Toronto's Current and Future Climate

Prepared for the City of Toronto
By Toronto and Region Conservation Authority - 2024

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Acknowledgements

We respectfully acknowledge that the lands we are situated on are Traditional Territories and Treaty Lands, in particular those of the Mississaugas of the Credit, the Anishinaabeg of the Williams Treaty First Nations, the Huron-Wendat, the Haudenosaunee, and are now home to many diverse First Nations, Inuit, and Métis peoples. We appreciate and respect the history and diversity of the land and are grateful to have the opportunity to work and meet in this territory.

We also acknowledge that this report represents a singular western scientific perspective of how the climate is changing and may continue to change in Toronto. It does not include perspectives from local Indigenous communities or knowledge held by those communities about their understanding of climate change in Toronto. Indigenous knowledge and perspectives will be invaluable towards cultivating a holistic understanding of Toronto's past and future climate and informing how we build a more climate resilient city for current and future generations.

This report was developed by Toronto and Region Conservation Authority (TRCA) for the City of Toronto. Our sincerest gratitude goes to the following City of Toronto staff who supported the development of this report:

- **Lisa MacTavish**, Environment and Climate Division
- **Dr. Stephanie Gower**, Environment and Climate Division
- **Cecilia Fernandez**, Environment and Climate Division

We are also grateful for the input and review provided by City staff across multiple divisions at key stages of this project (in alphabetical order):

- City Planning
- Corporate Real Estate Management
- Engineering and Construction Services
- Environment and Climate
- Indigenous Affairs Office
- Municipal Licencing and Standards
- Office of the Chief Financial Officer
- Parks, Forestry and Recreation
- Shelter, Support and Housing Administration
- Social Development, Finance and Administration
- Toronto Emergency Management
- Toronto Public Health
- Toronto Water
- Transportation Services

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Recommended Citation

Lam, S., Demirbas Caglayan, S., Mahya, M., and David, Y. (2024). Toronto's Current and Future Climate. Toronto and Region Conservation Authority. Toronto, ON.

Summary of key messages

Around the world, extreme weather events have become more frequent, intense, and severe due to human-caused climate change. With a changing climate, it is no longer sufficient to rely solely on historical climate data and trends. "Toronto's Current and Future Climate" report looks at how Toronto's climate has changed and what future climate conditions could be based on two possible climate scenarios.

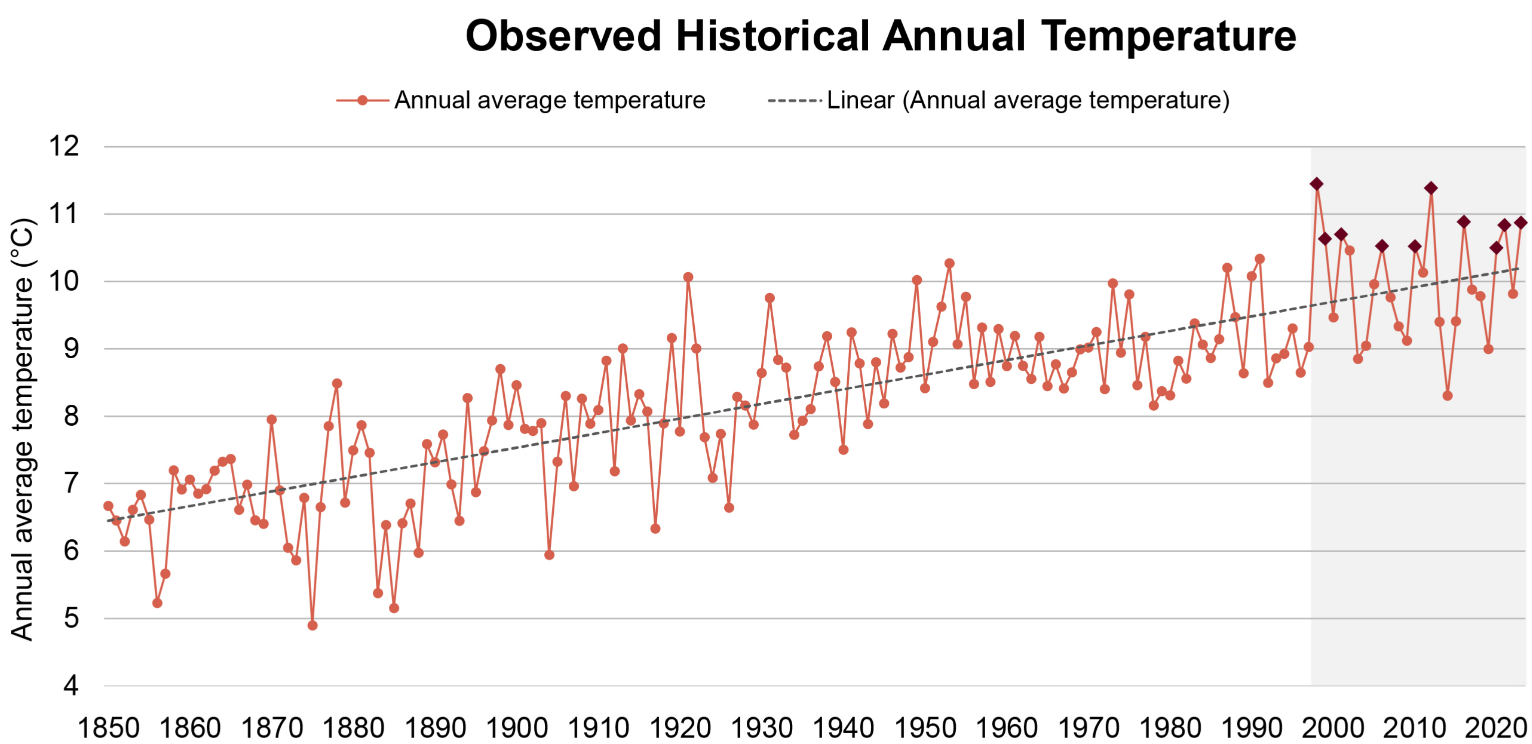
Key message 1: Toronto's climate is getting warmer, wetter, and wilder.

Data from the last 170+ years show that Toronto's climate has already changed. The costs and impacts associated with these changes continue to grow. For example, Toronto has seen at least four intense storms in the last 20 years (August 2005, July 2013, August 2018, and July 2024) that have exceeded the 100-year storm in parts of the city. Each of these caused extensive flooding and erosion damage across the city and resulted in hundreds of millions of dollars in insured damage. Exposure to heat is associated with heat-related illness and death in Toronto, and impacts are often unequally distributed across the population. These impacts are already occurring while global surface temperature has increased by more than 1°C since the pre-industrial period (1850-1900). With every additional increment of global warming, more devastating impacts are anticipated.

Key message 2: It has been getting hotter in Toronto since 1850.

In Toronto, the ten warmest years on record have all occurred since 1998 (Figure 1). Annual average temperature between 1991-2020 was 0.8°C warmer than 1961-1990, increasing from 8.9°C to 9.7°C.

The number of very hot days in a year with daily maximum temperature above 30°C is increasing – from 10 days between 1961-1990 to 14 days between 1991-2020. Meanwhile, the number of very cold days with daily minimum temperature below -20°C has hovered around 2 to 3 days a year in the last few decades but has generally declined over the past 170+ years. Heating demand for buildings is declining, while cooling demand is on the rise. In 1991-2020, heating demand decreased by 5.8% compared to 1961-1990, while cooling demand increased by 17.3% over the same period.



Rank	Year
1	1998
2	2012
3	2016
4	2023
5	2021
6	2001
7	1999
8	2006
9	2010
10	2020

Figure 1. Observed historical annual average temperature (1850-2023) based on data from the Toronto City climate station. Source data: Historical Climate (Toronto City climate station)

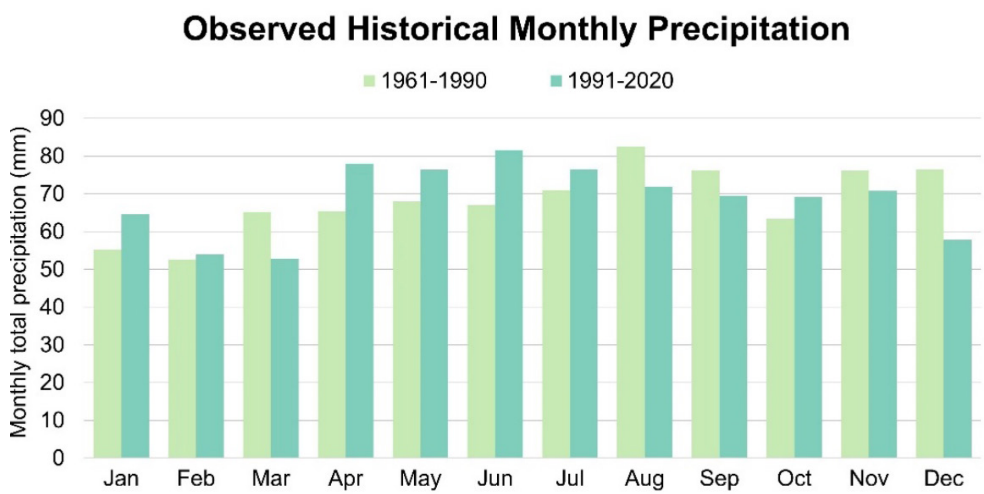


Figure 2. Comparing historical monthly total precipitation between two 30-year climate normal periods (1961-1990 and 1991-2020). Source data: Canadian Climate Normals (Toronto City climate station)

Key message 3: Precipitation is increasing, but patterns remain variable.

Warmer air can hold more moisture and increase evaporation to produce more storms. In downtown Toronto, annual total precipitation has increased by 0.5% during 1991-2020 compared to 1961-1990. However, it is important to note that precipitation can be very localized, so trends may vary across the city.

In the past few decades, some months have seen more precipitation than before, while others have seen less (Figure 2). June precipitation increased the most, followed by April and January. Meanwhile, December precipitation decreased the most over the same period, followed by March and August.

With warmer temperatures, the share of annual precipitation falling as snow has declined since 1850, with more precipitation falling as rain. On average, the proportion of total precipitation falling as snow has declined by 0.2% per decade between the 1850s and 1990s. Meanwhile, ice cover over Lake Ontario has also declined since the 1970s. On average, annual maximum ice cover has decreased by approximately 3.5% per decade between the 1970s and 2010s, while Lake Ontario's surface water temperature has been warming rapidly since the 1990s.

Lake Ontario water levels fluctuate naturally, with some high periods and some low periods. 2017 and 2019 saw some of the highest annual average lake levels ever recorded in Lake Ontario, which caused extensive flooding, erosion, and damage to Toronto's shorelines and Toronto Island Park.

Key message 4: Toronto's future climate depends on the choices we make now.

This study focused on two possible climate scenarios: a medium emissions scenario (SSP2-4.5) and a very high emissions scenario (SSP5-8.5), which translate to approximately 2.7°C and 4.4°C of global warming by the end of the century, respectively (IPCC, 2021). Based on current global emissions and countries' emissions reduction targets, we are tracking towards somewhere in between these two scenarios (UNEP, 2024; IPCC, 2023; IEA, 2023). Both scenarios would exceed the Paris Agreement goal of limiting global warming to well below 2°C above pre-industrial levels and pursuing efforts to limit global warming to 1.5°C.

Rapid and sustained actions to reduce greenhouse gas (GHG) emissions globally are required to meet those goals, which would avoid many of the climate changes described in this report. Toronto must do our part in contributing to the global effort to reduce GHG emissions to avoid the worst impacts of climate change for current and future generations. If global emissions are not significantly and urgently reduced, then Toronto's future climate can be expected to change in ways described in this report. Figure 3 shows how each scenario impacts future temperatures in Toronto.

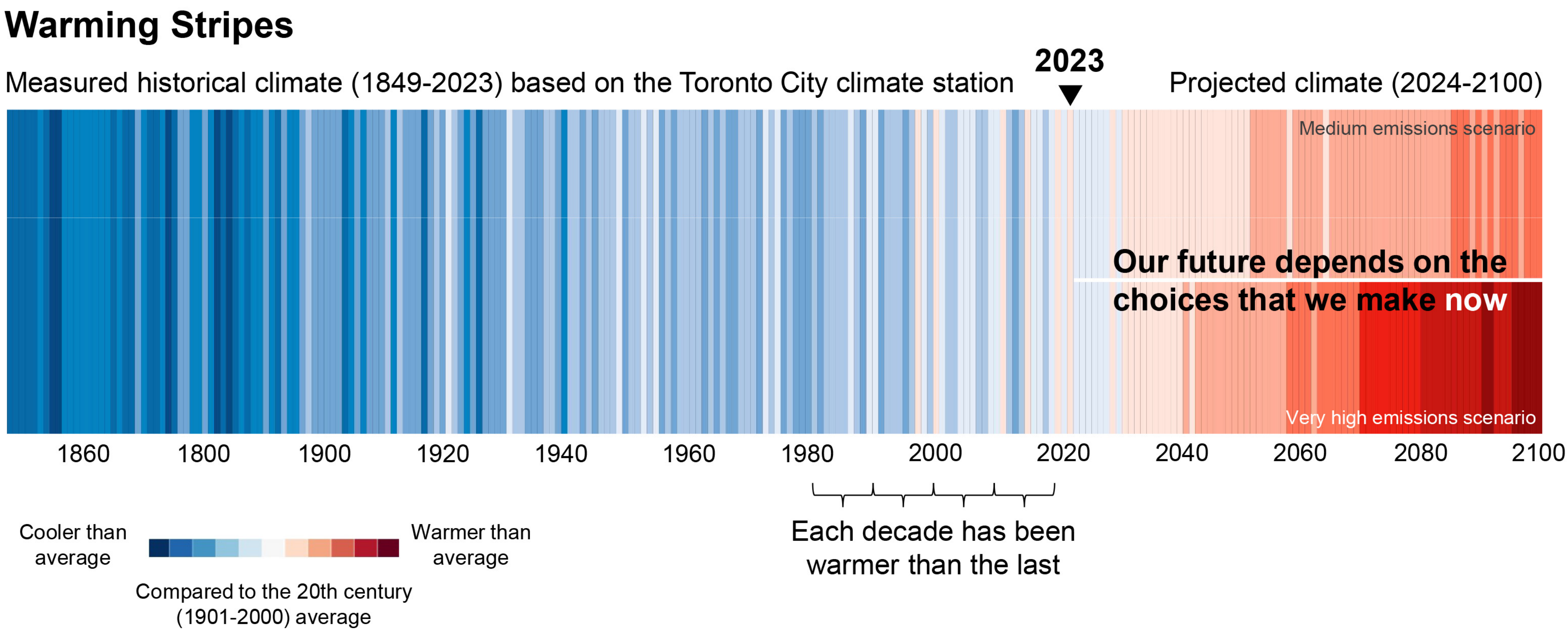
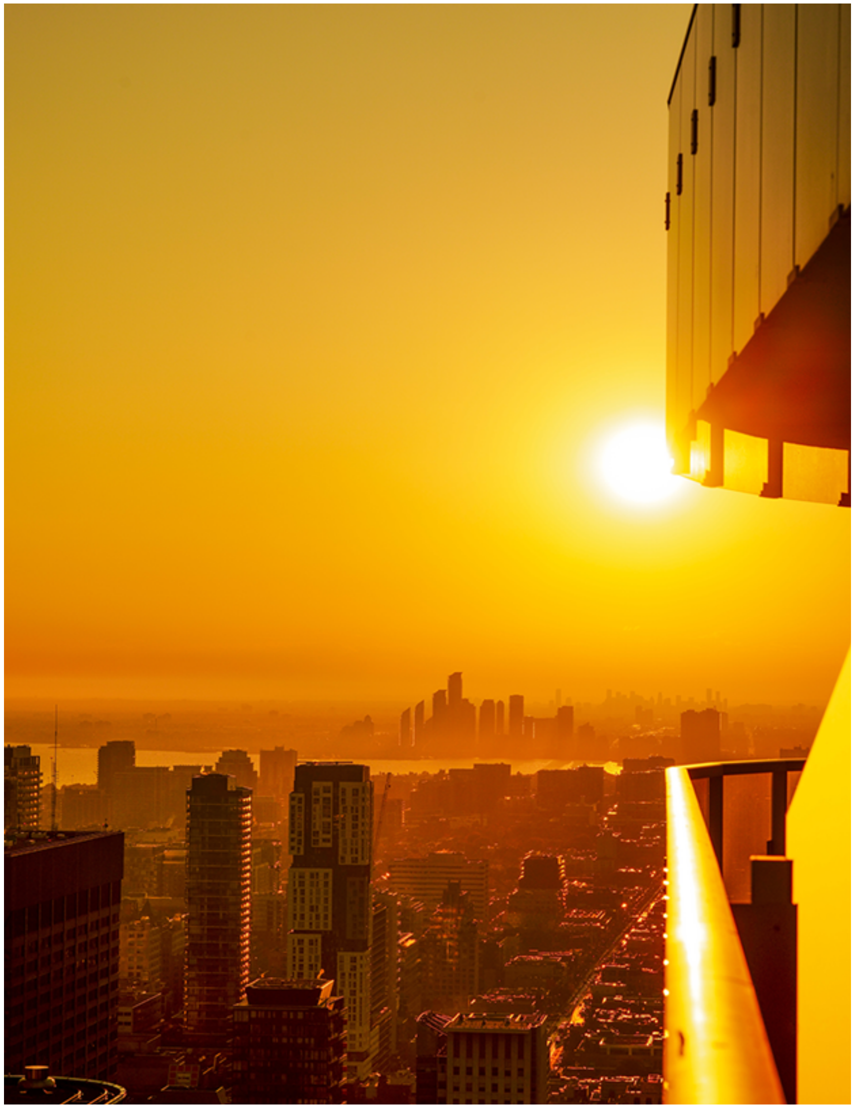


Figure 3. Warming stripes showing measured historical annual average temperature (1849-2023) based on data from the Toronto City climate station and projected annual average temperature (2024-2100) under the medium emissions (SSP2-4.5) and very high emissions scenarios (SSP5-8.5). Each bar shows the difference in annual average temperature for each year compared to the average temperature over the 20th century (1901-2000). Warmer than average years are represented by red stripes and cooler years are represented by blue stripes. The darker the stripe colour, the greater the difference from the 20th century average.



Key message 5: Toronto is expected to continue to get hotter. The more heat-trapping greenhouse gases (GHGs) we emit, the hotter it will become.

Under both scenarios, annual temperatures are expected to increase by 2°C in the short term (2015-2040) compared to the 1980s (Figure 4). By the end of the century, annual temperatures are expected to increase further by 4°C under the medium emissions scenario or 6-7°C under the very high emissions scenario compared to the 1980s. Every additional increase in average temperature can lead to more extreme weather events.

