Chapter

High-Resolution Regional Climate Projections for Ontario and the Canadian Great Lakes Basins

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Abstract

The IPCC-endorsed multiple model/scenario approach and a state-of-the-science combined downscaling methodology were applied to project the future climate changes over Ontario and the Canadian Great Lakes basins. Significant warming is expected across the province under all RCPs. Relative to 1986–2005 averages, the highest temperature rise is projected to occur in Ontario's Far North, 7.3°C warmer by the 2080s. The temperature over the Great Lakes Basin is projected to increase by 1.3–5.7°C. Ontario's annual total precipitation is projected to increase 86.9 mm (11%) by the 2080s under RCP 8.5, while summer precipitation is projected to decrease by 32.9 mm (12%) and winter precipitation to increase by 52.4 mm (48%). In the Great Lakes Basin, the greatest increase in annual average temperature (1.7–5.3°C) is projected to occur in the Lake Superior sub-basin by the 2080s. Winter warming is projected to exceed summer warming in all sub-basins. Annual total precipitation is projected to increase in all five sub-basins, with the largest increase in the Lake Superior sub-basin. Summer (winter) is projected to be drier (wetter) across the entire Great Lakes Basin. These projected changes could have implications on future water levels in the Great Lakes and many aspects over the study area.

Keywords: high-resolution regional climate projections, dynamical downscaling, combined downscaling, Canadian Great Lakes basin and sub-basins, Ontario, climate change impacts, water levels

1. Introduction

The impacts of climate change are broad in scope (both location-wise and sector-wise) and unprecedented in magnitude. The 5th assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) concludes that global warming leads to an intensification of the water cycle and attendant effects on heavy and extreme precipitation events and is likely to lead to more frequent daily precipitation extremes [1]. These changes have significant potential impacts on floods, erosion, infrastructure, agriculture, water resources, ecosystems, human health and ultimately the economy. IPCC's latest 6th assessment report (AR6) found that the warming and associated impacts are more severe than previously estimated [2]. Therefore, it is critical for governments, practitioners, and the public to be aware of future climate changes at local scales where adaptation/mitigation activities are most effective. High-resolution climate projection data at multiple time scales (e.g., annual, monthly, daily, even sub-daily) is necessary for governments to develop climate adaptation/mitigation strategies to assess and address local impacts. The geography of Ontario is unique; it is bordered by the Great Lakes in the south and Hudson Bay and James Bay in the North. Within Ontario, there are more than 250,000 inland lakes, large areas of uplands, particularly within the Canadian Shield which traverses the province from northwest to southeast and above the Niagara Escarpment in the south. Southern Ontario (south of Lake Nipissing) belongs to the Great Lakes/St. Lawrence River Basins [3, 4]. To generate projections of climate change in Ontario and the Great Lakes basin, the impacts of all these geophysical features specific to the study area should be considered [5]. IPCC has been promoting, in its recent reports, using novel methods to combine multi-model projections with observational constraints to provide robust projections of geographical patterns of climate change [2]; we are ahead of this game and developed a novel combined downscaling method which combines the Ensemble Optimal Interpolation (EnOI) and bias correction techniques [6]. The resulting high-resolution regional climate projections specific to Ontario and the Great Lakes basin are disseminated through the user-friendly Ontario Climate Data Portal [7–9], which has been supporting many practitioners in assessing climate change impacts and developing climate change pertaining policies and plans to mitigate and adapt to the changing climate (e.g., [10–13]).

To further help practitioners (including all levels of government) to mitigate and adapt to the changing climate, this chapter summarizes trends and spatial patterns of projected changes in annual and seasonal mean temperature and precipitation over Ontario, its three major watersheds (the Hudson Bay Basin, the Nelsen River Basin and the Great Lakes Basin) and the five sub-basins of the Canadian Great Lakes basin (Lake Superior, Lake Huron, Lake Erie, Lake Ontario and the Ottawa River).

The rest of this chapter is organized as the following. Section 2 describes the data and methodology used in this study; Section 3 are the results by basin and sub-basin; and conclusions and discussion are in Section 4.

2. Data and methodology

2.1 Data

Downscaling is used to increase the spatial resolution (i.e., to smaller grid sizes) from global climate model output (usually at much larger grids). Multiple sources can be found for downscaled climate projections, but most (if not all) of them are results of statistical downscaling directly from the global climate models (GCMs). In this study, a super ensemble of high-resolution regional climate projections using a state-of-the-science combined downscaling methodology [6–9] was used. Using the multiple model/scenario approach endorsed by the IPCC to address uncertainties in future projections, we developed a super ensemble (collectively 209 members) of high-resolution (~10 km × ~10 km) regional climate projections for Ontario and the Great Lakes basin based on all available creditable data sources at the time this study was carried out (including York University [6–9], the Pacific Climate Impacts Consortium (PCIC) [14], North America—Coordinated Regional Downscaling Experiment (NA-CORDEX) [15], University of Toronto [16, 17], and the University of Regina [18]).

There have been examples of papers/reports that have synthesized and reported on future climate projection information relevant to the study area [6, 19–22]. While previous studies have provided a wealth of information about climate change over the study area, this chapter is intended to provide an updated high-level comprehensive summary based on the future climate projections specific to the study area with the following most recent regional climate modeling advancements incorporated [6–9]:

- *Improved robustness*: to better consider uncertainties in future projections, a super-ensemble of Ontario-specific high-resolution climate projections has been developed based on 209 projections of 42 global climate models (GCMs) and 7 regional climate models (RCMs) which is far greater than the number of models used in other studies;

- *Improved downscaling techniques*: the super-ensemble of climate projections is based on state-of-the-science combined downscaling methodologies [6] with improved physical comprehension, in other words, improved consideration of the impacts of local geophysical features such as the Great Lakes, the Niagara Escarpment, and the Hudson Bay, which are very critical to Ontario's local weather and climate, especially extreme events (see **Figure 1**); and,

- *Improved consistency* in time frames with IPCC's AR5 (i.e., reference/base time period and future time periods).

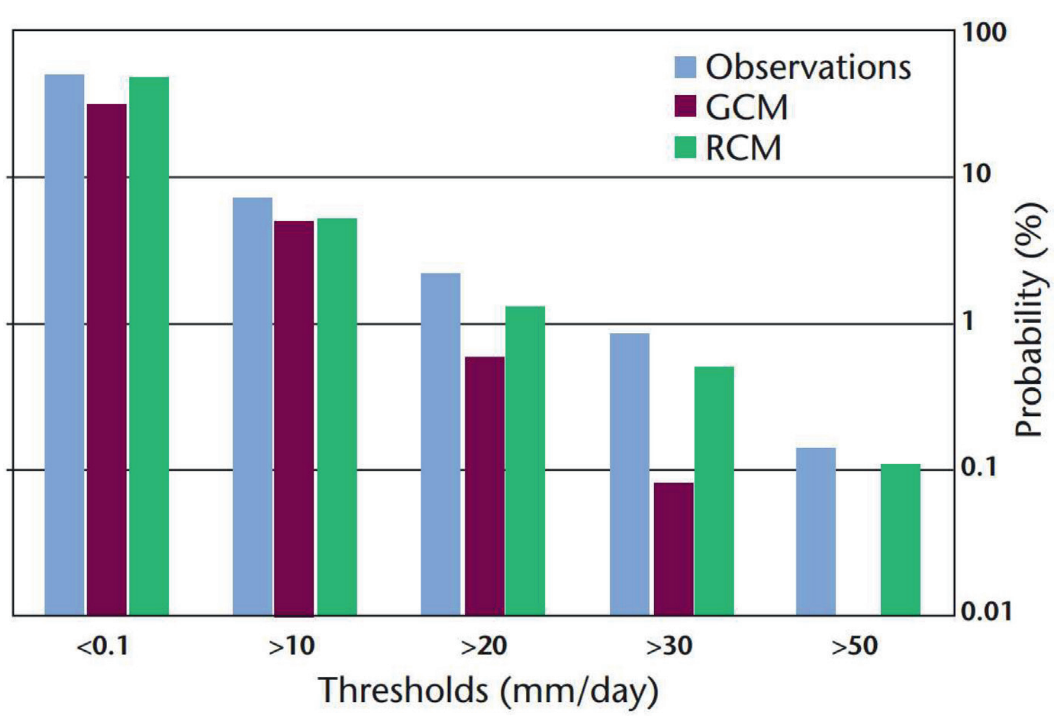

Figure 1.
Capability comparison between low-resolution global climate models (GCMs) and high-resolution regional climate models (RCMs) in simulating rainfall events in the Alps (source: [23]). This bar chart clearly demonstrates that RCMs are much more capable of predicting extreme rainfall events due to their much higher resolution which helps them to better consider the impacts from local geophysical features such as the Great Lakes and the Niagara Escarpment in Ontario.

2.2 Methodology

Projected changes in Ontario's climate are presented for three time periods (2030s: 2020–2049, 2050s: 2040–2069, and 2080s: 2070–2099) under three IPCC-defined greenhouse gas emission scenarios or representative concentration pathways (RCP 2.6, RCP4.5, and RCP8.5, see the following definitions and visual in **Figure 2**). The use of a more advanced combined downscaling methodology and more comprehensive historical meteorological data sets (based on both observations and modeled data) better accounts for the impacts of Ontario's local geophysical features such as the Great Lakes, Niagara Escarpment, Hudson Bay and James Bay on local weather and climate. Lastly, bias correction was applied to the final product. Bias correction is widely used in climate modeling. It aims to adjust selected statistics of a climate model's results so that they better match observed statistics over a present-day reference period which are then applied to correct the future projections. More details about the state-of-the-science combined downscaling methodology can be found in [6–9].

