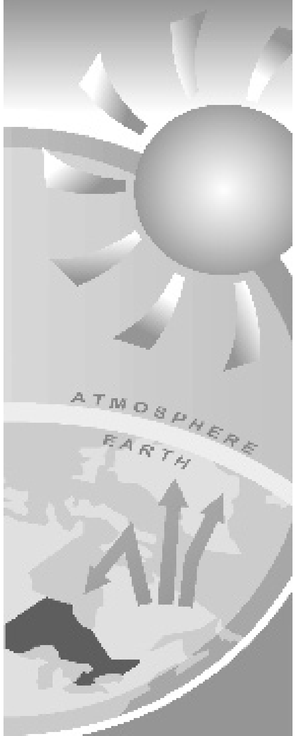
05

CLIMATE CHANGE RESEARCH REPORT

CCRR-05



Climate Change Projections for Ontario:

Practical Information for Policymakers and Planners

Responding to Climate Change Through Partnership

Ontario

Climate Change and MNR: A Program-Level Strategy and Action Plan

The following describes how the Ministry of Natural Resources works to contribute to the Ontario Government's commitment to reduce the rate of global warming and the impacts associated with climate change. The framework contains strategies and sub-strategies organized according to the need to understand climate change, mitigate the impacts of rapid climate change, and to help Ontarians adapt to climate change:

Theme 1: Understand Climate Change

Strategy #1: Gather and use knowledge in support of informed decision-making about climate change. Data and information gathering and management programs (e.g., research, inventory, monitoring, and assessment) that advances our knowledge of ecospheric function and related factors and forces such as climate change are critical to informed decision-making. Accordingly, MNR will work to:

- Strategy 1.A: Develop a provincial capability to describe, predict, and assess the important short- (0-5 years), medium- (5-20 years), and long-term (20+ years) impacts of climate change on the province's ecosystems and natural resources.
- Strategy 1.B: Model the carbon cycle.

Strategy #2: Use meaningful spatial and temporal frameworks to manage for climate change. A meaningful spatial and temporal context in which to manage human activity in the ecosphere and address climate change issues requires that MNR continue to define and describe Ontario's ecosystems in-space and time. In addition, MNR will use the administrative and thematic spatial units required to manage climate change issues.

Theme 2: Mitigate the Impacts of Climate Change

Strategy #3: Gather information about natural and cultural heritage values and ensure that this knowledge is used as part of the decision-making process established to manage for climate change impacts. MNR will continue to subscribe to a rational philosophy and corresponding suite of societal values that equip natural resource managers to take effective action in combating global warming and to help Ontarians adapt to the impacts of climate change.

Strategy #4: Use partnership to marshal a coordinated response to climate change. A comprehensive climate change program involves all sectors of society as partners and participants in decision-making processes. The Ministry of Natural Resources will work to ensure that its clients and partners are engaged.

Strategy #5: Ensure corporate culture and function work in support of efforts to combat rapid climate change. Institutional culture and function provide a "place" for natural resource managers to develop and/or sponsor proactive and integrated programs. The Ministry of Natural Resources will continue to provide a "home place" for the people engaged in the management of climate change issues.

Strategy #6: Establish on-site management programs designed to plan ecologically, manage carbon sinks, reduce greenhouse gas emissions, and develop tools and techniques that help mitigate the impacts of rapid climate change. On-site land use planning and management techniques must be designed to protect the ecological and social pieces, patterns, and processes. Accordingly, MNR will work to:

- Strategy 6.A: Plan ecologically.
- Strategy 6.B: Manage carbon sinks.
- Strategy 6.C: Reduce emissions.
- Strategy 6.D: Develop tools and techniques to mitigate the impacts of rapid climate change.

Theme 3: Help Ontarians Adapt

Strategy #7: Think and plan strategically to prepare for natural disasters and develop and implement adaptation strategies. MNR will sponsor strategic thinking and planning to identify, establish, and modify short- and long-term direction on a regular basis. Accordingly, MNR will work to:

- Strategy 7.A: Sponsor strategic management of climate change issues.
- Strategy 7B: Maintain and enhance an emergency response capability.
- Strategy 7.C: Develop and implement adaptation strategies for water management and wetlands.
- Strategy 7.D: Develop and implement adaptation strategies for human health.
- Strategy 7.E: Develop and implement adaptation strategies for ecosystem health, including biodiversity.
- Strategy 7.F: Develop and implement adaptation strategies for parks and protected areas for natural resource-related recreational opportunities and activities that are pursued outside of parks and protected areas.
- Strategy 7.G: Develop and implement adaptation strategies for forested ecosystems.

Strategy #8: Ensure policy and legislation respond to climate change challenges. Policy, legislation, and regulation guide development and use of the programs needed to combat climate change. MNR will work to ensure that its policies are proactive, balanced and realistic, and responsive to changing societal values and environmental conditions.

Strategy #9: Communicate. Ontarians must understand global warming, climate change, and the known and potential impacts in order to effectively and consistently participate in management programs and decision-making processes. Knowledge dissemination through life-long learning opportunities that are accessible and current is critical to this requirement. MNR will raise public understanding and awareness of climate change through education, extension, and training programs.

Climate Change Projections for Ontario:

Practical Information for Policymakers and Planners

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Summary

This publication is intended to help planners and policymakers in Ontario account for the potential impacts of climate change on people, infrastructure, and the environment. This overview of Ontario's future climate is based on the Canadian Coupled Global Circulation Model and uses two scenarios of future greenhouse gas emissions resulting from human activity in the 21st century, the A2 and the B2 scenarios. The A2 scenario projects future greenhouse gas concentrations reaching the equivalent of 1,320 ppm CO_2 by the year 2100 (pre-industrial levels were about 330 ppm). In an A2 world before the end of the century, summers in most of southern Ontario will on average be 5°C hotter and 20% less rain will fall from April to September compared with the period 1971-2000. Winters in some southern Ontario locations will be up to 6°C warmer, with 10 to 20% reductions in precipitation from October to March. In northern Ontario, temperatures in the A2 scenario will warm by up to 10°C in winter and 6°C in summer, with greatest warming adjacent to Hudson Bay. Large parts of the north will receive less precipitation, particularly in winter in areas near the Manitoba and Quebec borders. Up to 20% less summer precipitation will fall in the western half of northwestern Ontario by the end of the century. The B2 scenario is based on lower greenhouse gas emissions compared to scenario A2, with the atmosphere reaching the equivalent of 915 ppm CO_2 by 2100. As a result, the rate of climate change in a B2 world will be significant but less than if the A2 scenario comes about. In 2071-2100, for example, the B2 world will see 3 to 5°C warming in southern Ontario in summer and 4 to 5°C warming in winter compared with 1971-2000. Most of southern Ontario will receive up to 10% less precipitation during the warm season and up to 20% less precipitation in winter. In northern Ontario in 2071-2100, summers will warm by 3 to 5°C and winters by 4 to 9°C compared to 1971-2000. Temperature increases will be greatest in the far north. In the B2 world, much of northern Ontario will be considerably drier than in 1971-2000, with annual precipitation reduced by up to 10% in much of the northwest and some areas receiving 20 to 30% less cold season precipitation.

Résumé

Cette publication a pour but d'aider les planificateurs et les décideurs de l'Ontario à prendre en compte les effets potentiels des changements climatiques sur les personnes, les infrastructures et les environnements. Ce survol du futur climat de l'Ontario est basé sur le modèle canadien de circulation planétaire et il a recours à deux scénarios concernant les projections des émissions de gaz à effet de serre résultant de l'activité humaine au 21e siècle, les scénarios A2 et B2. Le premier prévoit de futures concentrations des gaz à effet de serre qui atteindraient l'équivalent de 1 320 ppm de CO_2 d'ici l'an 2100 (les niveaux préindustriels étaient d'environ 330 ppm). Selon le scénario A2, avant la fin du siècle on prévoit pour la plus grande partie du sud de l'Ontario des étés en moyenne plus chauds de 5 °C, avec 20 % moins de précipitations d'avril à septembre par rapport à la période 1971-2000. Dans certains emplacements du sud de l'Ontario les hivers seraient jusqu'à 6 °C plus chauds, avec de 10 à 20 % moins de précipitations d'octobre à mars. Toujours selon le scénario A2 dans le nord de l'Ontario, les hivers seraient jusqu'à 10 °C plus chauds et les étés jusqu'à 6 °C aussi, le réchauffement le plus marqué se situant près de la baie d'Hudson. De grandes parties du nord recevraient moins de précipitations surtout l'hiver, dans les secteurs frontaliers près du Manitoba et du Québec. La moitié ouest du nord-ouest de l'Ontario connaîtrait aussi jusqu'à 20 % moins de précipitations l'été d'ici la fin du siècle. Le scénario B2 est basé sur des niveaux d'émissions de gaz à effet de serre plus faibles par rapport au scénario A2, l'atmosphère atteignant l'équivalent de 915 ppm de CO_2 d'ici l'an 2100. En conséquence, les changements climatiques y seraient importants mais dans une moindre mesure par rapport au scénario A2. En 2071-2100 par exemple, on prévoit selon le scénario B2 des étés plus chauds de 3 à 5 °C pour le sud de l'Ontario et des hivers plus chauds de 4 à 5 °C par rapport à la période 1971-2000. La plus grande partie du sud de l'Ontario recevrait jusqu'à 10 % moins de précipitations pendant la saison chaude et jusqu'à 20 % moins de précipitations l'hiver. Dans le nord de l'Ontario en 2071-2100, les étés seraient de 3 à 5 °C plus chauds et les hivers de 4 à 9 °C plus chauds par

rapport à la période 1971-2000. Le réchauffement serait plus prononcé dans le grand nord. Selon le scénario B2, presque tout le nord de l'Ontario aurait un climat considérablement plus sec qu'en 1971-2000, avec une réduction des précipitations annuelles pouvant atteindre 10 % dans la plus grande partie du nord-ouest, certains secteurs recevant de 20 à 30 % moins de précipitations pendant la saison froide.

Acknowledgements

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The Province of Ontario has a key role to play in addressing climate change. There are still many legitimate debates ahead of us, and limited time. I encourage Ontario's policymakers to review for themselves the evidence regarding climate change. If they conclude, as I have, that the evidence is compelling, then it will be clear that the status quo is no longer an option, and they will be ready to focus on Ontario's response.

