period

[1]Adapted from: Sillmann et al. 2013a; Sillmann et al. 2013b; Auld et al. 2016; and Zhu et al. 2016

1.3 Climate Datasets

Historical trends in climate variables were analysed using a combination of gridded historical climate station-based time series acquired from Natural Resources Canada (Canadian Gridded Station Observation, CANGRD dataset)[1] (McKenney et al. 2011) and SENES Consultants Limited from the City of Toronto Extreme Weather Study (2011) (SENES Dataset). Future projections for York Region were derived using a number of different climate datasets for comparison, which aim to reflect localized trends based on climate modeling conducted in the IPCC's fourth assessment report (IPCC 2007) and fifth assessment report (IPCC 2013).

The climate variables and available datasets that were analysed in this study are summarized in Table 2.

Canadian Gridded Observed (CANGRD) Dataset

For this study, the most recent standard normal period of 1981-2010 was used to produce a baseline climate. Full details of the CANGRD interpolation procedure can be found in in Hopkinson et al. (2012) and McKenney et al. (2011), but a summary is provided below.

Observed daily station temperatures (maximum, minimum) and precipitation (including rain and snow) are used for interpolation between climate stations. A software package called ANUSPLINE uses a smoothing-spline technique to interpolate between stations to produce a continuous climate surface. Stations with data records greater than 5 years were included, and the procedure includes effects of station proximity and elevation. In general the CANGRD data represents the climate condition very well, but in data-sparse regions of Canada's north, the margin of error is large. This is not a factor in Southern Ontario, as the Environment Canada monitoring network is denser and more temporally consistent (Auld et al. 2015). Using a withholding technique (where 48 station observations across Canada were removed from the procedure), interpolated values showed average differences of 0.36°C, 0.66°C and 4.7mm compared to the observed maximum temperature, minimum temperature and total annual precipitation normals for 1971-2010. McKenney et al. (2011) has validated the use of CANGRD across Canada.

SENES Dataset

This dataset contains both historical and future climate based on four climate stations found in York Region: Whitchurch-Stouffville, King-Smoke Tree, Vaughan and East-Gwillimbury. It should be noted; however, that the historical baseline only includes years 2000 to 2009, and the future projections includes years 2040-2049 and is not representative of a full climate normal period. This implies that results using information associated with this dataset may be influenced more strongly by a particularly set of wet or dry years and thus may be skewed slightly compared to a climate ensemble produced dataset. It was out of scope as part of this summary report to examine these influences in more detail, but differences are illustrated

[1] https://cfs.nrcan.gc.ca/projects/3/4

between datasets for particular climate variables and Appendix C examines the SENES dataset more closely compared to CANGRD and compared to the future datasets.

While historical climate projections are simply station measurements, future climate statistics were generated using a regional climate from SENES Consultants Ltd. under a business-as-usual scenario. However, no ensemble approach was taken to develop future climate trends. More details are provided in terms of its development are provided in SENES (2011).

MOECC Climate Change Data Portal Dataset (MOECC CCDP)

This dataset consists of the UK PRECIS five-model ensemble (based on modelling from IPCC 2007) that has been dynamically downscaled to a high-resolution (25km x 25km) by the University of Regina. Only the business-as-usual scenario of A1B is analysed, and for the purposes of estimating general trends this most closely aligns with scenario RCP8.5 from the most recent modelling exercise by IPCC (2013). More details in terms of its development are provided in Wang et al. (2015).

York University LAMPS Dataset (YorkU LAMPS)

This dataset consists of 41 general circulation models (the most recent ensemble modeled as part of the IPCC in 2013) that have been statistically downscaled to a high-resolution (25km x 25km). Only the business-as-usual scenario of RCP8.5 is analysed, and for the purposes of estimating general trends this most closely aligns with scenario A1B from the previous generation of modelling by IPCC (2007). More details in terms of its development are provided in LAMPS (2014) and Zhu et al. (2015).

University of Wisconsin Dynamically Downscaled RCMs (MIROC5 and CNRM-CM5)

This dataset consists of dynamically downscaled simulations from two climate models from the CMIP5 ensemble using the business-as-usual emissions scenario RCP8.5. The two climate models used are the Model for Interdisciplinary Research on Climate version 5 (MIROC5) and the Centre National de Recherches Météorologiques Coupled Global Climate Model version 5 (CNRM-CM5). The downscaling associated with these simulations was performed by Dr. Michael Notaro at the University of Wisconsin (Notaro et al. 2015a, Notaro et al. 2015b) with a focus on the Great Lakes Basin. The Abdus Salam International Centre for Theoretical Physics (ICTP) Regional Climate Model version 4 (RegCM4) was used, coupled with a one-dimensional, energy-balance lake model with a 1 metre vertical resolution. The grid cells used in this dataset are 25km x 25km and the Great Lakes are represented by 431 grid cells. More details in terms of these two simulations' development are provided in Notaro et al. 2015a and 2015b.

Table 2: Summary of climate variables and datasets used for analysis

Climate Driver	Variable	Units	Historical Dataset(s)	Future Dataset(s)
Temperature	Average Maximum Temperature	DegC	CANGRD Daily (1981-2010) SENES Daily (2000-2009)	MOECC CCDP (2035-2065) YorkU LAMPS (2040-2069) CNRM & MIROC5 (2031-2058)
	Average Minimum Temperature	DegC	CANGRD Daily (1981-2010) SENES Daily (2000-2009)	
	Average Temperature	DegC	CANGRD Daily (1981-2010) SENES Daily (2000-2009)	
	Maximum Maximum Temperature	DegC	CANGRD Daily (1981-2010)	
	Maximum Minimum Temperature	DegC	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) CNRM & MIROC5 (2031-2058)
	Minimum Maximum Temperature	DegC	CANGRD Daily (1981-2010)	
	Minimum Minimum Temperature	DegC	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) YorkU LAMPS (2040-2069) CNRM & MIROC5 (2031-2058)
	Diurnal Temperature Range	DegC	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) CNRM & MIROC5 (2031-2058)
Precipitation	Total Precipitation	mm	CANGRD Daily (1981-2010) SENES Daily (2000-2009)	MOECC CCDP (2035-2065) YorkU LAMPS (2040-2069) CNRM & MIROC5 (2031-2058)
	Number of Wet Days	Days	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) CNRM & MIROC5 (2031-2058)
	Consecutive Wet Days	Days	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) YorkU LAMPS (2040-2069) CNRM & MIROC5 (2031-2058)
Extreme Precipitation	1-Day Maximum Precipitation	mm	CANGRD Daily (1981-2010) SENES Daily (2000-2009)	MOECC CCDP (2035-2065) YorkU LAMPS (2040-2069) CNRM & MIROC5 (2031-2058)
	5-Day Maximum Precipitation	mm	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) CNRM & MIROC5 (2031-2058)
	Simple Daily Intensity Index	mm/day	CANGRD Daily (1981-2010)	
	Heavy Precipitation Days (>10mm)	Days	CANGRD Daily (1981-2010)	
	Very Heavy Precipitation Days (>20mm)	Days	CANGRD Daily (1981-2010)	
Ice Storms	Ice Days (Tmax<0)	Days	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) YorkU LAMPS (2040-2069) CNRM & MIROC5 (2031-2058)
	Ice Potential	Events	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) CNRM & MIROC5 (2031-2058)

Extreme Cold	Number of Days with Minimum Temperature < -5C	Days	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) CNRM & MIROC5 (2031-2058)
	Number of Days with Minimum Temperature < -15C	Days	CANGRD Daily (1981-2010)	
	Number of Days with Minimum Temperature < -20C	Days	CANGRD Daily (1981-2010) SENES Daily (2000-2009)	
	Number of Days with Minimum Temperature < -25C	Days	CANGRD Daily (1981-2010)	
Extreme Heat	Number of Days with Maximum Temperature >25C (A.K.A. Summer Days)	Days	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) YorkU LAMPS (2040-2069) CNRM & MIROC5 (2031-2058)
	Number of Days with Maximum Temperature >30C	Days	CANGRD Daily (1981-2010) SENES Daily (2000-2009)	MOECC CCDP (2035-2065) CNRM & MIROC5 (2031-2058)
	Number of Days with Maximum Temperature >35C	Days	CANGRD Daily (1981-2010) SENES Daily (2000-2009)	
	Number of Days with Maximum Temperature > 38C	Days	CANGRD Daily (1981-2010)	
	Number of Days with Maximum Temperature >40C	Days	CANGRD Daily (1981-2010) SENES Daily (2000-2009)	
	Tropical Nights (Tmin >20C)	Days	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) YorkU LAMPS (2040-2069) CNRM & MIROC5 (2031-2058)
Growing Season	Growing Season Length	Days	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) CNRM & MIROC5 (2031-2058)
	Growing Season Start Date	Date	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065)
	Growing Season End Date	Date	CANGRD Daily (1981-2010)	
	Frost Days (Tmin <0)	Days	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) YorkU LAMPS (2040-2069) CNRM & MIROC5 (2031-2058)
Drought	Consecutive Dry Days	Days	CANGRD Daily (1981-2010)	MOECC CCDP (2035-2065) YorkU LAMPS (2040-2069) CNRM & MIROC5 (2031-2058)

2. METHODOLOGY

Figure 1 provides a graphical overview of the steps used in this study, which are detailed further throughout this section of the report. The datasets analysed were quality controlled using graphical methods comparing key climate statistics. For historical analysis trends in climate, the 30-year normal period representing the 1990s (1981-2010) was used. Analysis was completed on daily time series data with respect to monthly and annual trends for the 2050s (usually the time period between 2041-2070). Only one emissions scenario was analysed: business-as-usual (scenario RCP8.5 under the most recent IPCC modeling (2013) and scenario A1B under the previous generation (2007)).

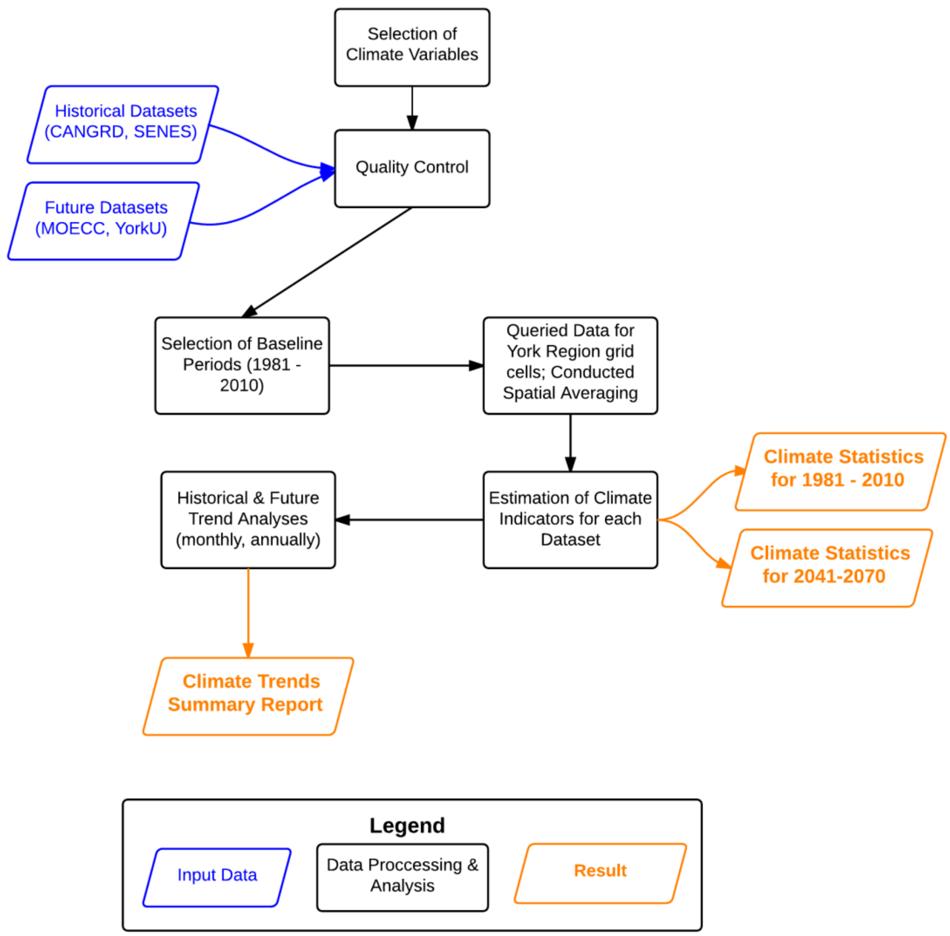

Figure 1: Conceptual diagram of the data inputs, processing steps outputs of this study

The future climate trend analysis was completed by comparing two model ensembles: (1) from the Ministry of Environment and Climate Change Data Portal[2] (MOECC CCDP) and (2) another York University Laboratory for Mathematical and Parallel Systems[3] (YorkU LAMPS). This was done by climate driver (e.g., temperature, precipitation), and by climate variable (e.g., maximum

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[2] http://www.ontarioccdp.ca/index_a1b.html
[3] http://lamps.math.yorku.ca/

annual temperature) to elucidate trends and the confidence in those trends as described by the IPCC (see Appendix B). In addition to these climate model ensembles, two regional climate models were included for contextual comparison only where appropriate. These included two dynamically downscaled datasets (Canadian Regional Climate Model (CNRM) and MIROC5) by the University of Wisconsin (Notaro et al. 2015a, Notaro et al. 2015b).

For each dataset, data in the grid cells that overlaid York Region were obtained (see Figure 2). In order to produce valid comparison, a spatial average of all grid cells in York Region was estimated to maintain consistency in projected climate variables. It should be noted that the number of grid cells found within York Region varies by climate dataset being used. This is a result of differing spatial resolutions used between datasets. For instance, the MOECC CCDP dataset contains six grid cells in York Region at a resolution of 25km x 25km, whereas the CANGRD dataset is interpolated to a 10km x 10km resolution and therefore contains 64 grid cells in the region. The SENES dataset is an exception, as it contains station-based information at four climate stations in York Region. This dataset was included at the interest of stakeholders in York Region since it has been used commonly in the past to provide climate information around the Greater Toronto Area.

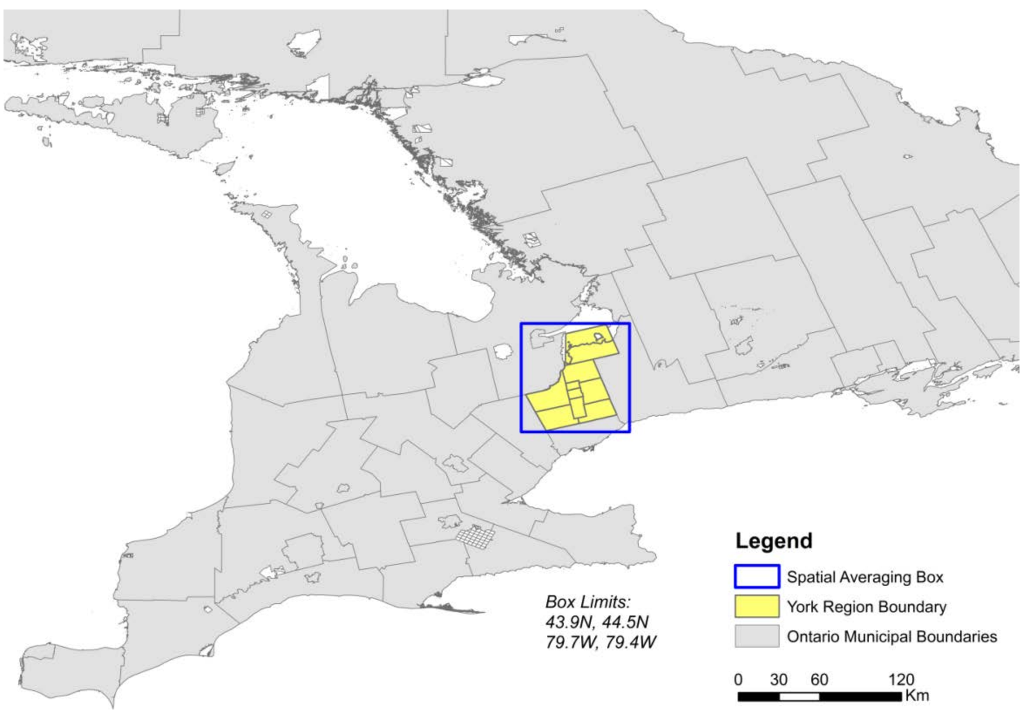

Figure 2: York Region Municipal Boundaries with Spatial Averaging Box Used in Climate Trend Analyses

Most of the climate variables analysed in this study required algorithms to estimate climate statistics based on daily records of temperature, precipitation, or some combination thereof. These were analysed for the 10th and 90th percentile to estimate the range of uncertainty in future climate projections and to demonstrate where the majority of climate projections fall (i.e. above or below the historical climate). The interpretation of the 10th to 90th percentile range is presented for the two ensemble datasets analysed (MOECC CCDP and YorkU LAMPS) in section 4 and more detail is available in Appendix C. Ensemble means, where available, were also examined for the climate variables. It should be noted that due to data availability, only one of the two future climate datasets contains ensemble mean values in this report (YorkU LAMPS).