- RCP8.5: This is often referred to as the "business-as-usual" greenhouse gas emission scenario, meaning no emission reductions, emissions continue to rise throughout the 21st century;
- RCP4.5: with more vigorous greenhouse gas reductions, emissions peaks around 2040 and then stabilize;
- RCP2.6: with the most vigorous greenhouse gas reductions, emissions peak around 2020 and then decline.

This chapter provides a high-level summary of annual and seasonal averages of daily mean temperature and daily total precipitation for Ontario's three primary basins (Hudson Bay Basin, the Nelsen River Basin and the Great Lakes Basin), as well as the

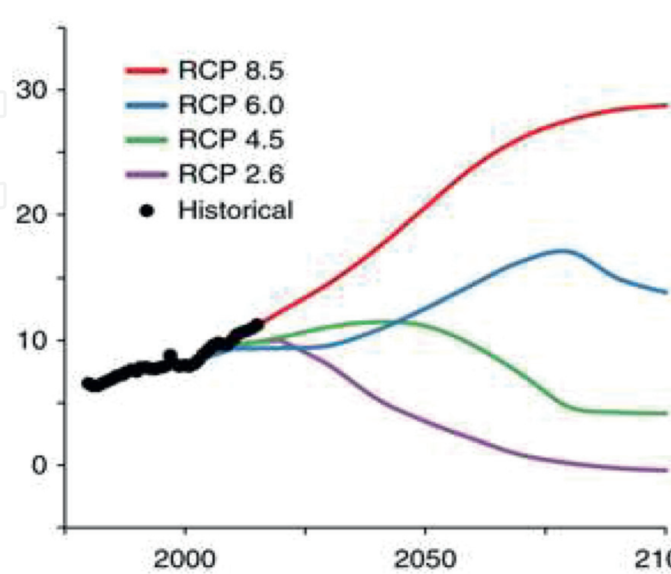

Figure 2.
Greenhouse gas emission scenarios (also known as representative concentration pathways or RCPs) are defined in the IPCC's AR5. In the vertical axis is the global carbon emissions in petagrams of carbon or 10^{15} grams of carbon per year (PgC/year)(source: [24]).

sub-basins of the Great Lakes Basin (Lake Superior, Lake Huron, Lake Erie, Lake Ontario and the Ottawa River) (**Figure 3**). Projections are, however, available for 42 climate variables, both typical variables (e.g., long-term averages of temperature and precipitation) and extreme variables (e.g., heat wave-related variables and extreme rainfall events) through York University's Ontario Climate Data Portal (ODCP) [7–9]. Readers are referred to the OCDP [7] and the references listed on the Portal for these additional variables and more details on the development of the super-ensemble of high-resolution (10 km × 10 km) climate projections specific to the study area. A high-level overview of the OCDP can also be found in [8] and more details regarding the super-ensemble projection downscaling methodology in [6, 7, 9, 24].

In this chapter, we present projected changes relative to their averages during the reference time period (1990s: 1986–2005) for the entire Province of Ontario, each of its three primary basins and the five sub-basins of the Great Lakes basin (see **Figure 3**), including the mean (average of each basin per period), standard deviation (spatial variation in the basin per period) and range (minimum and maximum across the basin per period). Projected changes in long-term averages of temperature and precipitation are presented in tabular, bar-chart and map formats at annual (January to December), summer (June to August) and winter (December to February) temporal scales. All maps of future climate are shown as the change in temperature and precipitation compared to the reference time period (1990s: 1986–2005). Generally speaking, the most dramatic changes are projected to occur in the winter months, and we have therefore chosen to focus on

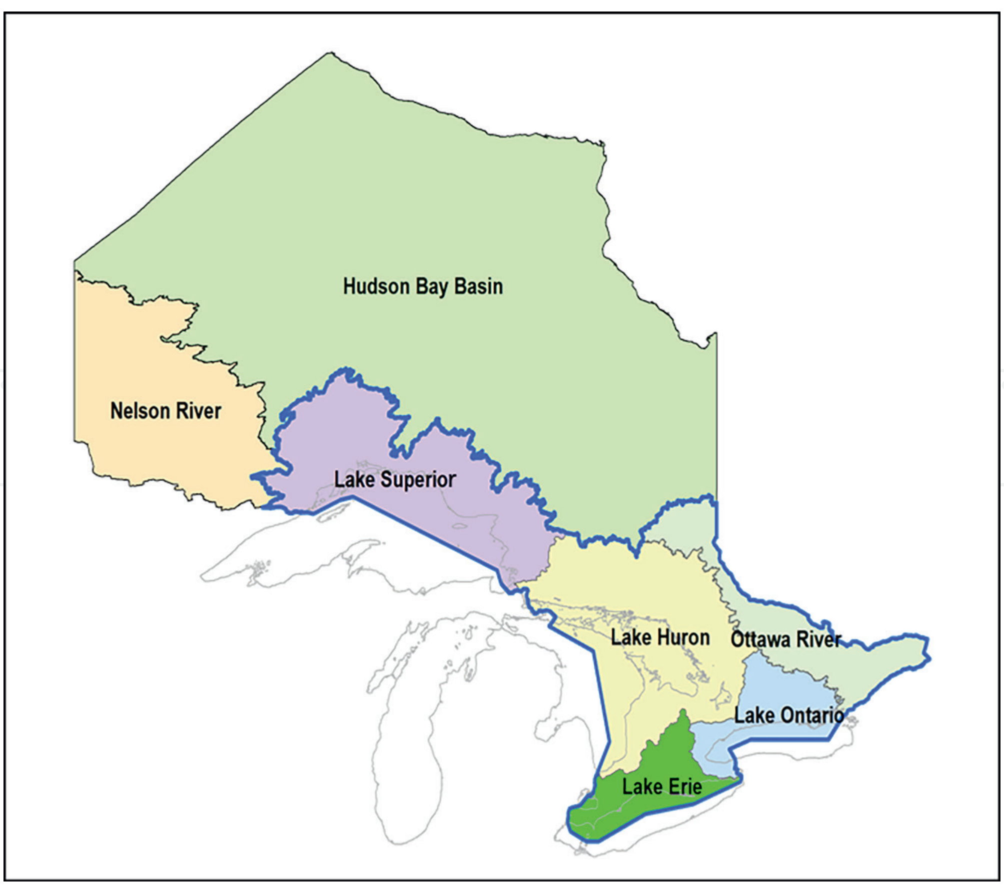

Figure 3.
Map of the Province of Ontario and its seven basins/sub-basins. The five sub-basins within the Great Lakes Basin are outlined by the blue polygon.

the summer and winter seasons to illustrate seasonal climate change extremes. It is important to note that this high-level summary focuses on long-term (annual and seasonal) averages over large areas (the entire province and its large basins) which is very different from extreme events (e. g., flooding, heat wave) that usually occur at much shorter temporal scales at specific locations. Readers are referred to the OCDP [7] for extreme variables.

3. Results

3.1 Historical climate trends in Ontario

Ontario's annual average air temperature has been warming at an average rate of 1.3°C per 100 years from 1901 to 2018 [25, 26]. This is consistent with the trend reported for 1948–2016 in Chapter 8 of the 2019 Canada's Changing Climate Report (CCCR2019) [19]. Annual mean daily temperatures in Ontario increased by 0.5°C to 1.5°C from 1950 to 2010, with the most dramatic increases occurring south of the Nelson River Basin and west of the Hudson Bay Basin [27]. Annual total precipitation has been increasing by 11.8% per 100 years from 1901 to 2016 [26, 28]. Ontario's annual total precipitation increased by 7.6% from 1979 to 2016; where summer precipitation increased by 4.3% and winter precipitation increased by 24% [28]. Weather station data in Ontario shows that rainfall has generally increased in all seasons with the most pronounced increases (by up to 50%) observed in northwestern Ontario (i.e., the vicinity of Thunder Bay) during the spring months. On average, the north shores of the Great Lakes have seen the most dramatic increases in precipitation, while the southern portion of the province near the Great Lakes snow-belt areas has seen the most significant winter snowfall increases (by 10–30%).

3.2 Future climate projections for Ontario

The annual average temperature is projected to increase across the entire province in this century when considering all RCPs (**Figures 4** and **5**). The most dramatic warming is projected to occur in the Far North which could be up to 7.3°C warmer by the 2080s under RCP 8.5 (**Table 1**; **Figure 5**) while the southern most parts of Ontario are projected to see a 4.0°C rise in temperature over the same time period. When considering both the RCP 2.6 and RCP 8.5 emissions scenarios, the projected average annual temperature across the province is expected to increase by 1.1–2.3°C by the 2030s, 1.4–4.1°C by the 2050s, and 1.3 –7.3°C by the 2080s (**Table 1**; **Figures 4** and **5**). Seasonally, warming is expected to be greater in winter than in summer (**Figures 4** and **5**) with the average winter temperature projected to increase by 1.3–11.7°C (**Table 1**, **Figures 4** and **6**). Lastly, the average summer temperature is projected to increase by 1.1–6.3°C (**Table 1**; **Figures 4** and **7**).