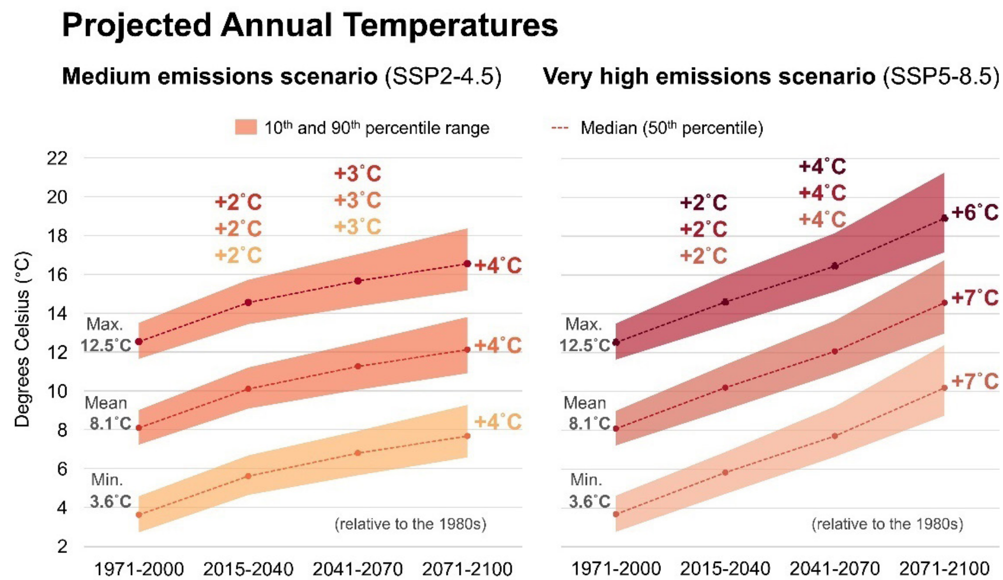


Figure 4. Projected annual temperatures (maximum, mean, and minimum) under the medium emissions (SSP2-4.5) and very high emissions scenarios (SSP5-8.5), with differences in median values compared to 1971-2000 (modelled historical)

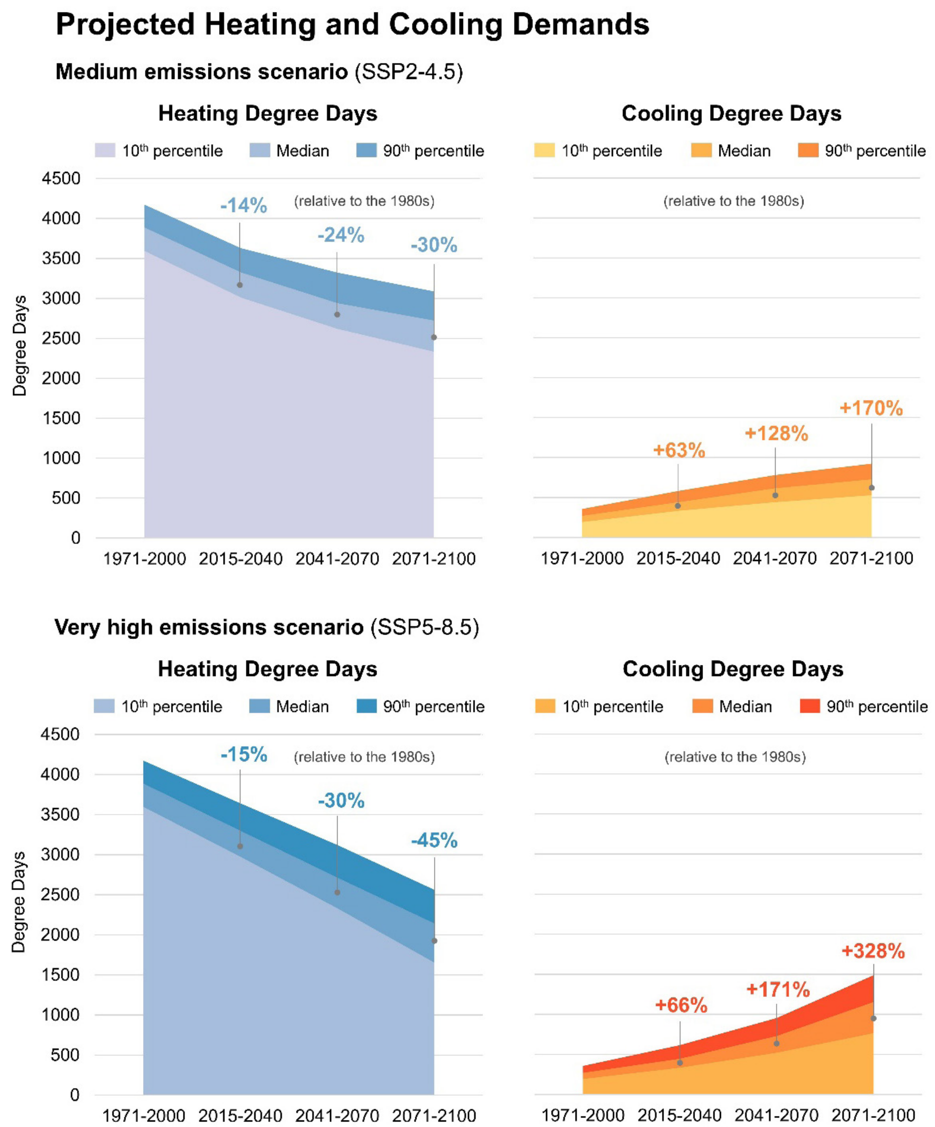


Figure 5. Projected changes in heating and cooling degree days under the medium emissions scenario (SSP2-4.5, top) and very high emissions scenario (SSP5-8.5, bottom), with percentage differences in median values compared to 1971-2000 (modelled historical). "Degree days" represents the difference in daily mean temperature that is accumulated above or below a specified base temperature. Daily mean temperature below 18°C is commonly used as the temperature threshold for assessing space heating demand in Canada. Conversely, daily average temperature above 18°C is commonly used for assessing space cooling demand. The heating degree days for a single day represents the number of degrees Celsius that the mean temperature is below 18°C, and this difference is added over a year for annual heating degree days.

Under both scenarios, extreme heat events that meet heat warning temperature thresholds are expected to occur more frequently and last longer, putting more people at risk of heat-related illnesses and death. In Southern Ontario, a heat warning is issued when there is a forecast of two or more consecutive days with daytime maximum temperatures of 31°C or warmer, together with nighttime minimum temperatures of 20°C or warmer, or when there is a forecast of two or more consecutive days with humidex values expected to reach 40 or higher (Ontario Ministry of Health, 2023). Meanwhile, the number of frost days (below 0°C), cold days (below -10°C), and very cold days (below -20°C) is expected to decrease as temperatures continue to rise.

On average, the temperature on the hottest day in a year in the 1980s used to be around 33°C. By the end of the century, hottest day temperature could increase by 4-7°C, reaching a sweltering 37°C and 40°C under the medium and very high emissions scenario, respectively. The number of days with high humidity is also anticipated to increase, bringing more uncomfortable and dangerously hot conditions.

With warming temperature, heating demand for buildings is expected to continue to decrease, while cooling demand is expected to increase by a lot – tripling or more than quadrupling by the 2080s compared to the 1980s, depending on the climate scenario (Figure 5).

Key message 6: Toronto is expected to get wetter. With increased warming, we can expect more precipitation overall and more extreme storms.

Annual total precipitation has generally increased in Toronto, but some years have seen drier-than-average conditions as well (Figure 6). Overall, precipitation is expected to increase under both climate scenarios. By the end of the century, annual total precipitation is expected to increase by approximately 11% under the medium emissions scenario and 16% under the very high emissions scenario compared to the 1980s.

Extreme precipitation is also expected to increase, with greater increases anticipated under the very high emissions scenario. Maximum total precipitation falling in one day may increase by 8-11% by the 2030s, 13-17% by the 2050s, and 18-27% by the 2080s, depending on the climate scenario. More rain is also anticipated to fall over short periods – within minutes to 24 hours – increasing the risk of flooding and erosion.

Key message 7: The length of the frost-free season is expected to start earlier and end later.

The frost-free season typically lasted 230 days a year in the 1980s. By the end of the century, the length of the frost-free season is expected to increase by 84-117 days under the medium and very high emissions scenario, respectively. While an extended warm-weather period is expected to benefit agricultural production, it also creates conditions that are more favourable for the growth and spread of insects and pests.

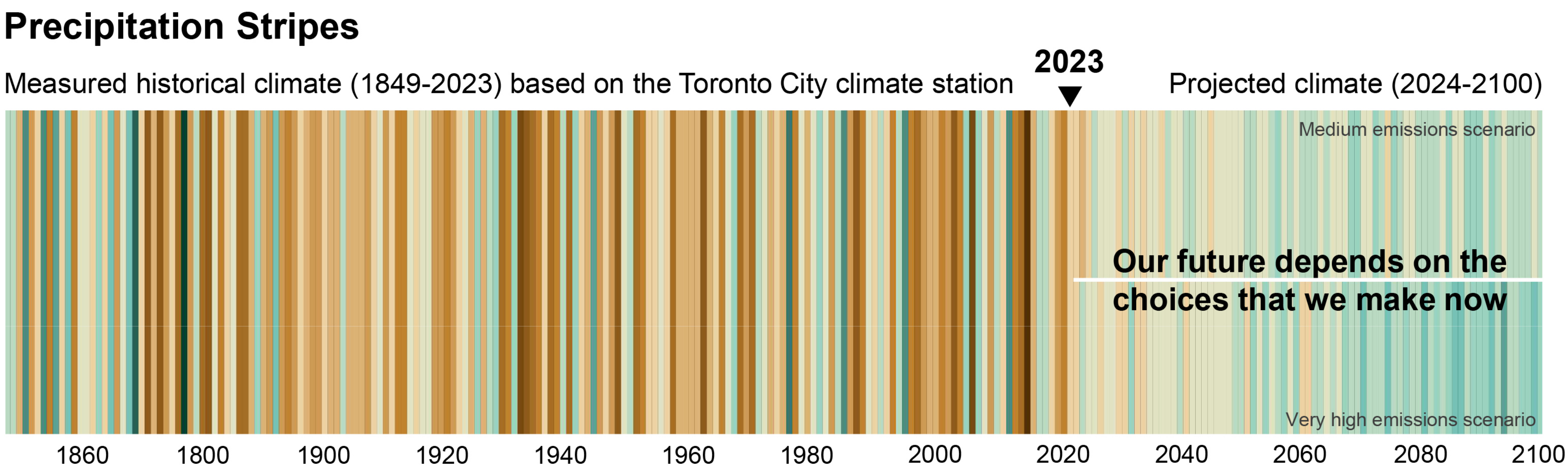


Figure 6. Precipitation stripes showing changes in measured historical annual total precipitation (1849-2023) based on data from the Toronto City climate station and projected annual total precipitation (2024-2100) under the medium emissions (SSP2-4.5) and very high emissions scenarios (SSP5-8.5). Each bar shows the percentage increase or decrease in annual total precipitation for each year compared to the average precipitation between 1950-2000. Measured historical precipitation (1849-2023) is compared to the observed average, while projected future precipitation (2024-2100) is compared to the modelled historical average. Wetter than average conditions are represented by green stripes and drier than average conditions are represented by brown stripes. The darker the stripe colour, the greater the difference from the 1950-2000 average (observed/modelled).

Figure 7. Illustration of anticipated changes in Toronto's future climate, and potential impacts on Toronto's people and communities if the concentration of heat-trapping greenhouse gases continues to rise. Adapted from: UK Met Office

Key message 8: Climate change in Toronto will lead to a wide range of impacts. The consequences depend on how quickly we can reduce GHG emissions and adapt equitably and sustainably.

Over the remainder of this century, Toronto can expect to see warmer temperatures, intensifying heat events, less extreme cold, a longer growing season, more extreme high and extreme low lake levels, and more extreme weather (Figure 7). These changes may lead to wide-ranging impacts – some of which we have already seen – such as increased disruption to infrastructure and services; increased maintenance and operations costs; detrimental impacts on people's health and well-being; increased spread of invasive species and pests; more flooding and erosion; gains and losses in species and ecosystems; more poor air quality days from wildfire smoke; global supply chain impacts; increased cost of living; loss of economic productivity; and increased damage to property and infrastructure. These impacts are often unequally distributed, affecting some people more than others including people who face multiple, overlapping stressors due to systemic and long-standing inequities.

The updated climate projections in this report can help the City better plan and prepare for changes in the current and future climate. They are a key input to Toronto's city-wide climate risk and vulnerability assessment, which is currently underway (as of late 2024). It uses local information to specifically identify the people, assets, and services that are most vulnerable to the impacts of climate change in Toronto. This equips the city with risk-based information to continue to support more proactive and effective adaptation and resilience-building efforts across the city.

This climate data can also help businesses, residents, and communities by building common understanding of the possible future changes in Toronto's climate if GHG concentrations continue to rise, and help initiate conversations about climate change in Toronto. By understanding what we need to avoid and why, we can collectively help shape a healthier and more resilient future – one in which current and future generations of people, plants, and animals can continue to thrive.

1. Introduction

This report describes how Toronto's climate has changed and what future climate conditions could be based on two possible climate scenarios.

As extreme weather events become more frequent, intense, and severe due to climate change, it is no longer sufficient to rely solely on historical climate data and trends. This report serves to update "Toronto's Future Weather and Climate Driver Study" that was completed in 2011 (SENES Consultants Ltd.) to provide an updated, comprehensive picture of what could be in store for Toronto if we do not significantly and urgently reduce greenhouse gas (GHG) emissions and achieve the global target of limiting global warming to well below 2°C compared to the pre-industrial period. Using the latest data and climate scenarios, this report describes:

- How Toronto's climate has changed based on long-term observation records;
- What Toronto's future climate could look like if GHG concentrations continue to rise under two possible climate scenarios; and
- How this data and information can be used to help inform Toronto's adaptation and resilience-building efforts.

Context

Global surface temperature has warmed by more than 1°C since the pre-industrial period (1850-1900), and this warming has already caused devastating impacts around the world, including in Canada (Intergovernmental Panel on Climate Change [IPCC], 2022, 2021). For example, the dangerous 2021 extreme heat event that affected western Canada and parts of the U.S. resulted in the deaths of over 600 people in British Columbia and would have been "virtually impossible" without human-caused climate change (Egilson et al., 2022; Philip et al., 2022).

Climate change is putting people's health, safety, and livelihoods at increasing risk, and the costs of climate change are rising across Canada (Berry and Schnitter, 2022; Canadian Climate Institute, 2020-2022). According to the Insurance Bureau of Canada (2024a, 2024b), insured damages from catastrophic weather events exceeded $3 billion in 2023 for the second year in a row, with 2024 on track to more than double this value. Some of Canada's costliest severe weather events based on insured losses have occurred in Toronto and surrounding areas.

Panel 1 illustrates some past extreme weather and climate-related events that have impacted Toronto's people and communities since 2000. Past impacts include widespread flooding and erosion; transportation disruptions; damage to infrastructure, trees, and public and private property; power outages; heat-related illnesses and deaths; and costs incurred by the City, residents, and businesses. However, the true cost of climate change and extreme weather is likely much higher due to uninsured damage and less tangible impacts such as impacts on people's mental health and well-being.

As these past events highlight, the impacts of extreme weather and climate-related events can be wide-ranging, affecting people's daily lives, health and safety, infrastructure and property, businesses and the economy, and the natural environment. In the last 20 years, Toronto has seen at least four intense storms (August 2005, July 2013, August 2018, and July 2024) that have exceeded the 100-year storm in parts of the city, which historically has a 1% chance of occurring in any given year. As the cost and pressures from such events continue to mount, it is imperative that we prepare for the shocks and stresses that we will continue to see under a rapidly changing climate.

Panel 1. Summary of some past extreme weather and climate-related events that have occurred in Toronto since 2000

2000

MAY 2000 storm

Overnight Friday, May 12 through May 13, 2000, a severe thunderstorm produced an average of 68 mm of rain across Toronto (up to 73 mm; Toronto Water, 2013; City Council, 2000). The storm resulted in widespread flooding and led to road closures, infrastructure damage, and erosion in ravines and watercourses (City Council, 2000). Over 3,000 basement flooding complaints were reported.

2005

August 2005 storm

On Friday afternoon of August 19, 2005, severe thunderstorms moved eastward over the city, bringing high winds, golf-ball sized hail, and heavy rain (Public Safety Canada, 2013b; Deputy City Manager and Chief Financial Officer, 2008). Over 100 mm of rain was recorded in the city in the span of 2-3 hours (up to 153 mm), which led to flash flooding and erosion along rivers, creeks, and ravines (Deputy City Manager and Chief Financial Officer, 2008; Toronto Water, 2006).

A culvert under Finch Avenue West was washed out and led to the collapse of a section of the road. Over 4,200 basement flooding complaints were received by Toronto Water (2008). The City incurred $44 million in multi-year operating and capital costs (Deputy City Manager and Chief Financial Officer, 2008). Over 15,000 insurance claims were submitted, totaling more than $500 million (Public Safety Canada, 2013b; Deputy City Manager and Chief Financial Officer, 2008).

Summer 2005 extreme heat events

During the summer of 2005, 8 Heat Alert days and 18 Extreme Heat Alert days were reported by Toronto Public Health (2007). While some days did not meet the criteria for a heat alert, there were 41 very hot days with daily temperatures above 30°C in 2005 (Health Canada, 2011b). At least 6 heat-related deaths were reported of individuals who lived in rooming and boarding homes (City Council, 2006). Over 200 emergency calls for heat-related illnesses were reported (City of Toronto, 2008).

2010

Summer 2010 extreme heat events

During the summer of 2010, 5 Heat Alert days and 11 Extreme Heat Alert days were reported by Toronto Public Health (2011). At least 6 heat-related deaths and 6 heat-related emergency calls were reported.

On July 5, 2010, a fire at a Hydro One transformer station (Manby) in Etobicoke left approximately 250,000 people without electricity during an extreme heat alert and smog advisory (Health Canada, 2011a). The power outage started around 4:45 pm with temperature rising to around 35°C and humidex around 40 (Health Canada, 2011a; CBC News, 2010). Commuter traffic was disrupted, and firefighters rescued some people who were trapped in elevators when the power failed. Power was fully restored by around 8:30 pm (The Canadian Press, 2010). If the power outage had lasted longer as it did in 2003, the consequences could have been much more dire (Health Canada, 2011a).

2013

July 2013 storm

In the early evening of Monday, July 8, 2013, a slow-moving cluster of thunderstorms drenched the city with heavy rain that resulted in power outages, downed trees, major disruptions to transportation during evening rush hour, and overwhelmed sewer and water systems (AMEC Environment and Infrastructure, 2014; City Manager, 2013). Over 100 mm of rain was recorded in the city in the span of approximately 3 hours (up to 138 mm; Toronto Water, 2013).

At least 300,000 Toronto residents and businesses were affected by power outages, which were reportedly caused by equipment failure due to flooding at two Hydro One transformer stations (Richview and Manby; Mortillaro and Armstrong, 2013). Large segments of the subway system were put out of service due to flooded stations and signal problems. Power outages trapped some subway trains in tunnels until commuters could be rescued (CTV Toronto, 2013).

Highways, arterial roads, and underpasses were flooded (City Manager, 2013). Railways and airlines were also disrupted, including a flooded GO train near Bayview Avenue and Pottery Road that stranded approximately 1,400 passengers for more than 7 hours before they could all be rescued.

Over 4,700 basement flooding complaints were received by Toronto Water, surpassing the number of complaints received during the August 2005 storm (City Manager, 2013). The City incurred $65 million in operating and capital costs, which were further exacerbated by the December 2013 ice storm a few months later (City Manager and Deputy City Manager and Chief Financial Officer, 2014; City Manager, 2013).

According to the Insurance Bureau of Canada, the storm caused approximately $940 million in insured property damage across the Greater Toronto Area (Public Safety Canada, 2013d). At the time, this was the most expensive natural disaster in Ontario's history based on insured damages (Flavelle, 2014; CityNews, 2014).

December 2013 ice storm

During the evening of Saturday, December 21 through December 22, 2013, an extreme winter storm battered the city with freezing rain for more than 40 hours, along with ice pellets, and wind (Toronto Hydro Corporation, 2023; City Manager, 2014).

Approximately two million trees were damaged across the city (Toronto Hydro Corporation, 2023). Downed trees and ice accumulation damaged approximately 500 power lines and led to widespread power outages (Toronto Hydro Corporation, 2023; City Manager, 2014; Public Safety Canada, 2013c).

Approximately 416,000 residents and businesses were without power, displacing thousands of people from their homes (Acting City Manager, 2015; City Manager, 2014). Some people were without power for days to weeks during the winter holiday season as electricity was fully restored on January 1, 2014 (City Manager, 2014). Call volume to Toronto's 311 service increased significantly during and following the storm, peaking at 5,800 calls on December 24. An increased volume of emergency calls was also experienced, including calls for slips, trips, falls, and carbon monoxide exposure. Fire Services responded to nine second alarm (or higher) fires – many of which were reportedly caused by residents' attempts to power and heat their homes.

The ice storm cost the city approximately $107 million, further exacerbating the financial pressures that the City was already facing following the July 8, 2013 storm event (City Manager and Deputy City Manager and Chief Financial Officer, 2014).

2017

2017 high lake levels and April 2018 windstorm

In the spring of 2017, Lake Ontario saw an unprecedented rise in water levels as snowmelt and an exceptionally rainy spring increased water supply to the lake (Toronto Parks, Forestry and Recreation, 2018). Water levels began rising in April and by May 4, impacts on residents and assets on Toronto Island Park began to be felt (Toronto Parks, Forestry and Recreation, 2017). On May 26, Toronto Public Health advised residents to avoid contact with floodwater due to potential risk of waterborne illnesses. The next day, water level peaked at 75.93 m (IGLD85[1]), which was 0.91 m above normal averages (Toronto Parks, Forestry and Recreation, 2018).

Flooding affected the entire span of Toronto's waterfront and Toronto Island Park, resulting in flooding and erosion damage. By the end of May, over 45,000 sandbags, 1,000 metre bags, and 27 industrial pumps were deployed by City and TRCA staff to protect Island residents and assets (Toronto Parks, Forestry and Recreation, 2017). Public access to the Island was restricted between May 4 and July 30, 2017 (except for approximately 800 Island residents), resulting in the loss of recreational opportunities for thousands of people who typically visit the Island during the summer. Seventy landslides were recorded along the Scarborough Bluffs where public access was also restricted.

By early June, Lake Ontario water level began to decline but remained elevated above average levels into early 2018 (Toronto Parks, Forestry and Recreation, 2018, 2017). On Monday, April 14 through April 15, 2018, a windstorm pummeled the city, exacerbating existing shoreline damage and caused further damages (Toronto Parks, Forestry and Recreation, 2018). The waves produced during the windstorm were the highest ever measured in Lake Ontario in at least the past 45 years. Over a 24-hour period, the windstorm produced the same amount of damage as the flooding that was experienced over the entire course of 2017.