Two of the future climate datasets analysed (MOECC CCDP and YorkU LAMPS) take an ensemble approach to generating future climate statistics. The ensemble, or multi-model, approach to projecting climate has the advantage of capturing a full range of possible climate scenarios and representing those projections using a statistical distribution. Statistical distributions are useful because they allow the user to interpret trends probabilistically and assess the uncertainty associated with climate modeling. Research has also indicated that the use of multi-model ensembles has the advantage of accounting for all possible biases associated with individual models and can therefore provide the user with the most robust analysis of overall trends in climate (IPCC-TGICA, 2007, Tebaldi and Knutti, 2007). Individual models represent climatological processes slightly differently and each has its own biases (Auld et al. 2015). The use of only one or two climate models can potentially introduce gross errors and lead to misinterpretation of future trends, given that certain individual model biases can become prominent. The use of numerous models, on the other hand, mitigates the persistence of random errors in individual models. Once model biases are adjusted, the remaining signal provided by the ensemble is that associated with trends in climate change.

It should be noted that both future datasets used in this analysis are not simply an ensemble of general circulation models (at a global scale which miss capturing local features such as the Great Lakes and common summertime convective precipitation in and around York Region), but employ the use of two different downscaling techniques: statistical downscaling (YorkU LAMPS) and dynamical downscaling (MOECC CCDP). Each of these methods has their own strengths and weaknesses in terms of producing a reliable climate representation and the direct comparison of MOECC CCDP and YorkU LAMPS must be done cautiously since they have been derived using different assumptions. Given the scope and timeline of the ongoing vulnerability and risk assessment in York Region, this trend report focuses on uncertainty associated with climate projections and general trends. Further analysis should be conducted to validate that the comparison between the two future datasets is reliable. Future climate trends are discussed in section 4. It should also be noted that the climate drivers of windspeed and humidity were considered out of scope for this summary trend report.

3. HISTORICAL CLIMATE IMPACTS

This section presents a narrative summarizing the climate events experienced in southern Ontario identified through a literature review and stakeholder consultation in York Region (Appendix A).

Over the last several decades, Southern Ontario has already experienced a significant number of adverse impacts of extreme weather events For instance, between January 2 and January 15, **1999**, a series of storms hit the city of Toronto releasing a year's amount of snow. The city recorded the greatest January snowfall total ever with 118.4 cm and the greatest snow on the ground at any one time with 65 cm. In the summer of the same year, numerous cities in Southern Ontario also experienced twice as many hot days (days exceeding 30 degrees Celsius) than the summer normal. In **2000**, in just two days, April 20-21st, the Windsor area registered 95mm of rain in a 24 hour period and the storm dumped almost 70 mm of rain on London, 50 mm in Sarnia and 40 mm in Toronto. As a result, sewer backed-ups, road wash outs and many power outages occurred. At the same time, the summer of **2000** was the wettest summer in 53 years with 13% more precipitation than normal.

On April 3rd and 4th of **2003**, a rare mid-spring ice storm struck southern Ontario. The storm was damaging because of its duration and the amount of ice accumulation. That same week, high winds blew in another 10 cm of snow into parts of southern Ontario. With all the blowing and drifting snow, and all the ice left over from the earlier blast, emergency crews were swamped responding to accidents. In London alone, 250 accidents were reported. However, just a few weeks later, on April 24th, the temperature climbed to 28°C at Windsor and 27.1°C in Toronto, making it the second highest temperature ever so early in the year. Hot weather and higher air conditioning demands contributed to the transboundary blackout affecting the Eastern Seaboard in August 2003, shutting down some municipal operations in Ontario for nearly 3 days.

One year later, in May **2004**, an intensive rainfall event in Hamilton set an all-time record. Another all-time record of 409 mm rainfall was set at Trent University in July. During a July storm in Peterborough, water in the city's wastewater system was five times the average capacity. Some roadways and sidewalks had to be completely rebuilt. An early estimate of insured losses exceeded $88 million. In addition, the Province of Ontario provided $25 million for emergency repair and restoration costs for city infrastructure. Consultants recommended that Peterborough spend upwards of $30 million for possible storm water and sanitary sewer system improvements over the next five years.

In August 19, **2005**, Toronto was hit by a storm with rainfall of up to 175 mm recorded in Yonge/Steeles area and 103 mm recorded in 1 hour at Environment Canada Downsview. Although the storm was only approximately 3 hours long, it caused severe flood related damage to parks and recreation facilities, sewer and wastewater systems, ravines, roadways and property damage. It also caused significant power outages, disruption to municipal services and considerable damage to CN rail and Toronto Hydro infrastructure. City of Toronto storm related costs are estimated $65,235,842 with an estimated excess of $850 million in private insurance claims. Also, June of 2005 was the warmest June in history of Toronto.

2007 was recorded as the fourth driest year ever from Chatham to Peterborough. It had 2-3 times the normal number of hot days in the summer. Toronto Pearson International Airport experienced its driest summer in nearly 50 years and a string of 95 consecutive days without a significant rainfall (above 12 mm) in the middle of summer. Moreover, it was a 10-month drought. Between January 1 and October 31, the Greater Toronto Area (GTA) experienced its second driest period on record. Toronto received only 413.2 mm of precipitation; about two-thirds of normal levels. In York Region, it was even drier. Aurora's rainfall totals from May to September amounted to a paltry 136 mm (compared to 215 mm in Toronto) and only 1/3 of the total rainfall in 2006.

Winter of **2008** was Toronto's third snowiest winter ever. In January, extreme wind cold and whiteout events forced closure of a large section of downtown Toronto. Approximately 140,000 homes and businesses lost power and 100 vehicles involved in chain reaction car accidents on Highway 400. In February 30 cm of snow, freezing rain, ice pellets, and wind gusts of 70 km/h in sub-zero temperatures caused hundreds of minor crashes on Southern Ontario area highways. On April 14th, **2008**, as a result of an extreme precipitation event, the City of Belleville declared a state of emergency after water from the Moira River flooded dozens of homes and shut down roads. Authorities handed out 36,000 sandbags to help homeowners protect their properties.

Furthermore, on July 26, **2009**, Hamilton had a 100-year rainstorm that flooded 7,000 basements, forced road and highway closures and cut power to thousands of customers. The storm was recorded as one of the most intense short duration rainfalls on record in Canada. Conditions were made worse because the ground was super-saturated from storms two days earlier. Flooding turned streets into rivers and insurance losses totaled between $200 and $300 million. Moreover, in August, there were two touchdowns of F2 tornadoes in the City of Vaughan, one in Woodbridge area and one in Maple area. About 600 homes, mostly in the communities of Maple and Woodbridge were damaged. 38 were demolished and declared unsafe.

In March **2010**, a 75 mm rainfall event led to widespread flooding across southern Ontario. Insured damages to property, especially from flooded basements, amounted to over $20 million. In addition, strong winds above 75 km/h pulled down tree limbs that fell on hydro lines, cutting power to thousands of customers. On June 27, thunderstorms soaked Toronto with 53 mm of rain. It was enough to boost the month's total rainfall to 191.6 mm – a new record high for June precipitation. In the same year, Toronto Public Health issued its first heat alert on May 24 – the earliest date since the heat health alert system started in 2001 – and the last one on September 2, which was the latest ever recorded at that time.

From March 4 to 6 of **2011**, a warm spring storm dropped in excess of 40 mm of rain on the frozen saturated ground across the lower Great Lakes. With the snow-melt already in full swing, the ground could not absorb the infusion of water, creating high flooding risks in several low-lying areas from Toronto to Windsor. During the April 27 to April 28 period, a series of powerful thunderstorms burst through Southern Ontario toppling trees and power lines, stripping buildings of siding and shingles, and causing traffic mayhem. More than 175,000 Hydro One customers in Ontario lost power as a result. In June, Southern Ontario experienced a violent thunderstorm with damaging winds, torrential downpours, mothball-sized hail and continuous lightning. The National Lightning Detection Network identified 80,000 flashes of lightning. Damage to the Ontario hydro grid was extensive, with 300 broken poles between Peterborough and Tweed alone, and consistent with the occurrence of downburst winds in the range of 120 to 140 km/h. At least 150,000 hydro customers in Ontario were without power at some time and several remained disconnected for five days. In addition to extreme precipitation, **2011** was also characterized by several extreme heat and tornado events. Humidex values peaked in the upper 40s across Ontario during the summer months, with one observing site in Toronto recording a humidex of nearly 51. For one hour on July 21, electricity demand in Ontario skyrocketed to about 25,300 megawatts – the highest it had been in four years. On September

10th, Buttonville (Markham) saw a record breaking maximum temperature of 35 degrees Celsius and a humidex of 44 degrees Celsius. While across Southern Ontario, five major airports reported record breaking maximum temperatures for September 10th, four of which also saw the hottest recorded day ever in September. Throughout August 21st to 22nd of **2011**, a F3 tornado touched down in the Town of Goderich causing extensive damage to roof tops, as well as vast fallen trees, gas leaks and hydroelectricity outages.

In **2012**, a series of severe thunderstorms raked parts of southern and eastern Ontario and western Quebec during the third week of July inflicting $100 million in property losses. Heavy downpours combined with hail and fierce winds to bring down trees and power lines, rip away roofs, dent vehicles and house siding, and trigger flash floods. On July 15 thunderstorms left basements in some areas of Toronto with sewage water to the ceiling. Scarborough received the brunt of the storm with about 88 mm of rain falling over a couple of hours. On July 22, an intense downpour in Hamilton dumped 140 mm on the city in less than four hours. The city of Toronto had five times more rain than snow from November to March, inclusive. Snow was virtually a no-show with a record low of 41.8 cm. However, during the summer season, days with temperature above 30°C numbered 38 in Hamilton compared to a normal of 10. In Toronto, there were 25 hot days compared to an average of 14. Paramedics were inundated with 10 per cent more calls from people complaining of shortness of breath, dizziness and heat exhaustion. Toronto had 16 nights with temperatures that stayed above 20°C compared to an average of 4. Unfortunately, the air in southern Ontario was not only hot and oppressively humid, it was also dirty. Prevailing southerly winds brought in pollutants, triggering both extreme heat and smog alerts for the region. Some Ontario cities had 15 to 20 days with smog advisories compared to one or two days in 2011.

In **2013**, unseasonably mild air pushed up into southern Ontario causing daytime highs to soar into the double digits in many locales including 14.6°C in Toronto on January 12, which was five degrees above the previous record set in 1995. Between 20 and 50 mm of spring-like rains accompanied the unseasonable warmth. The rush of water also overwhelmed drainage systems and flooded basements and back yards. Three weeks into spring, the winter storm brought a mix of ice pellets, snow and freezing rain along with strong winds. Power outages occurred when downed tree limbs fell on ice-encased power lines. Across Ontario, 115,000 customers were without power with some remaining shut down for three days. Moreover, a line of strong thunderstorms on April 18th featuring straight-line winds and a tornado inflicted property damage on parts of south-central Ontario. An EF-1 tornado, Canada's first of 2013, with winds between 135 to 175 km/h ripped through Dufferin County, knocking down hydro wires and bringing down trees. A round of thunderstorms brought excess rains to Toronto and parts of southern Ontario on May 29th, 2013. Port Stanley and Toronto East York reported the most rainfall, with 89.0 mm and 70.2 mm respectively. In Toronto, the rains flooded the Don Valley Parkway, which became completely impassable during the morning rush hour with sections in both directions either under water or coated in mud and debris. In July 8th, **2013**, Toronto faced two separate storm cells. The one-two weather punch delivered more rain in two hours than Toronto usually sees during an entire July. The following rainfall totals (mm) from in and around the GTA help to illustrate the event: Toronto Pearson 126.0; Toronto City 96.8; Toronto Island 85.5; Downsview 65.8; East York 51.5; Richmond Hill 19.8; Oshawa 4.8; Oakville 4.2; and

Hamilton 4.2. The 126.0 mm was a new daily rainfall record at Toronto Pearson Airport (station records date from November 1937) and a record for any July date. The July 8 storm also set a record for 30-minute and 1, 2, 6 and 12-hour rainfall totals at Toronto Pearson, all in excess of 100-year return periods. The storm was noteworthy because of the rain's intensity, far exceeding storm sewers' capacity, which caused flooding runoff to travel along city streets to creeks and rivers. Exacerbating the storm's impact was the 38 mm of rain that had fallen on the city the day before. Adding to that was an unusually wet spring and early summer since 2000. The Insurance Bureau of Canada estimated the July 8 storm costs at close to $1 billion in damages and declared it as the most expensive natural disaster ever in Toronto and Ontario.

On the weekend of December 21-22, **2013**, a strong ice storm moved through Southern Ontario resulting in the accumulation of 20-25 mm of ice which resulted in downed branches, trees and power lines, causing over 92,000 customers to lose power, predominantly in Aurora, Markham, Richmond Hill and Vaughan. The same year, Toronto's Pearson International Airport CC recorded 25 hot days (temperature above 30°C) compared to a normal 14. Humidex counts were also high. Between July 1 and August 10, there were 23 days with humidex at or above 35 compared to 3 days in 2009. In between, 16 heat and extreme alerts were issued. City paramedics received 51 per cent more complaints about breathing problems while fainting calls jumped 39 per cent. A second heat wave occurred in late August and early September. In Toronto, the temperature hit 34.5°C on August 30th making it the hottest day of the summer. On September 10th, high heat and humidity blanketed much of Southern Ontario with five major airports reporting record breaking maximum temperature, four of which also broke records for the hottest day ever in September. In Buttonville (Markham) September 10th marked a maximum temperature of 35 degrees Celsius.

On June 17, **2014** two tornadoes were confirmed in Central Ontario, the first being a high-end EF2, which hit the town of Angus. Around 100 homes were either destroyed or sustained damage before the twister dissipated in the South end of Barrie. The second tornado, an EF1, touched down near the Stroud area, and left a 750 meter path of uprooted trees and destroyed a farm shed. The same system also produced two unconfirmed tornadoes, one in Grey County, near Owen Sound Airport, and another near the Town of Hanover. On June 24th Southern Ontario again saw 2 tornadoes confirmed, spawning from the same storm system. The first, an EF1, travelled 7 km from Orangeville, Ontario to Amaranth, destroying an RV and causing damage to the roof of a house. It also downed numerous trees and snapped hydro poles. The second, also an EF1, happened around a half hour later in the town of New Tecumseth, northeast of Orangeville. It damaged 18 properties along a 10 km path, including a horse barn where one horse perished. In August **2014**, Burlington experienced rainfall amounts of 100 to 150 mm. The heavy rain flooded basements and intersections and forced the closure of many roads including Highways 403, 407 and the Queen Elizabeth Way (QEW). On some roads water reached above the roofs of vehicles, forcing motorists and passengers to swim to safety. The deluge backed up storm drains, caused mudslides and creeks to overflow, and left standing water on 300 properties and in 500 basements. Damages from flooding were estimated in excess of $90 million.