Provincial average annual precipitation is projected to increase up to 18.6 mm (2.4%) by the 2030s, 47 mm (6%) by the 2050s and 86.9 mm (11%) by the 2080s when considering all RCPs. Although average precipitation over the entire province is projected to increase for the rest of this century, the projected changes in precipitation are much more complicated than temperature and vary dramatically from region to region. For example, some locations in the Hudson's Bay Basin and the Great Lakes Basin are projected to become wetter with projected increases in

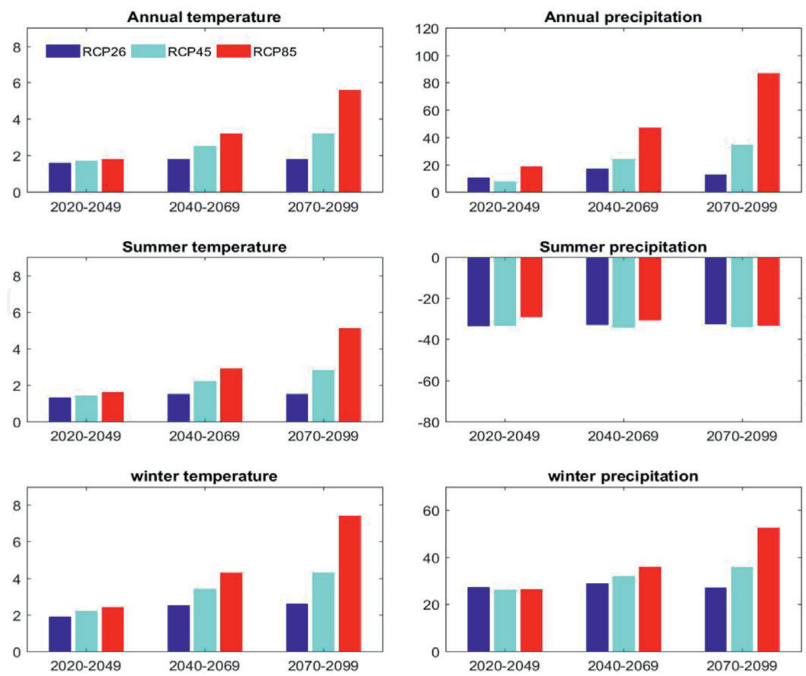

Figure 4.
Projected changes in Ontario's average annual temperature (°C) (upper-left), summer temperature (middle-left), winter temperature (lower-left), annual precipitation (mm) (upper-right), summer precipitation (middle-right), and winter precipitation (lower-right) relative to the 1986–2005 reference period, under representative concentration pathways (RCPs) 2.6, 4.5 and 8.5.

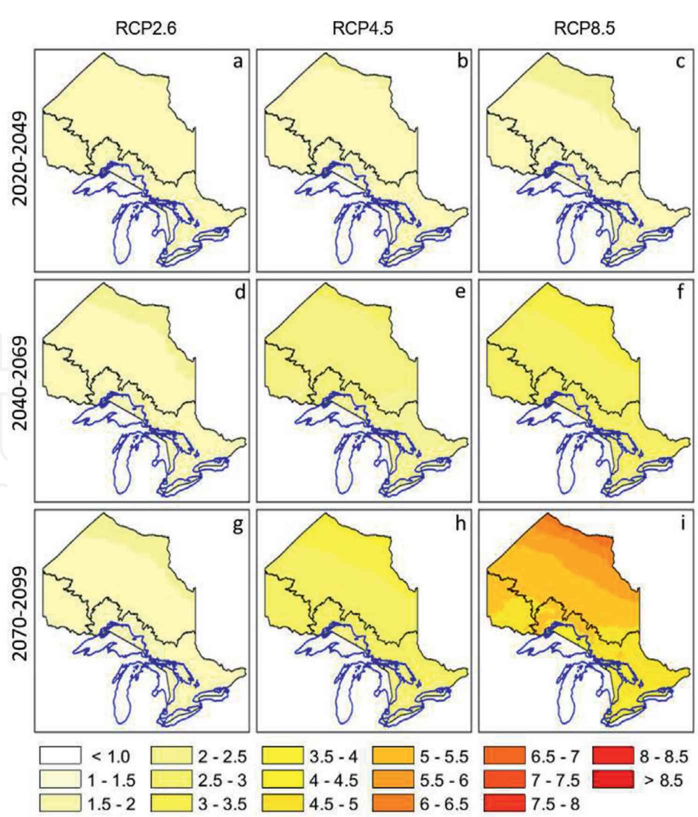

Figure 5.
Projected changes in Ontario's average annual temperature (°C) relative to the 1986–2005 reference period for representative concentration pathways (RCP) 2.6 (left column), 4.5 (middle column), and 8.5 (right column), over three 30-year time frames 2030s (2020–2049, top row), 2050s (2040–2069, middle row), and 2080s (2070–2099, bottom row). Maps reflect the 50th percentile of the super ensemble.

Change from 1986–2005 baseline		2020–2049			2040–2069			2070–2099		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Annual	Temperature (°C)	1.6(0.1)	1.7(0.1)	1.8(0.1)	1.8(0.1)	2.5(0.2)	3.2(0.3)	1.8(0.2)	3.2(0.3)	5.6(0.6)
		1.1–2.0	1.2–2.0	1.4–2.3	1.4–2.4	1.8–3.2	2.3–4.1	1.3–2.4	2.3–4.2	4.0–7.3
	Precipitation (mm)	10.5(33.6)	7.4(31.5)	18.6(25.8)	17(32.7)	23.9(32.4)	47(27.9)	12.6(37.1)	34.5(30.7)	86.9(29.8)
		−91 to 97	−73 to 92	−51 to 90	−93 to 108	−62 to 111	−27 to 121	−83 to 112	−50 to 122	7–177
Summer	Temperature (°C)	1.3(0.1)	1.4(0.1)	1.6(0.1)	1.5(0.1)	2.2(0.1)	2.9(0.1)	1.5(0.1)	2.8(0.1)	5.1(0.3)
		1.1–1.7	1.2–1.6	1.3–1.9	1.2–2.1	1.8–2.6	2.3–3.4	1.1–2.0	2.3–3.5	4.0–6.3
	Precipitation (mm)	−33.4(24.8)	−33.1(24.6)	−28.8(22.5)	−32.7(23.8)	−33.9(24.9)	−30.5(23.8)	−32.3(24.5)	−33.6(24.7)	−32.9(24.8)
		−111 to 17	−111 to 19	−98 to 19	−108 to 19	−113 to 19	−106 to 19	−109 to 26	−115 to 17	−112 to 16
Winter	Temperature (°C)	1.9(0.3)	2.2(0.4)	2.4(0.5)	2.5(0.4)	3.4(0.6)	4.3(0.8)	2.6(0.5)	4.3(0.8)	7.4(1.5)
		1.3–3.2	1.3–3.5	1.4–3.9	1.5–4.2	1.9–5.3	2.3–6.7	1.5–4.2	2.4–6.9	3.8–11.7
	Precipitation (mm)	27.3(9.0)	26.1(8.8)	26.4(7.7)	28.8(9.1)	31.7(9.0)	35.9(9.0)	27(8.6)	35.7(9.5)	52.4(10.1)
		−47 to 68	−26 to 60	−11 to 57	−51 to 65	−19 to 65	−2 to 71	−46 to 59	−21 to 74	15–89

For each entry, the first row is the provincial average, followed by the standard deviation (SD) in brackets. The second row is the range across the province (minimum to maximum).

Table 1.
Projected changes in temperature and precipitation relative to the 1986–2005 reference period for the entire province of Ontario, under three IPCC-defined representative concentration pathways (RCP2.6, RCP4.5, and RCP8.5), and for three time periods (2030s: 2020–2049, 2050s: 2040–2069, 2080s: 2070–2099).