Together, these two events resulted in a combined cost of approximately $28 million.

2018

August 2018 storm

On Tuesday, August 7, 2018, a slow-moving tropical storm fell over parts of North York and moved slowly south across downtown Toronto, producing 80-100 mm of rain within two hours (Opler et al., 2020; TRCA, 2018). The highly localized storm inundated the Black Creek watershed and western parts of the Don River and caused flash flooding in low-lying areas (TRCA, 2018).

The heavy rain caused power outages, inundated streets, damaged streetcars, and disrupted subway service on Line 1 between Finch West and Wilson stations due to flooding (Toronto Star, 2018). Several people were rescued from their vehicles due to flooded roads (Toronto Star, 2018; Public Safety Canada, 2013a). Two men were rescued from a flooded elevator in the basement of an office building in the city's north end (Welsh, 2019; Toronto Star, 2018).

The City received over 1,000 basement flooding complaints (Toronto Water, 2023). According to the Insurance Bureau of Canada, the storm caused more than $80 million in insured damage (CBC News, 2018).

[1]IGLD85 refers to the International Great Lakes Datum of 1985. Implemented in 1992, it is a commonly used height reference system to measure Great Lakes water levels (Vertical Control – Water Levels Subcommittee, 2017). New reference systems are established approximately every 25-30 years to account for the movement of the Earth's crust in the Great Lakes region.

2019

2019 high lake levels

In the spring of 2019, Lake Ontario water level once again rose to unprecedented levels, breaking the 2017 record with a peak height of 76.03 m (IGLD85) on May 29, 2019 (Toronto Parks, Forestry and Recreation, 2019). This further exacerbated erosion and damage along the shoreline and brought the cost of repairing damages to over $30 million since 2017 (TRCA Restoration and Infrastructure, 2020).

2024

June 2024 heat event

Between June 17-21, 2024, a heat warning was in effect in Toronto, among other parts of Ontario, Quebec, and Atlantic Canada (City of Toronto, 2024c; Shingler, 2024; Ramos, 2024). The dangerously hot and humid conditions were associated with a heat dome that centred over the eastern U.S. (Jiang, 2024b). Sweltering conditions lasted for most of the week, affecting millions of people across eastern Canada (Shingler, 2024). According to ECCC's rapid heat wave attribution analysis (2024b), the heat wave experienced in eastern Ontario was made "much more likely" by human-caused climate change.

July 2024 storm

Rain began to fall in the morning of Tuesday, July 16, 2024, which was followed by a series of intense thunderstorms that dumped more than 100 mm of rain in some Toronto areas in the span of three hours (Mortillaro, 2024; City of Toronto, 2024a; Jiang, 2024a). The heavy rain caused widespread flooding and power outages just as a heat warning remained in effect in Toronto, disrupting transportation, City services, and people's daily lives.

At the peak of the power outage, approximately 167,000 residents and businesses were without power due to flooding at a Hydro One transmission station (City of Toronto, 2024a; D'Cunha and Casaletto, 2024). Telecommunications services were also affected. By the next day, approximately 3,200 customers were still without power (City of Toronto, 2024b).

By the evening of July 16, the City received over 700 basement flooding complaints (City of Toronto, 2024a). Many people had to be rescued from elevators or vehicles as floodwaters rose. Flooding led to several road closures, including parts of the Don Valley Parkway. Subway service was affected on portions of Lines 1 and 2 due to flooding and power outages (Spurr et al., 2024).

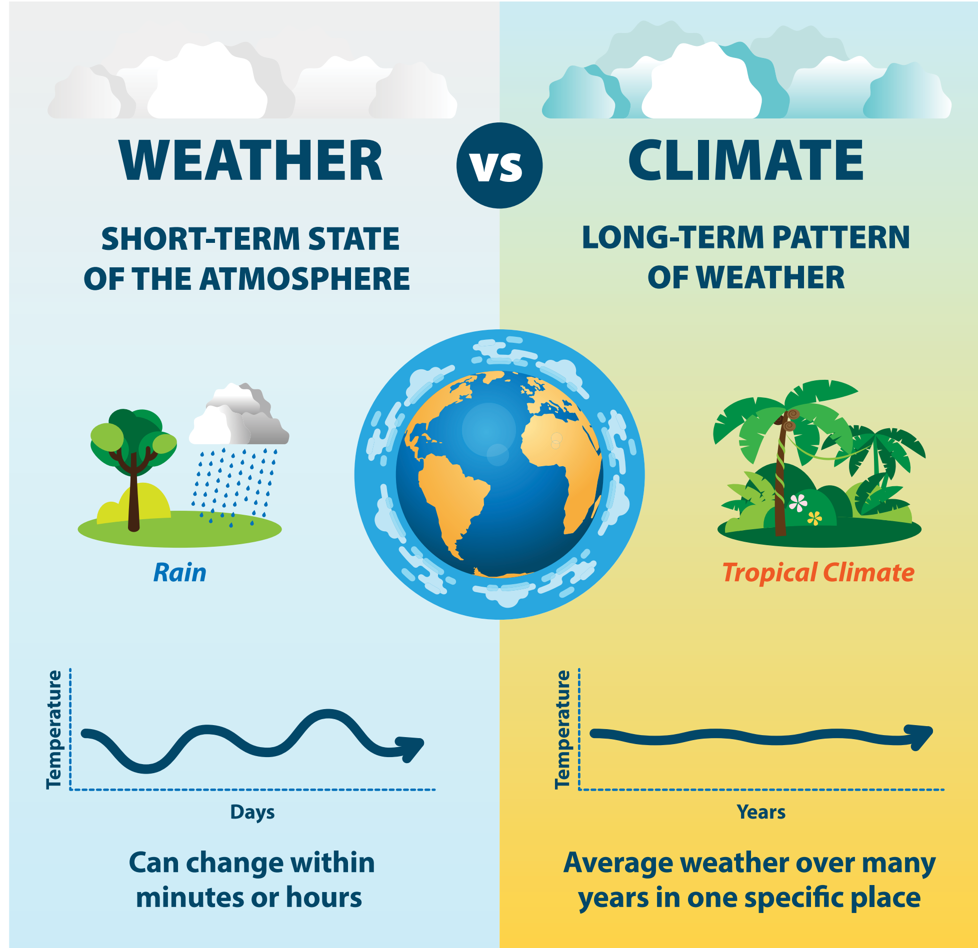
According to the Insurance Bureau of Canada, the storm cost more than $940 million in insured damage in Toronto and southern Ontario (Insurance Bureau of Canada, 2024b; Tsekouras, 2024).

2. How this report was prepared

2.1 Characterizing Toronto's historical climate

Long-term observation records from the Toronto City climate station, located in downtown Toronto, were used to illustrate changes that have already occurred in Toronto's climate over time. This climate station was selected because 30-year climate normal data for various historical periods are currently available, including the most recent 1991-2020 period. Climate normals are calculated by Environment and Climate Change Canada (ECCC) and consider changes in the number of stations across the country and measured data over time (ECCC, 2023). Therefore, the characterization of Toronto's historical climate was primarily based on this climate normal data.

Historical daily data measured at this station was also retrieved from ECCC to supplement this analysis. Daily data provides further information on how Toronto's climate has continuously changed over the past 170+ years, up to 2023. As the analysis relies on data from a single climate station within the city of Toronto, the results may not be representative of climate across the entire city, especially for precipitation which can be highly localized.



Weather is something we experience every day. It is the short-term state of the atmosphere and can change within minutes or hours (World Meteorological Organization [WMO], 2024a).

Climate is the average weather conditions over a long period of time. Thirty-year periods, known as "climate normals", are typically used to characterize the average climate.

2.3 Projecting Toronto's future climate

Projections of future climate are generated using computer models that account for the interactions of different elements such as the ocean, atmosphere, and land, which influence the climate (Lee et al., 2021; Flato et al., 2013). To make it easier for computers to process, the earth is divided by climate models into grid cells that are typically hundreds of kilometres in size (McSweeney and Hausfather, 2018; Flato et al., 2013). While this is useful at the global scale, 100 km is too large to be useful for local and regional planning, which is why we need to downscale global climate projections at a smaller scale for a specific region or area of interest such as Toronto.

This study relied on statistically downscaled climate projections available through PAVICS (Power Analytics and Visualization for Climate Science)[2]. PAVICS is part of a national suite of climate data portals supported by the Canadian Centre for Climate Services (CCCS), providing reliable and consistent projections across the country at a resolution of approximately 10 km (Government of Canada, 2021). These portals also provide climate projections based on the latest set of climate scenarios included in the Intergovernmental Panel on Climate Change's (IPCC's) most recent Sixth Assessment Report.

Since 1990, the IPCC continues to provide the most authoritative scientific assessments of the causes and potential impacts of climate change worldwide. IPCC assessments are updated every 5-7 years, synthesizing the latest science and research. In the latest Sixth Assessment Report, five new climate scenarios were included to provide illustrative warming scenarios up to 2100 (Figure 1).

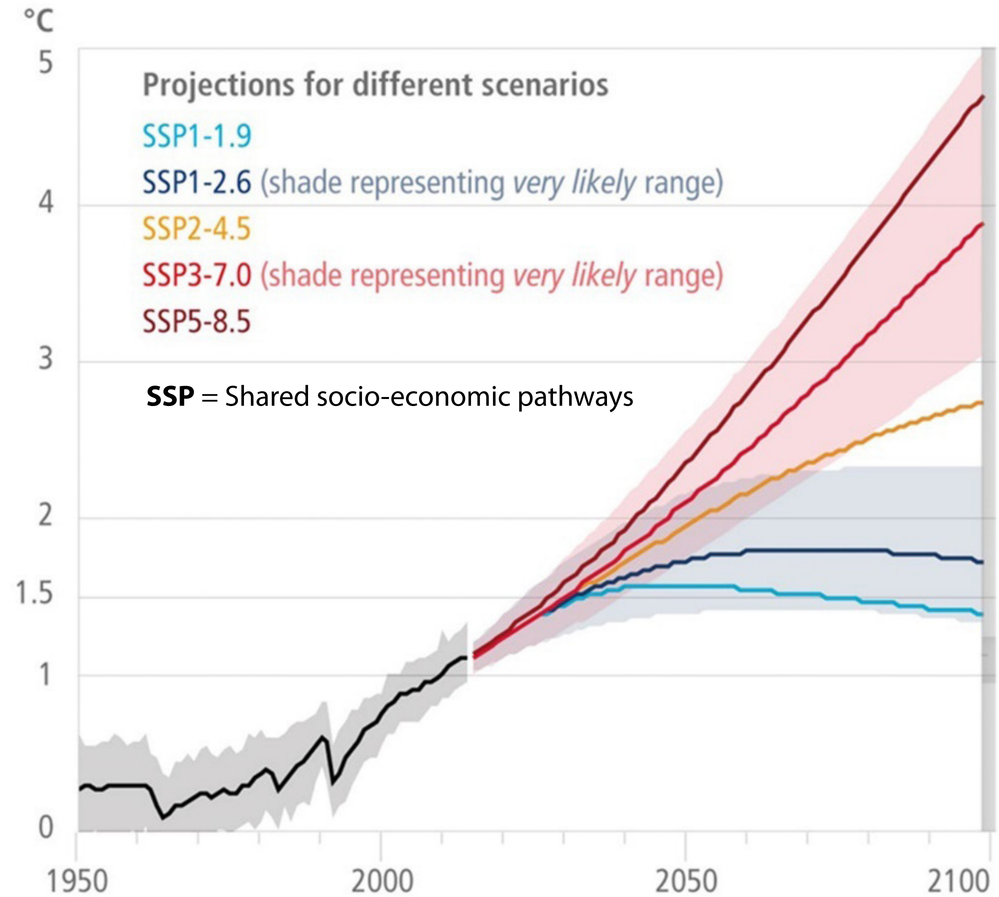


Figure 1. Projected changes in global surface temperature (°C) compared to 1850-1900 under five illustrative climate scenarios: very low emissions (SSP1-1.9), low emissions (SSP1-2.6), medium emissions (SSP2-4.5), high emissions (SSP3-7.0), and very high emissions scenario (SSP5-8.5). Source: IPCC Sixth Assessment Report, Working Group II, Technical Summary

[2]*This study used the CanDCS-U6 (Canadian Downscaled Climate Scenarios – Univariate, CMIP6) dataset, which was being used by ClimateData.ca at the time of the study. By the time of publication, ClimateData.ca switched their default dataset to the CanDCS-M6 (Multivariate) dataset, which may result in some differences between this report and data found in the portal moving forward.*

Only the very low emissions scenario (SSP1-1.9) would meet the Paris Agreement goal of limiting global warming to well below 2°C above pre-industrial levels, while pursuing efforts to limit global warming to 1.5°C (IPCC, 2021). Currently, we are tracking towards somewhere in between the medium and very high emissions scenarios, which translate to approximately 2.7°C and 4.4°C of global warming by the end of the century, respectively (United Nations Environment Programme [UNEP], 2024; IPCC, 2023; International Energy Agency [IEA], 2023). Therefore, this study focused on these two scenarios to illustrate possible climate futures for Toronto. By understanding what we need to avoid and why, we can collectively help shape the future that we want.

For this report, modelled historical and future daily projections were obtained from PAVICS and used to derive a comprehensive set of 12 climate parameters and 54 climate variables. These variables help to illustrate how Toronto's future climate may change across key climate indicators such as temperature, extreme heat, extreme cold, precipitation, extreme precipitation, frost-free season, and growing degree days. Almost all of these climate variables were derived from a total of 26 global climate models, except for the humidex variables which were based on 19 models. For more information about how these variables were derived and why they are important, please see Appendix B.

Data tables were prepared using R Studio to calculate summary statistics for a historical reference period (1971-2000) and three future periods (2015[3]-2040, 2041-2070, and 2071-2100). The short, medium, and long-term future are compared against the historical 1980s period to help characterize the extent, direction, and magnitude of change. Climate data is presented in more than one statistical output to depict uncertainty in the modelling and variation in future climate conditions (Appendix A1 and A2). Together, the 10th and 90th percentiles capture 80% of all projected values, excluding the top and bottom 10%. The 50th percentile (or median) indicates the middle value. Maps were produced in ArcGIS using the median values.

A rapid literature review was conducted for some additional climate variables of interest to City staff (Appendix A3). These include:

- **Lake Ontario:** Over-land air temperature, over-lake precipitation, lake levels, ice cover, and ice season length;
- **Infrastructure design values:** Hourly design temperature, rainfall loads, humidity, wind loads, snow loads, total precipitation and intensity rates for various short-duration rainfall (5-minute, 10-minute, 15-minute, 30-minute, 1-hour, 2-hour, 6-hour, 12-hour, 24-hour); and
- **Other climate variables:** Thunderstorms, wind, snow, rain-on-snow, freezing rain, joint precipitation and temperature extremes, and fire spread.

Many of these variables are more challenging to project and are often associated with greater uncertainty. Summary values for Toronto and relevant key findings were drawn from multiple sources, including government-supported resources and peer-reviewed articles.

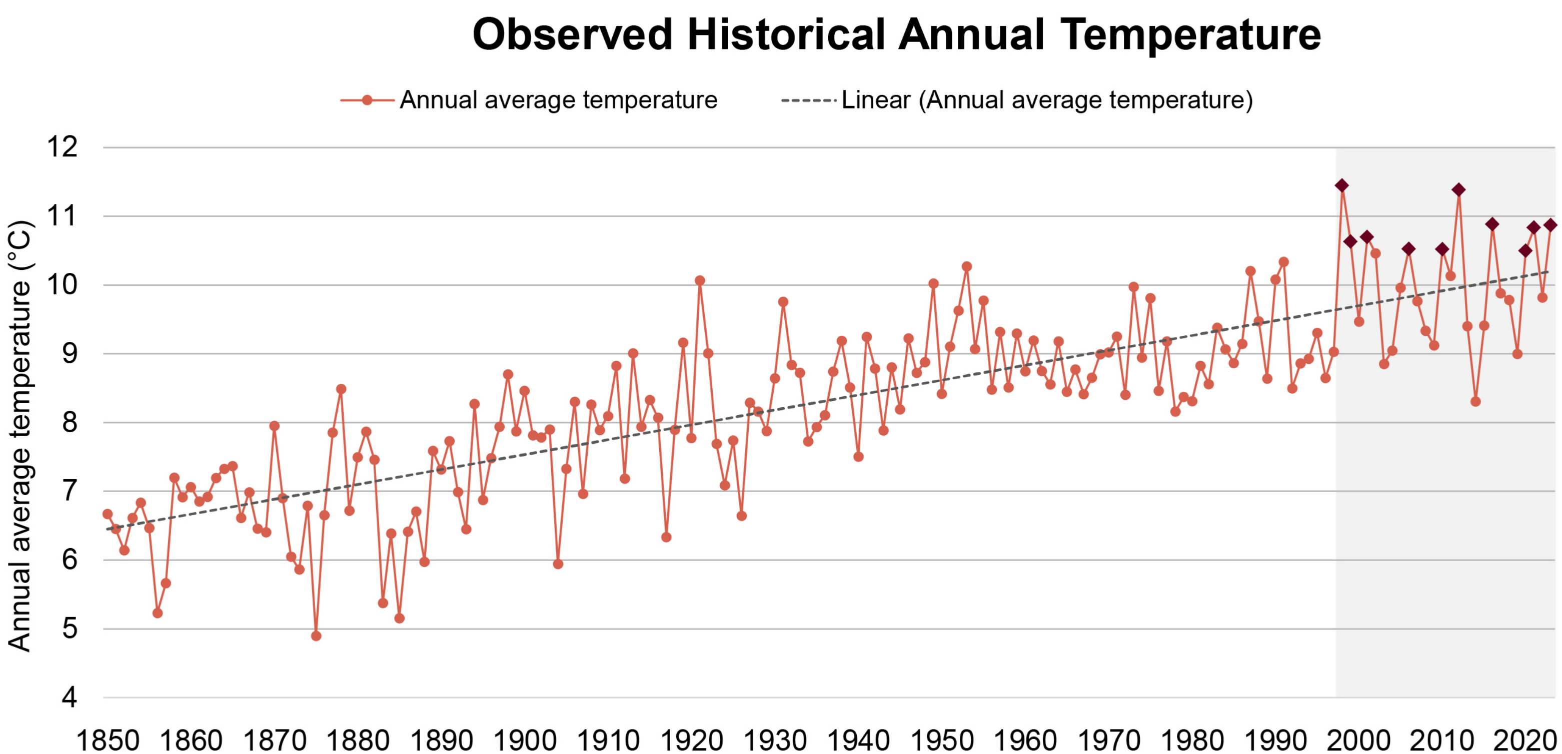
[3] The short-term future period starts in 2015 because this is the year that the future projections begin for the latest climate scenarios.

3. How Toronto's climate has already changed

Based on observed historical climate data measured in downtown Toronto, the city is already warmer and wetter due to human-caused climate change, leading to wilder weather. The following sections explore some key changes in Toronto's climate, including changes affecting Lake Ontario on which the city is situated.

3.1 Annual average temperature has been rising since 1850

Since 1850, Toronto's annual average temperature has been on the rise (Figure 2). Annual average temperatures have increased by approximately 0.2°C per decade since 1850. The ten warmest years on record have all occurred since 1998. While average temperature varies year-to-year due to many factors, the linear trend over this long-term data of more than 170 years demonstrates a clear increasing trend.



Rank	Year
1	1998
2	2012
3	2016
4	2023
5	2021
6	2001
7	1999
8	2006
9	2010
10	2020

Figure 2. Observed historical annual average temperature (1850-2023) based on data from the Toronto City climate station. Source data: Historical Climate (Toronto City climate station)

Monthly temperatures in Toronto have also increased, with warmer winters and earlier spring onset (Figure 3). Between 1961-1990 and 1991-2020, December has warmed the most (by +1.4°C), followed by February (+1.1°C). January and September are tied for third (+1°C).