Finally, in February **2015**, Southern Ontario experienced record breaking cold temperatures, making it the first February in 75 years where the temperature did not climb above the freezing mark. It was the coldest February on record at Toronto Pearson Airport with average temperatures of -12.6 degrees Celsius, 8 degrees below normal.

Previous analysis of the observed climate events in the last 16 years in Southern Ontario demonstrates substantial shifts in the timing, magnitude and frequency of extreme precipitation events and significant temperature variations. Sometimes even occurring concurrently, these changes have led to more intense and recurrent extreme weather events harmful to human dependent systems and local community wellbeing, such as **temperature fluctuations** (in years 2003, 2005, 2007, 2009, 2010, 2012, 2013), **extreme heat** (years 1999, 2001, 2003, 2005, 2006, 2010, 2011, 2012, 2013), extreme cold and ice storm (2003, 2013, 2015), **extreme precipitation events** (1999, 2000, 2004, 2007, 2008, 2009, 2010, 2013, 2014), **extreme wind** (2006, 2009, 2011, 2013, 2014), and **drought** (2001, 2002, 2007).

4. FUTURE CLIMATE TRENDS

4.1 Summary of Global Trends

The most recent round of reporting by the IPCC (2013) produced the CMIP5 model ensemble. As described in section 2, this report employs both the use of CMIP3 datasets and CMIP5 datasets for context, but also because datasets are widely still based on the CMIP3 ensemble, which was published in 2007. The following describes global trends in climate as determined based on the most recent science (IPCC 2013).

The warming of global temperatures is unequivocal since the 1950s, as exhibited in atmospheric and ocean warming, the amount of ice and snow diminishing, the rising of sea levels and the increasing concentrations of greenhouse gases in the atmosphere. These greenhouse gases include carbon dioxide, methane, and nitrous oxide, and have led to levels unprecedented in at least the last 800,000 years. These ever increasing greenhouse gas concentrations in the atmosphere have warmed the Earth, and since the 1990s, each decade has globally been successively warmer at the Earth's surface than any preceding decade since 1850. Global surface temperature change by 2100 is *likely* to exceed 1.5°C compared to 1850-1900 for all scenarios of emissions except RCP2.6, which assumes net negative GHG emissions after 2070 (or aggressively mitigated). It should be noted that while warming will continue beyond 2100 under all RCP scenarios except the most aggressively mitigated, global surface temperatures will continue to exhibit interannual-to-decadal variability and will not be regionally uniform.

Furthermore, human influence on the climate system is clear (IPCC, 2013). This is made evident from human reliance on burning fossil fuels contributing to greenhouse gas emissions, positive radiating forcing, observed warming and understanding the climate system. In its most recent report, the IPCC states it is *extremely likely* that human influences have been the dominant cause of observed warming since the mid-20th century.

Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

In addition to changes in the mean climate (e.g., temperature and precipitation), extreme climate events (e.g. extreme cold, extreme heat) will also be impacted, and in many cases the changes in the extremes are expected to be greater than mean changes. Of particular interest are some conclusions from the IPCC's "Special Report: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" (IPCC 2012), as follows:

- It is *virtually certain* that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century at the global scale.
- It is *very likely* that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas.
- It is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe.
- Extreme events will have greater impacts on sectors with closer links to climate, such as water, agriculture and food security, forestry, health, and tourism.
- Attribution of single extreme events to anthropogenic climate change is challenging.

The SREX report (IPCC 2012) provides further description and graphical examples of how changes in temperature increase the likelihood of extreme events through changes in mean, variability and symmetry of the overall probability distribution of the climate, which are beyond the scope of this report.

4.2 Summary of Regional Trends

Southern Ontario and York Region have already experienced changes in its historical climate (Wang et al. 2015), and it is very likely that further shifts in temperature, precipitation and other climate drivers will occur throughout the 21st century. When considering future climate trends, it is important to realize that trends will vary depending on the temporal scale examined (i.e. monthly temperature trends can differ from annual temperature trends) and the specific climate driver (i.e. temperature trends can differ from precipitation trends) as a result of atmospheric processes responding to climate change. The following summarizes results of a comparison of future climate trends for York Region. The probability that a particular trend may occur is described based on the confidence and uncertainty scale recommended by the Intergovernmental Panel on Climate Change in its fifth assessment report (IPCC 2013). Table 3 shows the terms and corresponding likelihoods for a given outcome. Further details on confidence and uncertainty can be found in Appendix B.

Table 3: **Confidence terminology employed by the IPCC in their official report AR5 (from IPCC 2013)**

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

Temperatures in York Region are *very likely* to increase in all seasons and on average across the year. Average monthly temperatures have historically (1981-2010) ranged from -7˚C in January to 20.4˚C in July. While the range in average monthly temperatures is not expected to change significantly, it is very likely average temperatures will increase in all months and seasons (by 3.3˚C on average across seasons). Winter and summer months will likely experience more warming than those in fall and spring by the 2050s (see Figure 3). Warmer winter temperatures lead to more precipitation falling as rain instead of snow in York Region, which can impact numerous sectors. Further, warmer air can retain more moisture, increasing the risk of heavier precipitation events falling over the region when more moisture is available to produce storms.

Two future climate ensembles were analysed (MOECC CCDP and YorkU LAMPS) for trends of average monthly temperature. Each of these datasets has different assumptions and methods embedded in how future projections are produced. While they each predict slightly different ranges, strong agreement is found between them for future mean monthly temperatures. This increases the confidence associated with future trends in temperatures.

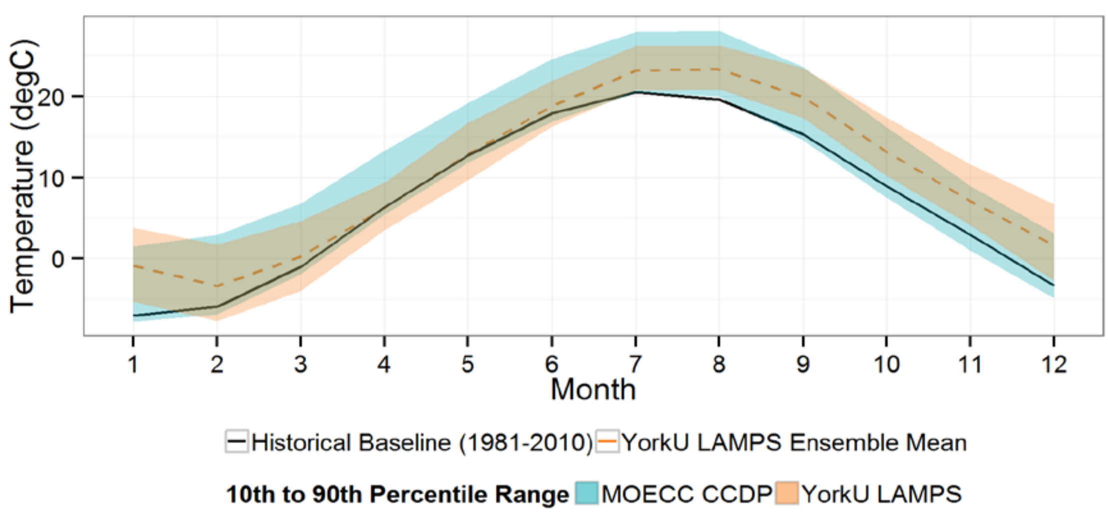

Figure 3: **Historical (1981-2010) and Future (2050s) Average Monthly Temperature**

Mean temperatures on an annual basis are also *very likely* to increase in York Region. Average temperatures have historically been 7.3˚C in the region over the year. By the 2050s, mean temperatures are expected to increase by approximately 3.3˚C overall (to between 10.6˚C – 10.9˚C). A study conducted by the City of Toronto (SENES 2011) projected future average temperatures of as high as 11.6˚C. On the other hand, the two dynamically downscaled RCMs (CNRM-CM5 and MIROC5) indicate that average temperatures may only warm to an average annual temperature between 9.6 and 10.2˚C. In general, warmer annual temperatures mean that days with extremely hot temperatures may become more likely in York Region and heat waves could occur more frequently. Moreover, these warmer temperatures may actually lead to other changes in the climate through feedback loops, such as shifts in weather patterns, snow and ice, and even the health of plants and animals in the natural environment.

In the past, the average **growing season** typically began on May 17th and ran until October 15th. Warming temperatures in the region are *likely* to increase the length of the growing season by the 2050s. With warming temperatures, particularly in summer and fall months, it is expected that the length could increase by approximately 30 days per year. This implies that the average future growing season could begin earlier in April (April 6th to May 17th) and last longer to end later in October or in November (October 11th to November 24th). These future trends are consistent with results found in other studies for areas in the Greater Toronto Area (e.g., Auld et al. 2015). Longer growing seasons could bring some benefits to farmers and agricultural land users in York Region, if the appropriate management practices are in place. However, it is important to realize that with warmer average temperatures comes more extreme heat and variability, which could pose a significant threat to agriculture.

An alternative way to examine future temperatures in York Region is to look at the maximum temperature reached at any point throughout the year. This temperature excludes any influence of humidity or ground surface (i.e. urban land use) and only considers the maximum temperature reached in the air. Historically, the region has experienced a **maximum temperature** of 35.9˚C in the summer months. Throughout the 2050s, this is *very likely* to increase even further by approximately 4.0˚C (to 39.4 – 40.3˚C). Once again, this implies an increase in the number of heat alerts or the number of days where extreme heat may pose a concern to residents' health. It should be noted that increases in extreme maximum temperatures reached throughout the year are modest compared to increases expected for extreme minimum temperatures historically experienced. For instance, the **minimum temperature** reached year-round in the region is -34.1˚C. Future trends indicate significant amounts of warming for minimum temperatures, and in fact estimate an increase of approximately 4.5˚C. This implies that the future extreme minimum temperature reached throughout the winter months could be much warmer (e.g., -29˚C at its coldest and potentially as warm as -18.6˚C). This high level of warming occurring for minimum temperatures may in fact have large impacts on the natural environment in York Region, where wildlife requires certain temperatures to survive.

Increases in **extreme heat** events, which are considered *very likely* to occur, pose more risk to human health due to other factors that may worsen its effects, such as urban heat island influences on ground temperatures, and pre-existing human health conditions that may make them more susceptible to extreme heat. To determine trends in extreme heat events, the number of days per year where temperatures exceeded various thresholds were used (see Figure 4). Simply put, all indicators examined indicate significant increases by the 2050s. The number of days in a year reaching a maximum temperature above 25˚C is expected to increase by approximately 38 days (from 57.9 days to 96.2 days). Perhaps more telling are days where maximum temperature reaches above 30˚C in the summer, which are predicted to increase by 25 days (from only 9.8 days to 34.4 days). Furthermore, it is expected that York Region could be reaching new thresholds of extreme heat. For example, no day from 1981 to 2010 had a maximum temperature exceeding 40˚C; however, future trends indicate that approximately 3.3 days per year may experience maximum temperature greater than 40˚C. These extremely hot temperatures may negatively impact a number of sectors in York Region, from drying or warming of the natural environment (i.e. reduced river flows) to stressing the vulnerable populations (i.e. seniors living in high-rise residential buildings).

One additional indicator was examined since it is commonly used in international climate modeling exercises (e.g., Sillmann et al. 2013a, Sillmann et al. 2013b): the number of 'tropical nights' that occur annually. A 'tropical night' is defined as one where the minimum (night-time) temperatures exceed 20˚C. These have historically occurred in summer months (4.2 days) where temperatures remain warm overnight following high maximum (daytime) temperatures due to warm weather systems remaining stagnant in the atmosphere. With a warming climate, tropical nights are expected to increase significantly to approximately 28.2 days. In other words, night-time temperatures will become much more common for residents in York Region by the 2050s. This could pose a significant issue since cool nights currently provide relief from the higher day temperatures.

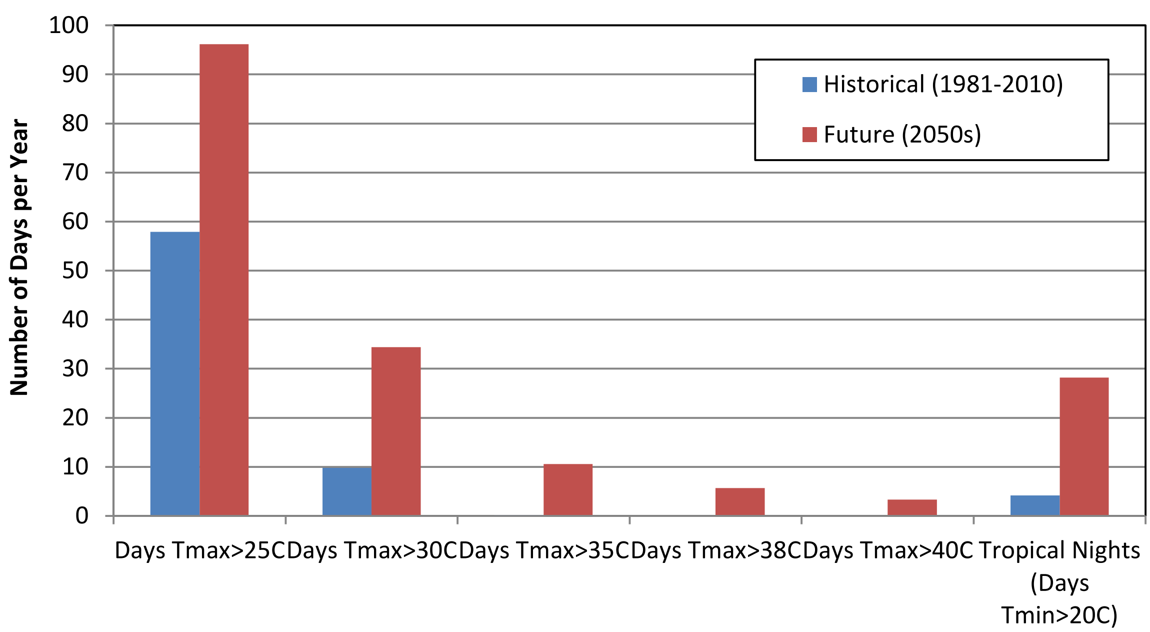

Figure 4: Extreme Heat Indices (Historical and Future) in York Region (CANGRD and MOECC CCDP, respectively).

Climate change is also expected to bring higher levels of variability in weather systems, and with it, some extreme cold temperatures. **Extreme cold** events, by the 2050s, are expected to decrease overall compared to York Region's historical climate. This trend is considered *very likely* to occur. However, it should be noted that recent trends in southern Ontario have demonstrated extremely cold temperatures in winter months being experienced as a result of a shifting polar jet stream. This condition has not yet been incorporated into climate modeling and as a result is largely uncertain and not reflected in these future trends. Emerging science on this topic suggests that extreme temperature variability will at least remain as large as what has been experienced in the past with continual warming; or in other words the probability of extreme cold days decreases in the longer term (e.g., 2050s), and extreme cold temperatures (i.e. due to a shifting jet stream) may be exhibited more in the short term (Meehl et al. 2000, Auld et al. 2016).