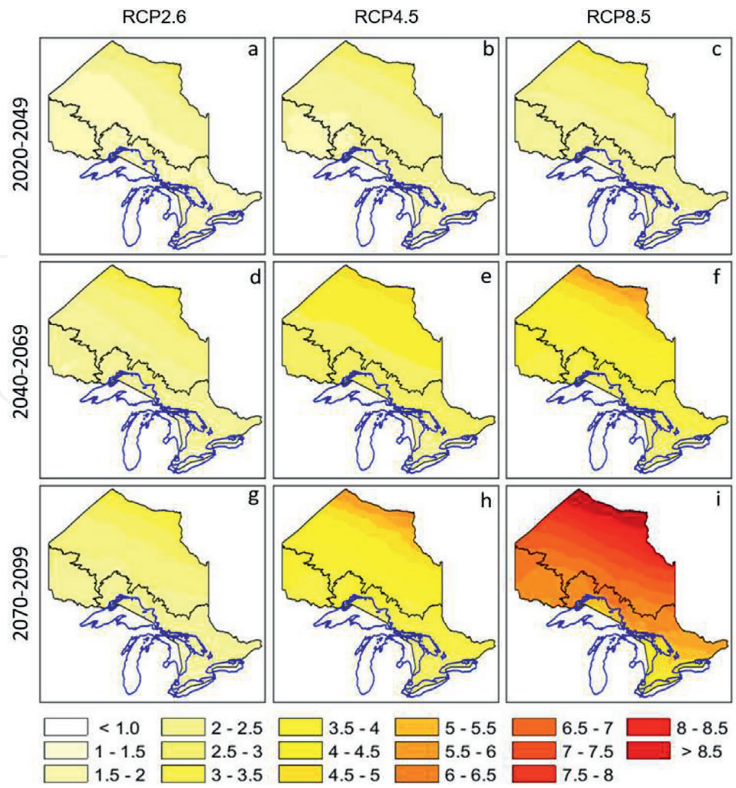

Figure 6.
*Same as in **Figure 5** but for winter temperature (°C).*

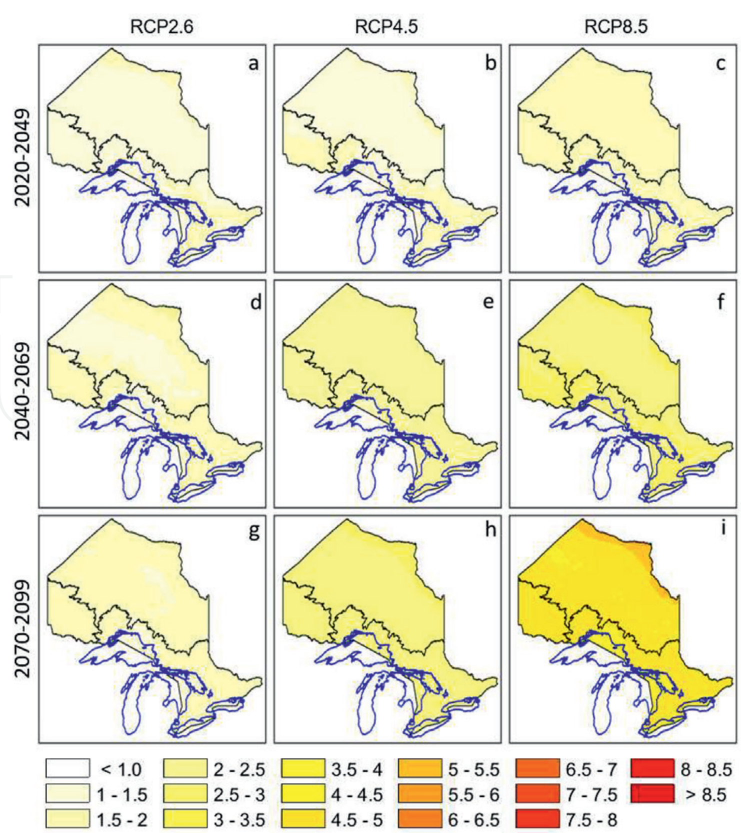

Figure 7.
*Same as in **Figure 5** but for summer temperature (°C).*

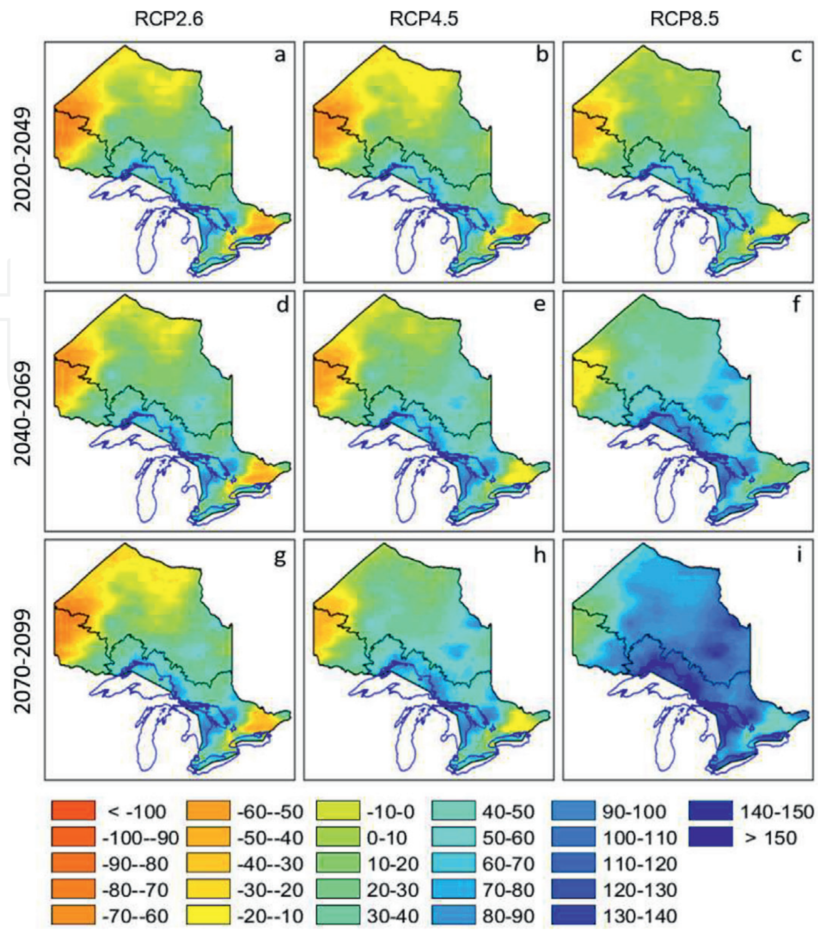

Figure 8.
*Same as in **Figure 5** but for annual total precipitation (mm).*

precipitation of more than 150 mm (**Table 1**; **Figures 4** and **8**), whereas the Nelsen River Basin and the western Hudson Bay Basin are projected to become drier with projected precipitation decreases of up to 93 mm relative to the 1986–2005 reference period (**Table 1**; **Figures 4** and **8**).

Provincial average summer precipitation is projected to decrease up to 33.4 mm (12.1%) by the 2030s, 33.9 mm (12.3%) by the 2050s and 33.6 mm (12.2%) by the 2080s when considering all RCPs; while provincial average winter precipitation is projected to increase up to 27.3 mm (25%) by the 2030s, 35.9 mm (33%) by the 2050s and 52.4 mm (48%) by the 2080s. Summer precipitation is projected to decrease up to 115 mm over the Nelson River basin by the 2080s (**Table 1**; **Figures 4** and **9**); while winter precipitation is projected to increase up to 89 mm over some Great Lakes' eastern coastal regions relative to the reference period (**Table 1**; **Figures 4** and **10**).

3.3 Climate projections for the Hudson Bay Basin

Mean annual air temperature is projected to increase over the Hudson Bay Basin for the rest of this century when considering all RCPs. Temperature increases are projected to range from 1.4 to 7.3°C across the basin relative to the 1986–2005 reference period under all RCPs (**Table 2**; **Figures 5** and **11**). The northern portion of the basin is projected to warm faster than the southern portion (**Figure 5**). The average annual temperature across the basin is expected to increase by 1.4–2.3°C by the 2030s, 1.7–4.1°C by the 2050s, and 1.7–7.3°C by the 2080s (**Table 2**; **Figures 5** and **11**).