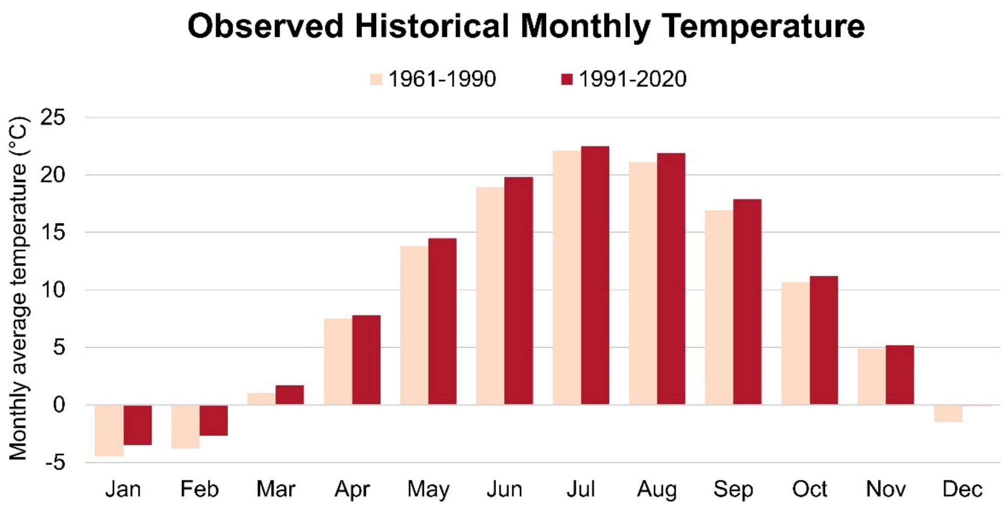
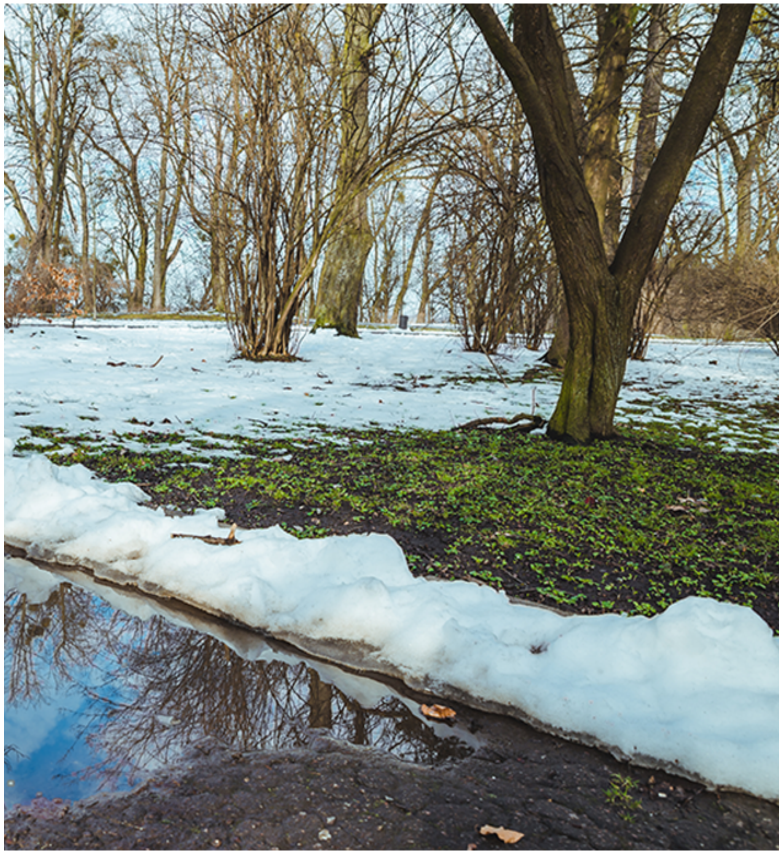


Figure 3. Comparing historical monthly average temperature between two 30-year climate normal periods (1961-1990 and 1991-2020). Source data: Canadian Climate Normals (Toronto City climate station)



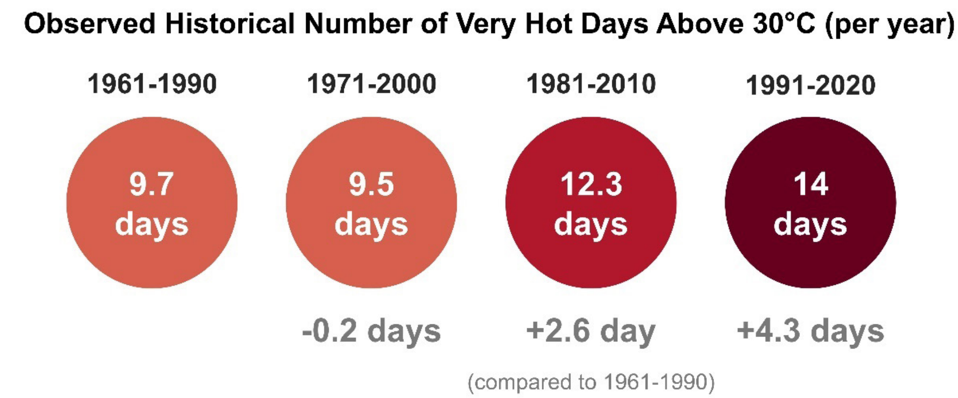


Figure 4. Comparing the historical number of very hot days with daily maximum temperature above 30°C in Toronto over four 30-year climate normal periods (1961-1990, 1971-2000, 1981-2010, and 1991-2020). Source data: Canadian Climate Normals (Toronto City climate station)

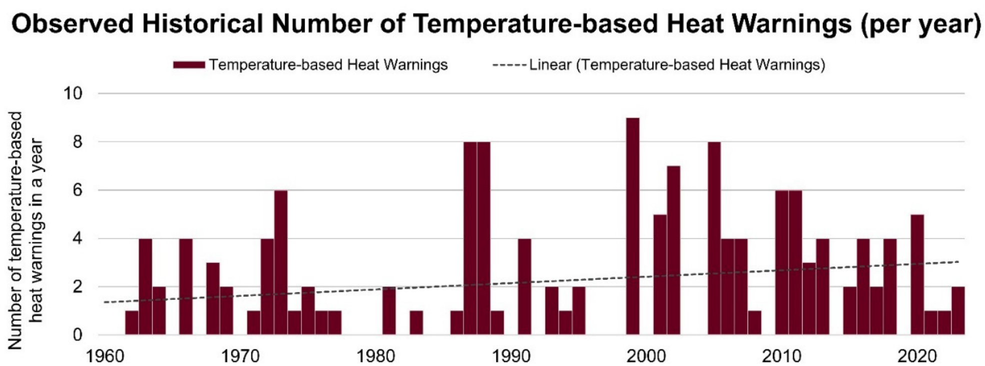


Figure 5. Observed historical temperature-based heat warnings in a year with two or more consecutive days with daytime maximum temperatures of 31°C or warmer, together with nighttime minimum temperatures of 20°C based on data from the Toronto City climate station. Source data: Historical Climate (Toronto City climate station)

3.2 The number of very hot days is on the rise

The number of very hot days in a year with daily maximum temperature above 30°C is also on the rise (Figure 4). Between 1961-1990, there used to be an average of 9.7 days with daily maximum temperature above 30°C in Toronto. In the most recent 1991-2020 period, the average number of very hot days has increased by approximately 4 days, reaching an average of 14 very hot days a year. Extreme heat puts everyone's health at risk, especially seniors, young children, people with pre-existing conditions, people with limited access to cooling, and people who must spend long hours outdoors.

In Southern Ontario, a heat warning is issued when there is a forecast of two or more consecutive days with daytime maximum temperatures of 31°C or warmer, together with nighttime minimum temperatures of 20°C or warmer, or when there is a forecast of two or more consecutive days with humidex values expected to reach 40 or higher (Ontario Ministry of Health, 2023). Using daily temperature records, the number of times in a year that conditions met the current temperature-based thresholds (excluding humidex[4]) for heat warnings has also been on the rise since 1960 (Figure 5)[5]. Between 1960 and 2023, the maximum length of a temperature-based heat event in Toronto was 8 days.

[4]Daily humidex records are currently unavailable, so humidity is not included.
[5]The criteria for issuing heat alerts and heat warnings have changed over time so this figure may not be reflective of historical records of heat alerts/warnings issued by the City.

3.3 The number of very cold days is declining

The number of very cold days with daily minimum temperature below -20°C has hovered around 2 to 3 days a year in the last few decades but has generally declined over the past 170+ years (Figure 6).

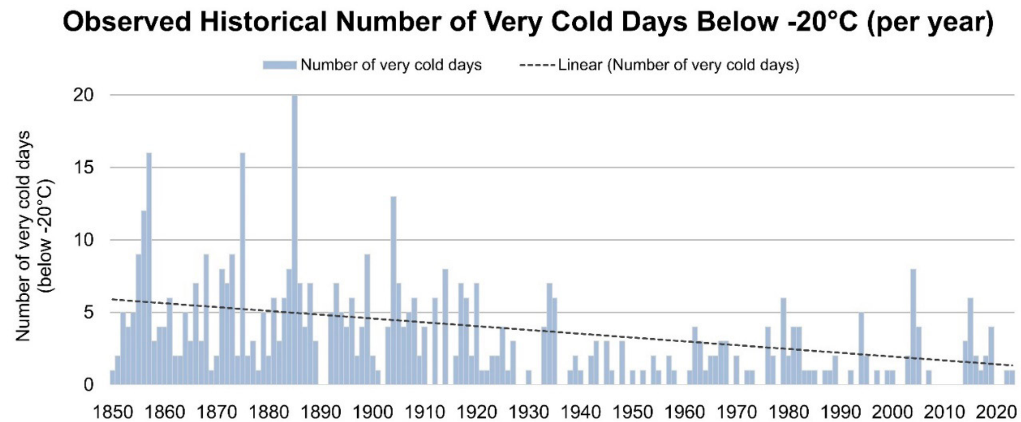


Figure 6. Observed historical number of very cold days in a year with daily minimum temperature below -20°C based on data from the Toronto City climate station. Source data: Historical Climate (Toronto City climate station)

3.4 Heating demand for buildings is declining, while cooling demand is rising

With Toronto's observed warming trends, heating demand for buildings is declining, while cooling demand is on the rise (Figure 7 and Figure 8). Daily average temperature below 18°C is commonly used as the temperature threshold for assessing space heating demand in Canada (MacDonald et al., 2023; Boyd, 1979). Conversely, daily average temperature above 18°C is commonly used as the temperature threshold for assessing space cooling demand. Total heating demand in a year can be characterized by the temperature difference that is accumulated daily when average temperature is below 18°C, known as "heating degree days (or HDDs)". Heating degree days for a single day represents the number of degrees Celsius that the mean temperature is below 18°C. This difference is added over a year for annual heating degree days. Meanwhile, total cooling demand in a year can be characterized by the temperature difference that is accumulated daily when average temperature is above 18°C, known as "cooling degree days (or CDDs)". Since mean air temperature does not account for humidity, cooling degree days likely underestimates the energy demand for cooling.

In 1991-2020, heating demand decreased by 5.8% compared to 1961-1990, while cooling demand increased by 17.3% over the same period.

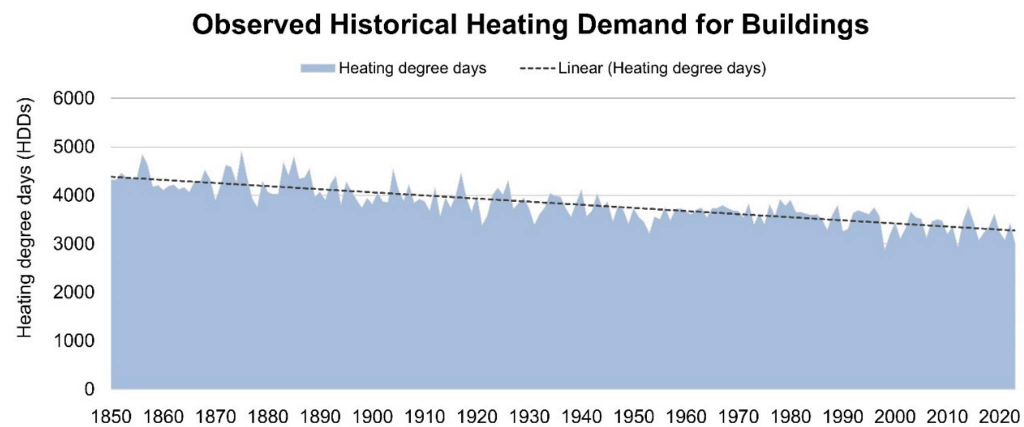


Figure 7. Observed historical heating degree days (i.e., temperature difference that is accumulated daily when mean temperature is below 18°C) based on data from the Toronto City climate station. Source data: Historical Climate (Toronto City climate station)

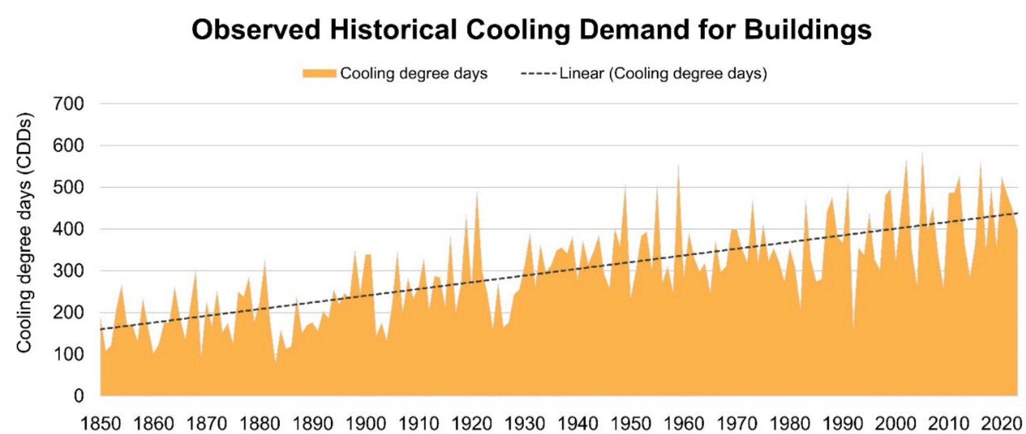


Figure 8. Observed historical cooling degree days (i.e., temperature difference that is accumulated daily when mean temperature is above 18°C) based on data from the Toronto City climate station. Source data: Historical Climate (Toronto City climate station)

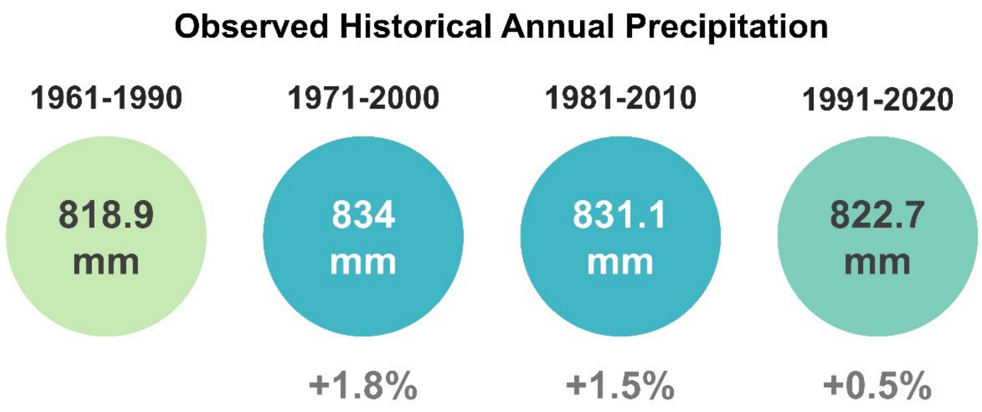


Figure 9. Comparing historical annual total precipitation over four 30-year climate normal periods (1961-1990, 1971-2000, 1981-2010, and 1991-2020). Source data: Canadian Climate Normals (Toronto City climate station)

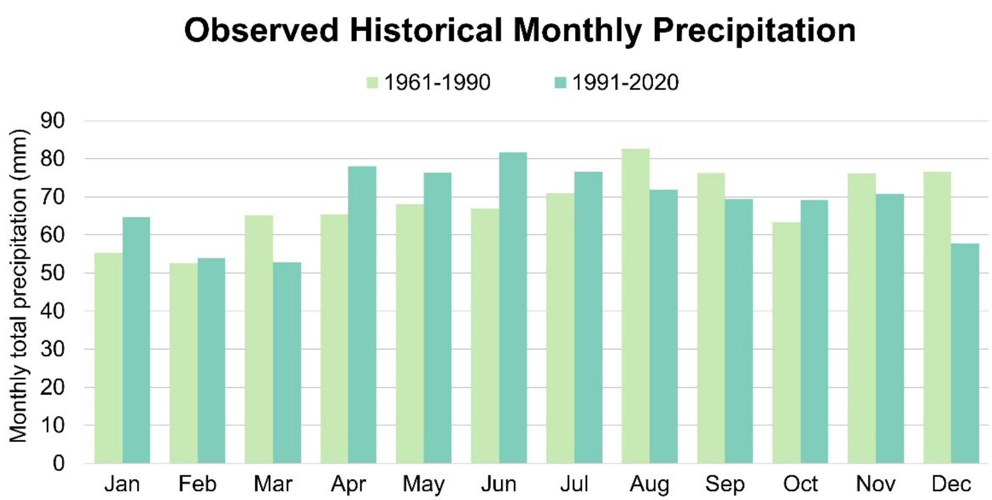


Figure 10. Comparing historical monthly total precipitation between two 30-year climate normal periods (1961-1990 and 1991-2020). Source data: Canadian Climate Normals (Toronto City climate station)

3.5 Precipitation is increasing, but patterns remain variable

Overall, Toronto is also getting wetter, but precipitation can be highly variable (Figure 9). In 1961-1990, annual total precipitation as recorded in downtown Toronto was around 819 mm. This total increased slightly by 0.5% in the most recent 1991-2020 climate normal period compared to 1961-1990. In contrast, annual total precipitation increased by 1.8% and 1.5% in 1971-2000 and 1981-2010, respectively, compared to 1961-1990. However, it is important to note that precipitation can be highly localized, so these precipitation records may not be representative of the entire city.

As illustrated in the Introduction, short-duration intense storms are also increasing in Toronto. In the last 20 years, Toronto has seen at least four intense storm events (August 2005, July 2013, August 2018, and July 2024) that have exceeded the 100-year storm in parts of the city, which historically has a 1% chance of occurring in any given year.

Observed changes in precipitation vary between months – some months have seen more precipitation than before, while others have seen less (Figure 10). Between 1961-1990 and 1991-2020, June precipitation has increased the most (by +21.8%), followed by April (+19.3%) and January (+17%). Meanwhile, December precipitation has decreased the most (by -24.4%) over the same period, followed by March (-19%) and August (-12.9%).

With warmer temperatures, the share of annual precipitation falling as snow has been declining since 1850, with more precipitation falling as rain. On average, the proportion of total precipitation falling as snow has been declining by 0.2% per decade between the 1850s and 1990s[6].

[6] *Daily total rain and snow records were not available from 2003 onwards for the Toronto City climate station.*

3.6 Lake Ontario is losing ice cover, with warmer water temperature and fluctuating lake levels

Not only is snow cover decreasing in Toronto, ice cover over Lake Ontario has also been declining since the 1970s (Figure 11). On average, annual maximum ice cover has decreased by approximately 3.5% per decade between the 1970s and 2010s.

The surface water temperature of Lake Ontario (as derived from satellite imagery) has also been warming rapidly since the 1990s (Figure 12). Recent years have seen the warmest surface water temperatures in Lake Ontario since the 1990s, with 2012 in the top spot, followed by 2016, 2021, 2023, and 2020.

While Lake Ontario water levels fluctuate naturally, recent years saw some of the highest annual average lake levels ever recorded in Lake Ontario, which caused extensive flooding, erosion, and damage to Toronto's shorelines and Toronto Island Park (see Introduction).

The measured historical data tells a clear story of how Toronto's climate is already getting warmer, wetter, and wilder. Climate and extreme weather-related impacts have already been felt in Toronto (as discussed in the Introduction), and these impacts will likely grow larger if global warming continues. In the next chapter, we will explore what Toronto's future climate could look like under two illustrative climate scenarios: a medium and very high emissions scenario.