A series of indicators were examined to describe the historical and future number of days per year with minimum temperatures being less than various thresholds (see Figure 5). For all indicators examined, the number of days reaching cold temperatures (less than -5˚C, -15˚C, -20˚C, and -25˚C) decreases. This is consistent with mean temperature trends indicating warming of the climate system. For example, York Region historically has experienced over 22 days per year with temperatures below -15˚C, and it is expected that only 7.2 days per year under these conditions may remain by the 2050s. Similarly, the region has historically experienced approximately 8 days per year with temperatures below -20˚C, but by the 2050s it is expected only 3.1 days per year (on average) may remain reaching these extreme cold temperatures. Future trends in these variables are consistent with those of extreme minimum temperatures described earlier, where significant warming is expected particularly in the winter months. It should be noted once again that these trends are for the 2050s climate normal (2041-2070) and do not reflect current and short-term trends in the climate (i.e. the extreme cold temperatures experienced in the winter seasons in southern Ontario), which may continue in the short-term, but this remains largely uncertain.

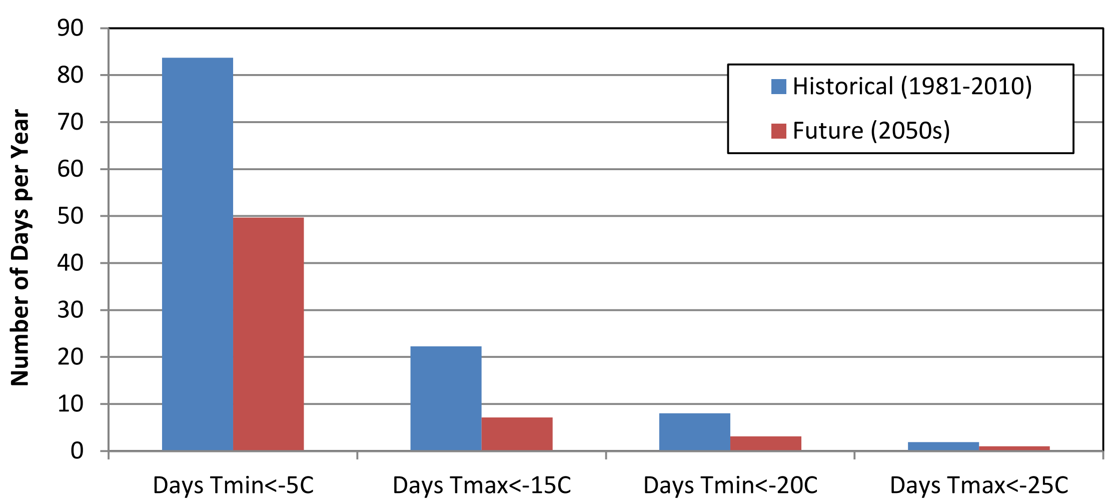

Figure 5: **Extreme Cold Indices (Historical and Future) in York Region (CANGRD and MOECC CCDP, respectively).**

Freezing conditions in the future is particularly important for a number of sectors. For instance, in agriculture it is important to know when approximately the first frost day occurs in the year, and similarly how many days below freezing may occur. Frost days simply means the number of days where night time temperatures reach below freezing (or 0˚C). Comparing trends, it is expected that the number of frost days is likely to decrease by approximately 31.4 days (from 146 days to approximately 115 days by the 2050s). This reflects the trend in the growing season described earlier, where nights with frost will likely begin later in the fall season and end earlier in the spring season. An equivalent indicator for daytime temperatures is the number of days where daytime temperatures dip below freezing (or 0˚C), or 'ice days'. It is expected that the total number of days with freezing temperatures will decline by approximately 35 days per year in the 2050s (from 61.6 historically to 26.6 by the 2050s). Comparing different future climate datasets for this indicator, strong agreement between projected ranges of uncertainty indicates a higher confidence that this declining trend will occur.

One particular future event of interest is **ice storms**. One indicator was analysed that provides proxy information for if an ice storm event may occur in the future: "ice potential." This indicator does not actually track the number of ice storm events that could occur. However, it determines trends in favorable conditions for the formation of ice storms to occur. Ice storms require daily temperatures to be within 2 degrees of the freezing point, and this indicator counts the number of days in a year when these conditions exist. Future trends in this indicator suggest that little change is expected from historical conditions. However, no definitive conclusions should be drawn regarding this variable with regards to future ice storms as it is a proxy and does not incorporate magnitude, or the totality of the atmospheric conditions necessary for an event like this to take place.

Drought was examined by analysing the number of days in a row that remain dry, or receive little to no precipitation (less than 1mm). While this is not a direct indicator of drought conditions, it is the best available given the datasets obtained from research organizations. No significant trend in the number of consecutive dry days was found; however, similar studies conducted surrounding York Region (e.g., Auld et al. 2015) have concluded that a likely overall drier growing season is expected. With the amount of total precipitation remaining relatively unchanged in the future summer season, and temperatures projected to increase as trends suggest, drier conditions may become more common. This would need to be validated through further analysis, including a comprehensive analysis on drought, which would require additional data such as solar radiation to estimate potential evapotranspiration and eventually a drought index.

Precipitation under a changing climate is *likely* to increase on an annual basis. However, unlike future temperatures however higher, month-to-month variations are anticipated. This means that some months may see increases and others decreases in total precipitation. York Region has historically experienced an average total amount of annual precipitation of 853.5mm, with higher amounts of rainfall likely occurring in the north and lesser amounts in the south of the region (Auld et al. 2015). Future projections from the MOECC CCDP indicate that total annual precipitation is likely to increase by 59mm (totaling 912.5mm). A study conducted by the City of Toronto (SENES 2011) projected future precipitation even higher to 988mm annually. Trends in the two dynamically downscaled RCMs (CNRM-CM5 and MIROC5) are less clear. For instance, CNRM-CM5 projects a total annual precipitation of 936.6mm (a value which falls between the MOECC CCDP ensemble projection and that of the SENES dataset); however, the MIROC5 model projects a slight decrease (12.3mm less) in precipitation annually. Given the agreement that an annual increase is projected in the two ensembles examined (MOECC CCDP and YorkU LAMPS), the SENES dataset and one of the RCMs (or four of the five datasets examined), annual precipitation may increase overall in York Region with the total number of days receiving precipitation expected to increase (from 142.1 to 146.8); however, this precipitation may not be delivered uniformly. For example, summer months are anticipated to have roughly the same amount of precipitation as the historical climate, whereas larger increases are likely in the winter months. Further, precipitation events over consecutive days may increase slightly in duration (from 6.9 days to ~7.4 days). This may begin to stress urban infrastructure systems, depending upon the amount of precipitation delivered and how localized (or 'targeted') it is.

Future increases in **extreme precipitation** events are *likely*. 1-Day and 5-day maximum precipitation amounts are projected to increase (from 39.3mm to 50.9mm and from 61.4mm to 78.4mm, respectively). The intensity of these future extreme precipitation events; however, is expected to remain relatively similar to the historical conditions of 5.8mm/day in York Region. It is important to note that storms are expected to become more frequent bringing heavier amounts of precipitation to the region, and thus while the average intensity may not change significantly; localized convective storms particularly in the summer months may bring high amounts of precipitation that could stress various systems. This is made evident by examining the number of heavy and very heavy precipitation days, or where precipitation exceeds 10 and 20mm. In both cases, it is *likely* these events will increase by 3 and 2 days respectively in York Region by the 2050s. In the case of extreme precipitation events, a conservative approach would suggest assuming an increase in the magnitude and frequency of heavy precipitation events due to increased warming and moisture that will be present in our atmosphere.

A summary of the climate indicators data in tabular and graphical format (where information was available) is available in Appendix C.

6. CONCLUSIONS

It is important to re-iterate that the purpose of these analyses was to provide an overview of climate trends relevant to York Region and to place these in context with global climate change. These analyses did not involve the running of climate models or the in-depth investigation of why a particular variable behaves in a certain way as part of a dataset. However, trends are discussed and potential reasoning for specific differences is presented. Key conclusions from this report are as follows:

- Of all temperature variables, the minima are anticipated to increase the most significantly by the 2050s in all seasons and on an annual basis (i.e. minimum minimum temperature, average minimum temperatures)
- Precipitation is expected to increase annually and over most months; however, may in fact remain relatively consistent or decrease compared with the current climate for the summer season
- Extreme events are anticipated to become more frequent and more extreme.
- Extreme heat indicators demonstrate that the number of days by the 2050s experiencing extreme temperatures will increase significantly. On the other hand extreme cold events are anticipated to decrease correspondingly by the 2050s, where the number of days exhibiting extremely cold temperatures could decrease
- Extreme precipitation events are likely to increase in magnitude and in frequency, particularly in the summer time when convective activity is highest in and surrounding York Region. The future trend of extreme precipitation intensity; however, is unclear. It is recommended that a conservative approach should be taken in planning and adapting for extreme precipitation events.
- The growing season in York Region is expected to lengthen by over 30 days by the 2050s. With this, the start date will shift earlier and the end date will shift later in the year. It is less certain, but more likely than not, that drier conditions will be present throughout the growing season in the 2050s as a result of no significant increase in precipitation over summer months and significant increases in temperatures.

Finally, it is important to characterize the uncertainty associated with all variables presented in this report. It is therefore recommended that under decision-making, not only the 'average' future condition is used but that a *range* of future conditions be considered as presented in section 4.

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APPENDIX A – LITERATURE REVIEW OF CLIMATE IMPACTS AND EXISTING ASSESSMENTS (SOUTHERN ONTARIO, 1985 – 2015)

Table A-1: Information collected through the literature review and stakeholder interviews on climate events experience in souther Ontario.

Year	Events	Location	Event Details
1985	• Tornado, severe thunderstorm and hail	• Barrie • Grand Valley • Orangeville • Tottenham	• Tornado, thunderstorm and hail storm resulted in eight people dead, 155 injured, 300 homes destroyed and approximately $100 million dollars in damage
1999	• Extreme precipitation • Extreme Heat	• City of Toronto • Southern Ontario	• Between January 2-15, 1999. A series of storms stalked the city of Toronto, dumping nearly a year's amount of snow in less than two weeks. The city recorded the greatest January snowfall total ever with 118.4 cm and the greatest snow on the ground at any one time with 65 cm. The storms cost the city nearly twice the annual budget in snow removal. • In the summer of 1999 cities in Southern Ontario also experienced twice as many hot days (exceeding 30 degrees Celsius) than the summer normal.
2000	• Heavy precipitation	• Southern Ontario	• During the period of April 20-21st, the Windsor area registered 95 mm of rain in a 24 hour period and the storm dumped almost 70 mm of rain on the London, 50 mm in Sarnia and 40 mm in Toronto. • Sewer backed ups, road wash outs and many power outages occurred. One child suffered injuries in Toronto due to violent winds that gusted up to 80 km/h • Wettest summer in 53 years with 13% more precipitation than normal • Excess Rainfall from May 8-12, 2000 was causative factor in Walkerton waterborne disease outbreak
2001	• Extreme heat	• Southern Ontario	• Driest growing season in 34 years; first ever "heat alert"; 14 nights with temperatures above 20°C (normal is 5 nights)
2002	• Weather Variability	• Southern Ontario	• Driest August at Pearson Airport since 1937; warmest summer in 63 years; 5th coldest Spring
2003	• Shoulder season extreme weather variability • Ice storm • Prolonged heat waves	• Southern Ontario	• City of Toronto registered nine cold weather alerts in winter 2003, many with multiple days of penetrating cold • On April 3 to 4, a rare mid-spring ice storm struck southern Ontario. The storm was the most damaging of the winter because of its duration and the amount of ice accumulation. Adding to the chaos, most private snow-clearing contracts had expired April 1. The Ontario Provincial Police fielded 900 calls from Toronto-area highways alone. Pearson Airport became a parking lot of grounded planes with ice-caked wings. Ground crews used up a month's supply of glycol de-icer in just 24 hours. That same week, high winds blew in another 10 cm of snow into parts of southern Ontario. With all the blowing and drifting snow, and all the ice left over from the earlier blast, emergency crews were swamped responding to accidents. In London, alone, 250 accidents were reported. • On April 24, the temperature soared to 28°C at Windsor and 27.1°C in Toronto, making it the second highest temperature ever so early in the year • Hot weather and higher air conditioning demands contributed to the transboundary blackout affecting the Eastern Seaboard in August 2003, shutting down some municipal operations in Ontario for nearly 3 days. Also placing vulnerable persons such as the elderly, young mothers and children in shelters, and persons in palliative care units at greater risk.

2004	• Extreme precipitation	• Southern Ontario	• It was the year without a summer; May rainfall in Hamilton set an all-time record; and another all-time record 409 mm rainfall was set at Trent University in July which was equivalent to 14 billion litres of water in 5 hours (a 200 year event) • During a July storm in Peterborough, water in the city's wastewater system was five times the average capacity. With backed up storm sewers, much of the downtown core and a third of the city proper was inundated by a metre or more of murky water. The Mayor declared a state of emergency that stayed in effect for 15 days. Hundreds of residents fled to shelters when roofs collapsed or water filled basements to waist-deep. Muddy waters turned streets into rivers, closed businesses and left cars floating. Power and telephone outages lasted for days and the clean-up took weeks to months. Some roadways and sidewalks had to be completely rebuilt. An early estimate of insured losses exceeded $88 million. In addition, the Province of Ontario provided $25 million for emergency repair and restoration costs for city infrastructure. Consultants recommended that Peterborough spend upwards of $30 million for possible storm water and sanitary sewer system improvements over the next five years.
2005	• Record breaking winter, spring and summer temperatures • Extreme winter, summer and fall precipitation	• Southern Ontario • City of Toronto • City of Vaughan	• Warmest January 17 since 1840 • January 22nd blizzard with whiteouts • Warmest June ever • Number of Toronto days greater than 30°C was 41 (normal is 14) • In Toronto, August 19 storm amounted in rainfall of up to 175 mm recorded in Yonge/ Steeles area and 103 mm recorded in 1 hour at Environment Canada Downsview. Although the storm was only approximately 3 hours in duration hours, it caused severe flood related damage to parks and recreation facilities, sewer and wastewater systems, ravines, roadways (washing out part of Finch Avenue and property damage. It also caused significant power outages, disruption to municipal services and considerable damage to CN rail and Toronto Hydro infrastructure. City of Toronto storm related costs are estimated $65,235,842 with an estimated excess of $850 million in private insurance claims • Numerous areas of the City of Vaughan experienced flooding and sewer back-ups during Aug 19th storm • A severe thunderstorm on October 29th left 30,000 Ontario residents without power
2006	• Extreme Heat • Tornados	• Ontario	• 23 tornadoes across Ontario (14 normal); record year of major storms • Record one-day power demand of 27,005 MW due to summer heat
2007	• Winter and fall weather variability • Drought	• City of Toronto • Town of Aurora • York Region	• Protracted January thaw; 2nd least snow cover ever in Toronto of ½ the normal amount. • Snowiest Valentine's Day ever • Recorded as fourth driest year ever from Chatham to Peterborough. It had 2-3 times the normal number of hot days in the summer. Toronto Pearson International Airport experienced its driest summer in nearly 50 years and a string of 95 consecutive days without a significant rainfall (above 12 mm) in the middle of summer. Moreover, it was a 10-month drought. Between January 1 and October 31, the Greater Toronto Area (GTA) experienced its second driest on record. Toronto received only 413.2 mm of precipitation; about two-thirds of normal levels. In York Region, it was even drier. Aurora's rainfall totals from May to September amounted to a paltry 136 mm (compared to 215 mm in Toronto) and only 1/3 of the total rainfall in 2006. • Toronto Pearson airport recorded 27 days with temperatures greater than 30°C and latest-in-season string of +30°C days were recorded around Thanksgiving • April 23, 2007, damages hydro wires at the intersection of Calvert Road and Woodbine Avenue due to microburst.
2008	• Extreme precipitation	• City of Toronto • City of Vaughan • York Region	• Toronto's 3rd snowiest winter ever. In January, extreme wind cold and whiteout events forced closure of a large section of downtown Toronto. GO Transit delayed because of debris on tracks. Approximately 140,000 homes and businesses lost power and 100 vehicles involved in chain reaction car accidents on Highway 400 While in February 30 cm of snow, freezing rain, ice pellets, and wind gusts of 70 km/h in sub-zero temperatures caused hundreds of minor crashes on Southern Ontario area highways; the vast majority single-car spinouts into ditches or guardrails. The storm forced the cancellation of more than 150 flights at Toronto Pearson International Airport. • Spring thaw brought a deluge of flood water to York Region, flooding basements throughout the Town of Georgina, particularly in flood plain areas. Large pieces of ice were found to be blocking ditches and storm sewer drains in the Town. • On April 14th the City of Belleville declared a state of emergency after water from the Moira River flooded dozens of homes and shut down roads. Authorities handed out 36,000 sandbags to help homeowners protect their properties. Six families were evacuated and more than 145 others were told to be prepared to leave. With massive flooding on the Otonabee River in south Peterborough, some residents faced evacuation for the fourth time in 2008.