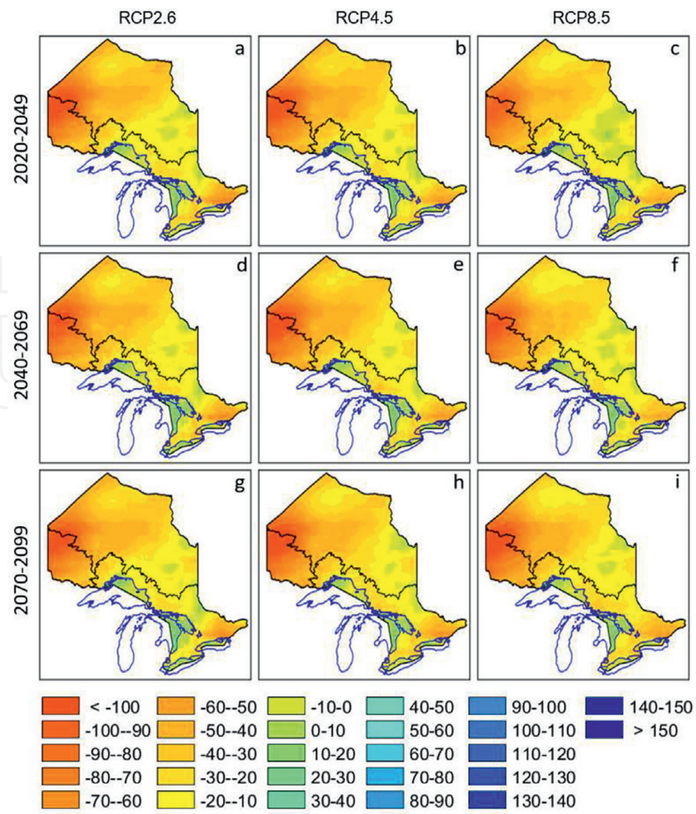

Figure 9.
*Same as in **Figure 8** but for summer total precipitation (mm).*

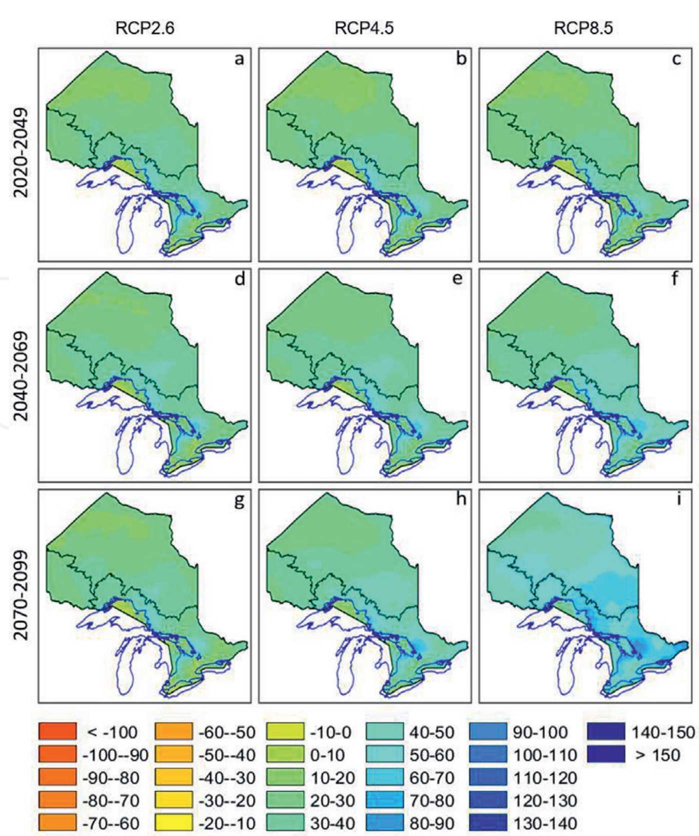

Figure 10.
*Same as in **Figure 8** but for winter total precipitation (mm).*

Change from 1986–2005 baseline		2020–2049			2040–2069			2070–2099		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Annual	Temperature (°C)	1.6(0.1)	1.7(0.1)	1.9(0.1)	1.9(0.1)	2.6(0.2)	3.4(02)	1.9(0.1)	3.4(0.2)	6.0(0.4)
		1.4–2.0	1.6–2.0	1.7–2.3	1.7–2.4	2.4–3.2	3.1–4.1	1.7–2.4	3.1–4.2	5.3–7.3
	Precipitation (mm)	5.8(25.7)	0.6(22.7)	14.8(18.2)	11.3(23.9)	17.6(23.8)	42.1(20.5)	3.6(26.7)	30.9(23.4)	84.6(23.6)
		−76 to 97	−72 to 85	−39 to 82	−64 to 103	−59 to 105	−22 to 121	−78 to 101	−43 to 122	15–177
Summer	Temperature (°C)	1.3(0.1)	1.4(0.1)	1.6(0.1)	1.5(0.2)	2.2(0.1)	2.9(0.1)	1.5(0.1)	2.8(0.2)	5.1(0.2)
		1.1–1.7	1.3–1.6	1.5–1.9	1.3–2.1	2.1–2.6	2.7–3.4	1.4–2.0	2.6–3.5	4.9–6.3
	Precipitation (mm)	−34.5(20.4)	−34.7(19)	−29(18.2)	−33.8(18.8)	−34.6(19.3)	−29.4(18.6)	−34.9(18.4)	−33(19.5)	−31.2(20.2)
		−111 to 8	−109 to 9	−95 to 11	−107 to 11	−110 to 10	−103 to 10	−108 to 7	−110 to 14	−110 to 13
Winter	Temperature (°C)	2.1(0.4)	2.4(0.4)	2.7(0.4)	2.7(0.5)	3.8(0.5)	4.8(0.6)	2.9(0.4)	4.8(0.7)	8.4(1.1)
		1.6–3.2	1.8–3.5	2.1–3.9	2.0–4.2	3.1–5.3	3.8–6.7	2.2–4.2	3.8–6.9	6.6–11.7
	Precipitation (mm)	25.2(6.2)	23.9(6)	24.9(5.2)	27.8(6.7)	29.8(6.7)	33.3(6.8)	26.2(6.1)	33.4(6.8)	50.1(8.4)
		1–41	5–43	10–39	4–47	11–47	19–51	3–44	16–51	35–69

Table 2.
*Same as in **Table 1** but for the Hudson Bay Basin.*

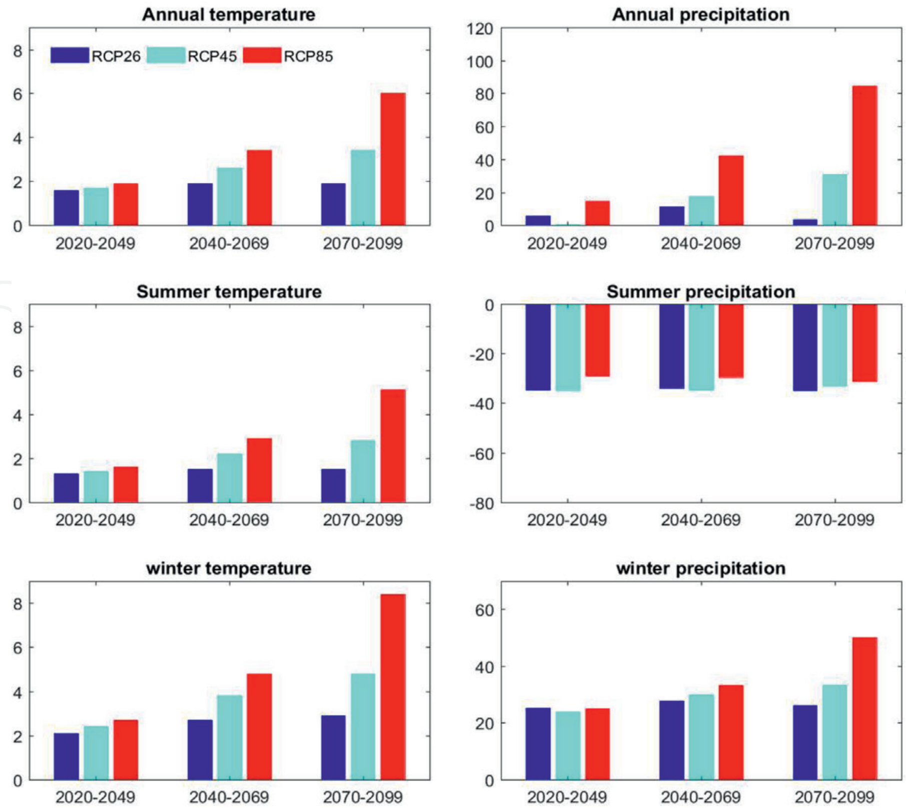

Figure 11.
*Same as in **Figure 4** but for the Hudson Bay Basin.*

Basin-averaged annual precipitation is projected to increase up to 14.8 mm (2%) by the 2030s, 42.1 mm (6%) by the 2050s and 84.6 mm (12%) by the 2080s (**Table 2**, **Figure 11**). Annual total precipitation is projected to increase in the southeastern area of the basin and decrease in the northwest (**Figure 8**).

Summer temperature across the Hudson Bay Basin is projected to increase 1.1–1.9°C by the 2030s, 1.3–3.4°C by the 2050s and 1.4–6.3°C by the 2080s when considering all RCPs (**Table 2**; **Figure 4**). Summer precipitation is projected to decline across the basin (**Table 2**; **Figures 9** and **11**), decreasing by up to 110 mm by the 2080s relative to the 1986–2005 reference period (**Table 2**; **Figure 9**). Basin-average summer precipitation is projected to decrease up to 34.7 mm (12.9%) by the 2030s, 34.6 mm (12.9%) by the 2050s and 34.9 mm (13.0%) by the 2080s when considering all RCPs (**Table 2**; **Figure 11**).

The average winter temperature across the Hudson Bay Basin is projected to increase 1.6–3.9°C by the 2030s, 2.0–6.7°C by the 2050s, and 2.2–11.7°C by the 2080s when considering all RCPs (**Table 2**; **Figure 11**). The most significant warming is expected to occur in the northern part of the province along the Hudson Bay coast under RCP 8.5 (**Figure 6**).

Basin-average winter precipitation is projected to increase up to 25.2 mm (30%) by the 2030s, 33.3 mm (41%) by the 2050s and 50.1 mm (61%) by the 2080s (**Table 2**; **Figure 11**). Average winter precipitation across the basin is projected to increase by 1–41 mm by the 2030s, 4–47 mm by the 2050s and 3–44 mm by the 2080s under RCP 2.6; and 10–39 mm by the 2030s, 19–51 mm by the 2050s, and 35–69 mm by the 2080s under RCP 8.5 (**Table 2**; **Figure 11**).

Change from 1986–2005 baseline		2020–2049			2040–2069			2070–2099		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Annual	Temperature (°C)	1.5(0.04)	1.7(0.05)	1.8(0.03)	1.8(0.05)	2.5(0.04)	3.2(0.05)	1.8(0.05)	3.2(0.06)	5.5(0.08)
		1.5–1.6	1.6–1.7	1.8–1.9	1.7–1.9	2.4–2.6	3.1–3.3	1.7–1.9	3.1–3.3	5.3–5.7
	Precipitation (mm)	−24(37.4)	−25.7(31.9)	−12.2(26.3)	−12.4(35.1)	−14.3(31.2)	15(28.8)	−24.9(37.3)	−1.6(30.5)	51.7(30.4)
		−78 to 51	−73 to 45	−51 to 48	−70 to 52	−62 to 56	−27 to 71	−83 to 51	−50 to 64	7–115
Summer	Temperature (°C)	1.3(0.05)	1.5(0.05)	1.7(0.05)	1.5(0.04)	2.2(0.04)	3.0(0.06)	1.5(0.03)	2.8(0.05)	5.2(0.07)
		1.2–1.5	1.4–1.6	1.5–1.8	1.4–1.6	2.1–2.4	2.9–3.1	1.4–1.6	2.7–2.9	5.1–5.5
	Precipitation (mm)	−69.9(24.5)	−71.8(23.3)	−65.2(20)	−69.1(21.8)	−74.7(23)	−72.3(20.7)	−69.1(23.6)	−74.8(23.9)	−75.7(22.6)
		−110 to −24	−111 to −28	−98 to −27	−108 to −29	−113 to −30	−106 to −32	−109 to −24	−115 to −31	−112 to −33
Winter	Temperature (°C)	1.6(0.1)	1.9(0.1)	2.2(0.1)	2.1(0.1)	3.2(0.1)	3.9(0.2)	2.3(0.1)	4.0(0.2)	6.8(0.3)
		1.5–1.8	1.8–2.1	2.1–2.4	1.9–2.4	3.0–3.4	3.7–4.3	2.1–2.6	3.7–4.3	6.3–7.5
	Precipitation (mm)	26.6(4.1)	26.3(3.5)	25.7(2.8)	28.4(4.1)	31.6(3.7)	33.5(2.9)	27.3(3.8)	33.5(3.9)	48.1(4)
		18–41	19–39	19–36	19–41	24–44	27–43	19–40	25–45	40–58

Table 3.
Same as in ***Table 1*** *but for the Nelson River Basin.*

3.4 Climate projections for the Nelson River Basin

Basin-averaged annual mean air temperature over the Nelson River Basin is projected to increase by up to 5.5°C by the 2080s (**Table 3**; **Figures 3** and **10**). Annual temperature is expected to increase, across the basin, 1.5 to 1.9°C by the 2030s, 1.7 to 3.3°C by the 2050s, and 1.7 to 5.7°C by the 2080s when considering all RCPs (**Table 3**). Although basin-wide average precipitation may increase by up to 51.7 mm (7%) by the 2080s (**Table 3**), there is significant variation across the basin. For example, total annual precipitation is likely to decrease under all RCPs for all periods in the western portion of the basin while slightly increasing in the eastern portion (**Figure 8**).