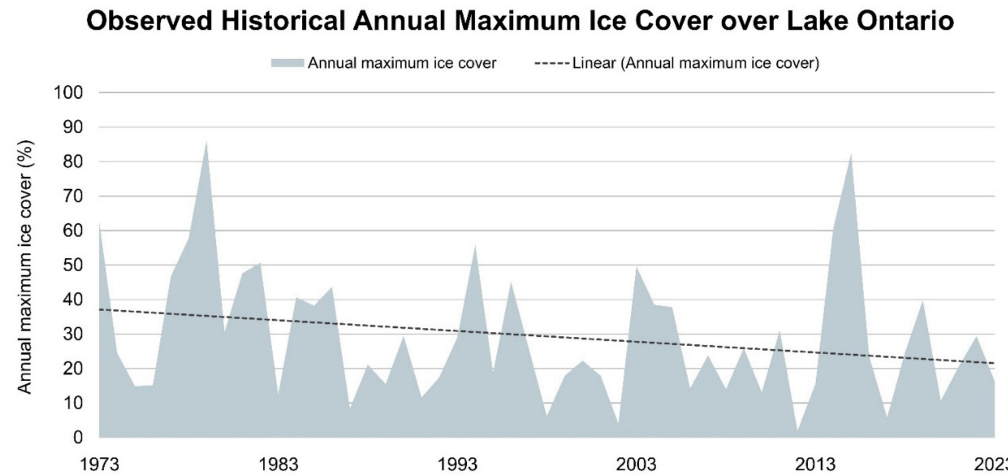


Figure 11. Observed historical annual maximum ice cover (%) over Lake Ontario. Source data: NOAA Great Lakes Environmental Research Laboratory (Lake Ontario)

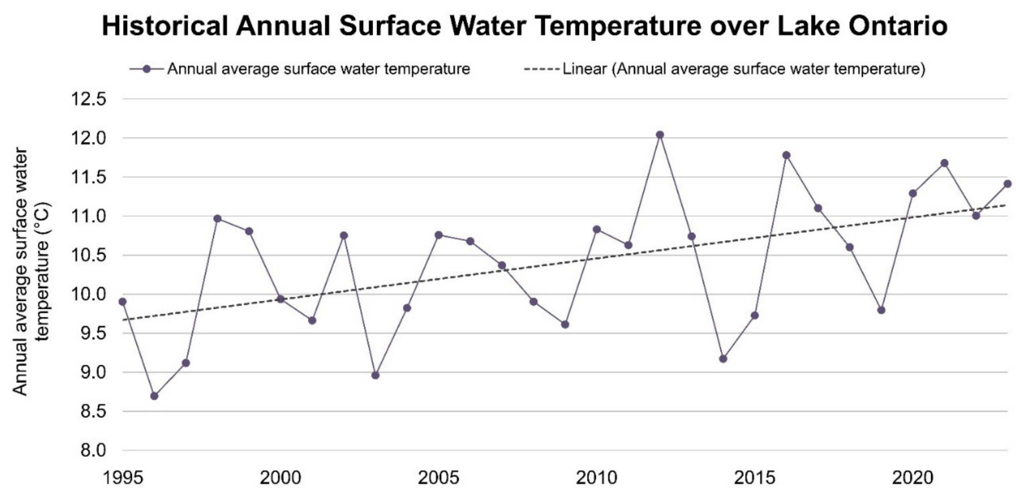


Figure 12. Estimated historical annual average surface water temperature over Lake Ontario. Source data: NOAA Great Lakes Surface Environmental Analysis (Lake Ontario)

4. What Toronto's future climate could look like

Using two climate scenarios, 54 modelled climate variables, and a rapid literature review, this study looks at what Toronto's future climate could look like over the course of this century. Overall, temperature and extreme heat variables are expected to increase under both climate scenarios. Extreme cold is expected to decrease, along with heating demand for buildings. Meanwhile, cooling demand for buildings is expected to increase.

Annual precipitation and extreme precipitation are anticipated to increase under both scenarios. Winter precipitation is anticipated to increase under the medium emissions scenario, while it may vary under the very high emissions scenario. Spring, summer, and fall precipitation are anticipated to vary under the medium emissions scenario, while these are anticipated to increase under the very high emissions scenario (except summer precipitation, which is anticipated to vary). The total number of dry days in a year is expected to increase under both scenarios and dry conditions are also anticipated to last longer.

With warmer temperatures anticipated, the frost-free season is expected to stretch over a longer period under both scenarios, starting earlier and ending later. The amount of heat available to support the growth of different crops is anticipated to increase under both scenarios, but an increased risk of pests is also anticipated.

Annual freeze-thaw cycles are anticipated to decrease under both scenarios. Meanwhile, the number of days with freezing rain potential is anticipated to remain about the same under both scenarios, with a slight increase anticipated under the medium emissions scenario and a mixed pattern anticipated under the very high emissions scenario.

Figure 13 presents some key indicators and overall projected trends for Toronto. A 'variable' trend indicates that there is a mix of increases and decreases in the data across the future periods.

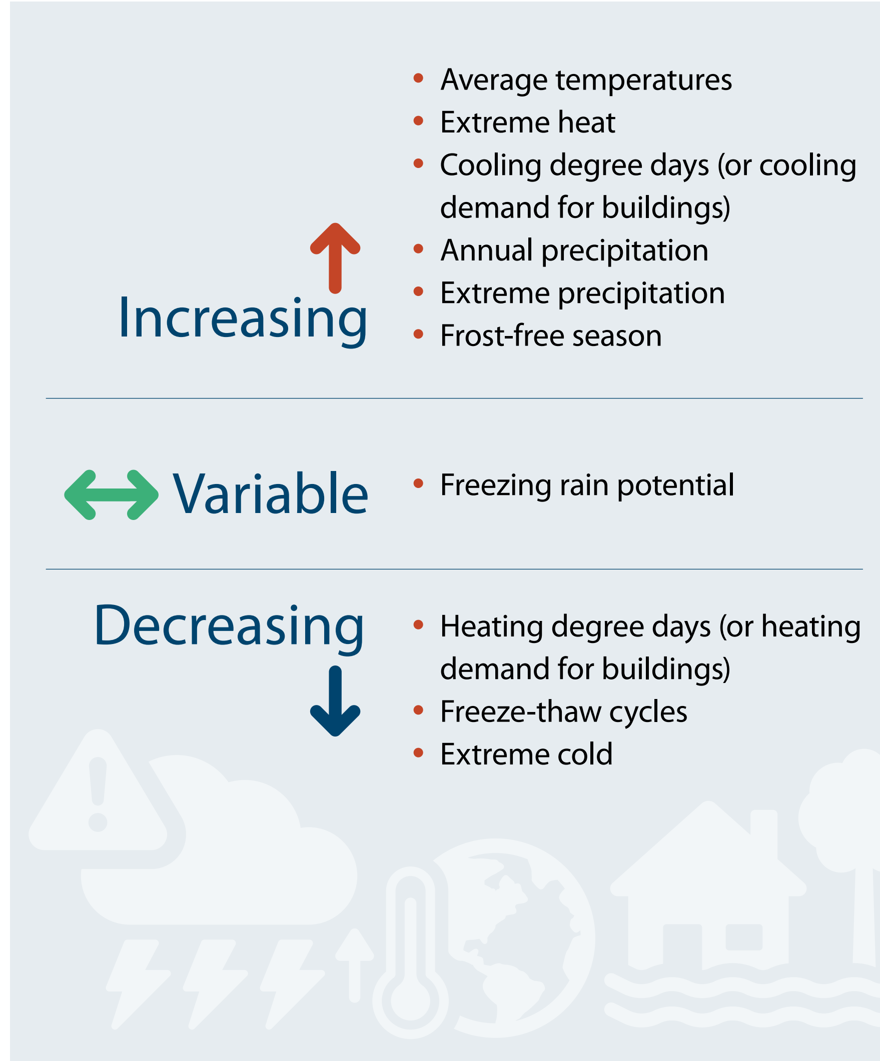


Figure 13. High-level summary of overall future climate trends for Toronto, under a medium and very high emissions scenario

The following sections (4.1 to 4.7) describe some of these anticipated changes in greater detail, with more focus on the very high emissions scenario. Based on current global emissions and countries' emissions reduction targets collectively, we are currently tracking in between the medium and very high emissions scenarios (UNEP, 2024; IPCC, 2023; IEA, 2023). In the short and medium-term future, the two scenarios are anticipated to lead to similar levels of global warming. By the end of the century, the two scenarios diverge significantly, with a difference of nearly 2°C. Understanding the very high emissions scenario can help inform risk-based planning and help the City, residents, and businesses prepare for more devastating impacts if they were to occur. This is also consistent with how other jurisdictions present scenarios in preparing for climate change. By highlighting the very high emissions scenario, we also hope to inspire urgent and collective action to avoid higher levels of warming, while shaping the future that we want.

For detailed data tables for all 54 variables for both emissions scenarios, please see Appendix A and the accompanying climate projection dataset. Climate trends for a selection of additional climate variables are also presented based on a rapid literature review, including projections for Lake Ontario, infrastructure design values, and other climate variables such as thunderstorms and wind (sections 4.8 to 4.10).

4.1 Temperatures are expected to continue to rise over the course of the century

Temperature is a direct indicator of climate change as a result of the rise in GHG concentrations from human activities (WMO, n.d.). Changes in temperature affect agriculture, infrastructure, people's health, water availability, energy use, recreation, and ecosystem health (ECCC, 2024a; ClimateData.ca, 2024).

As the observed data shows, Toronto's annual average temperature has gotten warmer, with an increase in the number of warmer- than-average years in recent decades (Figure 14). Since 1980, each decade has been warmer than the last. This warming trend is expected to continue over the course of this century under both climate scenarios.

In the 2030s period, Toronto is anticipated to see similar warming trends under both scenarios. By the 2050s, Toronto is expected to warm slightly more under the very high emissions scenario compared to the medium emissions scenario. However, by the end of the century, the temperature differences between the two scenarios grow larger – leading to a future Toronto that may be +4°C warmer or +6°C warmer by the end of the century. While the difference may seem small, every additional increase in average temperature can lead to more extreme weather events (Seneviratne et al., 2021). Therefore, what Toronto's future climate will look like depends on the choices we make now.

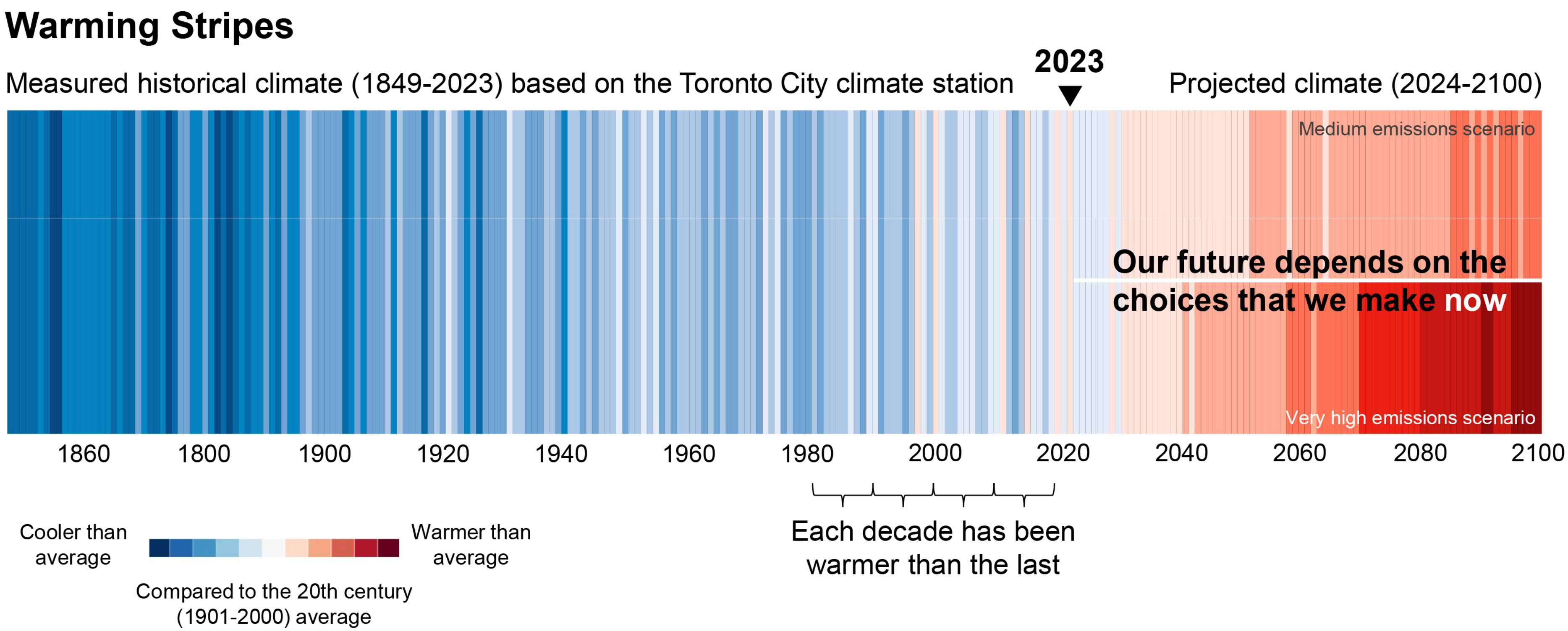


Figure 14. Warming stripes showing measured historical annual average temperature (1849-2023) based on the Toronto City climate station and projected annual average temperature (2024-2100) under the medium emissions (SSP2-4.5) and very high emissions scenarios (SSP5-8.5). Each bar shows the difference in annual average temperature for each year compared to the average temperature over the 20th century (1901-2000). Warmer than average years are represented by red stripes and cooler years are represented by blue stripes. The darker the stripe colour, the greater the difference from the 20th century average.

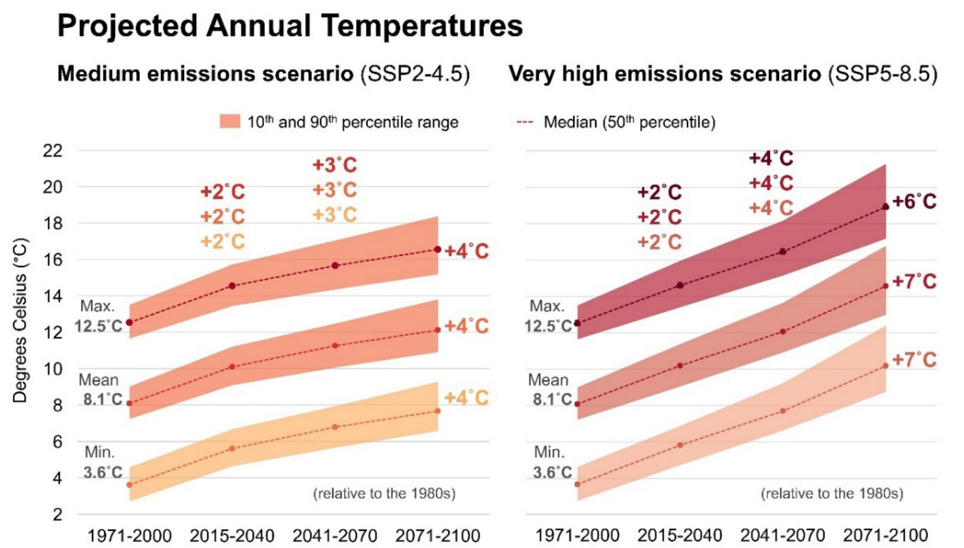


Figure 15. Projected annual temperatures (maximum, mean, and minimum) under the medium emissions (SSP2-4.5) and very high emissions scenarios (SSP5-8.5), with differences in median values compared to 1971-2000 (modelled historical)

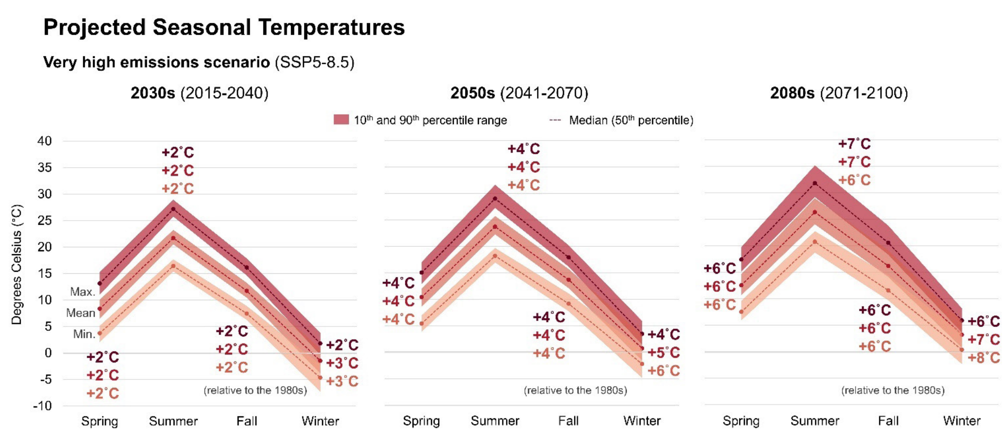


Figure 16. Projected seasonal temperatures (maximum, mean, and minimum) under the very high emissions scenario (SSP5-8.5), with differences in median values compared to 1971-2000 (modelled historical)

Annual maximum and minimum temperatures are also expected to increase by the 2030s, 2050s, and 2080s compared to the 1980s (Figure 15).

Seasonal temperatures are also expected to increase under both scenarios. Warmer maximum, mean, and minimum temperatures are expected across all seasons, bringing hotter summers, warmer winters, and greater variability in temperatures (e.g., Figure 16). Winter temperatures are expected to increase the most compared to the 1980s, with greater increases in winter mean and minimum temperatures. This may in turn influence energy management, recreation, agriculture, infrastructure, the spread of pests and diseases, water availability, and ecosystem health (ECCC, 2024a; Agriculture and Agri-Food Canada, 2020).

4.2 Extreme heat is expected to become more frequent, intense, and last longer, increasing the risk of heat-related illnesses and deaths

Extreme heat puts everyone's health at risk, especially seniors, young children, people with pre-existing conditions, people with limited access to cooling, and people who must spend long hours outdoors (World Health Organization [WHO], 2024; Health Canada, 2024). It can pose a risk to our built infrastructure such as buildings, transportation systems, and energy systems, depending on their design parameters (ClimateData.ca, 2024). Extreme heat also poses a threat to plants and animals that are not adapted to the heat or require stable temperature conditions.

Under both scenarios, the number of very hot days with daily maximum temperature above 30°C and 35°C is anticipated to increase. Greater increases are anticipated under the very high emissions scenario compared to the medium emissions scenario. Under the very high emissions scenario, days above 30°C could increase by more than two months' time by the end of the century compared to the 1980s (Figure 17). The number of days with high humidity is also anticipated to increase, bringing more uncomfortable and dangerously hot conditions.

Under both scenarios, extreme heat events (i.e., two or more days with maximum temperature ≥ 31°C and nighttime temperature ≥ 20°C) are expected to occur more frequently and last longer. More frequent and intense extreme heat events are expected under the very high emissions scenario compared to the medium emissions scenario, putting people at greater risk of heat-related illnesses and deaths (Figure 18).

On average, the temperature on the hottest day in a year in the 1980s used to be around 33°C. By the end of the century, hottest day temperature could increase by 4-7°C, reaching a sweltering 37°C and 40°C under the medium and very high emissions scenario, respectively.

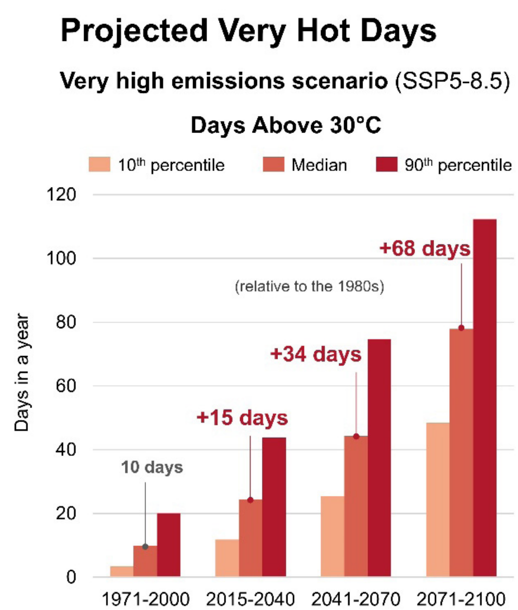


Figure 17. Projected number of very hot days with daily maximum temperature above 30°C under the very high emissions scenario (SSP5-8.5), with differences in median values compared to 1971-2000 (modelled historical)

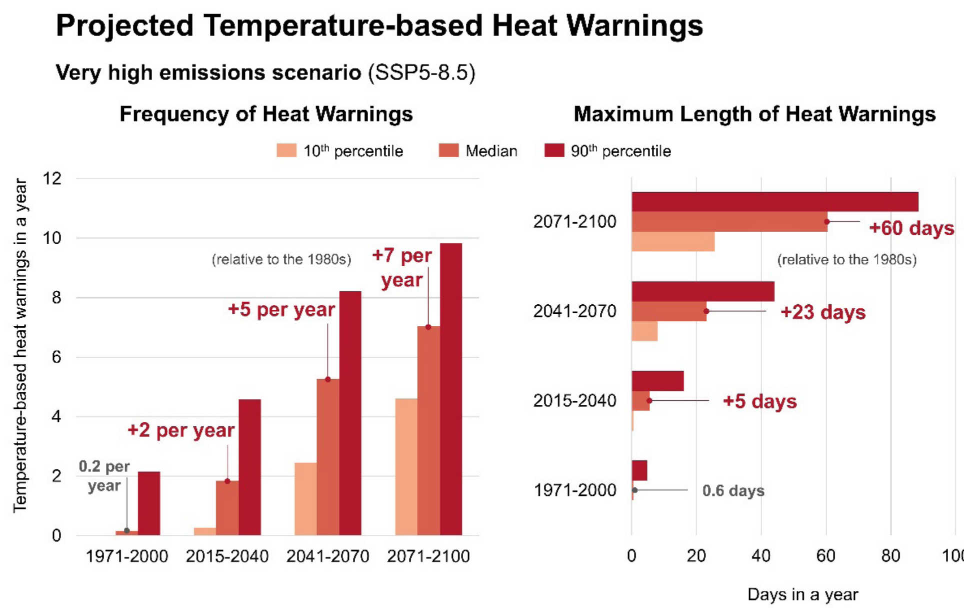


Figure 18. Projected number of temperature-based heat warnings[7] in a year (left) and maximum consecutive temperature-based heat warning days (right) under the very high emissions scenario (SSP5-8.5), with differences in median values compared to 1971-2000 (modelled historical)

[7] This is based on current temperature thresholds for issuing a heat warning in Southern Ontario and does not include humidity. Humidex projections are presented separately as projections that combine temperature and humidex are currently unavailable.