			• On April 17th, over a period of 24 hours, water levels in the tri-lakes increased by 12 centimetres. • Record for highest summer rainfall, producing high insect larvae levels • Repeated summer hail storms caused vast damage to fruit crops across Southern Ontario • Due to high intensity and duration of the follow precipitation events, the capacity of the minor storm sewer system in Vaughan was exceeded: -The storm of June 22, 2008 was approximately 100 minutes in duration. The maximum intensity of this storm was 180 mm/hr and lasted for 15 minutes. This resulted in an intensity of greater than a 100 year storm. Approx. 65 mm of rain was received on Thornhill. -The storm of June 23, 2008 reached a maximum intensity of 160 mm/hr for 15 minutes. Due to the saturated soil from the previous day's storm, the amount of absorption was severely limited, resulting in increased run-off, and discharge to the City's sewer network. The range of rainfall City-wide was 0-50mm, with the Thornhill area receiving 42mm. -The storm of July 22, 2008 produced a range of 16 – 82 mm across the City, with Thornhill receiving between 23 and 40 mm of rain.
2009	• Extreme precipitation • Seasonal weather variability	• City of Toronto • City of Hamilton • City of Vaughan • Town of Newmarket	• 3rd rainiest February in 70 years • On July 26th Hamilton had a 100-year rainstorm that flooded 7,000 basements, forced road and highway closures and cut power to thousands of customers. The storm was recorded as one of the most intense short duration rainfalls on record in Canada. Conditions were made worse because the ground was super-saturated from storms two days earlier. Flooding turned streets into rivers and insurance losses totaled between $200 and $300 million. • On July 26th parts of Lakeshore Boulevard in the City of Toronto were submerged and a giant sinkhole swallowed part of Finch Avenue West- big enough to hold a fleet of cars and deep enough to cover a four storey building. Water gushed through basement walls and more than a metre high through manhole covers. • In August, severe thundershowers, flooding, hail and winds in excess of 100 km/h battered and flooded the City of Toronto, leading to travel chaos with shut-down GO stations, diverted buses and disrupted flights. • One of the wettest summers on record • In August there were two touchdowns of F2 tornadoes in the City of Vaughan, one in Woodbridge area and one in Maple area. About 600 homes, mostly in the communities of Maple and Woodbridge were damaged. 38 were demolished and declared unsafe. Lampposts were shorn off and pieces of trees, fences and brick were strewn everywhere. Some houses had gaping holes and exposed roof beams. In the City of Toronto there were unconfirmed reports of a funnel cloud near the busy intersection of Yonge and Bloor – a rare occurrence, while flooding occurred along the Lakeshore of Toronto and at the peak of the storm Hydro One reported that 69,000 customers had lost power. • An unusually mild and storm-free November in Toronto – Downtown had a record no snow for the first time ever – first snow-free November at Pearson Airport since 1937
2010	• Extreme precipitation • Seasonal weather variability • Heat events • Lake effect snow squall	• Southern Ontario	• March rainfall totals of 75 mm led to widespread flooding across southern Ontario. Insured damages to property, especially from flooded basements, amounted to over $20 million. In addition, strong winds above 75 km/h pulled down tree limbs that – in turn – fell on hydro lines, cutting power to thousands of customers. The strong winds tossed debris around, toppled trees and blew garbage cans down the street. Rain and an accelerated snowmelt also led to a rapid rise in river levels. • Summer came early to Ontario around May 25 when all-time high temperature records for the month were set across the province. Thermostats hit the low to mid-thirties, while humidity values were also high with the humidex reaching the low forties. • On June 27, thunderstorms soaked Toronto with 53 mm of rain. It was enough to boost the month's total rainfall to 191.6 mm – a new record high for June precipitation. • Toronto Public Health issued its first heat alert on May 24 – the earliest date since the heat health alert system started in 2001 – and the last one on September 2, which was the latest ever record. • In December a whiteout caused by lake effect snow squall left an 80 kilometer stretch of Highway 402 closed for several days. As a result of the event, Lambton County declared a state of emergency.
2011	• Extreme heat • Extreme precipitation	• Southern Ontario • Goderich	• From March 4 to 6, a warm spring storm dropped in excess of 40 mm of rain on the frozen saturated ground across the lower Great Lakes. With the snow-melt already in full swing, the ground could not absorb the infusion of water, creating high flooding risks in several low-lying areas from Toronto to Windsor.

	• Tornado	• Buttonville (Markham)	• During the April 27 to April 28 period, a series of powerful thunderstorms burst through Southern Ontario toppling trees and power lines, stripping buildings of siding and shingles, and causing traffic mayhem. More than 175,000 Hydro One customers in Ontario lost power as a result. • In June Southern Ontario experienced a violent thunderstorm with damaging winds, torrential downpours, mothball-sized hail and continuous lightning. The National Lightning Detection Network identified 80,000 flashes of lightning over Southern Ontario. The City of Vaughan Fire Chief said the storm was one of the worst in recent memory for lightning-triggered house fires. Damage to the Ontario hydro grid was extensive, with 300 broken poles between Peterborough and Tweed alone, and consistent with the occurrence of downburst winds in the range of 120 to 140 km/h. At least 150,000 hydro customers in Ontario were without power at some time and several remained disconnected for five days. Hydro One officials called it one of the most damaging and difficult storms to hit southern Ontario in decades, and sent out more repair crews than it did following the massive ice storm of 1998. • Humidex values peaked in the upper 40s across Ontario during the summer months, with one observing site in Toronto recording a humidex of nearly 51. For one hour on July 21, electricity demand in Ontario skyrocketed to about 25,300 megawatts – the highest it had been in four years. In Toronto, worry about the health and safety of sports fans and players resulted in the Blue Jays ball club keeping the retractable roof at Rogers Centre closed for a matinee game. • Throughout August 21st to 22nd a F3 tornado touched down in the Town of Goderich causing extensive damage to roof tops, as well as vast fallen trees, gas leaks and hydroelectricity outages. Natural gas was off to 90% of the Town of Goderich as well as to residents in the surrounding municipalities. Power was not restored to most of the affected area until late August 22nd. The tornado resulted in devastating damage to the town's port and historic downtown center, as well as to several blocks of residential homes. Approximately forty people were injured and one person was killed by the tornado, Ontario's strongest since 1996. • On September 10th, Buttonville (Markham) saw a record breaking maximum temperature of 35 degrees Celsius and a humidex of 44 degrees Celsius. While across Southern Ontario, five major airports reported record breaking maximum temperatures for September 10th, four of which also saw the hottest recorded day ever in September.
2012	• Seasonal variability • Extreme Heat • Urban flooding	• Southern Ontario	• A series of severe thunderstorms raked parts of southern and eastern Ontario and western Quebec during the third week of July inflicting $100 million in property losses. Heavy downpours combined with hail and fierce winds to bring down trees and power lines, rip away roofs, dent vehicles and house siding, and trigger flash floods. On July 15 thunderstorms left basements in some areas of Toronto with sewage water to the ceiling. Scarborough received the brunt of the storm with about 88 mm of rain falling over a couple of hours. On July 22, an intense downpour in Hamilton dumped 140 mm on the city in less than four hours. • On July 25th 30,000 bolts of lightning triggered nighttime fires at homes and rural outbuildings between London and Toronto causing extensive damage. • The city of Toronto had five times more rain than snow from November to March, inclusive. Snow was virtually a no-show with a record low of 41.8 cm. There were no days with measurable snow after March 1 and there were only nine days with more than 1 cm of snow from November to April. The average winter temperature in the city was the warmest since 1840 (when record-keeping began). • During the summer season, above 30°C numbered 38 in Hamilton compared to a normal of 10. In Toronto, there were 25 hot days compared to an average of 14. Paramedics were inundated with 10 per cent more calls from people complaining of shortness of breath, dizziness and heat exhaustion. Sports authorities postponed games scheduled in the extreme heat. Toronto had 16 nights with temperatures that stayed above 20°C compared to an average of 4. At times the air in southern Ontario was not only hot and oppressively humid, it was also dirty. Prevailing southerly winds brought in pollutants, triggering both extreme heat and smog alerts for the region. Some Ontario cities had 15 to 20 days with smog advisories compared to one or two days in 2011.
2013	• Damaging freeze thaws • Extreme precipitation • Extreme heat • Ice Storm	• Southern Ontario • Buttonvile (Markham)	• Unseasonably mild air pushed up into southern Ontario causing daytime highs to soar into the double digits in many locales including 14.6°C in Toronto on January 12, which was five degrees above the previous record set in 1995. Between 20 and 50 mm of spring-like rains accompanied the unseasonable warmth. Roofing and general contracting companies were flooded with emergency calls after frequent freeze-thaw cycling led to serious roof leaks. The rush of water also overwhelmed drainage systems and flooded basements and back yards. • Three weeks into spring winter storm brought a mix of ice pellets, snow and freezing rain along with strong winds. Power outages occurred when downed tree limbs fell on ice-encased power lines. Across Ontario, 115,000 customers were without power with some remaining shut down for three days. Slick roads led to several crashes and shut schools. • A line of strong thunderstorms on April 18th featuring straight-line winds and a tornado inflicted property damage on parts of south-central Ontario. An EF-1 tornado, Canada's first of 2013, with winds between 135 to 175 km/h ripped through Dufferin County about

			6 km northwest of Shelburne, knocking down hydro wires, ripping at a barn roof and bringing down trees. • A round of thunderstorms brought excess rains to Toronto and parts of southern Ontario on May 29. Port Stanley and Toronto East York reported the most rainfall, with 89.0 mm and 70.2 mm respectively. In Toronto, the rains were enough to flood the Don Valley Parkway, which became completely impassable during the morning rush hour with sections in both directions either under water or coated in mud and debris. Flood waters rose as high as vehicle doors in some spots and also inundated GO Transit tracks. • Toronto faced two separate storm cells on July 8th– one on the heels of the other. The one-two weather punch delivered more rain in two hours than Toronto usually sees during an entire July. The following rainfall totals (mm) from in and around the GTA help to illustrate the bull's-eye target of the event on the downtown: Toronto Pearson 126.0; Toronto City 96.8; Toronto Island 85.5; Downsview 65.8; East York 51.5; Richmond Hill 19.8; Oshawa 4.8; Oakville 4.2; and Hamilton 4.2. The 126.0 mm was a new daily rainfall record at Toronto Pearson Airport (station records date from November 1937) and a record for any July date. The July 8 storm also set a record for 30-minute and 1, 2, 6 and 12-hour rainfall totals at Toronto Pearson, all in excess of 100-year return periods. The storm was noteworthy because of the rain's intensity, far exceeding storm sewers' capacity, which caused flooding runoff to travel along city streets to creeks and rivers. Exacerbating the storm's impact was the 38 mm of rain that had fallen on the city the day before. Adding to that was an abnormally wet spring and early summer – the dampest since 2000. The Insurance Bureau of Canada estimated the July 8 storm costs at close to $1 billion in damages – the most expensive natural disaster ever in Toronto and Ontario. The storm caused major transit halts and delays, road closures, flight cancellations and flooding across Toronto and Mississauga. Thousands were stranded, necessitating rescue by boat in some instances. Others abandoned their vehicles and walked thigh-high in water along roads that looked more like canals. About 500,000 households, mainly in the GTA's west end, were without power ranging from hours to days. Some 3,000 basements flooded in the rainstorm, causing major damages. • At Toronto's Pearson International Airport, there were 25 hot days (above 30°C) compared to a normal 14 and humidex counts were high. Between July 1 and August 10, there were 23 days with humidex at or above 35 compared to 3 days in 2009. In between, 16 heat and extreme alerts were issued. city's paramedics received 51 per cent more complaints about breathing problems and fainting calls jumped 39 per cent. A second heat wave occurred in late August and early September. In Toronto, the temperature hit 34.5°C on August 30 making it the hottest day of the summer • On September 10th high heat and humidity blanketed much of Southern Ontario with five major airports reporting record breaking maximum temperature, four of which also broke records for the hottest day ever in September. In Buttonville (Markham) September 10th marked a maximum temperature of 35 degrees Celsius. • Heavy bands of rain and scattered thunderstorms burst across much of southern Ontario on September 20 and 21. Total rainfall exceeded 100 mm in London (Dorchester), Wellesley, New Hamburg and Waterloo, while areas from southern Georgian Bay to Bancroft received nearly 50 mm of rain. • On the weekend of December 21-22, 2013, a significant ice storm moved through Southern Ontario Ice resulting in the accumulation of 20-25 mm of ice which resulted in downed branches, trees and power lines, causing over 92,000 customers to lose power (at the peak of the event) in PowerStream's service territory, predominantly in Aurora, Markham, Richmond Hill and Vaughan -Markham: 17,000 residents were without electricity, some for as long as eight days, approximately 10,000 trees lost, estimated $2.6 to 3.2 million – immediate cleanup costs and estimated $7 to 10 million – long-term recovery costs, which includes removing damage trees and replanting new trees -Aurora: Estimated $40,000 cost involving overtime and additional contract services -Vaughan: Over 32,500 city-owned street trees were impacted. Total cost of ice storm is estimated at $17.8 million which includes emergency response, clean up of damage and future tree canopy replacement -Richmond Hill: Estimated financial impact of the ice storm is $7.0 million which includes the immediate and long-term cleanup costs, as well as the repair and replacement of the tree canopy. - City of Toronto estimates that the cost of the storm event from for City divisions, agencies and corporations is approximately $106 million which includes incurred and estimated future 2014 expenses and lost revenue
2014	• Frost quakes • Heavy snow • Tornadoes • Flooding	• Southern Ontario • Belleville • Central	• In January frost quakes resulting from freezing water split deep soil, rock and caused frost heaving across Southern Ontario. The sudden expansion of the water in frozen soil or rocks put stress on the ground causing cracking, vibrating and booming noises which were mistaken for earthquakes and gunshots by many residents. The ground was saturated from previous precipitation which intensified the quakes.