Average summer temperatures across the Nelson River Basin are projected to increase 1.2 to 1.8°C by the 2030s, 1.4 to 3.1°C by the 2050s, and 1.4 to 5.5°C by the 2080s when considering all RCPs (**Table 3**; **Figures 7** and **12**). Average summer precipitation is projected to decline over the basin throughout the century (**Table 3**; **Figures 9** and **12**) and by the 2080s, rainfall may decrease by up to 115 mm relative to the 1986–2005 reference period (**Table 3**).

Winter temperatures across the Nelson River Basin are projected to increase 1.5 to 2.4°C by the 2030s, 1.9 to 4.3°C by the 2050s, and 2.1 to 7.5°C by the 2080s when considering all RCPs (**Table 3**; **Figure 6**). Winter precipitation is projected to increase by 18–58 mm across the basin under all RCPs (**Table 3**; **Figure 10**). Basin-averaged winter precipitation is projected to increase 25.7 mm (32%) by the 2030s, 33.5 mm (42%) by the 2050s and 48.1 mm (60%) by the 2080s under the business-as-usual greenhouse gas emission scenario (RCP 8.5).

3.5 Climate projections for the Great Lakes Basin

Annual average air temperature across the Great Lakes Basin is projected to increase 1.1 to 1.9°C by the 2030s, 1.4 to 3.3°C by the 2050s and 1.3 to 5.7°C by the

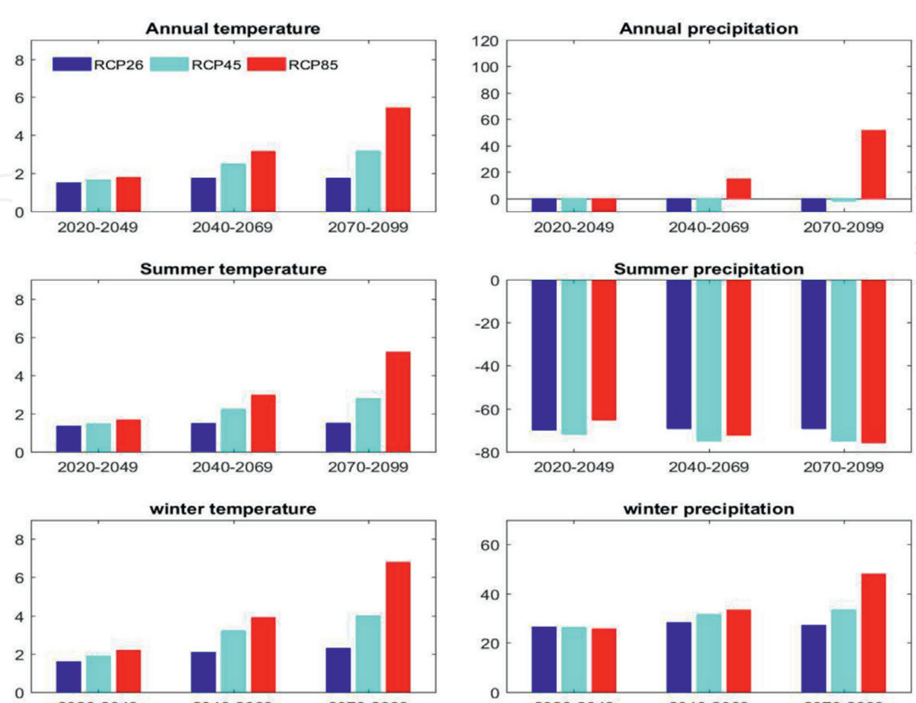

Figure 12.
*Same as in **Figure 4** but for the Nelson River Basin.*

Change from 1986–2005 baseline		**2020–2049**			**2040–2069**			**2070–2099**		
		RCP2.6	**RCP4.5**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP8.5**
Annual	Temperature (°C)	1.5(0.1)	1.6(0.1)	1.7(0.1)	1.8(0.1)	2.3(0.2)	3.0(0.2)	1.7(0.1)	3.0(0.2)	5.1(0.4)
		1.1–1.7	1.2–1.7	1.4–1.9	1.4–2.0	1.8–2.6	2.3–3.3	1.3–1.9	2.3–3.3	4.0–5.7
	Precipitation (mm)	30.4(31)	30.2(27.9)	35.7(23.5)	37(32.7)	47.7(26.8)	66.5(23.8)	40.6(32.5)	53(28)	103.2(26.7)
		−91 to 97	−55 to 92	−30 to 90	−93 to 108	−49 to 111	−3 to 119	−83 to 112	−48 to 114	18–168
Summer	Temperature (°C)	1.4(0.1)	1.4(0.1)	1.6(0.1)	1.5(0.1)	2.2(0.1)	2.9(0.2)	1.5(0.1)	2.7(0.1)	4.9(0.3)
		1.1–1.7	1.2–1.6	1.3–1.8	1.2–1.8	1.8–2.4	2.3–3.2	1.1–1.7	2.3–3.0	4.0–5.4
	Precipitation (mm)	−18.8(16.4)	−16.9(15.5)	−16 (14.2)	−18.3(16.5)	−18.6(15.6)	−17.9(14.3)	−15.4(16.4)	−20.2(15.2)	−20.9(14.4)
		−72 to 17	−59 to 19	−54 to 19	−66 to 19	−63 to 19	−53 to 19	−67 to 26	−66 to 17	−57 to 16
Winter	Temperature (°C)	1.8(0.2)	1.9(0.2)	2.0(0.2)	2.2(0.2)	2.8(0.4)	3.5(0.5)	2.2(0.2)	3.5(0.4)	6.0(0.8)
		1.3–2.0	1.3–2.2	1.4–2.3	1.5–2.6	1.9–3.4	2.3–4.3	1.5–2.5	2.4–4.3	3.8–7.4
	Precipitation (mm)	31.1(12.3)	29.6(12.2)	29.2(10.9)	30.6(12.7)	35(12.1)	41(11)	28.3(12.3)	40.2(12.6)	57.6(11.8)
		−47 to 68	−26 to 60	−11 to 57	−51 to 65	−19 to 65	−2 to 71	−46 to 59	−21 to 74	15–89

Table 4.
*Same as in **Table 1** but for the Great Lakes Basin.*

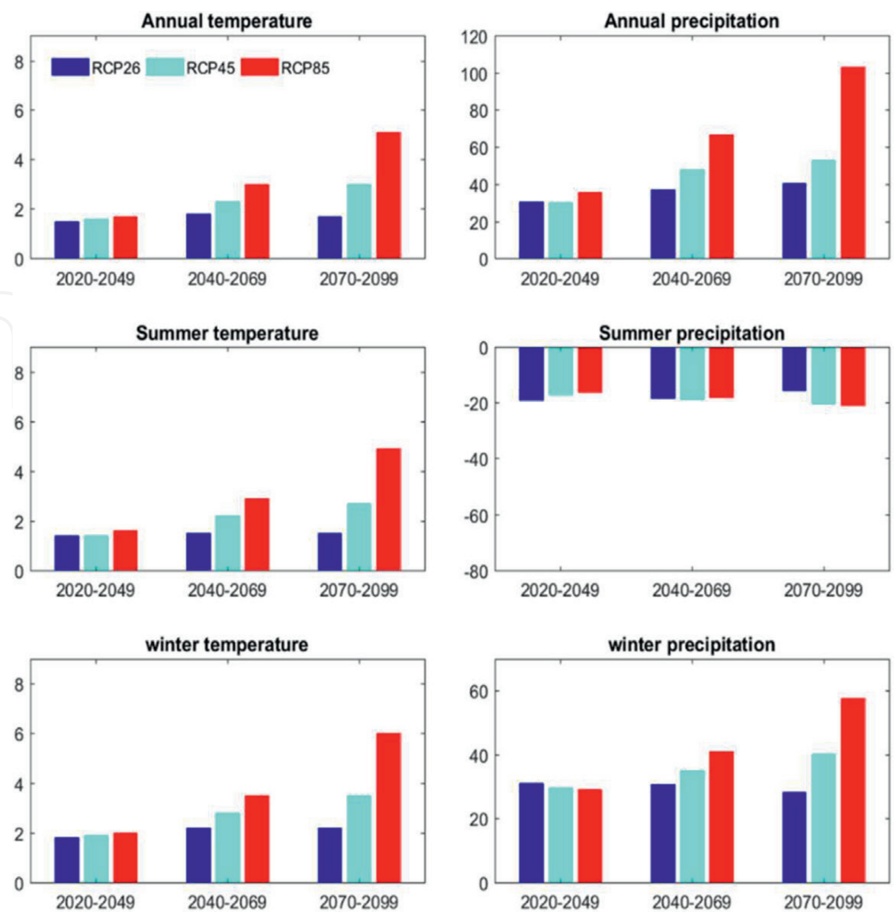

Figure 13.
Same as in ***Figure 4*** *but for the Great Lakes Basin.*

2080s when considering all RCPs (**Table 4**; **Figures 5** and **13**). Warming is projected to be more significant in the northern portion of the basin compared to its southern portion (**Figure 5**). Basin-averaged annual precipitation is projected to increase 35.7 mm (4%) by the 2030s, 66.5 mm (7%) by the 2050s and 103.2 mm (11%) by the 2080s under RCP8.5 (**Table 4**). The greatest change is expected to occur in the Lake Superior Basin (**Figure 8**). Lake effect precipitation is also evident in most future projections (**Figure 8**).