Gordon Miller (2002)
Environmental Commissioner of Ontario

Our overriding environmental challenge is the worldwide problem of climate change, global warming — the gathering crisis that requires worldwide action. The vast majority of scientists have concluded unequivocally that if we don't reduce the emission of greenhouse gases, at some point in the next century we'll disrupt our climate and put our children and grandchildren at risk.

U.S. President Bill Clinton
State of the Union, January 27, 1998.

We are the generation fated to live in the most interesting of times, for we are now the weather makers, and the future of biodiversity and civilization hangs on our actions.

Tim Flannery (2005)
The Weather Makers

Foreword

Most scientists hold the view that human activities are releasing greenhouse gases into the atmosphere in quantities sufficient to change Earth's climate. For this reason, the Ontario Ministry of Natural Resources is committed to helping Ontarians reduce the rate of global warming, respond to the impacts of climate change, and adapt to climate change.

To support Ontarians in meeting these objectives, we must understand climate change and the potential positive and negative impacts it may have on our communities, our people, and the ecosystems on which we depend. Understanding these impacts is a difficult task, because we do not know exactly how much greenhouse gas will be added to the atmosphere during the 21^{st} century and beyond. Therefore, we do not know precisely how Earth's temperature and precipitation will change: Will temperature increase a little, say 1^{o}C, or a lot, perhaps 8^{o}C?

Given this uncertainty, we believe it is wise to consider a range of possible outcomes for Ontario's climate. In this report and CD-ROM, two representations of how Ontario's climate could change throughout the 21^{st} century are presented. The climate conditions described are provided to stimulate discussion and support strategic planning and policy and program development in our changing world.

Fraser Dunn

Director
Applied Research and Development Branch
Ontario Ministry of Natural Resources

Contents

Introduction

Humans have adapted to live in most of Earth's climates, ranging from the arid, hot regions of North Africa to the cold Arctic climates of Canada's far north. Ontario's climate is diverse and includes areas with permafrost and long, cold winters, such as at Fort Severn on the shore of Hudson Bay to Windsor, where winters are mild, summers are hot and humid, and nearby vineyards flourish.

Although climate can be somewhat stable for several centuries, it changes due to natural variation in the amount of sunlight reaching the lower atmosphere. For example, solar radiation varies with shifts in Earth's orbit and its tilt relative to the Sun, both of which change over tens of thousands of years (Ruddiman 2001). The Sun itself releases varying amounts of energy, affecting global climate (Alverson *et al.* 2001). Large volcanic eruptions also affect climate by adding a veil of fine particles to the upper atmosphere that prevents incoming solar radiation from reaching the Earth's surface and heating the air near the ground. This veil of particles can cause climates to cool and in extreme cases affect global climate for several years (Robock 2000).

Such natural factors affect climate by altering the amount of the Sun's energy in the atmosphere. Climatologists have determined that greenhouse gases from industrial emissions are also causing climate change by altering the amount of the Sun's energy that is trapped in the atmosphere. Increased concentrations of greenhouse gases in the air keep more long-wave solar radiation in the lower atmosphere, increasing temperatures and altering precipitation (IPCC 2001). Since the start of the industrial revolution, humans have added large amounts of greenhouse gases to the atmosphere, mainly by burning fossil fuels that release carbon dioxide (CO_2) as a by-product of combustion. The fact that global temperature has increased dramatically since 1978, while the energy reaching the Earth from the Sun has remained constant, has led scientists to conclude that this rise in temperature is due to human activity (National Academies of Science 2006). They expect global climate change to accelerate unless people act now to reduce the rate at which greenhouse gases are emitted into the atmosphere (IPCC 2001). The rate and size of the projected changes in climate have raised public concerns about negative impacts on society and the environment.

Climate affects most aspects of our society, including human health, transportation infrastructure, employment, clean water, energy production and distribution, agriculture, and forestry (IPCC 2001). And as a major force in Earth's water cycle (e.g., rainfall, snowfall, stream and river flows, and lake levels), climate also influences the distribution, abundance, and behaviour of plants and animals.

Climate change will affect many of the societal and environmental values that Ontarians take for granted. As a result, the timing and extent of climate change and its potential harmful and/or beneficial effects need to be better understood, especially in sectors where long-term planning is needed. Knowing when to act, what actions to take, and whether it is wiser to be proactive in managing for potential change or to react to changes as they occur depend on understanding the potential benefits as well as the risks to Ontario's infrastructure, human activities, and ecosystems.

A proactive approach to management in a time of rapidly changing climate relies on understanding how climate may change. This report and the accompanying CD-ROM show selected potential future climates for Ontario, which policymakers and planners in public and private service may find useful in their work to help avoid dangerous and damaging situations and to take advantage of opportunities that may arise.

Methods

We present future climates of Ontario for 3 time periods and 2 scenarios of atmospheric greenhouse gas levels, produced using version 2 of Environment Canada's climate model, the Canadian Coupled Global Circulation Model (CGCM2) (Flato and Boer 2001). The climate data were interpolated to a finer spatial resolution by McKenney *et al.* (2006a, b). Maps of future climate are shown as the difference in temperature or precipitation compared with the climate of 1971-2000 (Figure 1).

Climate models predict the effect of higher greenhouse gases based on increasing amounts of heat trapped in the atmosphere. Increased heat affects virtually all aspects of weather, including precipitation, winds, air pressure, and humidity. Many global climate models have been developed. Each climate model is unique, based on different assumptions, and produces somewhat different projections of future climate when provided the same data. Readers interested in seeing how some other climate models portray Ontario's future climate can visit http://www.glfc.cfs.nrcan.gc.ca/landscape/climate_change_into_e.html (a website presented by the Geo-spatial Tools and Economic Analysis Group at the Canadian Forest Service – Sault Ste. Marie Landscape Analysis Unit). At this site, users can view potential future climates projected by the Hadley (British), CSIRO (Commonwealth Scientific and Industrial Research Organization – Australia), and the Canadian climate models. We show the results from the Canadian climate model in this publication and the accompanying CD-ROM.

Future levels of greenhouse gas in the atmosphere are modelled based on scenarios describing different possible ways the world may develop in the next 100 years. Forty scenarios have been approved by the Intergovernmental Panel on Climate Change to be used in assessments of climate change and its impacts. Each scenario has a different set of assumptions about future social and economic conditions. Scenarios are possible outcomes, not predictions, since the amount of greenhouse gas in the future depends on highly variable factors such as global population, human behaviour, technological development, and the carbon sink/source behaviour of land and water ecosystems. In addition, even if we could predict the future amounts of greenhouse gases in the

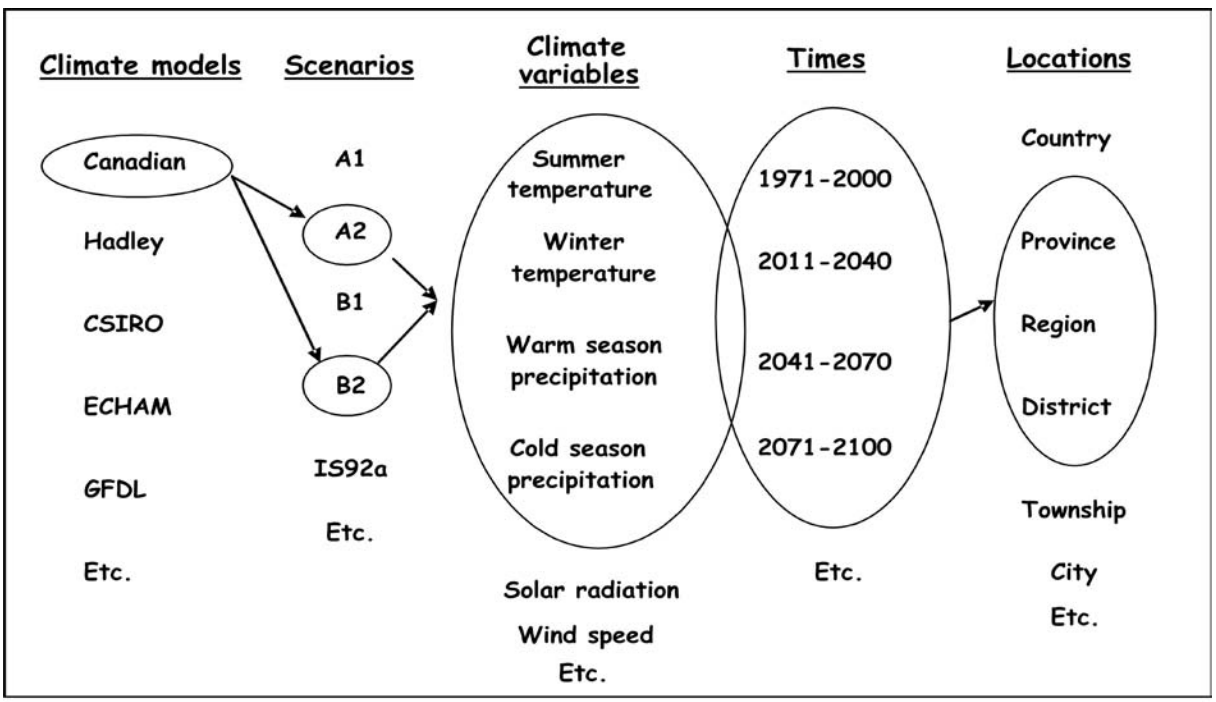


Figure 1. Climate presentation options provided in this publication and accompanying CD-ROM.