		Ontario • Burlington	• The region also experiences a fast moving snowstorm in February that caused huge car pileups- North of Toronto there was a 96-vehicle pileup on Highway 400. • Belleville declared state in emergency in April 2014 due to flooding on Moira River. • On June 24th Southern Ontario again saw 2 tornadoes confirmed, spawning from the same storm system. The first, an EF1, travelled 7 km from Orangeville, Ontario to Amaranth, destroying an RV and causing damage to the roof of a house. It also downed numerous trees and snapped hydro poles. The second, also anEF1, happened around a half hour later in the town of New Tecumseth, northeast of Orangeville. It damaged 18 properties along a 10 km path, including a horse barn where one horse perished. A house also sustained major damage to the garage where the roof was torn off. No injuries were reported from either twister. • In June 17, Two tornadoes were confirmed in Central Ontario, the first being a high-end EF2, which hit the town of Angus. Around 100 homes were either destroyed or sustained damage before the twister dissipated in the South end of Barrie. A tornado warning was in effect for the area at the time, and only a few minor injuries were reported.[156] The second tornado, an EF1, touched down near the Stroud area, and left a 750 metre path of uprooted trees and destroyed a farm shed.[157] The same system also produced two unconfirmed tornadoes, one in Grey County, near Owen Sound Airport, and another near the Town of Hanover. • In August Burlington experienced rainfall amounts of 100 to 150 mm.The heavy rain flooded basements and intersections and forced the closure of many roads including Highways 403, 407 and the Queen Elizabeth Way, or QEW. On some roads water reached above the roofs of vehicles, forcing motorists and passengers to swim to safety. The deluge backed up storm drains, caused mudslides and creeks to overflow, and left standing water on 300 properties and in 500 basements. Damages from flooding were estimated in excess of $90 million.
2015	• Extreme Cold	• Southern Ontario	• In February Southern Ontario experienced record breaking cold temperatures, making it the first February in 75 years where the temperature did not climb above the freezing mark. It was the coldest February on record at Toronto Pearson Airport with average temperatures of -12.6 degrees Celsius, 8 degrees below normal.

Data Sources:

- The Canadian Disaster Database
- Council reports (City of Vaughan, York Region, City of Toronto)
- Environment Canada's Top 10 Weather Stories (1985-Present)
- Toronto's Future Weather and Climate Driver Study
- York Region Emergency Management Staff
- York Region Joint Municipal Working Group

Table A-2: Inventory of Climate Risk and Vulnerability Assessments in the Greater Toronto – Hamilton Area (GTHA)

Jurisdiction / Proponent	Assessment Theme	Geography	Year Completed	Climate Information	Adaptation Policy / Framework	Assessment Protocol / Tools	Assessment Tier*
Region of Peel	Public Health	Peel	2013	None	ICLEI	WHO (2003)	II
	Agriculture	Caledon, Brampton	2015 (ongoing)	Auld et al. (2015)	ICLEI	P-CRAFT**	II
	Natural Heritage	Peel	2015 (ongoing)	Auld et al. (2015)	ICLEI	P-CRAFT & Gleeson et al. (2011)	II
	Hydrology	Credit Valley Watershed	2015 (ongoing)	TBD	ICLEI	PIEVC***	III
	Economy	Mississauga	2015 (ongoing)	Auld et al. (2015)	ICLEI	-	II
	Municipal critical infrastructure / services(roadways, electrical distribution, shoreline, private property, public health)	Port Credit	2015 (ongoing)	Auld et al. (2015)	ICLEI	P-CRAFT	II
Greater Toronto Airports Authority	Stormwater Infrastructure	Pearson International Airport	2014	CCCSN 2007a, CCCSN 2007b, AR4 2007(TRCA 2009)	Internal risk management	PIEVC	III
Region of Durham	All municipal service areas (Public Health, Transportation, Flooding, Electrical Grid, Agriculture/food,)	Durham	2014	Senes (2011) Senes (2014)	ICLEI	-	I
City of Toronto	Transportation services	City of Toronto	2014	Senes (2011)	Resiliency strategy	Deloitte Tool	III
York Region	Stormwater management	Vaughan	2015 (ongoing)	Regridded CMIP5 (from Reclamation 2013); Senes (2011)	ICLEI	Deloitte Tool & P-CRAFT	III
City of Hamilton & Conservation Hamilton	Hydrology and stormwater	Spencer Creek watershed	2015 (ongoing)	TBD	TBD	TBD	III
Credit Valley Conservation	Hydrology and stormwater	Cooksville Creek watershed	2015 (ongoing)	Auld et al. (2015)	-	PIEVC	III
Ontario Ministry of Natural Resources and Forestry	Terrestrial and Aquatic Ecosystems	Lake Simcoe watershed	2012	McKenney et al. (2011)	Gleeson et al. (2011)	Gleeson et al. (2011)	II
WeatherWise Partnership	Electrical transmission and distribution infrastructure case studies	City of Toronto and Mississauga	2015	(TRCA 2009)	-	PIEVC	III

Notes:
*Assessment Tier definitions based on UKCIP risk assessment types in Willows and Connell (2003):
I – screening assessment
II – semi-quantitative, sector/theme focused
III – full quantitative, sector/theme detailed analysis
** P-CRAFT = Peel Climate Risk Analysis Framework and Templates (for conducting systematic review of risk information)
*** PIEVC = Public Infrastructure Engineering Vulnerability Committee's risk assessment protocol (for detailed engineering assessments)

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APPENDIX B – CONFIDENCE AND UNCERTAINTY

The confidence in climate projections varies by climate driver, as well as by model given the inherent assumptions embedded with atmospheric processes being captured. As a result, this report adopts language used in the IPCC's most recent assessment reporting as the basis for describing confidence and uncertainty in a particular climate driver. Confidence wording in the IPCC documents is characterized by the use of specific terms such as 'very likely' or 'virtually certain' (see Table A-1). There has been a gradual increase in confidence of the projections from climate models over time. With each IPCC report there are increasing quantity and higher quality observations of the changing climate and improvements in the model equations, parameterizations, and their spatial and temporal detail. The IPCC reports continue to provide the best science-based information on projected climate change assembled from the best climate researchers worldwide. Generally, evidence is considered to be more robust when there are multiple, consistent, independent sources of high quality information (IPCC 2012) (see Table A-2).

Table B-1: Confidence terminology employed by the IPCC in their official reports (AR5) (from IPCC 2013)

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

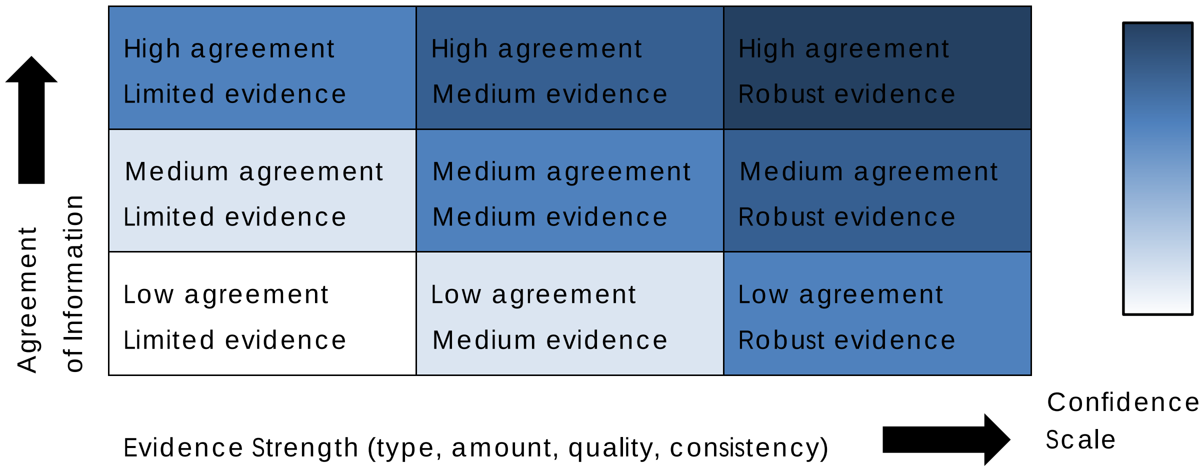

Figure B-1: Conceptual depiction of the relationship between evidence and confidence (adapted from IPCC 2012).

Given that the quantification of uncertainty associated with future climate projections was a key element of the these analyses, it was felt that using a large range (from the 10th to the 90th percentile) of climate model projections in an ensemble was the most robust way of capturing the range of uncertainty associated with climate projections in York Region. Both statistical and dynamical downscaling techniques rely on general circulation models (GCMs) to drive local-scale modeling and analysis, and ideally the uncertainty associated with the GCMs should be propagated through the downscaling process. Historical and downscaled local climate estimates of extreme events have been observed in many studies to lie within the uncertainty bounds of raw GCM ensembles.

Analyses in this report were limited to data availability and particularly to those climate datasets which are reputable, commonly known and/or robustly created. While a full climate model ensemble (i.e. CMIP5) was not independently run, other datasets do capture these projections in a more locally-relevant format for York Region. For example, the York University LAMPS dataset accessed (LAMPS 2014) produced climate variables for the 2050s using the full CMIP5 ensemble statistically downscaled format. While it should be noted that statistical downscaling relies on historical relationships among climate variables of various scales, and there is uncertainty as to whether these relationships will hold under evolving conditions associated with climate change, the York University LAMPS dataset provides a valuable initial look at the CMIP5 model ensemble. Further analyses could derive climate variables using a dynamical downscaling approach based on the CMIP5.

APPENDIX C – HISTORICAL AND FUTURE TRENDS FOR YORK REGION (DATA TABLES AND FIGURES)

Temperature

Table C-1: Summary of Temperature Indicators

Time Period	CANGRD Baseline (°C)	Future Change (Delta)						
		MOECC CCDP 2050s (°C)		YorkU LAMPS 2050s (°C)		SENES Future 2040-2049 (°C)	CNRM-CM5 Model 2031-2058 (°C)	MIROC5 Model 2031-2058 (°C)
	Mean	P10	P90	P10	P90	Mean	Mean	Mean
Average Maximum Temperature								
Annual	12.1	+3.4	+3.7	+1.5	+5.3	+4.3	+2.1	+2.6
Winter	-1.3	+3.6	+3.7	-0.2	+8.2	+5.6	+1.3	+2.4
Spring	11.2	+3.2	+3.5	-1.9	+6.1	+3.6	+2.0	+6.8
Summer	25.0	+3.9	+4.2	-0.2	+6.4	+4.1	+2.6	+0.1
Fall	13.6	+2.8	+3.5	+1.4	+9.3	+3.9	+1.8	-1.1
Average Minimum Temperature								
Annual	2.4	+3.3	+3.6	+1.9	+5.5	+4.5	+2.3	+2.9
Winter	-9.3	+3.9	+4.1	+0.1	+10.8	+6.1	+2.5	+3.5
Spring	0.8	+3.0	+3.3	-1.4	+5.5	+4.3	+2.0	+5.9
Summer	13.7	+3.5	+3.9	+0.9	+5.6	+3.7	+2.0	+0.5
Fall	4.5	+2.6	+3.3	+1.6	+8.2	+4.0	+1.9	-0.4
Average Temperature								
Annual	7.3	+3.3	+3.6	+1.7	+5.4	+4.3	+2.1	+2.7
Winter	-5.3	+3.7	+3.9	+0.2	+9.5	+5.7	+1.9	+2.9
Spring	6.0	+3.0	+3.4	-1.6	+5.5	+4.0	+1.9	+6.2
Summer	19.4	+3.6	+4.0	+0.3	+5.8	+3.8	+2.3	+0.3
Fall	9.0	+2.7	+3.4	+1.6	+8.5	+3.9	+1.8	-0.7
Maximum Maximum Temperature								
Annual	35.9	+3.5	+4.4	-0.3	+7.4	-	+0.1	+3.5
Winter	15.6	+2.3	+2.6	-	-	-	+0.2	+5.6
Spring	28.8	+3.7	+3.9	-	-	-	+3.4	+8.1
Summer	35.1	+3.9	+7.0	-	-	-	+2.2	-2.1
Fall	27.7	+3.7	+4.4	-	-	-	+3.3	-4.1
Minimum Minimum Temperature								
Annual	-34.1	+3.9	+5.1	+1.7	+15.5	-	+5.8	+2.7
Winter	-30.3	+6.1	+7.5	-	-	-	+4.7	+0.6
Spring	-14.7	+4.9	+5.9	-	-	-	+2.8	+8.4
Summer	3.9	+2.6	+3.9	-	-	-	+1.1	-0.1
Fall	-8.1	+2.0	+3.3	-	-	-	+3.1	+0.3
Diurnal Temperature Range								
Annual	9.7	+0.1	+0.0	-	-	-	-0.2	-0.2
Winter	8.0	-0.3	-0.4	-	-	-	-1.2	-1.0
Spring	10.4	+0.0	+0.3	-	-	-	+0.0	+0.9
Summer	11.2	+0.4	+0.2	-	-	-	+0.5	-0.4
Fall	9.1	+0.1	+0.0	-	-	-	-0.1	-0.7

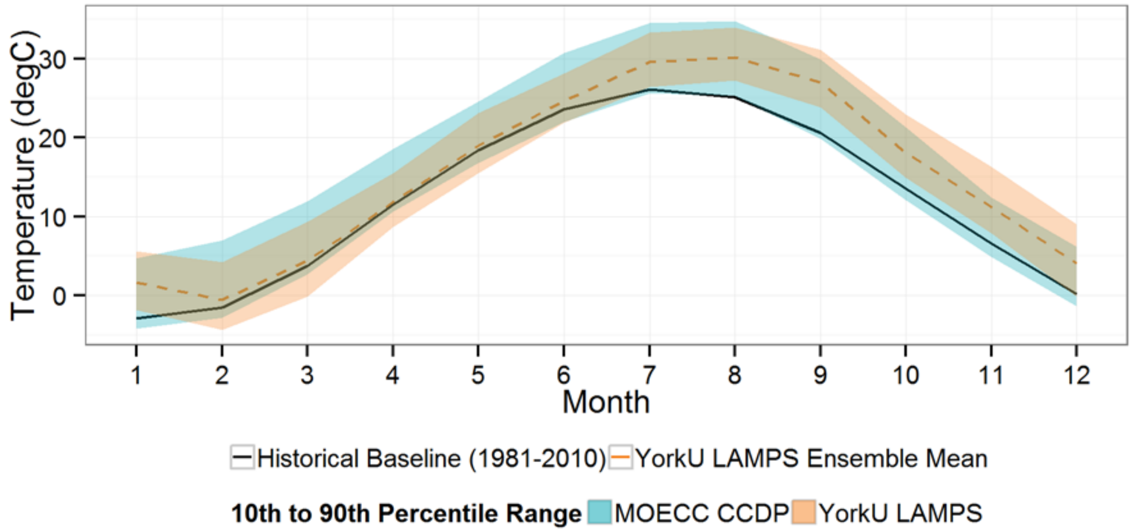

Figure C-1: Historical (1981-2010) and Future (2050s) Average Maximum Monthly Temperature in York Region

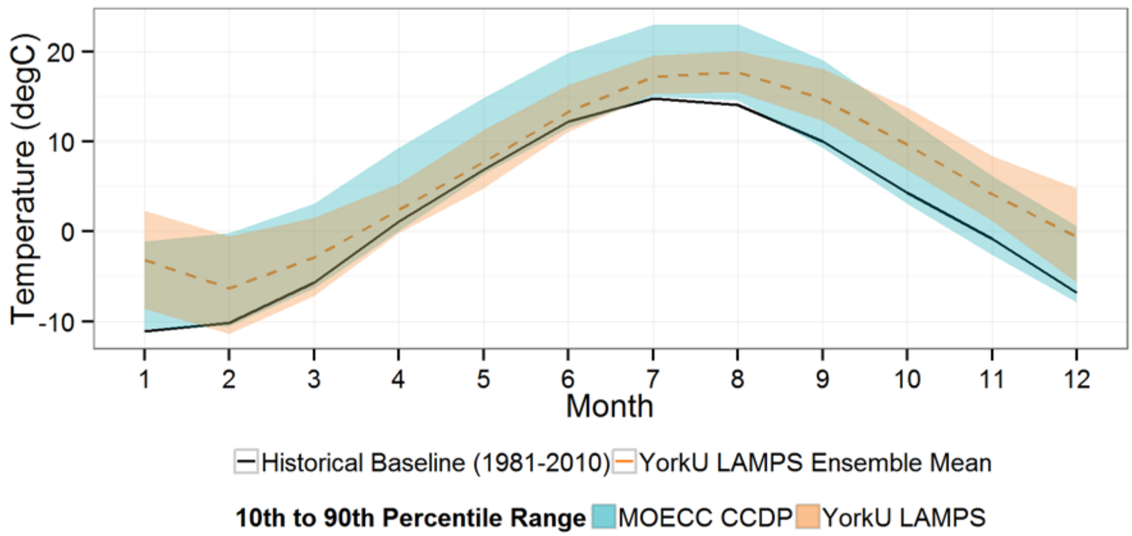

Figure C-2: Historical (1981-2010) and Future (2050s) Average Minimum Monthly Temperature in York Region