Average summer temperatures across the Great Lakes Basin are projected to increase 1.1 to 5.4°C by the 2080s (**Table 4**; **Figures 7** and **13**). Summer temperature changes are relatively uniform in space. Summer precipitation is projected to decrease over most portions of the basin except for slight increases over lakes and some over-land locations (**Figure 9**). Under RCP 8.5, basin-averaged precipitation is projected to decrease 16 mm (6%) by the 2030s, 17.9 mm (7%) by the 2050s, and 20.9 mm (8%) by the 2080s (**Table 4**).

Average winter temperature across the Great Lakes Basin is projected to increase 1.3 to 2.3°C by the 2030s, 1.5 to 4.3°C by the 2050s, and 1.5 to 7.4°C by the 2080s (**Table 4**; **Figures 6** and **13**). Winter precipitation is expected to increase across the basin under all RCPs. Basin-averaged winter precipitation is projected to increase 29.2 mm (18%) by the 2030s, 41 mm (25%) by the 2050s and 57.6 mm (35%) by the 2080s under RCP 8.5 (**Table 4**; **Figure 13**).

	Change from 1986–2005 baseline		**2020–2049**			**2040–2069**			**2070–2099**		
			RCP2.6	**RCP4.5**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP8.5**
Lake Superior Basin	Annual	Temperature (°C)	1.5(0.1)	1.6(0.1)	1.7(0.1)	1.8(0.1)	2.4(0.1)	3.1(0.2)	1.7(0.1)	3.1(0.2)	5.3(0.3)
			1.3–1.7	1.4–1.7	1.4–1.9	1.5–2.0	2.0–2.6	2.6–3.3	1.4–1.9	2.6–3.3	4.5–5.7
		Precipitation (mm)	44.6(12.4)	41.1(14.8)	45.3(15)	52.3(14.9)	56(15.5)	75.3(16.3)	50.9(15.3)	65.4(14.8)	120(16.4)
			19–88	10–84	15–87	24–99	24–99	44–119	21–95	36–112	87–168
	Summer	Temperature (°C)	1.3(0.1)	1.4(0.1)	1.5(0.1)	1.4(0.1)	2.1(0.1)	2.8(0.2)	1.4(0.1)	2.7(0.1)	4.9(0.3)
			1.1–1.5	1.2–1.6	1.3–1.8	1.2–1.6	1.8–2.3	2.4–3.1	1.2–1.6	2.4–2.9	4.4–5.4
		Precipitation (mm)	−16.7(12.2)	−18.8(13)	−16.5(11.8)	−19.5(13.2)	−19.9(13.6)	−20(12.7)	−15.9(12.6)	−21.5(12.5)	−20.7(13.1)
			−43 to 14	−44 to 15	−40 to 11	−47 to 10	−47 to 11	−45 to 8	−41 to 13	−48 to 8	−47 to 9
	Winter	Temperature (°C)	1.8(0.1)	2(0.1)	2.1(0.2)	2.3(0.1)	3.1(0.2)	3.8(0.3)	2.3(0.1)	3.8(0.3)	6.6(0.6)
			1.5–2.0	1.7–2.2	1.7–2.3	2.0–2.6	2.6–3.4	3.0–4.3	2.0–2.5	3.2–4.3	5.3–7.4
		Precipitation (mm)	30.8(12.7)	30.1(14)	28.8(12.5)	33.8(12.9)	35.4(13.5)	38.1(12.2)	31.5(13.1)	38.3(13.9)	53.5(12.6)
			−1 to 53	−1 to 56	1–50	3–55	5–61	11–61	1–55	8–64	25–78
Lake Huron Basin	Annual	Temperature (°C)	1.5(0.1)	1.6(0.1)	1.7(0.1)	1.8(0.1)	2.3(0.1)	3.0(0.2)	1.7(0.1)	3.0(0.2)	5.0(0.3)
			1.2–1.6	1.4–1.7	1.5–1.8	1.5–2.0	2.0–2.5	2.5–3.3	1.5–1.9	2.5–3.2	4.3–5.5
		Precipitation (mm)	44.2(23.6)	43.9(20.8)	45.9(18)	51(24.4)	61.1(21)	75.5(19.8)	58.2(23.8)	65.7(20.3)	109(21.4)
			−33 to 97	−26 to 92	−15 to 90	−33 to 108	−2 to 111	15–119	−21 to 112	−4 to 114	36–155
	Summer	Temperature (°C)	1.4(0.1)	1.5(0.1)	1.6(0.1)	1.6(0.1)	2.2(0.1)	2.9(0.2)	1.5(0.1)	2.7(0.1)	5.0(0.3)
			1.2–1.7	1.3–1.6	1.4–1.8	1.3–1.8	1.9–2.4	2.5–3.1	1.3–1.7	2.4–3.0	4.3–5.3
		Precipitation (mm)	−12.4(13.6)	−9.7(13.6)	−9.4(12.7)	−10.2(13.9)	−11.8(14.2)	−11.2(13)	−8(14.1)	−13.4(13.5)	−15.8(14.1)
			−46 to 17	−42 to 19	−41 to 19	−45 to 19	−41 to 19	−41 to 19	−41 to 26	−44 to 17	−43 to 16
	Winter	Temperature (°C)	1.8(0.1)	1.9(0.2)	2.0(0.2)	2.2(0.2)	2.8(0.3)	3.4(0.4)	2.1(0.2)	3.5(0.3)	5.8(0.7)
			1.5–2.0	1.5–2.1	1.5–2.3	1.7–2.5	2.1–3.2	2.6–3.9	1.7–2.4	2.7–3.9	4.4–6.8
		Precipitation (mm)	37.5(10.9)	33.9(11.5)	32(10.4)	34.7(11.7)	39(11.6)	44.2(10.7)	32.6(11)	44.7(12.3)	60.6(10.9)
			12–68	7–60	7–57	8–65	13–65	19–71	7–59	17–74	35–89

Change from 1986–2005 baseline			2020–2049			2040–2069			2070–2099		
			RCP2.6	**RCP4.5**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP8.5**
Lake Erie Basin	Annual	Temperature (°C)	1.4(0.1)	1.5(0.1)	1.6(0.1)	1.7(0.2)	2.2(0.2)	2.8(0.2)	1.6(0.1)	2.7(0.2)	4.6(0.4)
			1.2–1.6	1.2–1.6	1.4–1.7	1.4–1.9	1.8–2.4	2.3–3.1	1.3–1.8	2.3–3.0	4.0–5.1
		Precipitation (mm)	23.5(21.4)	25(19.6)	30.2(17.8)	30.3(22.8)	45.4(21.1)	65.5(19.1)	35.8(23.9)	40.1(20.3)	89.5(20.7)
			−84 to 70	−54 to 75	−30 to 72	−78 to 82	−49 to 90	−3 to 105	−83 to 84	−48 to 88	18–132
	Summer	Temperature (°C)	1.4(0.1)	1.4(0.1)	1.6(0.1)	1.6(0.2)	2.2(0.2)	2.9(0.2)	1.5(0.1)	2.7(0.2)	4.9(0.4)
			1.1–1.6	1.2–1.6	1.4–1.8	1.2–1.8	1.8–2.4	2.5–3.2	1.2–1.7	2.3–3.0	4.1–5.3
		Precipitation (mm)	−18.3(12.1)	−15.6(11.8)	−17.2(10.5)	−15.4(12.9)	−16.7(11.6)	−15(10.2)	−10.9(10.9)	−19(10.8)	−19.5(9.8)
			−49 to 11	−44 to 14	−42 to 8	−47 to 12	−45 to 10	−40 to 7	−40 to 13	−49 to 10	−43 to 6
	Winter	Temperature (°C)	1.5(0.1)	1.6(0.1)	1.6(0.1)	1.8(0.2)	2.2(0.2)	2.7(0.3)	1.8(0.2)	2.9(0.2)	4.6(0.4)
			1.3–1.7	1.3–1.8	1.4–1.9	1.5–2.2	1.9–2.6	2.3–3.3	1.5–2.1	2.4–3.4	3.8–5.5
		Precipitation (mm)	17.5(9.6)	17.7(8.8)	18.5(6.8)	15.6(9.3)	21.8(8.7)	32.3(7.6)	14.6(9.7)	29.3(10)	48.5(8.1)
			−47 to 47	−26 to 44	−11 to 38	−51 to 45	−19 to 48	−2 to 50	−46 to 43	−21 to 55	15–67
Lake Ontario Basin	Annual	Temperature (°C)	1.4(0.1)	1.5(0.1)	1.6(0.1)	1.7(0.2)	2.2(0.2)	2.9(0.2)	1.6(0.1)	2.8(0.2)	4.8(0.4)
			1.1–1.6	1.3–1.7	1.4–1.8	1.4–1.9	1.9–2.4	2.4–3.1	1.3–1.8	2.4–3.0	4.0–5.2
		Precipitation (mm)	−10.4(30)	−6.7(24.2)	6.5(21.9)	−7.3(31.9)	14.9(25.7)	39.5(23.8)	−3.3(32.3)	16.6(27.7)	70.1(26.1)
			−91 to 55	−55 to 47	−30 to 59	−93 to 59	−49 to 71	−3 to 94	−83 to 62	−48 to 79	18–132
	Summer	Temperature (°C)	1.4(0.1)	1.4(0.1)	1.7(0.1)	1.5(0.2)	2.2(0.1)	2.9(0.2)	1.5(0.2)	2.7(0.2)	4.9(0.3)
			1.1–1.6	1.2–1.6	1.4–1.8	1.2–1.8	1.8–2.4	2.3–3.1	1.1–1.7	2.3–3.0	4.0–5.3
		Precipitation (mm)	−35.9(18.7)	−30.2(16.9)	−29.5(15.1)	−34.8(17.6)	−32(16.3)	−29.1(14.7)	−30.8(19.2)	−32.7(18.1)	−31.6(14.4)
			−72 to 6	−59 to 10	−54 to 8	−66 to 4	−63 to 6	−53 to 7	−67 to 9	−66 to 9	−57 to 2
	Winter	Temperature (°C)	1.7(0.1)	1.7(0.1)	1.8(0.2)	2.1(0.2)	2.5(0.2)	3.2(0.3)	2.0(0.2)	3.2(0.3)	5.3(0.5)
			1.4–1.8	1.5–1.9	1.6–2.1	1.7–2.4	2.1–2.9	2.7–3.6	1.7–2.3	2.7–3.6	4.4–6.1
		Precipitation (mm)	24.2(10.3)	24.4(9.3)	26.8(8.7)	21.2(10.2)	30.8(9.6)	41.4(9.2)	19.9(9.4)	38.3(9.8)	59.9(10.5)
			−40 to 55	−22 to 51	−11 to 51	−41 to 52	−15 to 58	−2 to 64	−41 to 49	−16 to 66	15–83