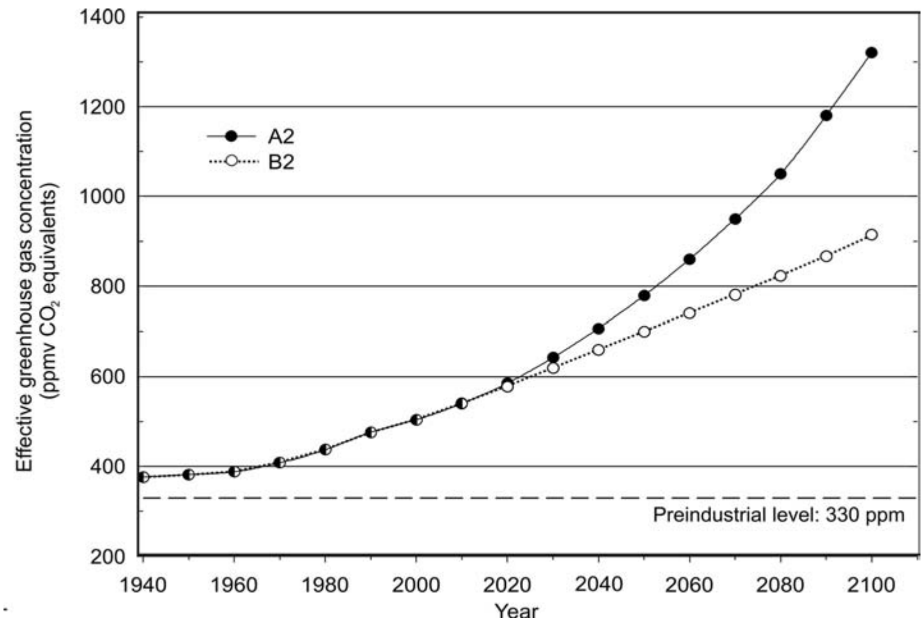


Figure 2. Historic and projected greenhouse gas concentration for the A2 and B2 scenarios. The A2 scenario assumes higher global population growth and greater energy use than the B2 scenario. Data from the Canadian Centre for Climate Modelling and Analysis, Environment Canada (http://www.cccma.ec.gc.ca/data/cgcm/ cgcm_ forcing.shtml).

atmosphere as already noted, different climate models produce varying projections. As a result, the projections of Ontario's climate shown here are not certain. However, they are likely to be closer to future reality than assuming that the future climate will be similar to that of the past 30, 60, or 100 years.

We provide maps depicting Ontario's future climate based on the A2 and B2 scenarios. The maps in this publication demonstrate the A2 climate scenario while the CD-ROM included with this report contains climate projections for both the A2 and B2 scenarios (Figure 2). The A2 scenario anticipates higher greenhouse gas levels by the century's end (Nakicenovic 2000), reaching 1,320 parts per million by volume (ppmv) in CO_2 equivalents[1] compared with 915 ppmv for B2[2]. In the A2 world, the human population reaches 15 billion by 2100, and reliance on fossil fuels is higher than in a B2 world, which projects a world population of 10.4 billion people by 2100 (Nakicenovic 2000). In addition, environmental protection, resulting in lower greenhouse gas emissions, is more important in the B2 scenario than in A2 (Nakicenovic 2000).

There are many ways to describe Ontario's future climate (Figure 1). Since climate change varies with the time of year and location, we use four seasonally-based climatic variables and a regional subdivision of the province. In this way we illustrate potential climate change with maps of differences in summer and winter temperature and warm period precipitation change (April to September) and cold season precipitation change (October to March) for three time periods: 2011-2040 (early), 2041-2070 (mid), and 2071-2100 (late) compared to 1971-2000.

Maps in the report are organized by region (southern, northeastern, and northwestern), while the accompanying CD-ROM shows the province by region and at a finer geographic scale based on the 26 administrative districts used by the Ontario Ministry of Natural Resources. Each map set includes a baseline map of 1971-2000 conditions for the selected climatic variable, followed by maps showing change in the climate variable (temperature or precipitation) in the early (2011-2040), mid (2041-2070), and late (2071-2100) time periods.

[1]A CO_2 equivalent expresses the energy-trapping properties of any greenhouse gas and the length of time it remains in the atmosphere in terms of the amount of CO_2 producing the same warming effect.

[2]Values from http://www.cccma.bc.ec.gc.ca/data/cgcm/cgcm_forcing.shtml viewed September 6, 2006.

Climate Projections

Figure 3 presents changes in annual temperatures across the province in 2071-2100, based on the A2 scenario. The entire province will see significant warming, with the greatest increases (6 to 7°C) projected for people living in the far north, near Hudson Bay. Increases in annual average temperature of 5 to 6°C will be experienced by people as far south Kashechwan, Armstrong, Sandy Lake and Kenora. The annual average temperature of southwestern Ontario, including Toronto and the Niagara Peninsula, will increase 5 to 6°C. Average annual temperature in the rest of the province is projected to increase 4 to 5°C. Across the province, warming will be greater in winter than summer, and greater in the north than the south. These results are shown in Figures 4 to 15, which depict historic and future seasonal climates that will be seen by people living in an A2 world in southern, northeastern, and northwestern Ontario.

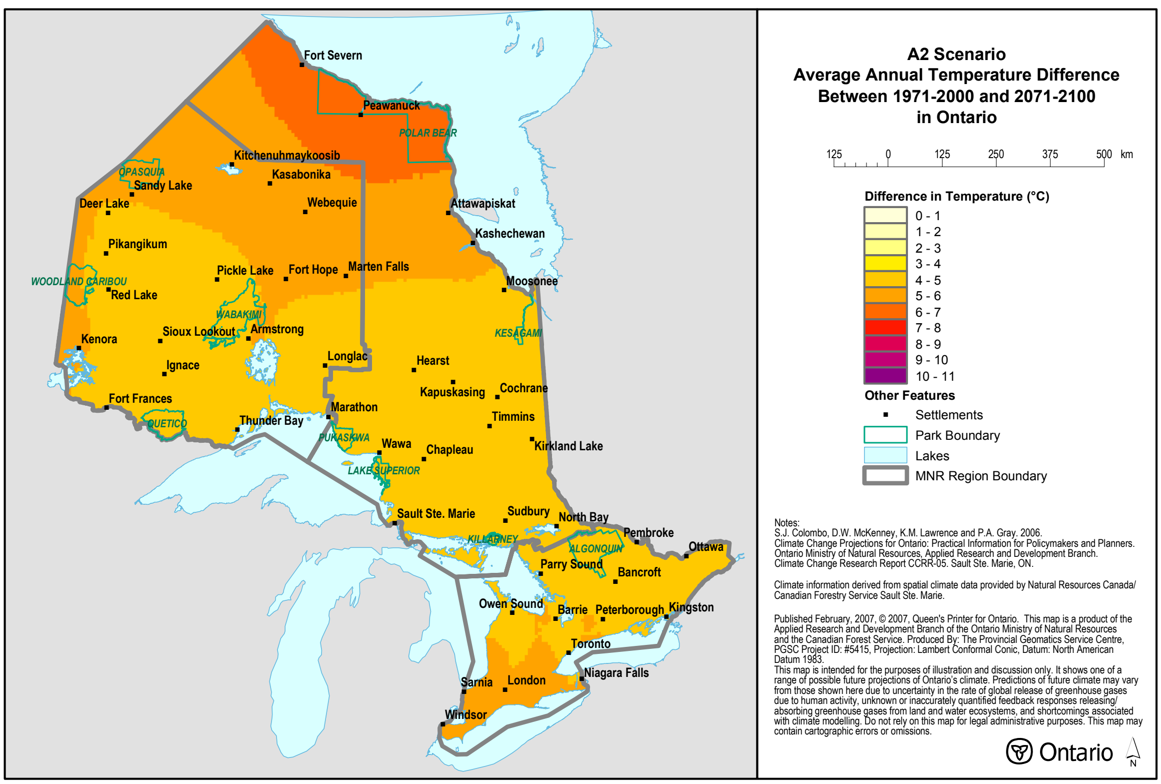


Figure 3. Projected change in average annual temperature in Ontario in 2071 to 2100 compared to 1971 - 2000 using the A2 scenario in the Canadian Coupled Global Climate model.

Southern Ontario

Summer climate

Southern Ontario summer temperatures have historically been warmest in the Niagara Peninsula, the western shore of Lake Ontario from Oshawa to Hamilton, and the southwestern part of the region that includes Windsor and the north shore of Lake Erie (Figure 4a).

For people living in an A2 world, most of southern Ontario will have summers that are 2 to 3^{o}C warmer by mid-century and 4 to 5^{o}C warmer by 2071 (Figure 4c and d). These changes mean that by 2071 people in much of southern Ontario, from the Bruce Peninsula to the Ottawa Valley, will experience the types of hot summers that presently occur only in Windsor and Essex County of southwestern Ontario. For people living in the area from Windsor and Sarnia east to Niagara and the Greater Toronto Area, the 5 to 6^{o}C increase in average summer temperature will make it about as hot as summers in present day Virginia.

Across southern Ontario, precipitation from April-September has historically been 400 to 600 mm, with the Parry Sound District and an area east of Ottawa-Brockville being the wettest (Figure 5a). In 2011-2040, almost all of southern Ontario south of a line from Owen Sound to Pembroke will receive up to 10% less rainfall (Figure 5b); rainfall will increase by up to 10% north of that line. By 2071-2100 in an A2 world, a significant part of Ontario's prime agricultural land in Kent, Essex, and Lambton counties will receive 10 to 20% less precipitation from April to September (Figure 5d).

Winter climate

People who live in the area encompassed by Toronto-Niagara-Windsor-Sarnia receive the warmest winters in Ontario, with average temperatures just below freezing from December through February (Figure 6a). In contrast, people in and around Algonquin Park experience the coldest winters in southern Ontario, averaging -10 to -15^{o}C. Winter temperatures in the rest of southern Ontario, including Ottawa, Kitchener, and Owen Sound average -5 to -10^{o}C.

Between 2011 and 2040, winter temperatures in most of southern Ontario will warm by 1 to 2^{o}C (Figure 6b). An exception is eastern Ontario, including Ottawa, where people will see little change in winter temperature in 2011-2040. By mid-century average winter temperatures in most of the south could increase by 3 to 4^{o}C (Figure 6c). By 2071, winter temperatures will increase by 4 to 5^{o}C in most of southern Ontario and in some parts of the region (e.g., the Bruce Peninsula, Collingwood, Sarnia, and Toronto) by as much as 5 to 6^{o}C (Figure 6d). As a result, in an A2 world in 2071-2100, people living in Barrie, Brockville, and Parry Sound will have winters like those currently found in Niagara and Windsor. The already-mild winters of the Golden Horseshoe, Sarnia, and Chatham will be even milder in 2071 in an A2 world, with average winter temperatures more like the current winter temperatures in southern Ohio and Indiana.