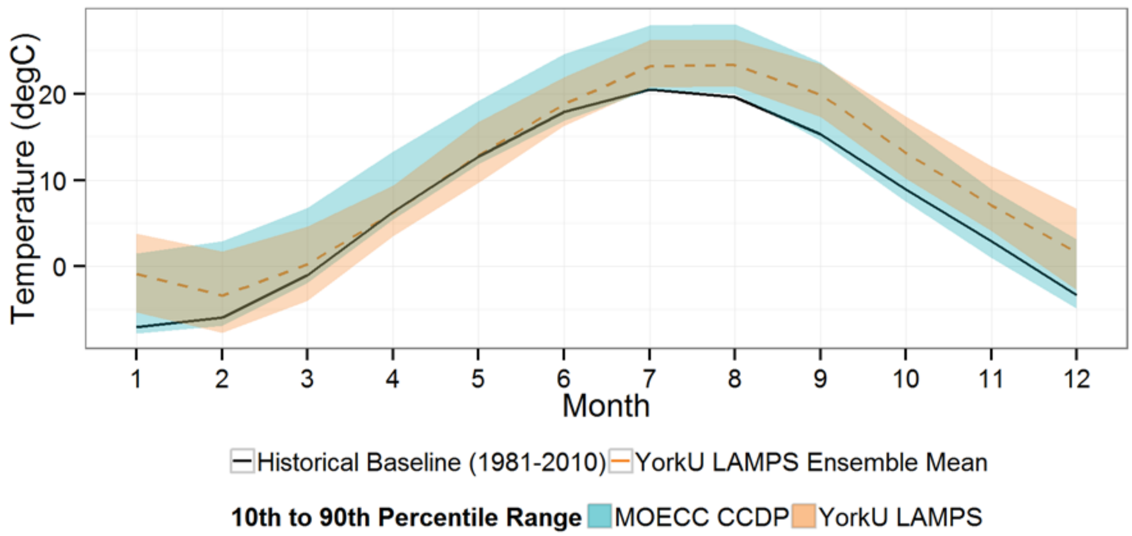

Figure C-3: **Historical (1981-2010) and Future (2050s) Average Monthly Temperature in York Region**

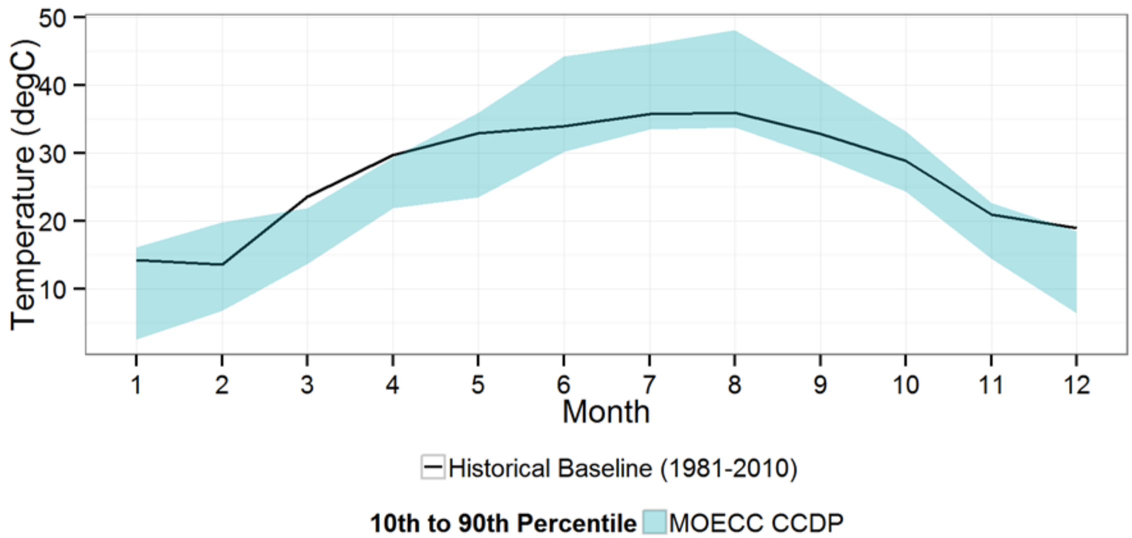

Figure C-4: **Historical (1981-2010) and Future (2050s) Maximum Maximum Monthly Temperature in York Region**

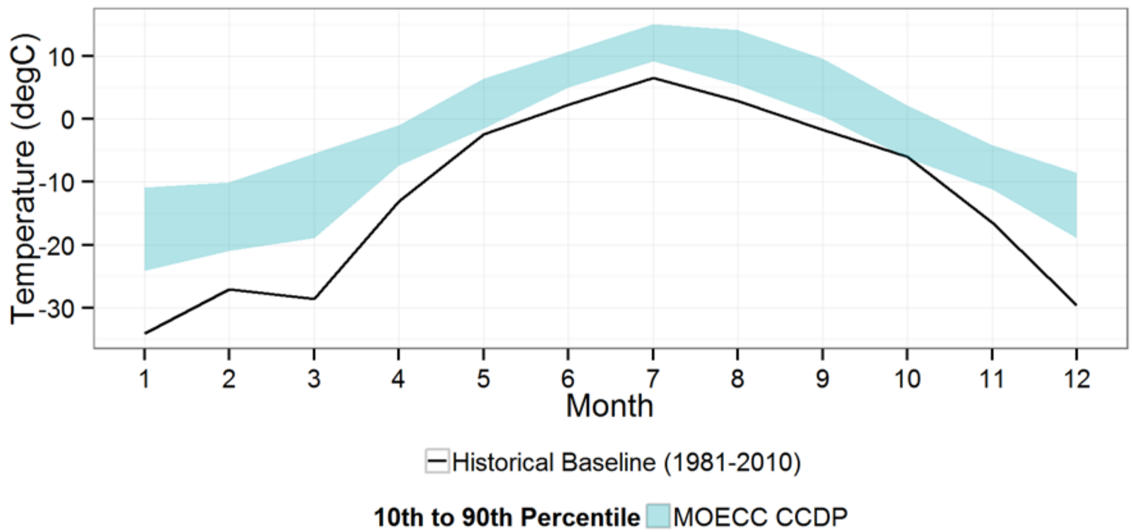

Figure C-5: **Historical (1981-2010) and Future (2050s) Minimum Minimum Monthly Temperature in York Region**

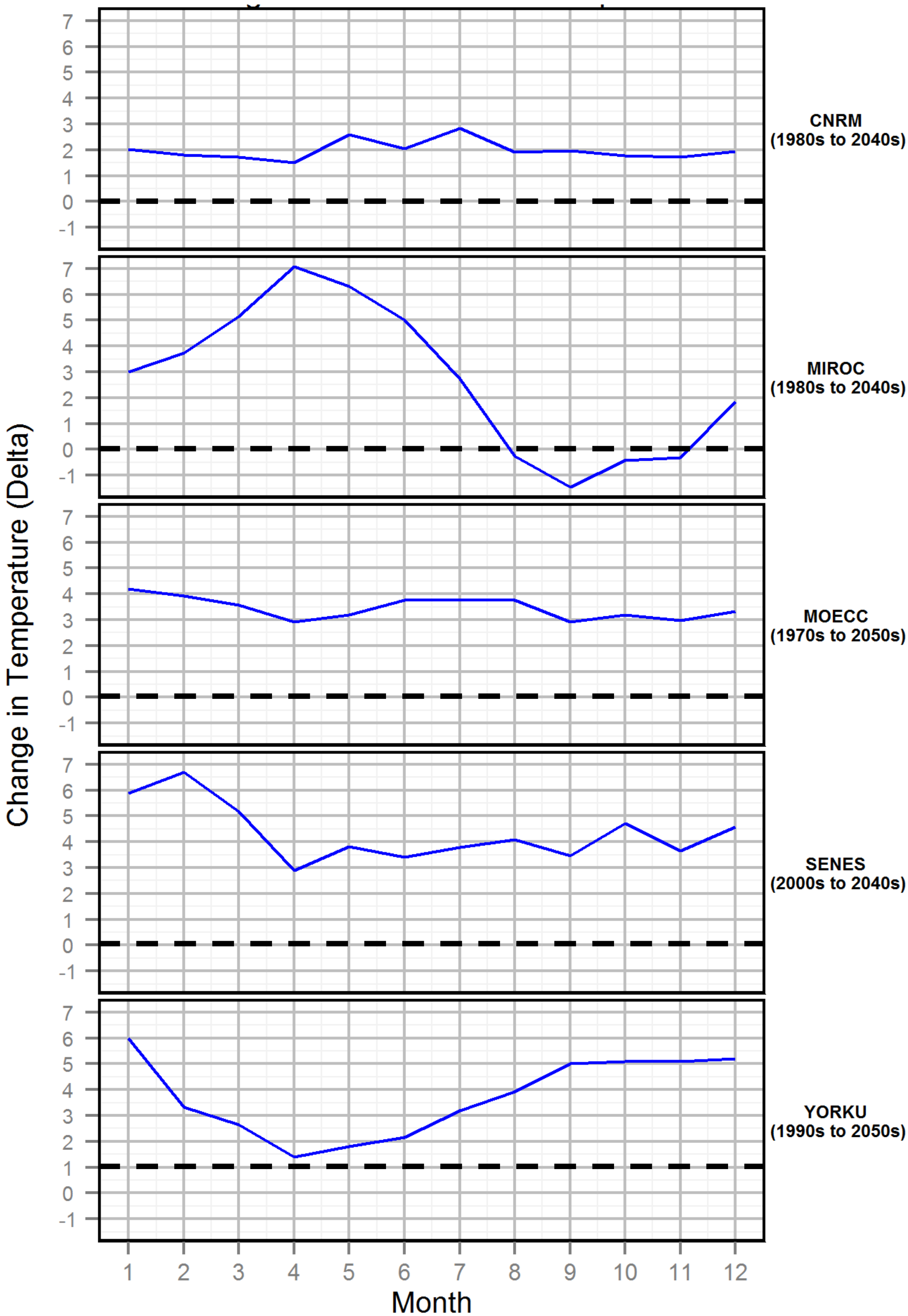

Figure C-6: **Future Average Temperature Delta Change for each Dataset (in blue). Baseline and Future Period shown on right. Dotted black lines denote no future change (delta=0)**

Precipitation

Table C-2: Summary of Precipitation Indicators

Time Period	CANGRD Baseline	Future Change (Delta)						
		MOECC CCDP		YorkU LAMPS		SENES Future	CNRM-CM5 Model	MIROC5 Model
		2050s		2050s		2040-2049	2031-2058	2031-2058
	Mean	P10	P90	P10	P90	Mean	Mean	Mean
Total Precipitation [mm]								
Annual	853.5	+48.3	+69.7	-93.9	+180.0	+134.5	+83.1	-12.3
Winter	187	+23.5	+26.4	-	-	+3.6	+7.0	-2.7
Spring	202.3	+19.7	+38.7	-	-	-24.9	+4.9	+1.6
Summer	228.7	-2.8	-0.1	-	-	+153.6	+6.1	-2.5
Fall	235.4	-2.3	+4.5	-	-	+2.2	+7.2	-9.9
Number of Wet Days [days]								
Annual	142.1	+4.5	+4.9	-	-	-	-0.4	-0.9
Winter	39.8	-1.8	+1.8	-	-	-	+0.5	-0.8
Spring	33.3	-0.5	+0.7	-	-	-	+0.1	-1.4
Summer	32.8	-0.3	+0.6	-	-	-	-1.8	-1.1
Fall	36.2	-1.9	-1.8	-	-	-	-0.4	-0.3
Consecutive Wet Days [days]								
Annual	6.9	-0.1	+0.6	-3.0	+3.8	-	-0.3	+0.2

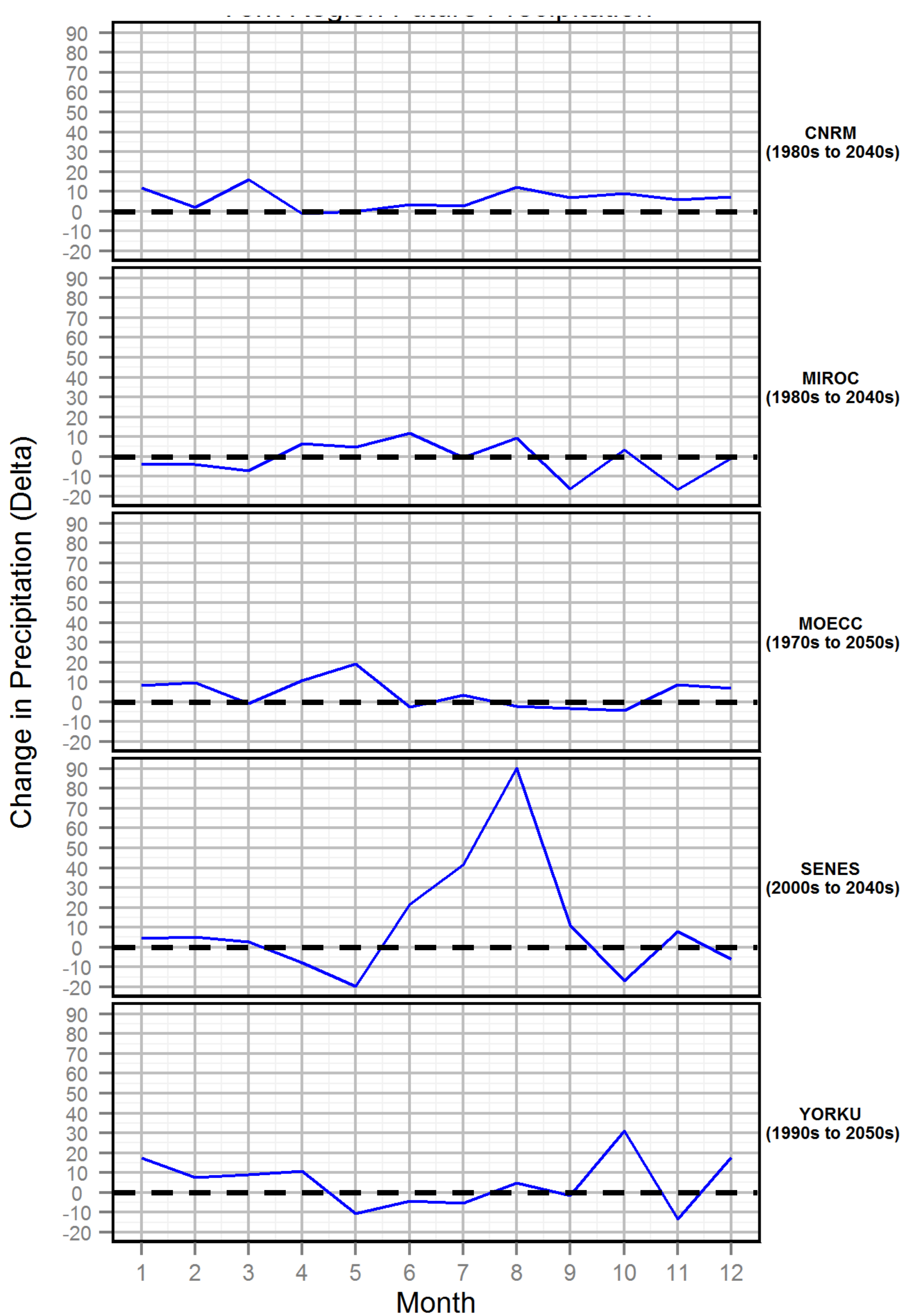

Figure C-7: **Future Total Precipitation Delta Change for each Dataset (in blue). Baseline and Future Period shown on right. Dotted black lines denote no future change (delta=0)**