	Change from 1986–2005 baseline		2020–2049			2040–2069			2070–2099		
			RCP2.6	**RCP4.5**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP8.5**	**RCP2.6**	**RCP4.5**	**RCP8.5**
Ottawa River Basin	Annual	Temperature (°C)	1.53(0.05)	1.62(0.04)	1.77(0.04)	1.90(0.02)	2.38(0.04)	3.10(0.03)	1.8(0.04)	3.0(0.05)	5.2(0.11)
			1.5–1.6	1.5–1.7	1.6–1.8	1.8–1.9	2.3–2.4	2.8–3.2	1.7–1.8	2.8–3.1	4.8–5.4
		Precipitation (mm)	−1.7(32)	2.5(29.5)	13.4(23)	3.7(32.8)	21.4(26.6)	43.4(20.3)	9.7(35.3)	28.1(30.3)	80.9(22.9)
			−66 to 62	−50 to 59	−26 to 62	−64 to 74	−31 to 78	6–84	−65 to 79	−32 to 88	35–122
	Summer	Temperature (°C)	1.43(0.06)	1.45(0.05)	1.67(0.05)	1.58(0.05)	2.2(0.03)	2.9(0.06)	1.5(0.05)	2.76(0.05)	5.1(0.06)
			1.3–1.5	1.4–1.5	1.6–1.8	1.5–1.7	2.1–2.3	2.8–3.0	1.4–1.6	2.7–2.8	4.8–5.2
		Precipitation (mm)	−28.8(18.9)	−22.6(17)	−22 (15)	−26.7(17.5)	−25.4(16)	−24.4(13.8)	−24.8(18)	−26.8(16.6)	−28.8(12.9)
			−72 to 4	−59 to 6	−54 to 4	−65 to 4	−63 to 2	−53 to −1	−65 to 7	−66 to 0	−57 to −7
	Winter	Temperature (°C)	1.9(0.1)	2.0(0.1)	2.2(0.1)	2.4(0.1)	3.0(0.1)	3.8(0.2)	2.3(0.1)	3.8(0.2)	6.4(0.3)
			1.7–2.0	1.8–2.2	1.9–2.3	2.2–2.5	2.6–3.3	3.3–4.1	2.1–2.4	3.3–4.1	5.4–7.1
		Precipitation (mm)	32.2(5.4)	31.4(4.9)	33.5(4.8)	31(5.8)	37.7(4.8)	46.2(5.7)	27.4(5.9)	44.2(5.4)	65.1(6.6)
			23–54	22–48	25–47	19–50	28–55	38–63	16–48	33–62	54–84

Table 5.
*Same as in **Table 1** but for the five Great Lakes sub-basins.*

3.6 Climate projections for the Great Lakes sub-basins

By the 2080s, the greatest increase in basin-averaged annual mean temperature is projected to occur over the Lake Superior sub-basin (1.7–5.3°C warmer relative to the 1986–2005 reference period), followed by the Ottawa River sub-basin (1.8–5.2°C warmer), the Lake Huron sub-basin (1.7–5.0°C warmer), the Lake Ontario sub-basin (1.6–4.8°C warmer), and the Lake Erie sub-basin (1.6–4.6°C warmer) when considering all RCPs (**Table 5**).

Basin-averaged annual precipitation is projected to increase over all five sub-basins under almost all RCPs (**Table 5**). By the 2080s, annual precipitation is likely to increase the most over the Lake Superior sub-basin (50.9–120 mm above 1986–2005 reference period when considering all RCPs), followed by the Lake Huron sub-basin (58.2–109 mm), the Lake Erie sub-basin (35.8–89.5 mm), the Ottawa River sub-basin (9.7–80.9 mm) and the Lake Ontario sub-basin (−3.3 to 70.1 mm) (**Table 5**).

Projected changes in basin-averaged summer mean air temperature are relatively uniform across the five sub-basins (**Figure 7**; **Table 5**). By the 2080s, the basin-averaged summer air temperature increases are projected to range from 1.5 to 4.9°C over the Lake Ontario sub-basin, 1.4 to 4.9°C over the Lake Superior sub-basin, 1.5 to 5.1°C over the Ottawa River basin, 1.5 to 5.0°C over the Lake Huron sub-basin and 1.5 to 4.9°Cover the Lake Erie sub-basin, when considering all RCPs (**Table 5**).

Summer precipitation is projected to decrease over all sub-basins (**Table 5**; **Figure 9**). By the 2080s, the greatest summer precipitation decrease is projected to occur over the Lake Ontario sub-basin (a decrease of 30.8–32.7 mm), while the least summer precipitation decrease is projected to occur over the Lake Huron sub-basin (a decrease of 8–15.8 mm) (**Table 5**; **Figure 9**) when considering all RCPs.

Significant spatial variation is found in the projected changes in winter air temperatures among the Great Lakes sub-basins. By the 2080s, the basin-averaged winter temperature is projected to be 2.0–5.3°C above the 1986–2005 reference values for the Lake Ontario sub-basin, 2.3–6.6°C for the Lake Superior sub-basin, 2.3–6.4°C for the Ottawa River sub-basin, 2.1–5.8°C for the Lake Huron sub-basin, and 1.8–4.6°C for the Lake Erie sub-basin when considering all RCPs (**Table 5**). The Lake Superior sub-basin may experience the greatest winter warming by the 2080s (up to 6.6°C warmer than the reference period under RCP8.5), followed by the Ottawa River sub-basin (up to 6.4°C warmer), the Lake Huron sub-basin (up to 5.8°C warmer), the Lake Ontario sub-basin (up to 5.3°C warmer), and the Lake Erie sub-basin (up to 4.6°C warmer) (**Table 5**).

Among the five sub-basins, the Ottawa River sub-basin is projected to experience the greatest increase in winter precipitation by the 2080s (27.4–65.1 mm above the reference period), followed by the Lake Huron sub-basin (32.6–60.6 mm), the Lake Ontario sub-basin (19.9–59.9 mm), the Lake Superior sub-basin (31.5–53.5 mm), and the Lake Erie sub-basin (14.6–48.5 mm), when considering all RCPs (**Table 5**). Dramatic spatial variations are found in the projected winter precipitation changes, even within a sub-basin. For example, the lake-effect snow belt areas in the Lake Huron sub-basin could expect up to 89 mm more winter precipitation than the 1986–2005 baseline values by the 2080s under RCP8.5, much higher than the rest of this sub-basin (**Table 5**; **Figure 10**).

4. Conclusions and discussion

The purpose of this chapter is to summarize the trends and spatial patterns in projected changes in annual and seasonal mean temperature and precipitation over the entire Province of Ontario, its three primary watersheds and associated sub-basins, under three IPCC's AR5 scenarios. These projections were developed using the IPCC-endorsed CMIP5 climate projections and state-of-the-science combine downscaling methodologies [6–9, 19].

These Ontario-specific high-resolution climate projections presented in this chapter indicate that increases in average annual temperature are expected to continue through the 21st century across the Province of Ontario; the Hudson Bay Basin could experience the largest increase in temperature (6.0°C) by the 2080s as compared to the Nelson River Basin (5.5°C) and the Great Lakes Basin (5.1°C) under the business-as-usual greenhouse gas emission scenario (RCP 8.5).

Projected changes in precipitation vary more significantly from region to region than the projected changes in temperature. While annual precipitation in the Nelson River Basin may decrease, precipitation may increase in other basins. The Great Lakes Basin is expected to experience precipitation increases, particularly over and near the lakes and in the Lake Superior sub-basin, and most dramatically in winter.

More detailed analyses on projected climate changes for 42 climate variables (including extremes) over 50 regions and 150 municipalities in Ontario are available through York University's Ontario Climate Data Portal (ODCP) [7–9]. Readers are referred to the OCDP and its references for these additional variables and more details on the development of the super-ensemble of Ontario-specific high-resolution climate projections.

While this study is based on the latest available science and data to us when this study was carried out, we understand that climate science and climate modeling techniques evolve rapidly [2]; therefore, as new data becomes available, specifically new CMIP6-based high-resolution regional projections using more advanced downscaling methodologies specific to the study area, this chapter should be updated to reflect the most up-to-date science and data.

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Conflict of interest

The authors declare no conflict of interest.

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