Cold season precipitation has historically been heaviest in the snow belts on the shores of Lake Huron and Georgian Bay, with most precipitation falling near Owen Sound and Parry Sound (Figure 7a). In an A2 world, from 2011-2040 and onwards, most of southern Ontario will receive up to 10% less cold season precipitation. People living in an A2 world in parts of central Ontario near Parry Sound, north of Peterborough, and east of Bancroft can in future expect to get 10 to 20% less cold season precipitation (Figure 7b, 7c, and 7d).

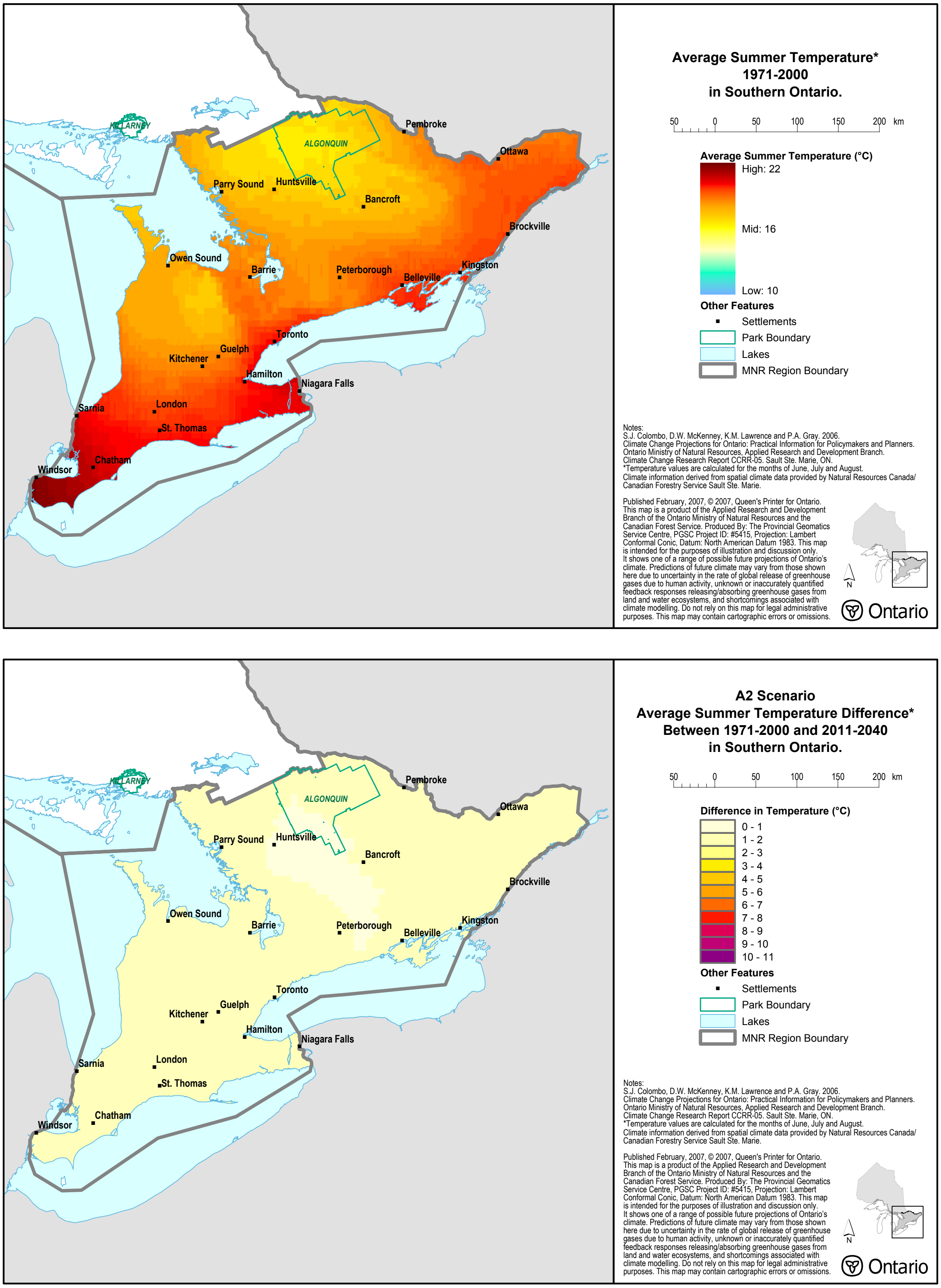


Figure 4a and b. Average summer temperatures in southern Ontario for 1971-2000 and projected change in summer temperatures for 2011-2040.

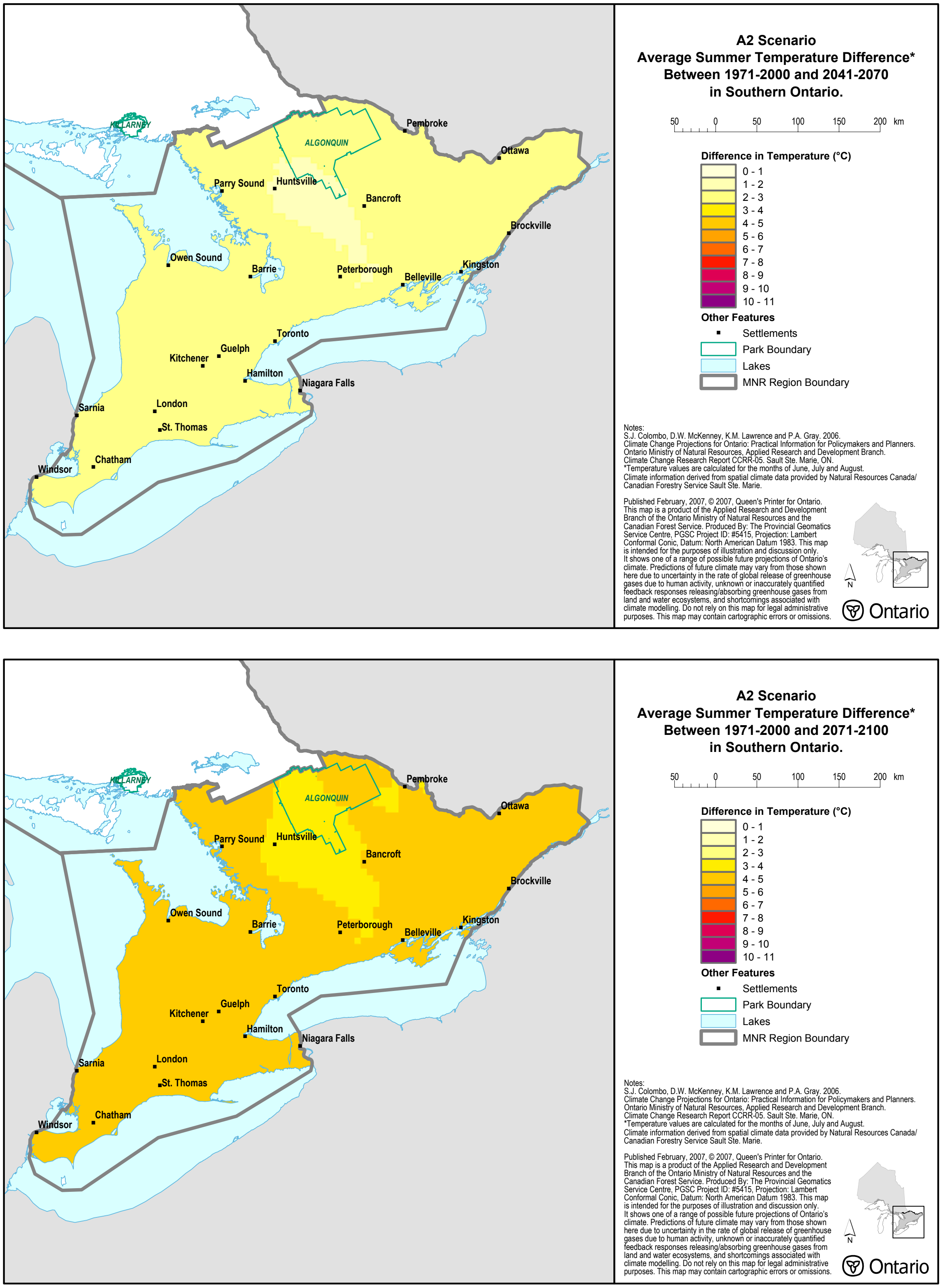
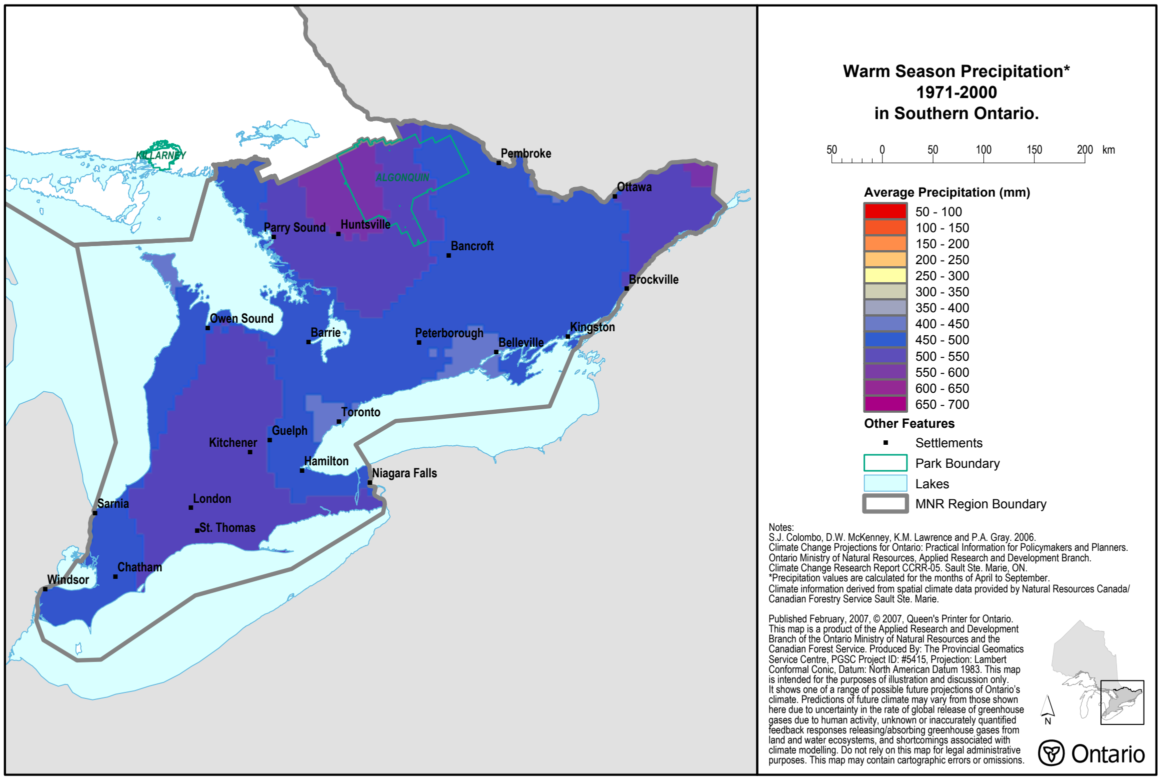


Figure 4c and d. Projected change in summer temperatures in southern Ontario for 2041-2070 and 2071-2100.