Extreme Precipitation

Table C-3: Summary of Extreme Precipitation Indicators

Time Period	CANGRD Baseline	Future Change (Delta)						
		MOECC CCDP		YorkU LAMPS		SENES Future	CNRM-CM5 Model	MIROC5 Model
		2050s		2050s		2040-2049	2031-2058	2031-2058
	Mean	P10	P90	P10	P90	Mean	Mean	Mean
1 Day Maximum Precipitation [mm]								
Annual	39.3	+4.4	+18.7	-12.1	+21.6	+33.5	+45.7	+30.9
Winter	27.3	+10.4	+13.7	-	-	-0.1	+5.8	-14.7
Spring	36.7	+2.0	+7.9	-	-	+14.6	+15.3	+10.6
Summer	42.1	+0.6	+11.4	-	-	+11.3	+19.3	+1.8
Fall	51.4	+4.5	+41.6	-	-	+7.7	+14.6	+10.6
5 Day Maximum Precipitation [mm]								
Annual	61.4	+11.5	+22.4	-	-	-	+28.4	+43.5
Winter	48.7	+15.5	+2.5	-	-	-	+7.4	-9.8
Spring	61.4	+16.8	+29.1	-	-	-	+26.3	+6.2
Summer	66	+6.0	+45.9	-	-	-	-0.6	+14.1
Fall	69.6	+7.5	+11.9	-	-	-	+10.2	-2.9
Heavy Precipitation Days (>10mm) [days]								
Annual	22.7	+2.8	+3.1	-2.1	+12.6	-	+0.2	+0.0
Winter	3.6	+0.9	+1.7	-	-	-	+0.4	+0.0
Spring	5.4	+1.5	+1.0	-	-	-	+0.0	+0.0
Summer	6.9	+0.2	+0.1	-	-	-	+0.2	+0.1
Fall	6.8	+0.2	+0.3	-	-	-	+0.4	-0.3
Very Heavy Precipitation Days (>20mm) [days]								
Annual	5.2	+1.7	+1.9	-	-	-	+0.2	+0.1
Winter	0.6	+0.6	+0.7	-	-	-	+0.0	+0.0
Spring	1.2	+0.9	+0.7	-	-	-	+0.1	+0.3
Summer	1.8	+0.0	-0.2	-	-	-	+0.3	+0.1
Fall	1.6	+0.2	+0.3	-	-	-	+0.3	-0.3
Simple Daily Intensity Index (SDII) [mm/day]								
Annual	5.8	+0.6	+0.7	-	-	-	+0.7	+0.5

Extreme Heat

Table C-4: Summary of Extreme Heat Indicators

Time Period	CANGRD Baseline (°C)	Future Change (Delta)						
		MOECC CCDP 2050s (°C)		YorkU LAMPS 2050s (°C)		SENES Future 2040-2049 (°C)	CNRM-CM5 Model 2031-2058 (°C)	MIROC5 Model 2031-2058 (°C)
	Mean	P10	P90	P10	P90	Mean	Mean	Mean
Number of Days Tmax > 25˚C [days]								
Annual	57.9	+37.2	+39.3	+3.6	+54.0	-	+2.0	+2.5
Winter	0.0	+0.0	+0.0	-	-	-	+0.0	+0.0
Spring	4.9	+3.1	+5.4	-	-	-	+1.1	+5.3
Summer	47.3	+28.1	+24.8	-	-	-	+5.9	+1.4
Fall	5.8	+6.0	+9.1	-	-	-	+0.9	-0.2
Number of Days Tmax > 30˚C [days]								
Annual	9.8	+20.2	+29.0	-	-	+27.6	+1.2	+2.0
Winter	0.0	+0.0	+0.0	-	-	+0.0	+0.0	+0.0
Spring	0.3	+0.5	+1.2	-	-	+0.9	+0.3	+2.2
Summer	8.8	+16.9	+23.6	-	-	+24.0	+4.2	+2.2
Fall	0.7	+2.8	+4.2	-	-	+2.8	+0.3	+0.0
Number of Days Tmax > 35˚C [days]								
Annual	0.2	+6.6	+14.1	-	-	+5.6	+0.3	+0.8
Winter	0.0	+0.0	+0.0	-	-	+0.0	+0.0	+0.0
Spring	0.0	+0.0	+0.2	-	-	+0.2	+0.0	+0.4
Summer	0.2	+6.1	+12.5	-	-	+5.4	+1.3	+0.8
Fall	0.0	+0.5	+1.4	-	-	+0.1	+0.0	+0.0
Number of Days Tmax > 38˚C [days]								
Annual	0.0	+2.8	+8.5	-	-	-	+0.1	+0.3
Winter	0.0	+0.0	+0.0	-	-	-	+0.0	+0.0
Spring	0.0	+0.0	+0.1	-	-	-	+0.0	+0.0
Summer	0.0	+2.6	+7.6	-	-	-	+0.4	+0.2
Fall	0.0	+0.2	+0.8	-	-	-	+0.0	+0.0
Number of Days Tmax > 40˚C [days]								
Annual	0.0	+1.4	+5.2	-	-	-	+0.0	+0.1
Winter	0.0	+0.0	+0.0	-	-	-	+0.0	+0.0
Spring	0.0	+0.0	+0.0	-	-	-	+0.0	+0.0
Summer	0.0	+1.3	+4.8	-	-	-	+0.1	+0.0
Fall	0.0	+0.1	+0.4	-	-	-	+0.0	+0.0
Tropical Nights, where Tmin >20˚C [nights]								
Annual	4.2	+16.7	+31.3	+8.2	+48.2	-	+0.6	+1.5
Winter	0.0	+0.0	+0.0	-	-	-	+0.0	+0.0
Spring	0.0	+0.7	+1.5	-	-	-	+0.0	+0.4
Summer	3.9	+13.8	+25.7	-	-	-	+2.3	+2.2
Fall	0.3	+2.2	+4.1	-	-	-	+0.1	+0.0

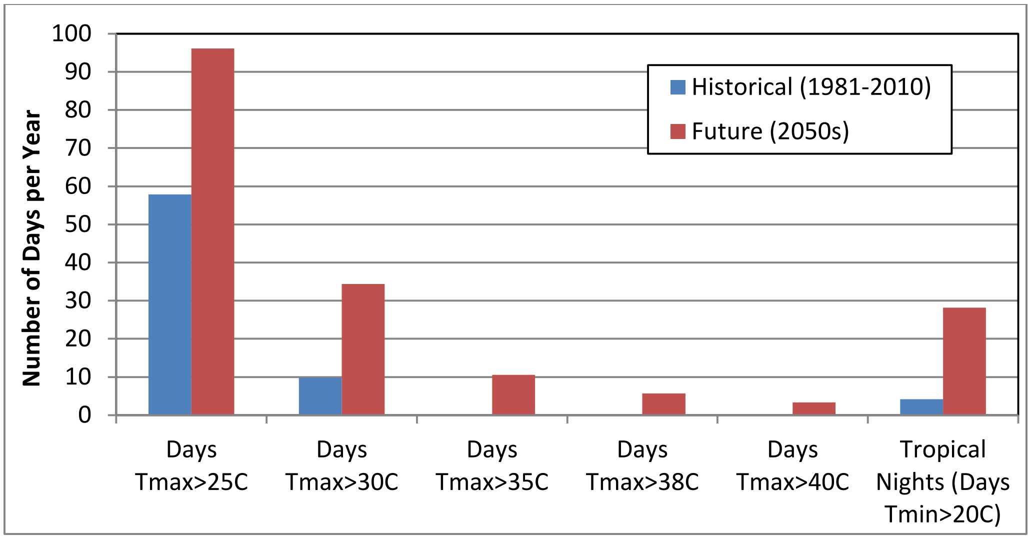

Figure C-8: Extreme Heat Climate Indices in York Region using CANGRD (Historical) and MOECC Ensemble Median Values (Future)

Extreme Cold

Table C-5: Summary of Extreme Cold Indicators

Time Period	CANGRD Baseline (°C)	Future Change (Delta)				
		MOECC CCDP 2050s (°C)		SENES Future 2040-2049 (°C)	CNRM-CM5 Model 2031-2058 (°C)	MIROC5 Model 2031-2058 (°C)
	Mean	P10	P90	Mean	Mean	Mean
Number of Days Tmin < -5˚C [days]						
Annual	83.7	-36.8	-31.3	-	-1.8	-2.5
Winter	61.5	-22.4	-17.4	-	-4.7	-5.3
Spring	21.1	-9.3	-8.6	-	-1.6	-4.7
Summer	15.5	+0.0	+0.0	-	+0.0	+0.0
Fall	2.0	-5.1	-5.3	-	-0.9	-0.1
Number of Days Tmin < -15˚C [days]						
Annual	22.3	-11.1	-19.2	-	-0.9	-1.4
Winter	19.6	-10.2	-16.7	-	-3.0	-5.0
Spring	2.6	-0.9	-2.4	-	-0.6	-0.8
Summer	0.0	+0.0	+0.0	-	+0.0	+0.0
Fall	0.1	+0.0	-0.1	-	+0.0	+0.0
Number of Days Tmin < -20˚C [days]						
Annual	8	-2.9	-6.9	-1.3	-0.5	-0.6
Winter	7.4	-2.8	-6.5	-1.1	-1.6	-2.3
Spring	0.6	-0.1	-0.4	-0.3	-0.2	-0.1
Summer	0.0	+0.0	+0.0	+0.0	+0.0	+0.0
Fall	0.0	+0.0	+0.0	+0.0	+0.0	+0.0
Number of Days Tmin < -25˚C [days]						
Annual	1.9	-0.3	-1.5	-	-0.1	-0.1
Winter	1.8	-0.3	-1.5	-	-0.5	-0.6
Spring	0.1	+0.0	-0.1	-	+0.0	+0.0
Summer	0.0	+0.0	+0.0	-	+0.0	+0.0
Fall	0.0	+0.0	+0.0	-	+0.0	+0.0

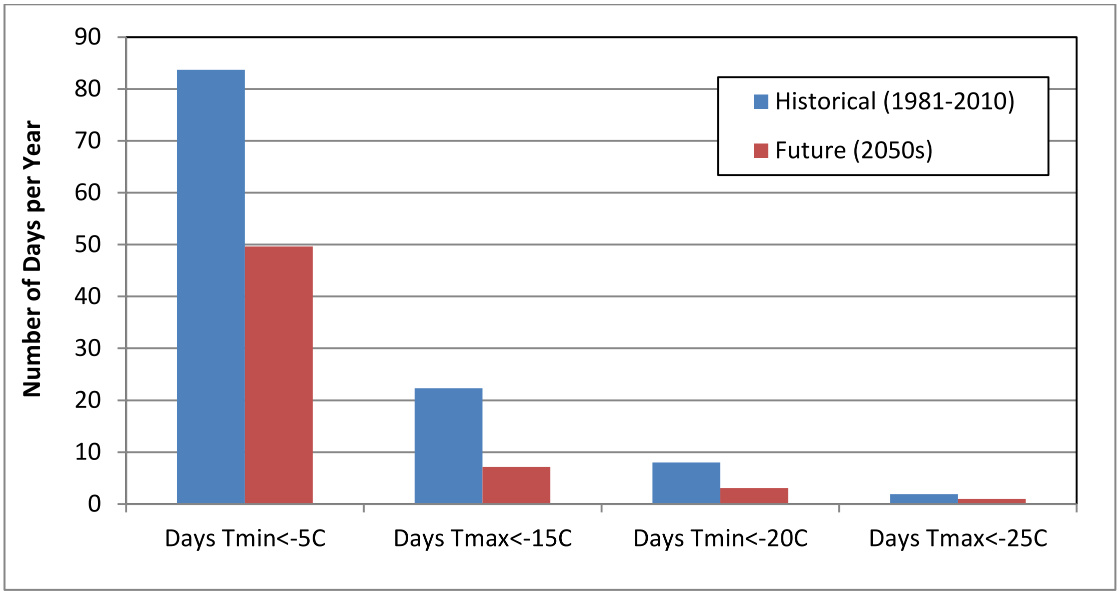

Figure C-9: Extreme Cold Climate Indices in York Region using CANGRD (Historical) and MOECC CCDP Ensemble Median Values (Future)

Growing Season

Table C-6: Summary of Growing Season Indicators

Time Period	CANGRD Baseline	Future Change (Delta)					
		MOECC CCDP 2050s		YorkU LAMPS 2050s		CNRM-CM5 Model 2031-2058 (°C)	MIROC5 Model 2031-2058 (°C)
	Mean	P10	P90	P10	P90	Mean	Mean
Growing Season Length [days]							
Annual	154.7	+28.1	+31.0	-	-	+13.3	+22.3
Growing Season Start Date [day]							
Annual	May 17th	May 17th	Apr. 6th	-	-	-	-
Growing Season End Date [day]							
Annual	Oct. 15th	Oct. 11th	Nov. 24th	-	-	-	-
Frost Days, Tmin <0˚C [day]							
Annual	146.4	-28.2	-34.5	-10.7	-53.3	-1.9	-2.1
Winter	83.3	-6.9	-10.1	-	-	-0.9	-0.5
Spring	40.1	-10.5	-12.2	-	-	-3.5	-8.3
Summer	0.0	+0.0	+0.0	-	-	+0.0	+0.0
Fall	23.1	-10.8	-12.2	-	-	-3.3	+0.6

Ice Storms

Table C-7: Summary of Ice Storm Indicators

Time Period	CANGRD Baseline	Future Change (Delta)					
		MOECC CCDP 2050s		YorkU LAMPS 2050s		CNRM-CM5 Model 2031-2058 (°C)	MIROC5 Model 2031-2058 (°C)
	Mean	P10	P90	P10	P90	Mean	Mean
Ice Days (Tmax <0) [days]							
Annual	61.6	-33.0	-37.0	-4.3	-44.8	-1.3	-1.9
Winter	50.1	-22.9	-25.9	-	-	-3.2	-6.0
Spring	9.0	-4.9	-7.3	-	-	-1.0	-2.4
Summer	0.0	+0.0	+0.0	-	-	+0.0	+0.0
Fall	2.5	-2.2	-2.5	-	-	-1.0	+1.1
Ice Potential [events]							
Annual	2.4	-0.2	-0.3	-	-	+0.1	+0.1
Winter	1.4	+0.1	+0.4	-	-	+0.6	+0.3
Spring	0.5	-0.1	-0.3	-	-	-0.1	+0.0
Summer	0.0	+0.0	+0.0	-	-	+0.0	+0.0
Fall	0.5	-0.3	-0.5	-	-	-0.2	+0.4

Drought

Table C-8: Summary of Drought climate Indicators

Time Period	CANGRD Baseline	Future Change (Delta)					
		MOECC CCDP 2050s		YorkU LAMPS 2050s		CNRM-CM5 Model 2031-2058 (°C)	MIROC5 Model 2031-2058 (°C)
	Mean	P10	P90	P10	P90	Mean	Mean
Consecutive Dry Days [days]							
Annual	14.4	-1.5	+1.0	-3.5	+5.5	-1.25	+3.7