4.3 Cold weather days are expected to continue to decrease as winters get warmer

Cold weather conditions can directly impact people's health, especially seniors, young children, people with pre-existing conditions, people who must spend long hours outdoors, and people with limited access to electricity or heat (Toronto Public Health, 2024; Health Canada, 2018). Extreme low temperatures and temperature fluctuations between freezing and non-freezing temperatures can pose a risk to our built infrastructure, depending on their design parameters (ClimateData.ca, 2024). Extreme cold also poses a threat to plants and animals that are not adapted to the cold or require stable temperature conditions.

Under both scenarios, the number of frost days (below 0°C), cold days (below -10°C), and very cold days (below -20°C) is expected to decrease as temperatures continue to rise. A greater decline in these cold weather days is anticipated under the very high emissions scenario compared to the medium emissions scenario. For example, under the very high emissions scenario, the number of frost days could decrease by nearly a months' time by the 2030s, nearly two months' time by the 2050s, and nearly three months' time by the 2080s compared to the 1980s (Figure 19). Meanwhile, the number of very cold days (below -20°C) is expected to become increasingly rare by the 2030s, 2050s, and 2080s compared to the 1980s – decreasing from 3 days to nearly 0 days a year.

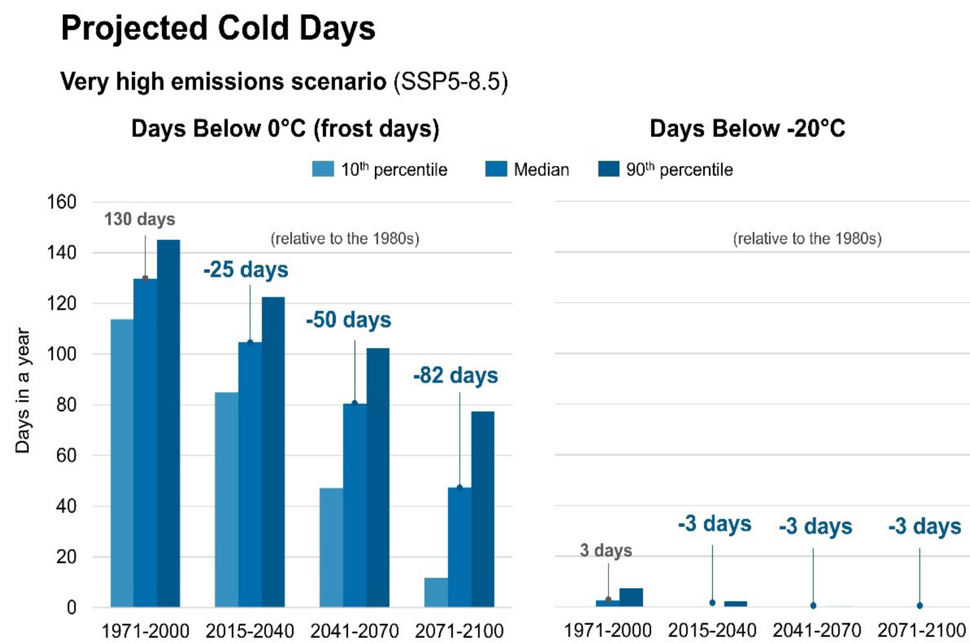


Figure 19. Projected number of cold days with daily minimum temperature below 0°C and -20°C under the very high emissions scenario (SSP5-8.5), with differences in median values compared to 1971-2000 (modelled historical)

Projected Heating and Cooling Demands

Medium emissions scenario (SSP2-4.5)

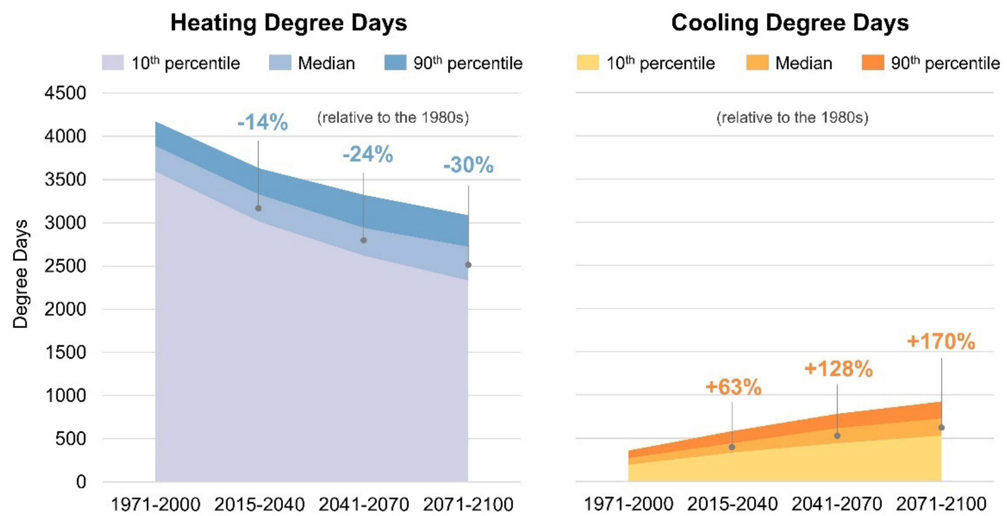


Figure 20. Projected changes in heating and cooling degree days[8] under the medium emissions scenario (SSP2-4.5), with percentage differences in median values compared to 1971-2000 (modelled historical)

Very high emissions scenario (SSP5-8.5)

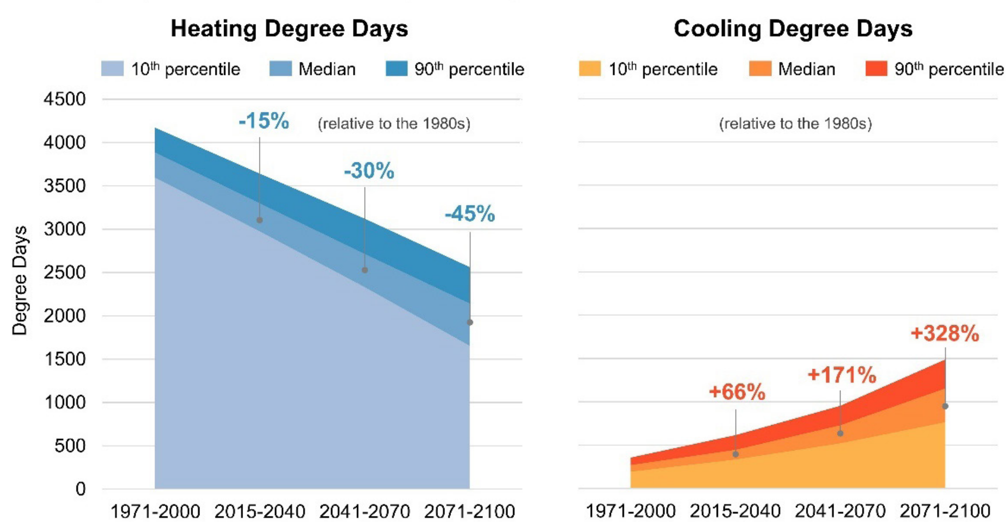


Figure 21. Projected changes in heating and cooling degree days under the very high emissions scenario (SSP5-8.5), with percentage differences in median values compared to 1971-2000 (modelled historical)

4.4 Heating demand for buildings is expected to continue to decrease, while cooling demand is expected to increase significantly

Under both climate scenarios, heating demand for buildings is expected to decrease, while cooling demand is expected to increase (Figure 20 and Figure 21). By the end of the century, heating demand may decrease by 30-45% compared to the 1980s, while cooling demand may nearly triple or more than quadruple compared to the 1980s, depending on the climate scenario.

[8] "Degree days" represents the difference in daily mean temperature that is accumulated above or below a specified base temperature. Daily mean temperature below 18°C is commonly used as the temperature threshold for assessing space heating demand in Canada. Conversely, daily average temperature above 18°C is commonly used for assessing space cooling demand. The cooling degree days for a single day represents the number of degrees Celsius that the mean temperature is above 18°C, and this difference is added over a year for annual cooling degree days. Since mean air temperature does not account for humidity, cooling degree days likely underestimates the energy demand for cooling.

4.5 Precipitation is expected to continue to increase overall, with wetter and drier conditions possible

Precipitation is a fundamental aspect of the climate and a key indicator of how human-induced climate change is affecting the Earth's water cycle (WMO, 2024b). Changes in precipitation affect agriculture, infrastructure, people's health, water availability, recreation, and ecosystem health (ClimateData.ca, 2024).

Annual total precipitation has generally increased in Toronto, but some years have seen drier-than-average conditions as well (Figure 22). Overall, precipitation is expected to increase under both climate scenarios, with greater increases in wetter-than-average conditions anticipated under the very high emissions scenario compared to the medium emissions scenario.

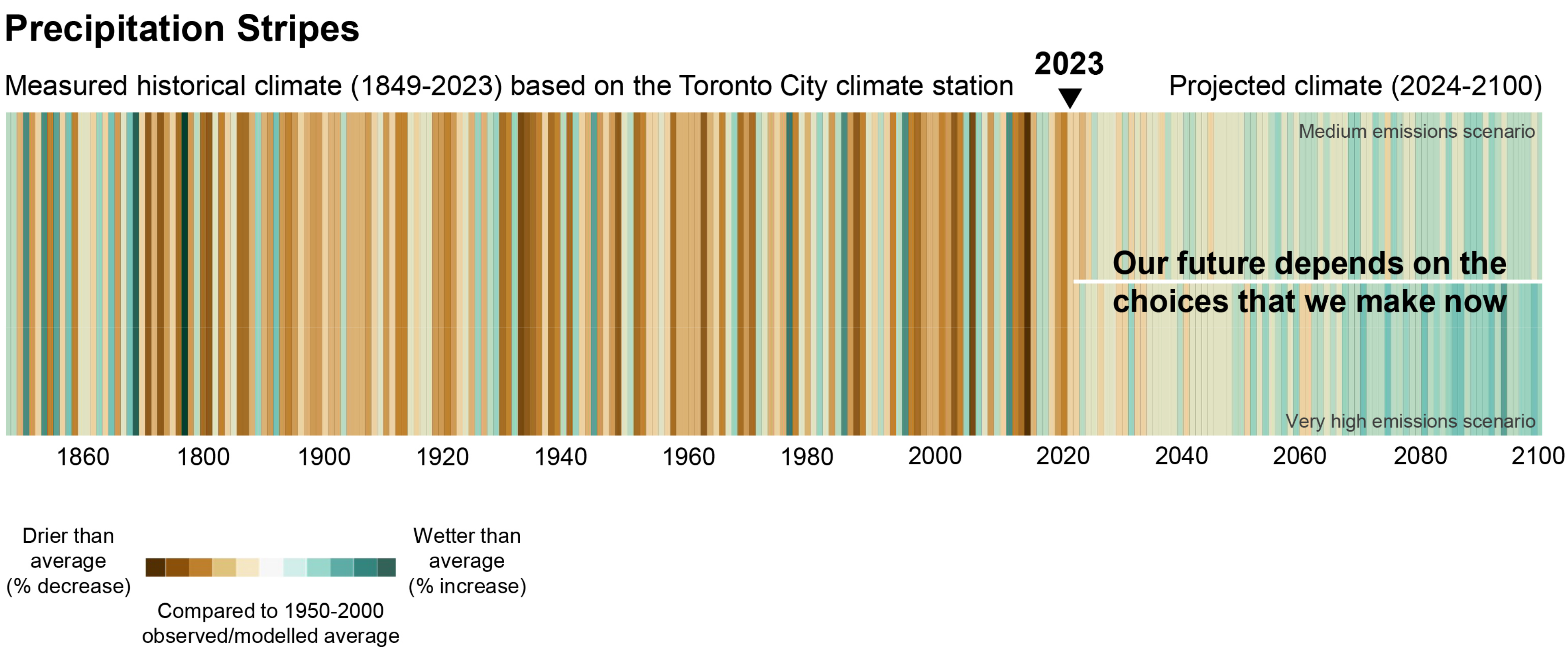


Figure 22. Precipitation stripes showing changes in measured historical annual total precipitation (1849-2023) based on data from the Toronto City climate station and projected annual total precipitation (2024-2100) under the medium emissions (SSP2-4.5) and very high emissions scenarios (SSP5-8.5). Each bar shows the percentage increase or decrease in annual total precipitation for each year compared to the average precipitation between 1950-2000. Measured historical precipitation (1849-2023) is compared to the observed average, while projected future precipitation (2024-2100) is compared to the modelled historical average. Wetter than average conditions are represented by green stripes and drier than average conditions are represented by brown stripes. The darker the stripe colour, the greater the difference from the 1950-2000 average (observed/modelled).

Under both scenarios, annual total precipitation is anticipated to increase by the 2030s, 2050s, and 2080s compared to the 1980s (Figure 23). By the 2030s and 2050s, annual total precipitation is anticipated to see similar increases under both scenarios, increasing by 5-6% by the 2030s and 10% by the 2050s compared to the 1980s. By the 2080s, annual total precipitation is expected to increase by approximately 11% under the medium emissions scenario and 16% under the very high emissions scenario compared to the 1980s.

Under both scenarios, seasonal total precipitation is generally anticipated to increase (e.g., Figure 24). Under the very high emissions scenario, the range in precipitation (i.e., 10th and 90th percentile) increases by the end of the century, making wetter- and drier-than-average conditions possible in any given year. Winter total precipitation is anticipated to increase the most under both scenarios, followed by spring precipitation. As more precipitation is expected to fall as rain instead of snow, more rain may fall on frozen ground during winter and spring, which may in turn lead to increased flooding and ice jams (TRCA Flood Risk Management, 2024).

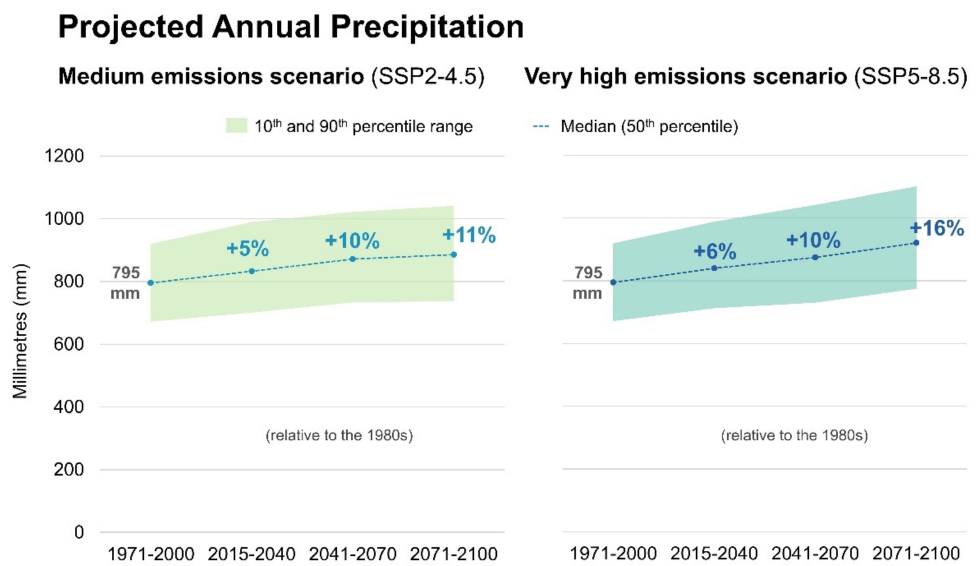


Figure 23. Projected annual total precipitation under the medium emissions scenario (SSP2-4.5) and very high emissions scenario (SSP5-8.5), with percentage differences in median values compared to 1971-2000 (modelled historical)

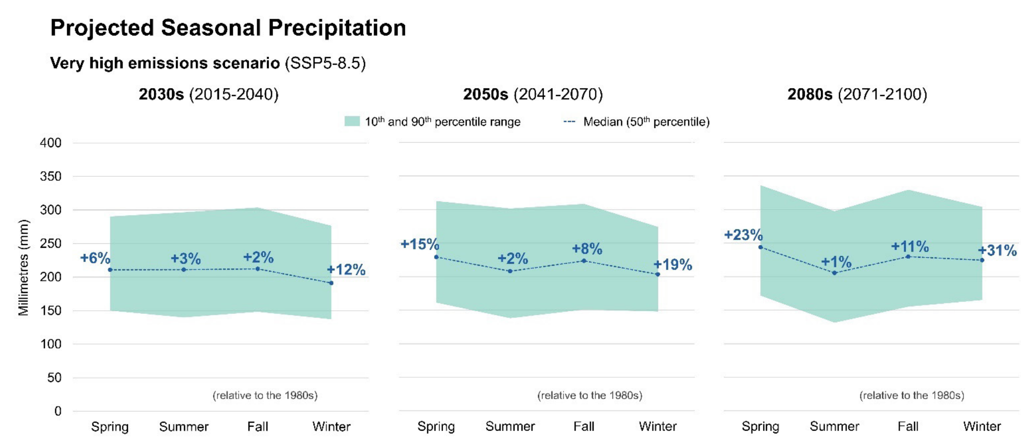


Figure 24. Projected seasonal total precipitation under the very high emissions scenario (SSP5-8.5), with median temperature differences compared to 1971-2000 (modelled historical)

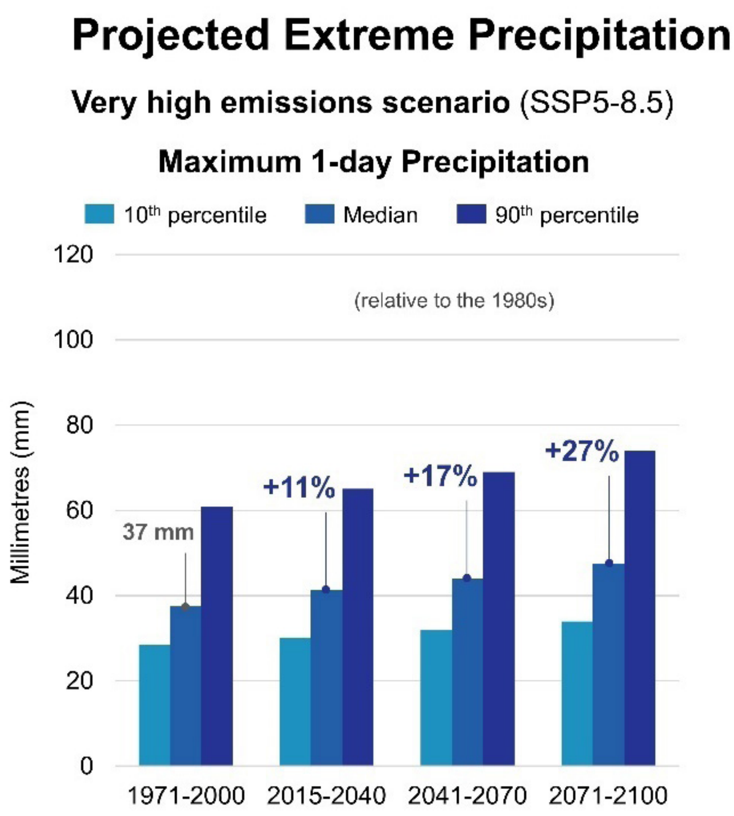


Figure 25. Projected maximum 1-day precipitation under the very high emissions scenario (SSP5-8.5), with percentage differences in median values compared to 1971-2000 (modelled historical)

Extreme precipitation is also anticipated to increase under both climate scenarios. Greater increases are anticipated under the very high emissions scenario, especially by the end of the century. For example, under the very high emissions scenario, the maximum amount of precipitation that would typically fall in a day may increase by 11% by the 2030s, 17% by the 2050s, and 27% by the 2080s compared to the 1980s (Figure 25).

At the high end (i.e., 90th percentile), days with more than a month's worth of precipitation (currently around 68 mm) falling in a day are expected to become more common. In the past two decades, Toronto has experienced several major storms that have exceeded this value and the 100-year storm, which has a 1% chance of occurring in any given year based on historical conditions. With increasing precipitation, what used to be a 1-in-100 year storm can be expected to occur more frequently as suggested by climate-adjusted intensity-duration-frequency (IDF) curves (section 4.9).