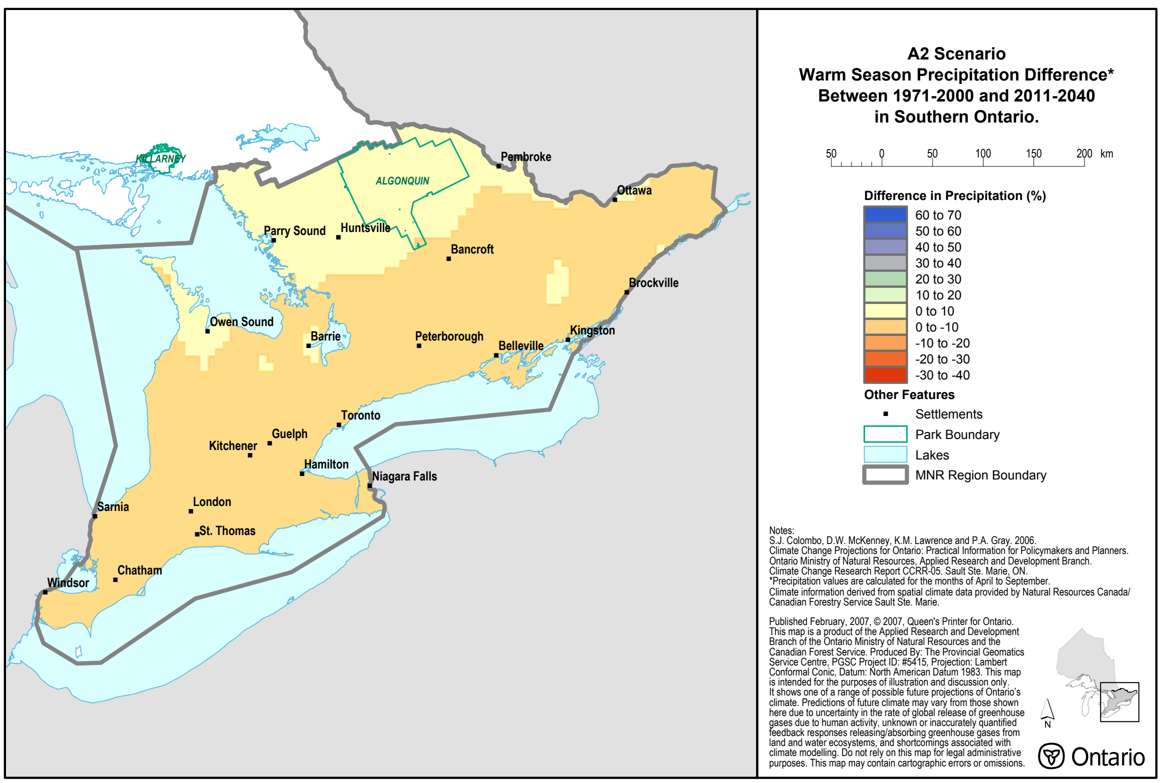


Figure 5a and b. Average warm season precipitation in southern Ontario for 1971-2000 and projected change in precipitation for 2011-2040.

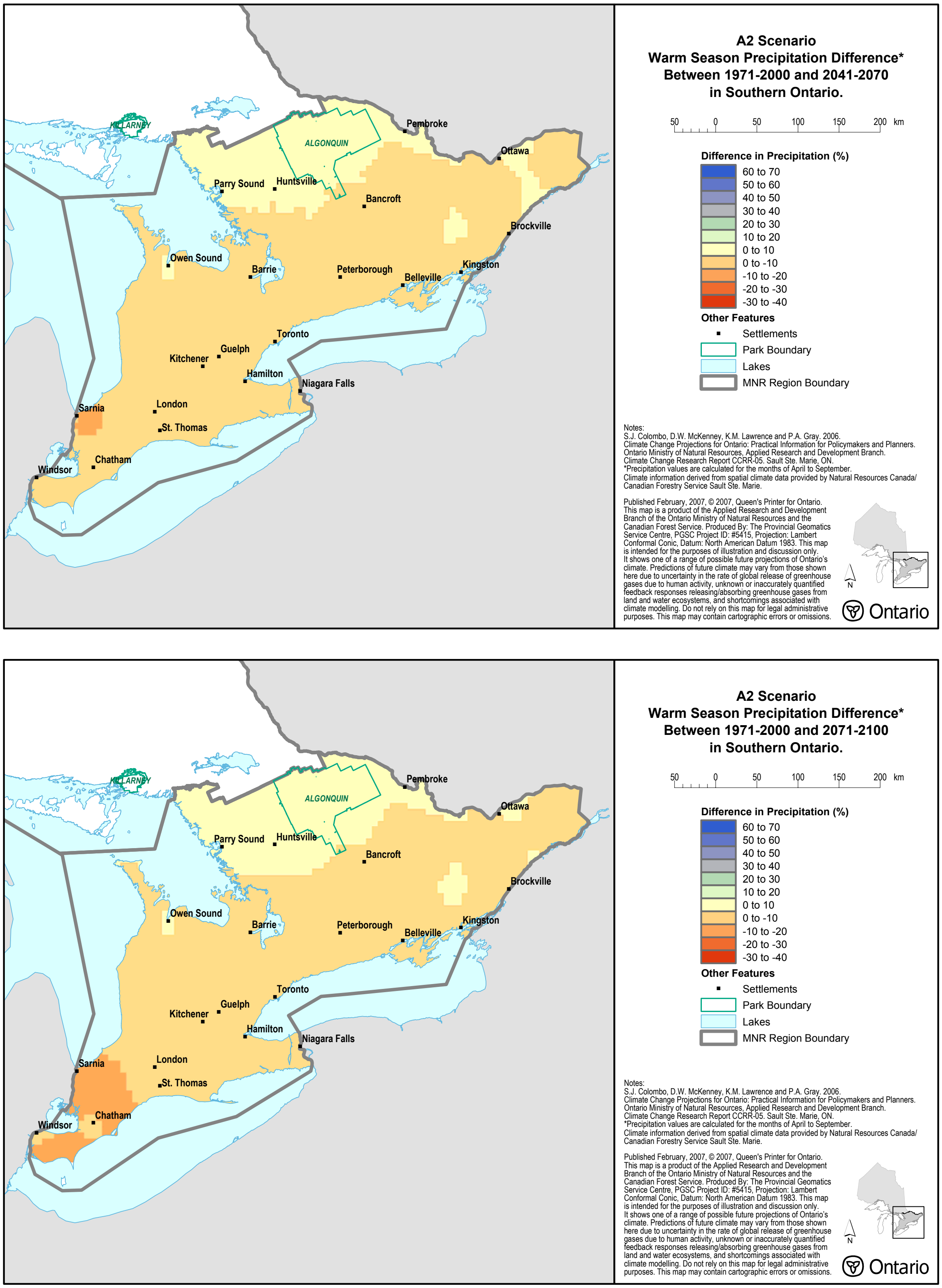


Figure 5c and d. Projected change in warm season precipitation in southern Ontario for 2041-2070 and 2071-2100.