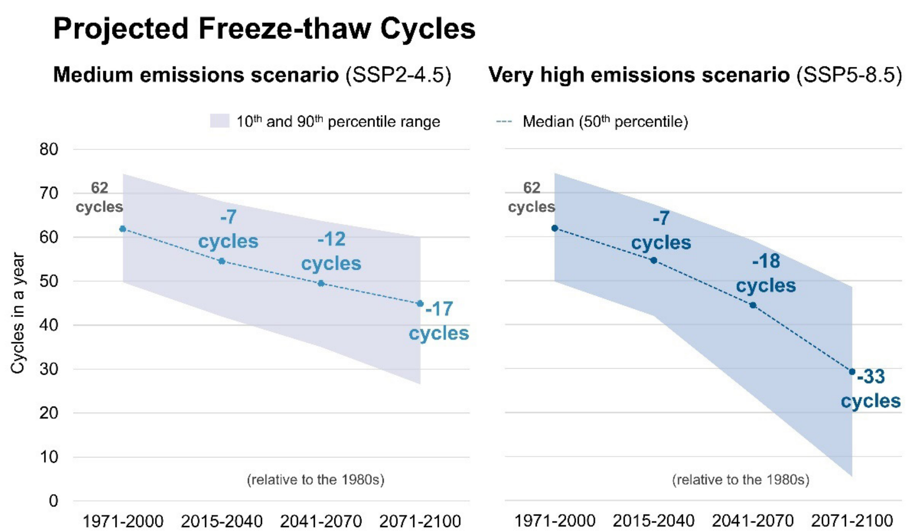


Figure 26. Projected freeze-thaw cycles under the medium emissions scenario (SSP2-4.5) and very high emissions scenario (SSP5-8.5), with differences in median values compared to 1971-2000 (modelled historical)

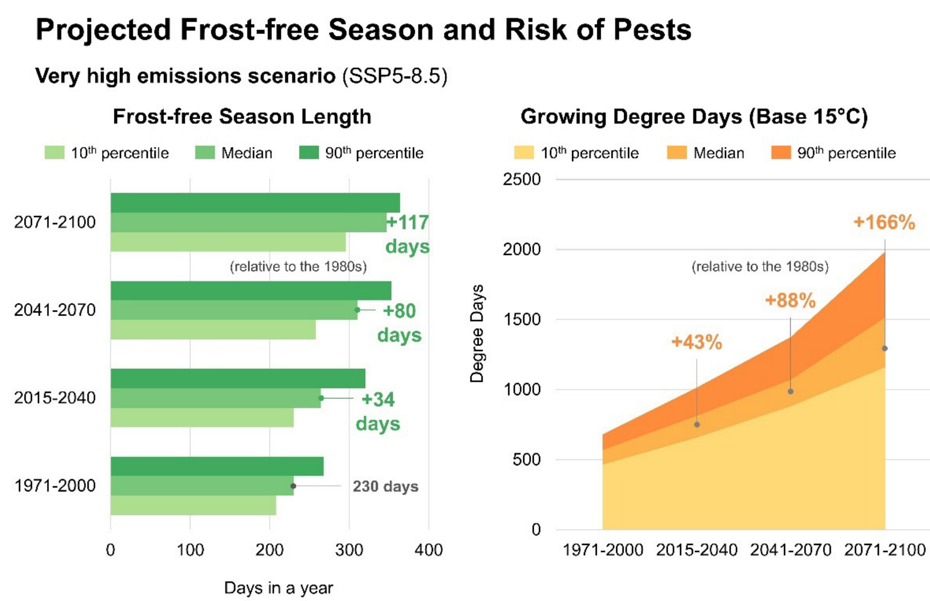


Figure 27. Projected frost-free season length (left) and growing degree days with base temperature of 15°C (right) under the very high emissions scenario (SSP5-8.5), with differences in median values compared to 1971-2000 (modelled historical)

4.6 Freeze-thaw cycles are expected to decrease, while days with freezing rain potential are expected to remain about the same

Freeze-thaw cycles can have major impacts on infrastructure (ClimateData.ca, 2024). Water expands when it freezes, so the freezing, melting and re-freezing of water can cause significant damage to roadways, sidewalks, and other outdoor structures over time. Under both scenarios, the number of freeze-thaw cycles in a year is anticipated to decrease as winters are expected to get warmer (Figure 26). A shorter winter season may also lead to more freeze-thaw cycles occurring over a shorter period of time (i.e., become more concentrated).

Freezing rain can create slippery road conditions that endanger people's health and safety (Ouranos, 2024; Public Safety Canada, 2011). It can also affect infrastructure, recreation, and ecosystem health. The median number of days with freezing rain potential is expected to remain about the same (at approximately 2-3 days) under both scenarios, but this may vary widely year-to-year. However, temperature is only one of many factors that influence the production of freezing rain. One study by McCray and others (2022) found that the frequency of freezing rain may increase over parts of western and central Canada under the high emissions scenario (RCP8.5; as noted in section 4.10).

4.7 The frost-free season is expected to become longer, but may also be accompanied by a growing risk of pests

Changes in the length and timing of the growing season affect agriculture, energy use, recreation, and ecosystem health, which can affect daily life in Toronto (ClimateData.ca, 2024; Agriculture and Agri-Food Canada, 2020). Under both scenarios, the length of the frost-free season is expected to become longer, with the transition from colder to warmer weather expected to start earlier and the transition back to colder weather expected to start later in a year (e.g., Figure 27). Under the very high emissions scenario, the length of the frost-free season may increase by 117 days by the end of the century compared to the 1980s. While an extended warm-weather period is expected to benefit agricultural production, it also creates conditions that are more favourable for the growth and spread of insects and pests, which can harm agriculture and natural ecosystems.

4.8 Anticipated changes for Lake Ontario will also affect Toronto

As Toronto is situated on the northern shores of Lake Ontario, changes in the climate over Lake Ontario and its hydrology can have a significant impact on the city. Throughout the year, Lake Ontario moderates temperature in its vicinity (Wuebbles et al., 2019), helping to keep Toronto cool in the summer and warm in the winter.

The following trends are based on available projections under the medium (RCP4.5) and high emissions scenarios (RCP8.5), which are comparable to SSP2-4.5 and SSP5-8.5, respectively. More detailed summary tables of the projected values are available in Appendix A3.

Under the medium and high emissions scenarios, over-land air temperature around Lake Ontario is expected to increase by the late century (Lam and Dokoska, 2022). Annual average lake levels are also expected to increase under both scenarios, with more extreme high and extreme low lake levels possible. Under the high emissions scenario, annual and seasonal over-lake precipitation are expected to increase, while ice cover and ice season length are expected to decrease. Winter over-lake precipitation is also anticipated to increase under the medium emissions scenario but otherwise, over-lake precipitation is anticipated to vary under this scenario.

4.9 Climate-adjusted infrastructure design values indicate increasing pressures on existing and new infrastructure

Climate-adjusted infrastructure design values have been developed by the Pacific Climate Impacts Consortium (PCIC) in collaboration with ECCC and the National Research Council (NRC). Using the online Design Value Explorer tool (version 2.4.0), available historical and projected future design values for the Toronto City Hall location were obtained including design temperature, humidity, precipitation loads, and wind loads. These projections can help inform infrastructure planning and design under a changing climate based on different levels of global mean temperature change, or global warming levels (GWLs).

With each 0.5°C increase in global warming, various design values are anticipated to increase, including July (hot weather) design temperatures, rainfall loads, humidity, and most wind loads (except driving rain wind pressures, which is expected to vary). Meanwhile, January (cold weather) design temperatures and snow loads are expected to decrease as global warming continues. More detailed summary tables of the projected values can be found in Appendix A3.

Precipitation intensity-duration-frequency (IDF) curves also provide important information for the planning and design of infrastructure and stormwater management. Various climate-adjusted IDF curves are available for Ontario and Canada. Here, available historical and projected IDF curves from Western University's IDF_CC tool (version 7.5) and from ClimateData.ca (version 3.30) were retrieved for the Toronto City gauge. Cilmate-adjusted IDF curves are derived using different methods, which enable helpful comparison:

- Precipitation fitted to the Generalized Extreme Value (GEV) distribution was retrieved from the IDF_CC tool[9]; and
- Precipitation intensity scaled based on temperature (or the Clausius-Clapeyron relation) was retrieved from ClimateData.ca, whereby precipitation intensity is anticipated to increase by 7% for every 1°C of temperature increase.

Both sets of climate-adjusted IDF curves indicate an increase in precipitation intensity rates across all short-duration rainfall under both climate scenarios. With more rain anticipated to fall over a short period, total precipitation (or rainfall depth) is also anticipated to increase, amplifying the risk of flooding and erosion.

[9] *Precipitation fitted to the Gumbel distribution is also available through the IDF_CC tool (version 7.5).*

4.10 Thunderstorms and other variables are also anticipated to change, bringing more variable and extreme weather

Drawing on available academic articles, this section summarizes some high-level trends for future thunderstorms, wind, snow, rain-on-snow, freezing rain, joint precipitation and temperature extremes, and fire spread. Studies have focused on various climate scenarios and geographic scales. Here, we highlight findings that may be most relevant for Toronto.

Thunderstorms

The number of days with conditions favourable for thunderstorms in Southern Ontario is expected to increase under the high emissions scenario (RCP8.5; Huryn et al., 2020). The risk of thunderstorms could as much as triple over the year and during the summer over the course of the century. While thunderstorms commonly form during warmer months, another study also found that fall, spring, and winter are expected to see an increase in favourable conditions for thunderstorms over North America (Canada and U.S.; Lepore et al., 2021).

Wind

Mean wind speed over northern and eastern parts of Canada is expected to increase under the medium (RCP4.5) and high emissions scenarios (RCP8.5; Jeong and Sushama, 2019). Some increases in the future 50-year return levels of 3-hourly wind speed and hourly wind gust are also anticipated over North America under both scenarios.

The frequency of extreme stagnant winds is anticipated to increase over the eastern Great Lakes under the high emissions scenario (RCP8.5; Morris et al., 2024). Meanwhile, changes in high wind speeds over the eastern Great Lakes vary under the high emissions scenario (RCP8.5) depending on model resolution.

Future driving rain wind pressure (DRWP) with a 5-year return period are projected to increase over western, eastern, and northern Canada under the high emissions scenario (RCP8.5; Jeong et al., 2020), though this is anticipated to vary for the Toronto City Hall location based on PCIC's Design Value Explorer tool (as noted in section 4.9).

One study that simulated wind loads on high-rise buildings in Toronto did not find substantial changes in mean design wind speed with a 50-year return period under the medium (RCP4.5) and high emissions scenarios (RCP8.5) but noted that the risk of increased wind loads should not be ruled out (Teran et al., 2022).

Snow, rain-on-snow, and freezing rain

Future 50-year return levels of snow water equivalent (SWE) loads are anticipated to decrease for southern Canada (Jeong and Sushama, 2018). More rain-on-snow is anticipated during November to March for most regions in Canada under the medium (RCP4.5) and high emissions scenarios (RCP8.5; Jeong and Sushama, 2018).

The frequency of freezing rain is anticipated to increase over parts of western and central Canada under the high emissions scenario (RCP8.5; McCray et al., 2022).

Extreme precipitation and temperature occurring together

Most parts of southern Canada are expected to see a coinciding increase in precipitation and temperature extremes during the summer under the high emissions scenario (RCP8.5; Singh et al., 2022). This may result in an increased risk of flooding during extreme heat days, amplifying the risk to people's health and safety, especially as past storm events have also led to extensive power outages across the city (see Introduction).

Fire spread

The frequency of seasons with many potential fire spread days is expected to increase for most parts of Canada's forested regions under future climate scenarios (Wang et al., 2017). Meanwhile, a review of wildfire studies found that fire spread days, area burned, and seasonal severity rating are anticipated to increase across Canada (Coogan et al., 2019). These increases are expected to intensify the risk of poor air quality days from wildfire smoke, which is already having far-reaching effects across Canada and around the world (e.g., Health Canada, 2024b; Byrne et al., 2024).

5. From climate data to climate action

The City of Toronto has been a municipal leader on climate action. In October 2019, City Council joined a growing number of municipalities and governments around the world in declaring a climate emergency (City Council, 2019). Prior to this, Toronto has had a GHG reduction target in place since 2007 (Deputy City Manager and Deputy City Manager and Chief Financial Officer, 2007). Following the global adoption of the Paris Agreement in 2015, City Council unanimously adopted "TransformTO: Climate Action for a Healthy, Equitable and Prosperous Toronto" in 2017, with refreshed targets and a roadmap to achieve them (City Council, 2017). With its declaration of a climate emergency, the City further strengthened its carbon-reduction goal and has since adopted enhanced targets and actions for achieving net zero by 2040 (City Council, 2021).

Through these initiatives, the need to advance climate adaptation and resilience along with mitigation has been well recognized. For example, the City's "Climate Change, Clean Air and Sustainable Energy Action Plan" (2007) called for the development of a climate change adaptation strategy, which led to the release of "Ahead of the Storm: Preparing Toronto for Climate Change" in 2008. In 2019, Toronto released its first Resilience Strategy, which highlighted many climate resilience initiatives across the City. In 2024, the City moved to refocus on information development and coordinated leadership to further address climate risks and build resilience (Toronto Environment and Climate Division, 2024).

Figure 28. Overview of the adaptation planning process. Source: Brown et al., 2021

Understanding how the climate is changing often forms the first key step in adaptation planning (Figure 28). Since 2011, the City has been leveraging local climate projections to guide its work based on "Toronto's Future Weather and Climate Driver Study" (SENES Consultants Ltd., 2011). With updated climate scenarios and improved availability of high-quality climate projections across Canada, this report provides an updated, comprehensive outlook of Toronto's future climate over the remainder of the 21st century.

Using these updated climate projections, the City is undertaking a city-wide climate risk and vulnerability assessment, which will help identify the people, assets, and services that are most vulnerable to the impacts of climate change (Toronto Environment and Climate Division, 2024). This will better equip the city with risk-based information to continue to support proactive adaptation and resilience-building efforts across the city. In addition, there are many other ways this data is expected to be used by City staff to ensure that future climate is considered now for projects and initiatives that will affect services, assets, and people for years to come. Some additional TRCA and other datasets are also detailed in Appendix C, which may help further inform the city-wide climate risk and vulnerability assessment or other assessments, plans, or policies that the City may undertake.

This climate data can also help businesses, residents, and communities prepare for a hotter, stormier, and more disruptive future. We hope that this report can help build common understanding of the possible future changes in Toronto's climate if GHG concentration continues to rise and help initiate conversations about climate change. By the end of the century, Toronto may see warmer temperature, intensifying heat events, less extreme cold, a longer growing season, more extreme high and extreme low lake levels, and more extreme weather (Figure 29). These changes may lead to a wide range of impacts – some of which we have already seen – such as:

- Increased disruption to infrastructure and services;
- Increased maintenance and operations costs;
- Detrimental impacts on people's health and well-being;
- Increased spread of invasive species and pests;
- More flooding and erosion;
- Impacts on native species and ecosystems;
- More poor air quality days from wildfire smoke;
- Global supply chain impacts;
- Increased cost of living;
- Loss of economic productivity; and
- Increased damage to property and infrastructure.

Figure 29. Anticipated changes in Toronto's future climate and potential impacts on Toronto's people and communities if the concentration of heat-trapping greenhouse gases continues to rise. Adapted from: [UK Met Office]

These impacts are often unequally distributed, affecting some people more than others including people who face multiple, overlapping stressors due to systemic and long-standing inequities.

Building on these potential changes and associated impacts, residents and businesses can make further connections between climate change and their personal lives. Similarly, this information can help City staff make connections with their work. By understanding what we need to avoid and why, we can collectively help shape the future that we want. The most devastating impacts of climate change can still be avoided by rapidly reducing heat-trapping GHG emissions, while reducing vulnerability and enhancing resilience. What Toronto's future climate could look like depends on the choices we make now. A safer, healthier, and more resilient city is possible if we plan and adapt now.

References

Acting City Manager. (2015, June 16). Staff Report – Transmittal of Toronto Hydro Report: Status of Recommendations from December 2013 Ice Storm Report as of May 31, 2015. https://www.toronto.ca/legdocs/mmis/2015/ex/bgrd/backgroundfile-81756.pdf

Agriculture and Agri-Food Canada (AAFC). (2020). Climate change impacts on agriculture. https://agriculture.canada.ca/en/environment/climate-change/climate-change-impacts-agriculture

AMEC Environment and Infrastructure. (2014). July 8th, 2013 Extreme Rainfall Event Summary & Analysis Report. https://trcaca.s3.ca-central-1.amazonaws.com/app/uploads/2020/07/07094436/14-12-17-Summary-Analysis-Repor1.pdf

Berry, P., and Schnitter, R. (Eds.). (2022). Health of Canadians in a Changing Climate: Advancing our Knowledge for Action. Government of Canada, Ottawa, ON. https://changingclimate.ca/health-in-a-changing-climate/

Boyd, D. W. (1979). Degree days: the different types. Building Research Note, 1979-01. Government of Canada, Ottawa, ON. https://nrc-publications.canada.ca/eng/view/ft/?id=085ebb1c-4a0a-47ab-af05-bcce30cab8a8

Brown, C., Jackson, E., Harford, D. and Bristow, D. (2021): Cities and Towns; Chapter 2 in Canada in a Changing Climate: National Issues Report, (ed.) F.J. Warren and N. Lulham; Government of Canada, Ottawa, Ontario. https://changingclimate.ca/national-issues/chapter/2-0/

Byrne, B., Liu, J., Bowman, K.W. et al. (2024). Carbon emissions from the 2023 Canadian wildfires. Nature, 633, 835–839. https://doi.org/10.1038/s41586-024-07878-z

Canadian Climate Institute. (2020-2002). Costs of Climate Change series. https://climateinstitute.ca/reports/the-costs-of-climate-change/

CBC News. (2010, July 5). Toronto power returns after blackout. CBC News. https://www.cbc.ca/news/canada/toronto/toronto-power-returns-after-blackout-1.925931

CBC News. (2018, September 7). August rainstorm caused $80M in damage, Insurance Bureau says. CBC News. https://www.cbc.ca/news/canada/toronto/rain-insured-damage-1.4814852

City Council. (2000, July 4, 5 and 6). Impacts of Storm Event on May 12 and 13, 2000, and Engagement of Consultants for the Provision of Engineering Services to Undertake the Development of the Wet Weather Flow Management Master Plan (All Wards). https://www.toronto.ca/legdocs/2000/agendas/council/cc/cc000704/pof9rpt/cl014.pdf

City Council. (2006, July 25). Notice of Motion – Extreme Heat Alerts. https://www.toronto.ca/legdocs/2006/agendas/council/cc060725/nomj(28).pdf

City Council. (2017, July 4, 5, 6 and 7). TransformTO: Climate Action for a Healthy, Equitable and Prosperous Toronto. https://secure.toronto.ca/council/agenda-item.do?item=2017.PE19.4

City Council. (2019, October 2 and 3). Declaring a Climate Emergency and Accelerating Toronto's Climate Action Plan. https://secure.toronto.ca/council/agenda-item.do?item=2019.MM10.3

City Council. (2021, December 15, 16 and 17). TransformTO - Critical Steps for Net Zero by 2040. https://secure.toronto.ca/council/agenda-item.do?item=2021.IE26.16

City Manager. (2013, September 10). Staff Report – Impacts from the July 8, 2013 Storm Event on the City of Toronto. https://www.toronto.ca/legdocs/mmis/2013/ex/bgrd/backgroundfile-61502.pdf

City Manager. (2014, January 8). Staff Report – Impacts from the December 2013 Extreme Winter Storm Event on the City of Toronto. https://www.toronto.ca/legdocs/mmis/2014/cc/bgrd/backgroundfile-65676.pdf

City Manager and Deputy City Manager and Chief Financial Officer. (2014, January 21). Staff Report – Proposed Funding of 2013 Extreme Weather Events. https://www.toronto.ca/legdocs/mmis/2014/ex/bgrd/backgroundfile-66238.pdf

City of Toronto. (2008). Ahead of the Storm: Preparing Toronto for Climate Change – Highlights. https://www.toronto.ca/legdocs/mmis/2008/pe/bgrd/backgroundfile-12951.pdf

City of Toronto. (2019). Toronto's First Resilience Strategy. https://www.toronto.ca/ext/digital_comm/pdfs/resilience-office/toronto-resilience-strategy.pdf

City of Toronto. (2024a, July 16). City of Toronto provides an update on response efforts following heavy rainfall. https://www.toronto.ca/news/city-of-toronto-provides-an-update-on-response-efforts-following-heavy-rainfall/