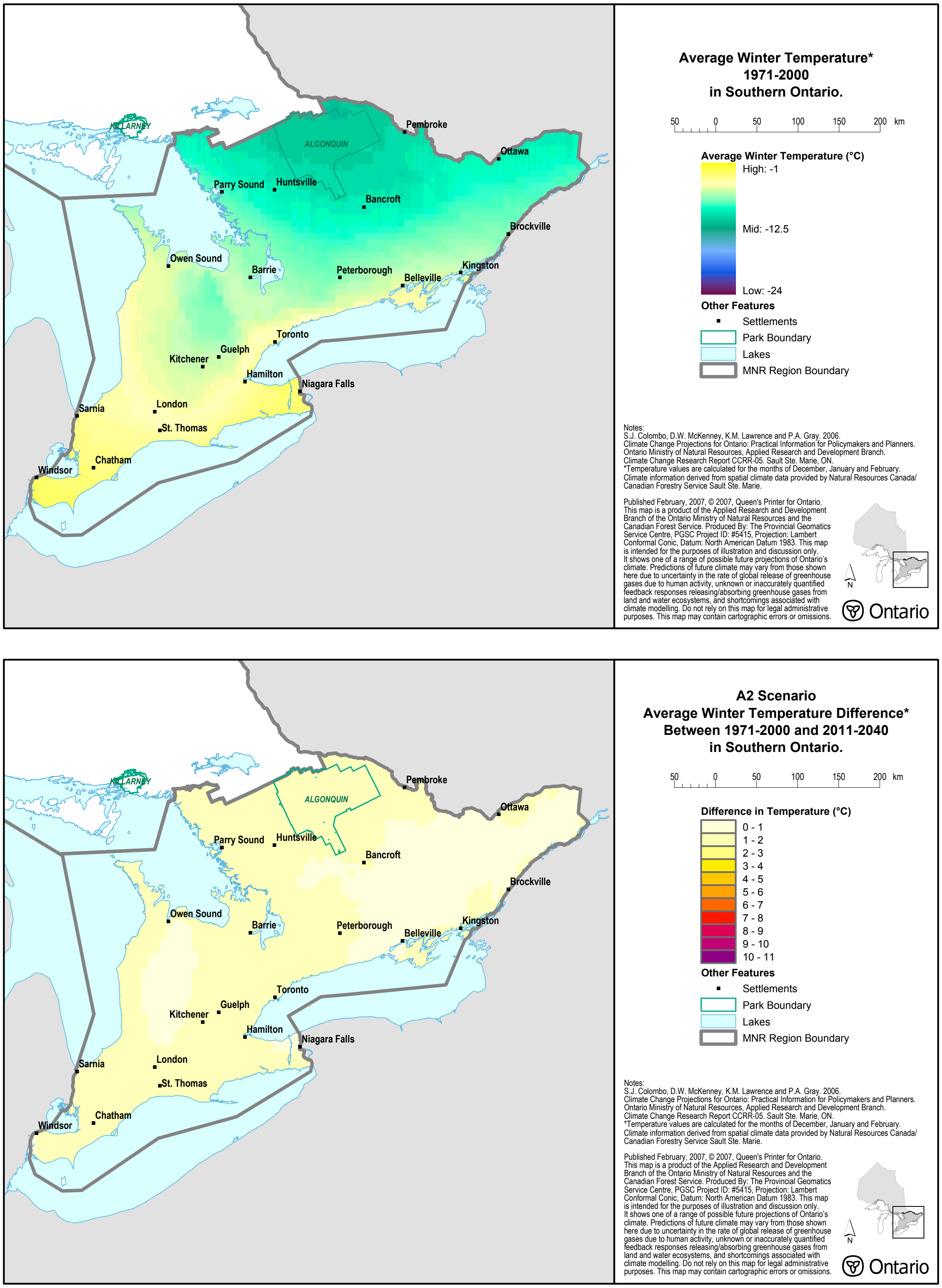
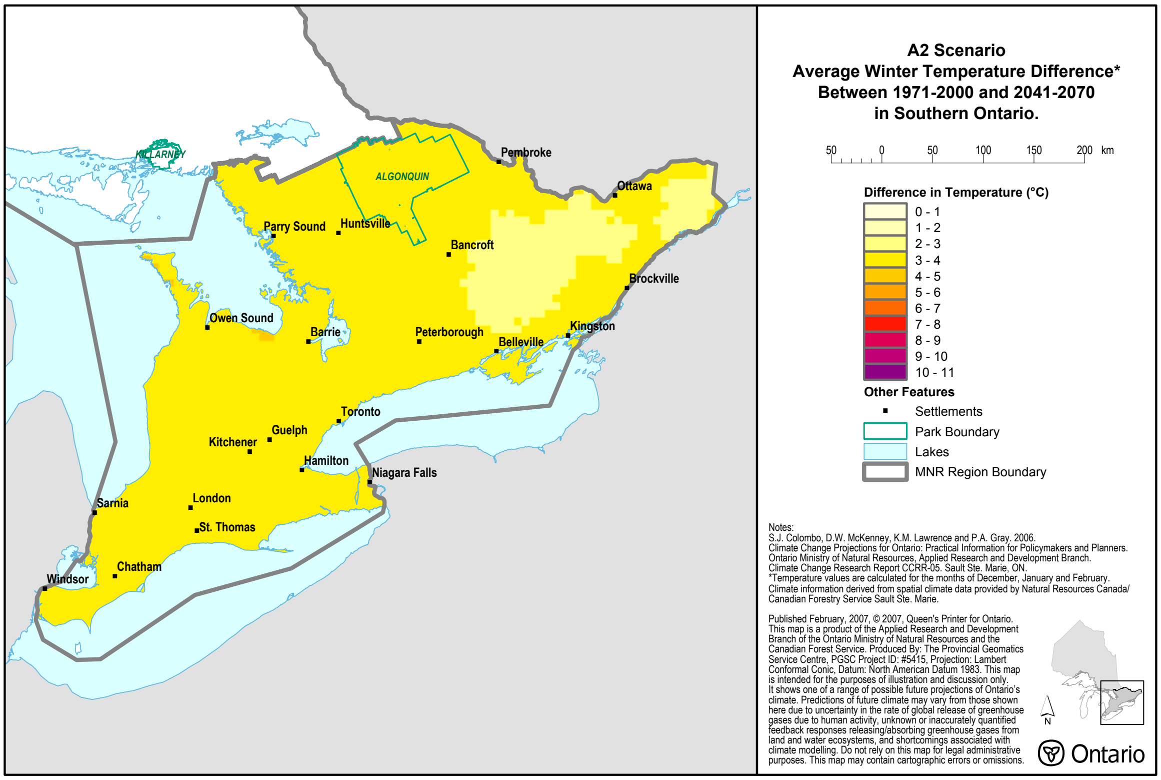


Figure 6a and b. Average winter temperatures in southern Ontario for 1971-2000 and projected change in winter temperatures for 2011-2040.



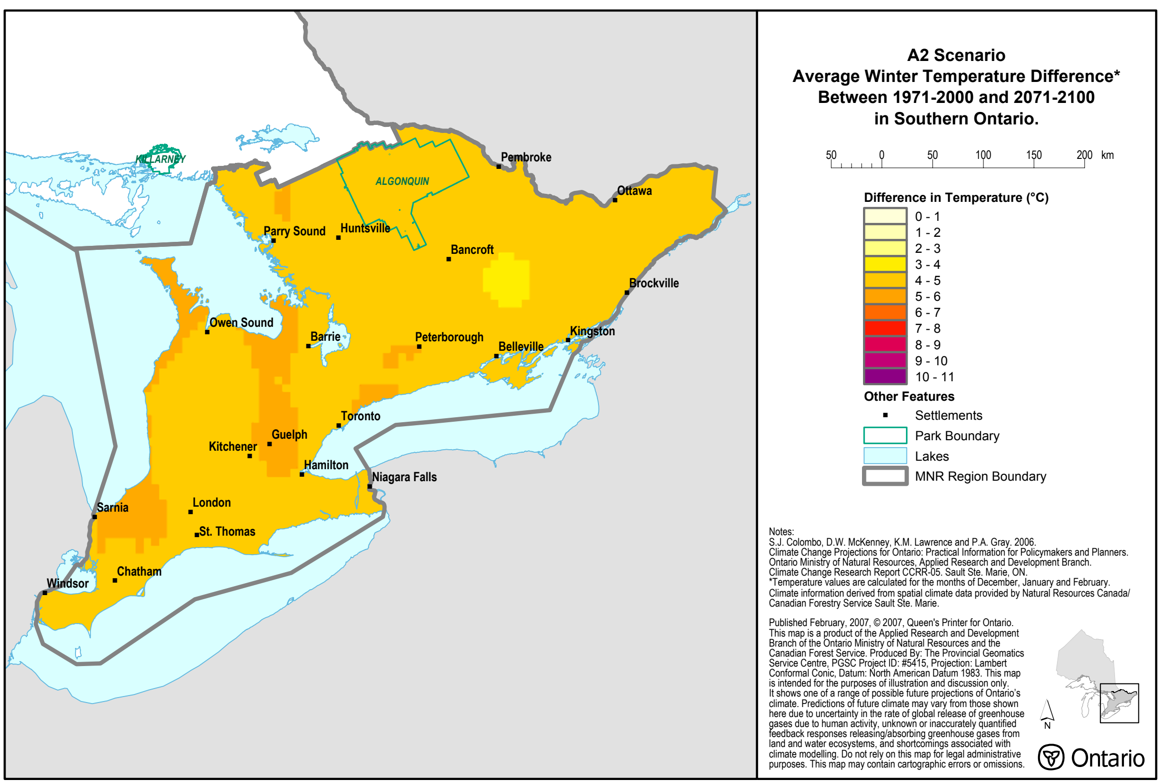


Figure 6c and d. Projected change in winter temperatures in southern Ontario for 2041-2070 and 2071-2100.

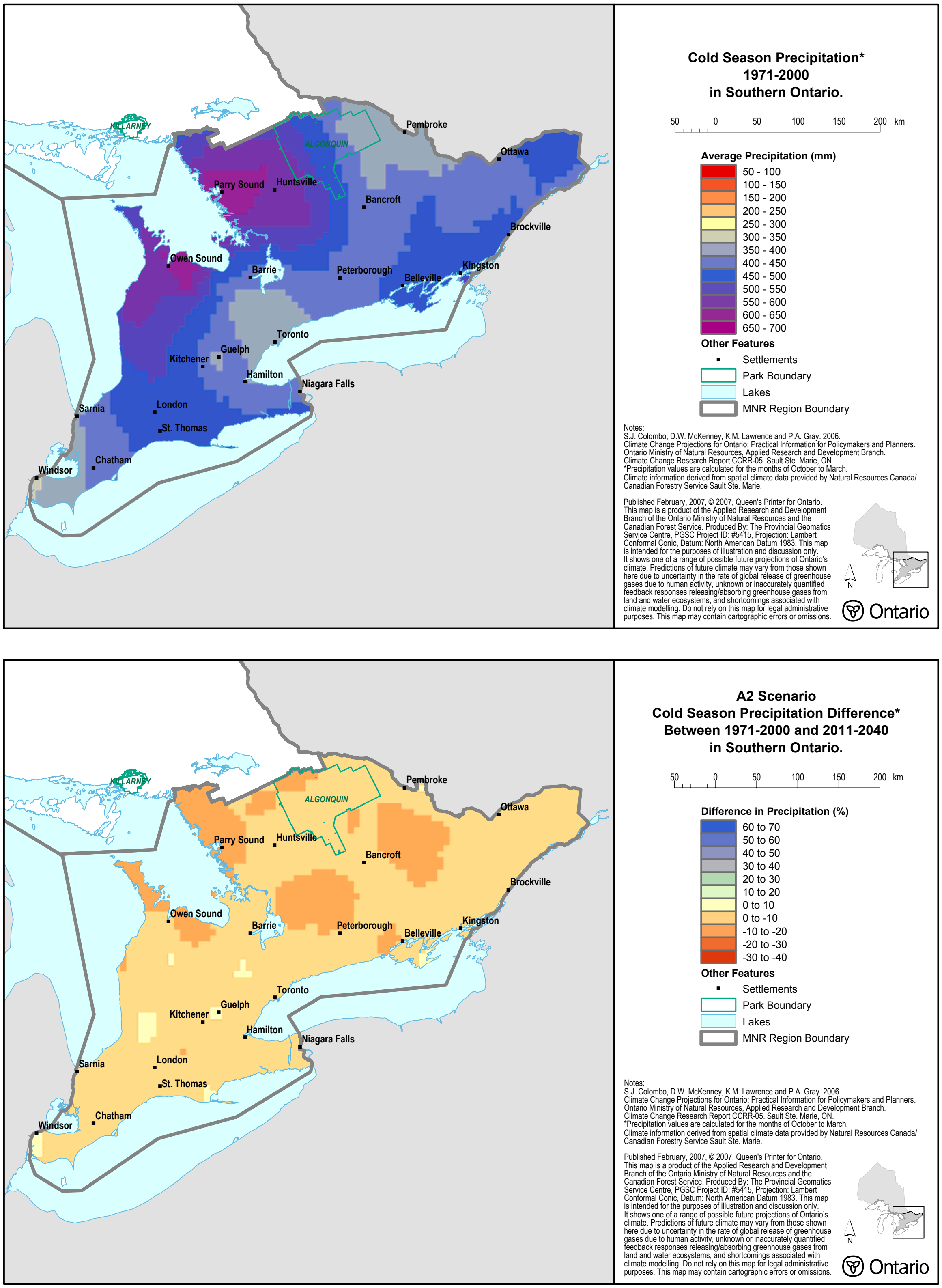


Figure 7a and b. Average cold season precipitation in southern Ontario for 1971-2000 and projected change in precipitation for 2011-2040.

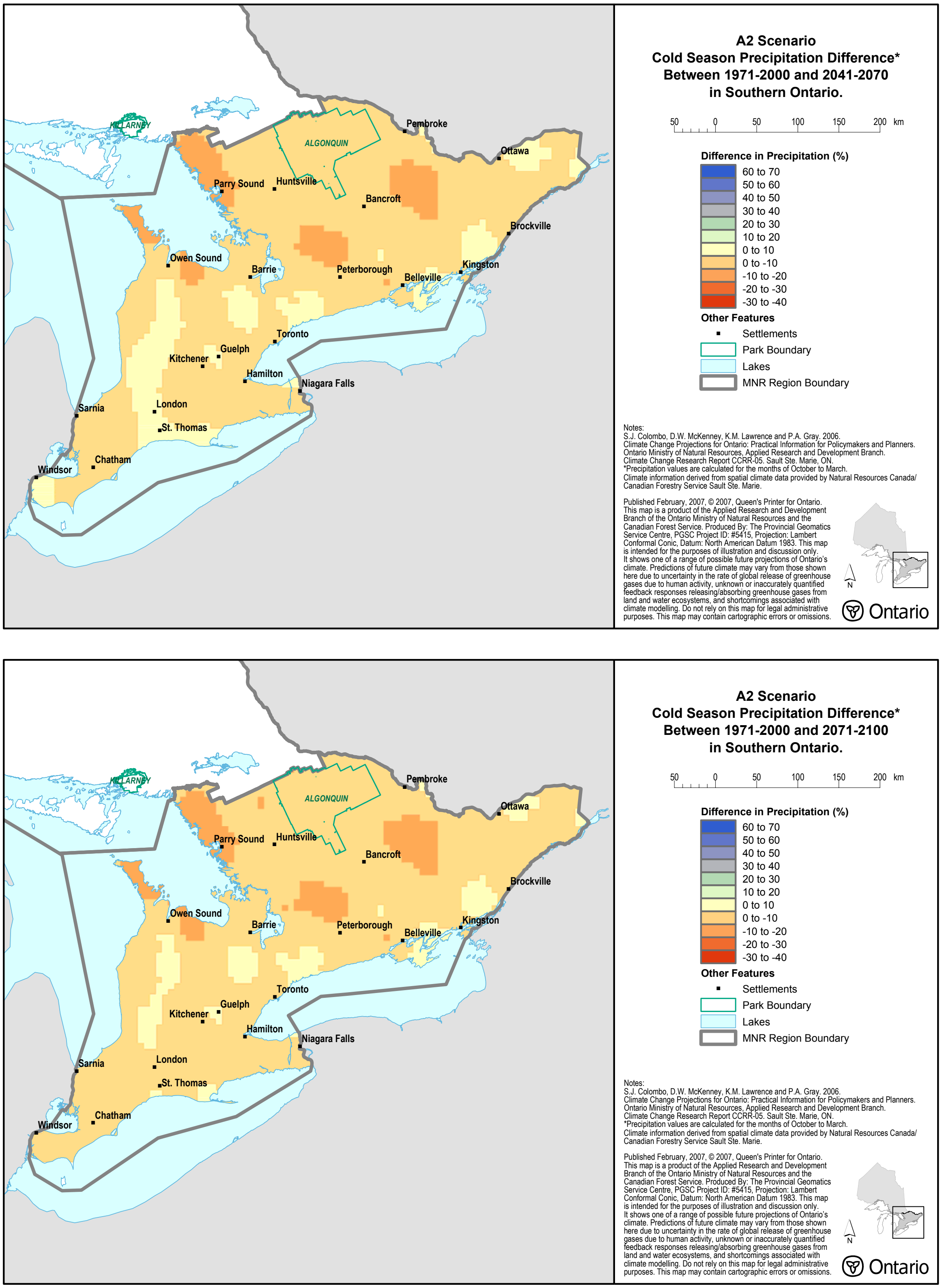


Figure 7c and d. Projected change in cold season precipitation in southern Ontario for 2041-2070 and 2071-2100.

Northeastern Ontario

Summer climate

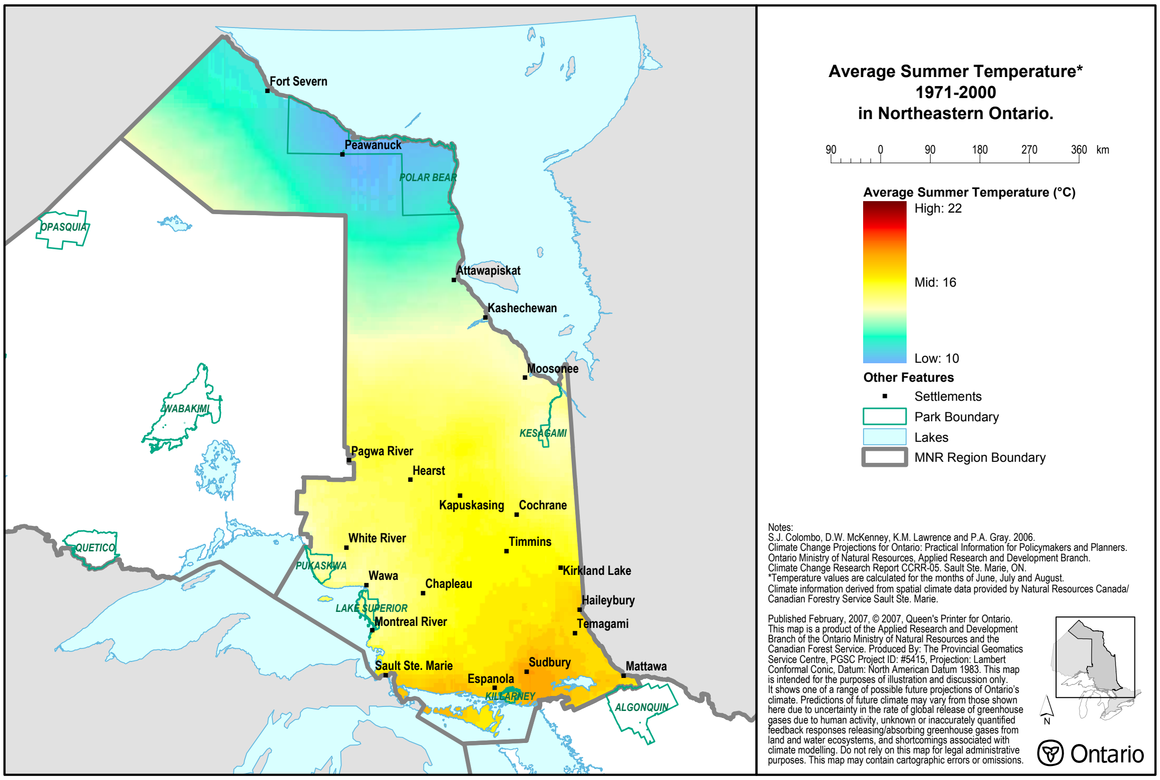
During 1971-2000, summer temperatures in northeastern Ontario ranged from about 10°C around Peawanuck near Hudson Bay to about 18°c in Sudbury (Figure 8a). In an A2 world, people in the far north of Ontario will see summers become much warmer than they were during 1971-2000. By 2011 to 2040, it is projected by the Canadian CGCM2 climate model that summers over most of northeastern Ontario will warm by 1 to 2°C (Figure 8b). By 2071, people living in Ontario's far north, including those in Fort Severn and Kashechewan, will experience summers 5 to 6°C warmer (Figure 8d). As a result, in an A2 world their future summer temperatures will be similar to the 1971-2000 summers in Huntsville and Orillia in southern Ontario. In 2071 to 2100, average summer temperatures in most of the area bounded by Sudbury, Mattawa, Kirkland Lake, and Chapleau, will warm by 3 to 4°C (Figure 8d), making them like the average summer temperatures found from 1971-2000 in Hamilton and Toronto.

Warm season precipitation during 1971-2000 was lowest near Hudson Bay and highest in parts of the northeastern region bordering Quebec and along the eastern shore of Lake Superior, north of Sault Ste. Marie (Figure 9a). In an A2 world between 2011 and 2040, warm season precipitation will decrease by up to 10% in two large areas, one to the north of Hearst and Kapuskasing and one to the west of Peawanuck (Figure 9b). However, beginning 2041, most of northeastern Ontario will receive the same or slightly more precipitation as it did from 1971-2000 (Figure 9c and d).

Winter climate

Between 1971 and 2000, people in northeastern Ontario saw winter temperatures that averaged from -24°C for Fort Severn and Peawanuck to about -11°C for Sault Ste. Marie and Manitoulin Island. The speed and extent of winter warming in an A2 northeastern Ontario will greatly exceed the rate of change in southern Ontario. An increase of 2 to 3°C will occur as early as 2011 in the area adjacent to Moosonee and Attawapiskat, while at the same time near Hudson Bay, including Polar Bear Provincial Park, Peawanuck, and Fort Severn, the temperature will warm by 3 to 4°C (Figure 10b). Within 35 years (by 2041), people and ecosystems in the far north of this region will experience winters 6 to7°C warmer than they were in 1971-2000 (Figure 10c). By 2071 in an A2 world, people living in the Hudson Bay area will experience winters that are 9 to 10°C warmer and the area from Kashechewan west will warm by up to 8°C (Figure 10d). By 2071, in the more heavily populated southern parts of the northeast (for example, Sault Ste. Marie, Espanola, and North Bay), the winters will warm by 4 to 5°C.