City of Toronto. (2024b, July 17). City of Toronto continues response efforts following heavy rainfall. https://www.toronto.ca/news/city-of-toronto-continues-response-efforts-following-heavy-rainfall/

City of Toronto. (2024c, June 16). City of Toronto shares advice for residents to keep cool during first heat event of summer. https://www.toronto.ca/news/city-of-toronto-shares-advice-for-residents-to-keep-cool-during-first-heat-event-of-summer/

CityNews. (2014, July 7). REWIND: July 2013 storm pummels Toronto causing transit chaos & widespread damage. https://toronto.citynews.ca/2014/07/07/rewind-july-2013-storm-pummels-toronto-causing-transit-chaos-widespread-damage/

ClimateData.ca. (2024). All Variables. https://climatedata.ca/variable/

Coogan, S. C. P., Robinne, F.-N., Jain, P., and Flannigan, M. D. (2019). Scientists' warning on wildfire—A Canadian perspective. Canadian Journal of Forest Research, 49(9), 1015–1023. https://doi.org/10.1139/cjfr-2019-0094

CTV Toronto. (2013, July 9). Toronto battered by storm, flooding; thousands stranded. CTV News. https://www.ctvnews.ca/canada/toronto-battered-by-storm-flooding-thousands-stranded-1.1358719

D'Cunha, P., and Casaletto, L. (2024, July 17). Power mostly restored in Toronto after flooding at Hydro One transmission station causes widespread outages. CityNews. https://toronto.citynews.ca/2024/07/16/power-outages-toronto-hydro/

Deputy City Manager and Deputy City Manager and Chief Financial Officer. (2007, June 13). Climate Change, Clean Air and Sustainable Energy Action Plan: Moving from Framework to Action. https://www.toronto.ca/legdocs/mmis/2007/pe/bgrd/backgroundfile-4982.pdf

Deputy City Manager and Chief Financial Officer. (2008, March 14). Staff Report – Funding Strategies to Mitigate Financial Impacts on the City Due to Extreme Weather Conditions. https://www.toronto.ca/legdocs/mmis/2008/ex/bgrd/backgroundfile-11747.pdf

Egilson, M. et al. (2022). Extreme Heat and Human Mortality: A Review of Heat-Related Deaths in B.C. in Summer 2021. Report to the Chief Coroner of British Columbia. https://www2.gov.bc.ca/assets/gov/birthadoption-death-marriage-and-divorce/deaths/coroners-service/death-reviewpanel/extreme_heat_death_review_panel_report.pdf

Environment and Climate Change Canada (ECCC). (2023). Canadian Climate Normals 1991-2020. https://collaboration.cmc.ec.gc.ca/cmc/climate/Normals//Canadian_Climate_Normals_1991_2020_Calculation_Information.pdf

Environment and Climate Change Canada (ECCC). (2024a). Canadian Environmental Sustainability Indicators: Temperature change in Canada. Government of Canada, Gatineau, QC. https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/temperature-change.html

Environment and Climate Change Canada (ECCC). (2024b). Extreme weather event attribution: June 2024 Attribution analysis. https://www.canada.ca/en/environment-climate-change/services/climate-change/science-research-data/extreme-weather-event-attribution.html

Flato, G., J. Marotzke, B. Abiodun, P. Braconnot, S.C. Chou, W. Collins, P. Cox, F. Driouech, S. Emori, V. Eyring, C. Forest, P. Gleckler, E. Guilyardi, C. Jakob, V. Kattsov, C. Reason, and M. Rummukainen. (2013). Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Flavelle, D. (2014, July 5). A year after the Toronto flood. Toronto Star. https://www.thestar.com/business/personal-finance/a-year-after-the-toronto-flood/article_b70c1a90-c3ff-533b-aaf2-f98aa3a879d0.html

Government of Canada. (2021). Display and download climate data. https://www.canada.ca/en/environment-climate-change/services/climate-change/canadian-centre-climate-services/display-download.html

Health Canada. (2011a). Adapting to Extreme Heat Events: Guidelines for Assessing Health Vulnerability. Government of Canada, Ottawa, ON. https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/climat/adapt/adapt-eng.pdf

Health Canada. (2011b). Communicating the Health Risks of Extreme Heat Events: Toolkit for Public Health and Emergency Management Officials. Government of Canada, Ottawa, ON. https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/climate-change-health/communicating-health-risks-extreme-heat-events-toolkit-public-health-emergency-management-officials-health-canada-2011.html

Health Canada. (2018). Extreme cold. It's your health. Government of Canada, Ottawa, ON. https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/hl-vs/alt_formats/pdf/iyh-vsv/environ/cold-extreme-froid-eng.pdf

Health Canada. (2024a). Extreme heat events: Health risks and who is at risk of extreme heat events. https://www.canada.ca/en/health-canada/services/climate-change-health/extreme-heat/who-is-at-risk.html

Health Canada. (2024b). Human Health Effects of Wildfire Smoke. Government of Canada, Ottawa, ON. https://www.canada.ca/en/health-canada/services/publications/healthy-living/human-health-effects-wildfire-smoke.html

Huryn, S. M., Mohsin, T., Gough, W. A., and Butler, K. (2020). Determining future thunderstorm-prone environments in Southern Ontario by using statistical downscaling to project changes in convective available potential energy (CAPE). Theoretical and Applied Climatology, 141(3), 1235–1249. https://doi.org/10.1007/s00704-020-03260-x

Insurance Bureau of Canada. (2024a, January 8). Severe Weather in 2023 Caused Over $3.1 Billion in Insured Damage. https://www.ibc.ca/news-canada/services/publications/healthy-living/human-health-effects-wildfire-smoke.html

Insurance Bureau of Canada. (2024b, September 24). Summer 2024 shatters records for severe weather damage: Over $7 billion in insured losses from floods, fires and hailstorms. https://www.ibc.ca/news-insights/news/summer-2024-shatters-records-for-severe-weather-damage-over-7-billion-in-insured-losses-from-floods-fires-and-hailstorms

Intergovernmental Panel on Climate Change (IPCC). (2021). Summary for Policymakers. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, Ö. Yelekçi, R. Yu, and B. Zhou (Eds.), Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

Intergovernmental Panel on Climate Change (IPCC). (2022). Summary for Policymakers. In H.-O. Pörtner, D. C. Roberts, E. S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, and A. Okem (Eds.), Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

Intergovernmental Panel on Climate Change (IPCC). (2023) Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf

International Energy Agency (IEA). (2023). Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach, IEA, Paris. https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach

Jeong, D. I., Cannon, A. J., and Morris, R. J. (2020). Projected changes to wind loads coinciding with rainfall for building design in Canada based on an ensemble of Canadian regional climate model simulations. Climatic Change, 162(2), 821–835. https://doi.org/10.1007/s10584-020-02745-y

Jeong, D. I., and Sushama, L. (2018). Projected changes to extreme wind and snow environmental loads for buildings and infrastructure across Canada. Sustainable Cities and Society, 36, 225–236. https://doi.org/10.1016/j.scs.2017.10.004

Jeong, D. I., and Sushama, L. (2019). Projected Changes to Mean and Extreme Surface Wind Speeds for North America Based on Regional Climate Model Simulations. Atmosphere, 10(9), Article 9. https://doi.org/10.3390/atmos10090497

Jiang, K. (2024a, July 17). A 'parade' of storms: How Toronto got more than a month's worth of rain in just over three hours. Toronto Star. https://www.thestar.com/news/gta/a-parade-of-storms-how-toronto-got-more-than-a-months-worth-of-rain-in/article_b4792d96-444c-11ef-b780-67cf81f0e86b.html

Jiang, K. (2024b, June 18). What is a heat dome? Ontario is facing 'dangerously high' heat and humidity this week — here's why. Toronto Star. https://www.thestar.com/news/canada/what-is-a-heat-dome-ontario-is-facing-dangerously-high-heat-and-humidity-this-week/article_43ed1770-2ca7-11ef-8607-73fc3aa66641.html

Lam, S., and Dokoska, K. (2022). Climate Change in the Great Lakes Basin: Summary of Trends and Impacts. Toronto, Ontario: Toronto and Region Conservation Authority. https://binational.net/wp-content/uploads/2022/11/Climate-Change-in-the-Great-Lakes-Basin_English-1.pdf

Lee, J.-Y., J. Marotzke, G. Bala, L. Cao, S. Corti, J.P. Dunne, F. Engelbrecht, E. Fischer, J.C. Fyfe, C. Jones, A. Maycock, J. Mutemi, O. Ndiaye, S. Panickal, and T. Zhou. (2021). Future Global Climate: Scenario-Based Projections and Near-Term Information. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 553–672, doi: 10.1017/9781009157896.006

Lepore, C., Abernathey, R., Henderson, N., Allen, J. T., and Tippett, M. K. (2021). Future Global Convective Environments in CMIP6 Models. Earth's Future, 9(12), e2021EF002277. https://doi.org/10.1029/2021EF002277

MacDonald, H., Pedlar, J., McKenney, D. W., Lawrence, K., de Boer, K., and Hutchinson, M. F. (2023). Heating degree day spatial datasets for Canada. Data in Brief, 49, 109450. https://doi.org/10.1016/j.dib.2023.109450

McCray, C. D., Paquin, D., Thériault, J. M., and Bresson, É. (2022). A Multi-Algorithm Analysis of Projected Changes to Freezing Rain Over North America in an Ensemble of Regional Climate Model Simulations. Journal of Geophysical Research: Atmospheres, 127(14), e2022JD036935. https://doi.org/10.1029/2022JD036935

McSweeney, R. and Hausfather, Z. (2018, January 15). Q&A: How do climate models work? CarbonBrief. https://www.carbonbrief.org/qa-how-do-climate-models-work/

Morris, M., Kushner, P. J., Moore, G. W. K., and Mercan, O. (2024). Resolution Dependence of Extreme Wind Speed Projections in the Great Lakes Region. https://doi.org/10.1175/JCLI-D-23-0547.1

Mortillaro, N., and Armstrong, J. (2013, July 8). Heavy rain pounds Toronto, temporarily halts subway service. Global News. https://globalnews.ca/news/701696/special-weather-statement-issued-for-toronto/

Mortillaro, N. (2024, July 17). 2nd major flooding in 11 years a sign Toronto is not adapting quickly enough, say climate experts. CBC News. https://www.cbc.ca/news/canada/toronto/toronto-flood-adaptation-1.7265581

Ontario Ministry of Health. (2023). A Harmonized Heat Warning and Information System for Ontario (HWIS). https://www.ontario.ca/page/harmonized-heat-warning-and-information-system-ontario-hwis

Opler, S.E., Buggle, C., Orfanakos, A., and Zavitz, K. (2020). Ombudsman Toronto Report: Enquiry into how the City of Toronto Handles Homeowner Third-Party Liability Claims for Basement Flooding and Sewer Backups. https://www.toronto.ca/legdocs/mmis/2020/cc/bgrd/backgroundfile-158635.pdf

Ouranos. (2024). Freezing rain – Impacts. https://www.ouranos.ca/en/climate-phenomena/freezing-rain-impacts

Philip, S. Y., Kew, S. F., van Oldenborgh, G. J., Anslow, F. S., Seneviratne, S. I., Vautard, R., Coumou, D., Ebi, K. L., Arrighi, J., Singh, R., van Aalst, M., Pereira Marghidan, C., Wehner, M., Yang, W., Li, S., Schumacher, D. L., Hauser, M., Bonnet, R., Luu, L. N., … Otto, F. E. L. (2022). Rapid attribution analysis of the extraordinary heat wave on the Pacific coast of the US and Canada in June 2021. Earth System Dynamics, 13(4), 1689–1713. https://doi.org/10.5194/esd-13-1689-2022

Public Safety Canada. (2011). Severe Storms: What to do? https://www.getprepared.gc.ca/cnt/rsrcs/pblctns/svrstrms-wtd/svrstrms-wtd-eng.pdf

Public Safety Canada. (2013a). Canadian Disaster Database: August 7, 2018. https://cdd.publicsafety.gc.ca/dtpg-eng.aspx?

Public Safety Canada. (2013b). Canadian Disaster Database: August 19, 2005. https://cdd.publicsafety.gc.ca/dtpg-eng.aspx?

Public Safety Canada. (2013c). Canadian Disaster Database: December 21, 2013. https://cdd.publicsafety.gc.ca/dtpg-eng.aspx?

Public Safety Canada. (2013d). Canadian Disaster Database: July 8, 2013. https://cdd.publicsafety.gc.ca/dtpg-eng.aspx?

Ramos, D. (2024, June 24). https://www.thestar.com/news/gta/heat-warning-lifted-for-toronto-and-parts-of-ontario-after-a-sweltering-week-in-the/article_b9ae660c-2fe6-11ef-bbd2-5bffe749e2ba.html

SENES Consultants Ltd. (2011). Toronto's Future Weather and Climate Driver Study. https://www.toronto.ca/legdocs/mmis/2013/pe/bgrd/backgroundfile-55151.pdf

Seneviratne, S.I., X. Zhang, M. Adnan, W. Badi, C. Dereczynski, A. Di Luca, S. Ghosh, I. Iskandar, J. Kossin, S. Lewis, F. Otto, I. Pinto, M. Satoh, S.M. Vicente-Serrano, M. Wehner, and B. Zhou. (2021). Weather and Climate Extreme Events in a Changing Climate. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1513–1766, doi:10.1017/9781009157896.013

Shingler, B. (2024, June 17). 4 things to know about the 'oppressive' heat wave in Ontario, Quebec and Atlantic Canada. CBC News. https://www.cbc.ca/news/climate/ontario-quebec-environment-canada-heat-wave-1.7237102

Singh, H., Najafi, M. R., and Cannon, A. (2022). Evaluation and joint projection of temperature and precipitation extremes across Canada based on hierarchical Bayesian modelling and large ensembles of regional climate simulations. Weather and Climate Extremes, 36, 100443. https://doi.org/10.1016/j.wace.2022.100443

Spurr, B., Allen, K., Habibinia, M., Cohen, B., and Oved, M.C. (2024, August 1). Toronto simply 'not designed to handle' this much rain, city warns. Toronto Star. https://www.thestar.com/news/gta/toronto-simply-not-designed-to-handle-this-much-rain-city-warns/article_1f02886a-439e-11ef-85b0-77b0ae117608.html

Teran, A. S., Agrawal, S., Naderian, H., Wong, J. K., Song, J., Mercan, O., Kushner, P. J., Mardukhi, J., and Zhang, X. (2022). Towards a Computational Workflow for Studying the Effects of Climate Change on Wind Loads on High-Rise Buildings in Urban Areas. Atmosphere-Ocean, 60(2), 124–140. https://doi.org/10.1080/07055900.2022.2061412

The Canadian Press. (2010, July 5). Power outage hits city during heat wave, royal visit. CP24. https://www.cp24.com/power-outage-hits-city-during-heat-wave-royal-visit-1.529410

Toronto and Region Conservation Authority (TRCA). (2018, August 15). Toronto and Region Conservation Authority Responds to Recent Storm Events. https://trca.ca/news/storm-events-august-2018/

Toronto and Region Conservation Authority (TRCA) Flood Risk Management. (2024). 2024 Flood Contingency Manual. https://trcaca.s3.ca-central-1.amazonaws.com/app/uploads/2024/01/24130516/5.3.2-TRCA-2024-Flood-Contingency-Manual_For-WEB_Jan2024.pdf

Toronto and Region Conservation Authority (TRCA) Restoration and Infrastructure. (2020, April 24). Staff Report – 2020 Erosion Risk Management Program Update. https://pub-trca.escribemeetings.com/filestream.ashx?DocumentId=5664

Toronto Environment and Climate Division. (2024, March 13). Toronto's Climate Change Readiness: Updates on commitments and a refreshed mandate for coordinating resilience activities. https://www.toronto.ca/legdocs/mmis/2024/ie/bgrd/backgroundfile-244181.pdf

Toronto Hydro Corporation. (2023, December 19). Powering Forward: Toronto Hydro Marks Tenth Anniversary of Ice Storm. https://www.newswire.ca/news-releases/powering-forward-toronto-hydro-marks-tenth-anniversary-of-ice-storm-806793732.html

Toronto Parks, Forestry and Recreation. (2017, June 27). Staff Report – Damages Sustained from Rising Lake Water Levels and Restoration Plans for Waterfront Parks. https://www.toronto.ca/legdocs/mmis/2017/cc/bgrd/backgroundfile-105457.pdf

Toronto Parks, Forestry and Recreation. (2018, July 6). Staff Report – Capital Repair and Remediation Cost of 2017 Flooding of Waterfront Parks. https://www.toronto.ca/legdocs/mmis/2018/ex/bgrd/backgroundfile-118141.pdf

Toronto Parks, Forestry and Recreation. (2019, October 2). Staff Report – Update on Flood Mitigation and Damage Repair for Toronto's Waterfront and Toronto Island Park. https://www.toronto.ca/legdocs/mmis/2019/ie/bgrd/backgroundfile-138551.pdf

Toronto Public Health. (2007, April 10). Staff Report – Hot Weather Response Plan Update. https://www.toronto.ca/legdocs/mmis/2007/cd/bgrd/backgroundfile-3286.pdf

Toronto Public Health. (2011, July 6). Staff Report – Protecting Vulnerable People from Health Impacts of Extreme Heat. https://www.toronto.ca/legdocs/mmis/2011/hl/bgrd/backgroundfile-39468.pdf

Toronto Public Health. (2024). Cold Weather Information for Health Professionals. https://www.toronto.ca/community-people/health-wellness-care/information-for-healthcare-professionals/environmental-health-infomation-for-health-professionals/extreme-cold-weather-alerts-information-for-health-professionals/

Toronto Star. (2018, August 7). TTC closures remain in effect following Tuesday night flash floods. Toronto Star. https://www.thestar.com/news/gta/ttc-closures-remain-in-effect-following-tuesday-night-flash-floods/article_02bdec46-1e96-5d6a-91aa-15a6d958ffa9.html

Toronto Water. (2006, February 20). Staff Report – Emergency Repairs Undertaken by Toronto Water as a Result of the August 19, 2005 Storm (City-wide). https://www.toronto.ca/legdocs/2006/agendas/committees/wks/wks060307/it026.pdf

Toronto Water. (2008, August 18). Staff Report – Update on the Engineering Review Addressing Basement Flooding. https://www.toronto.ca/legdocs/mmis/2008/ex/bgrd/backgroundfile-15074.pdf

Toronto Water. (2013, September 6). Staff Report – Impact of July 8, 2013 storm on the City's Sewer and Stormwater Systems. https://www.toronto.ca/legdocs/mmis/2013/pw/bgrd/backgroundfile-61363.pdf

Toronto Water. (2023, November 15). Staff Report – Expanding the Basement Flooding Protection Subsidy Program Eligibility Criteria to Include Registered Property Owners of Existing Residential Fourplexes. https://www.toronto.ca/legdocs/mmis/2023/ie/bgrd/backgroundfile-240737.pdf

Tsekouras, P. (2024, August 19). Flooding in Toronto, southern Ontario in July caused more than $940M in claims: Insurance bureau. CP24. https://www.cp24.com/news/flooding-in-toronto-southern-ontario-in-july-caused-more-than-940m-in-claims-insurance-bureau-1.7006058

United Nations Environment Programme (UNEP). (2024). Emissions Gap Report 2024: No more hot air… please! With a massive gap between rhetoric and reality, countries draft new climate commitments. Nairobi. https://doi.org/10.59117/20.500.11822/46404

Vertical Control – Water Levels Subcommittee. (2017). Updating the International Great Lakes Datum (IGLD). Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. https://naref.org/igld/pubs/IGLD_Update_20170929_opt.pdf

Wang, X., Parisien, M.-A., Taylor, S. W., Candau, J.-N., Stralberg, D., Marshall, G. A., Little, J. M., and Flannigan, M. D. (2017). Projected changes in daily fire spread across Canada over the next century. Environmental Research Letters, 12(2), 025005. https://doi.org/10.1088/1748-9326/aa5835

Welsh, M. (2019, May 21). When the Rain Falls Hard. Toronto Star. https://projects.thestar.com/climate-change-canada/toronto-flooding/

World Health Organization (WHO). (2024). Heat and health. https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health

World Meteorological Organization (WMO). (2024a). Climate. https://wmo.int/topics/climate

World Meteorological Organization (WMO). (2024b). Water. https://wmo.int/topics/water

World Meteorological Organization (WMO). (n.d.). Global Climate Indicators. https://gcos.wmo.int/en/global-climate-indicators

Wuebbles, D., Cardinale, B., Cherkauer, K., Davidson-Arnott, R., Hellmann, J., Infante, D., Johnson, L., and de Loë, R. (2019). An Assessment of the Impacts of Climate Change on the Great Lakes by Scientists and Experts from Universities and Institutions in the Great Lakes Region. Environmental Law & Policy Center. https://elpc.org/resources/the-impacts-of-climatechange-on-the-great-lakes/