Cold season precipitation in northeastern Ontario has historically been greatest in the snowbelt to the lee of Lake Superior, between Wawa and Sault Ste. Marie (Figure 11a). In an A2 world, cold season precipitation by 2071 in this area is projected to increase by up to 20%. If all of this precipitation falls as snow, Montreal River will receive an additional 1 metre or more snow per year, for a total as much as about 8 metres. While snowfall in Montreal River and areas near White River, Hearst, and James Bay will increase, large parts of the northeast will receive significantly less snow than has been the historical norm. For example, in the A2 scenario, people living in a corridor running north from Espanola and Mattawa to Moosonee will get up to 20% less cold season precipitation by 2011 (Figure 11b). Precipitation will decrease most to the southwest of Moosonee. People living in the far north historically receive less cold season precipitation than anywhere else in Ontario, averaging only 150 to 200 mm (Figure 11a). In an A2 world, people in much of this part of the northeast will receive even less cold season precipitation, with levels dropping to only about 100 mm of cold season precipitation in the severest cases, in areas west of Fort Severn (Figure 11b, 11c, and 11d).



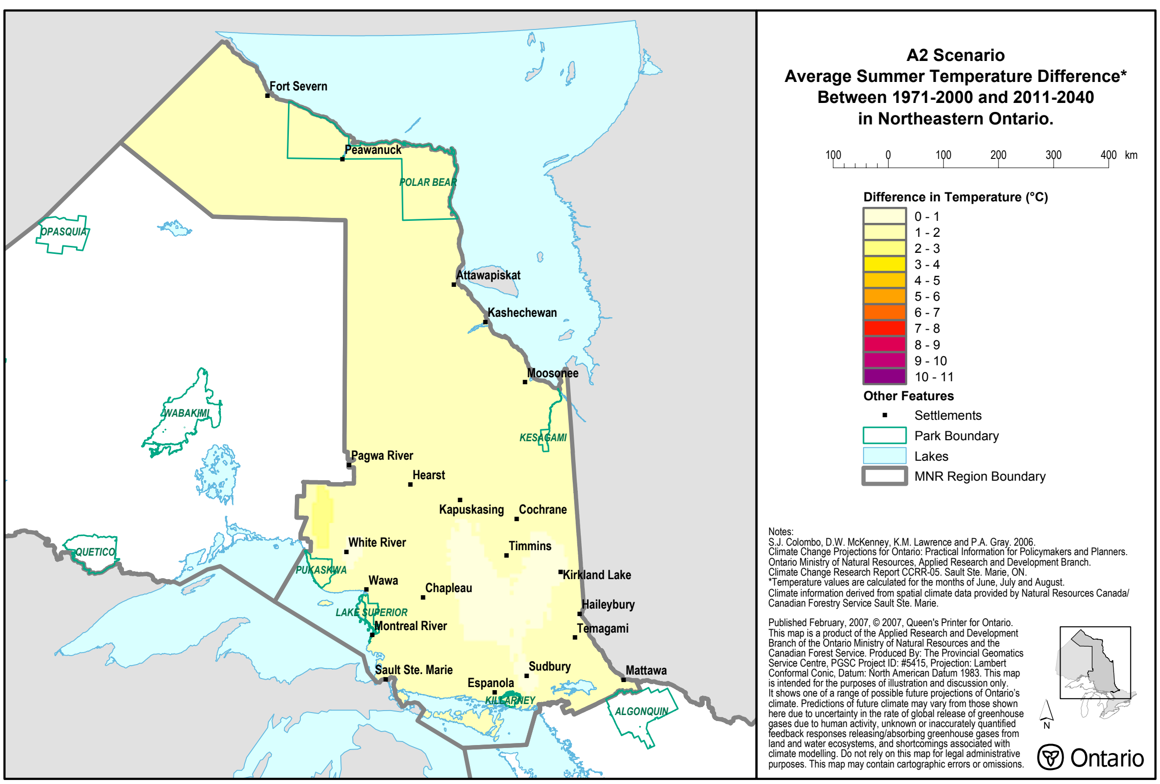
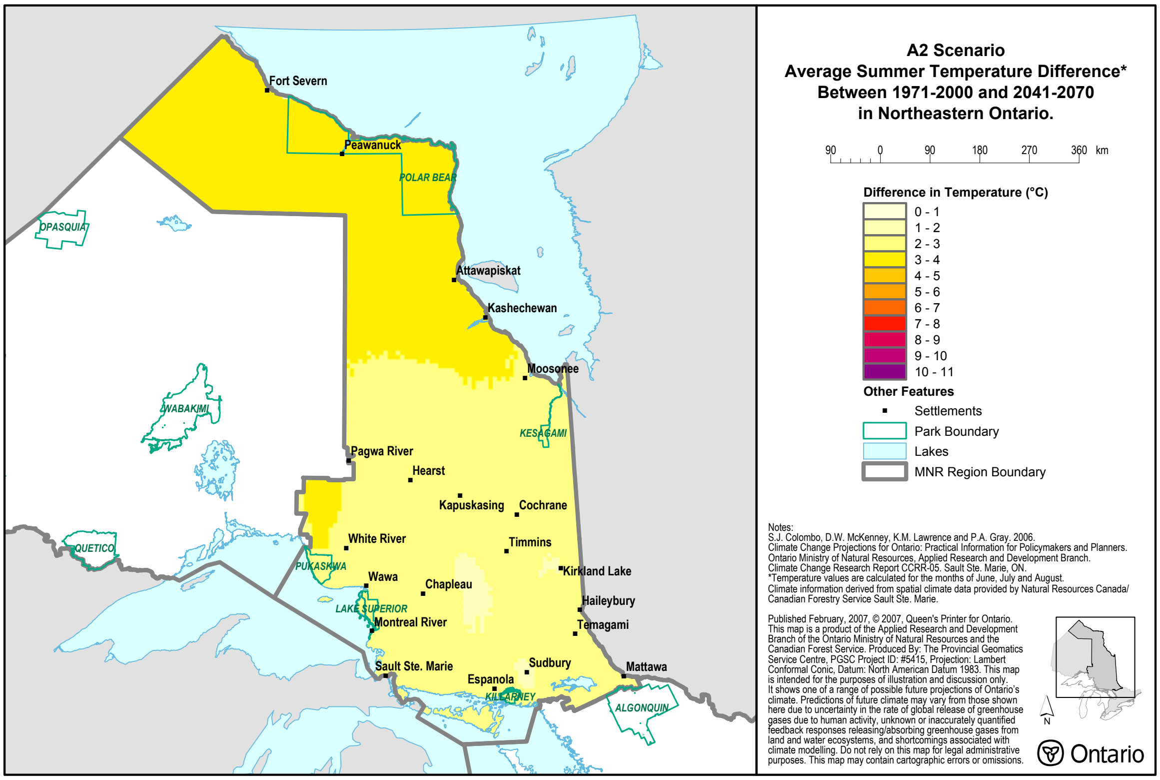


Figure 8a and b. Average summer temperatures in northeastern Ontario for 1971-2000 and projected change in summer temperatures for 2011-2040.



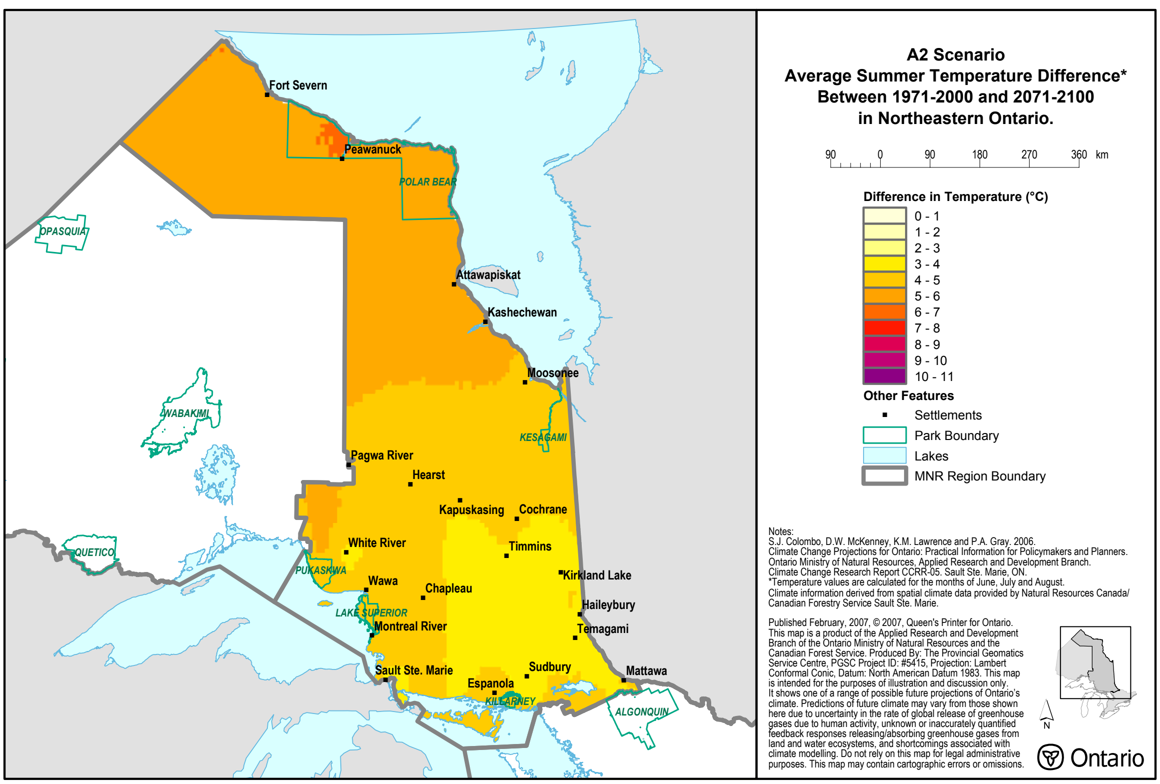
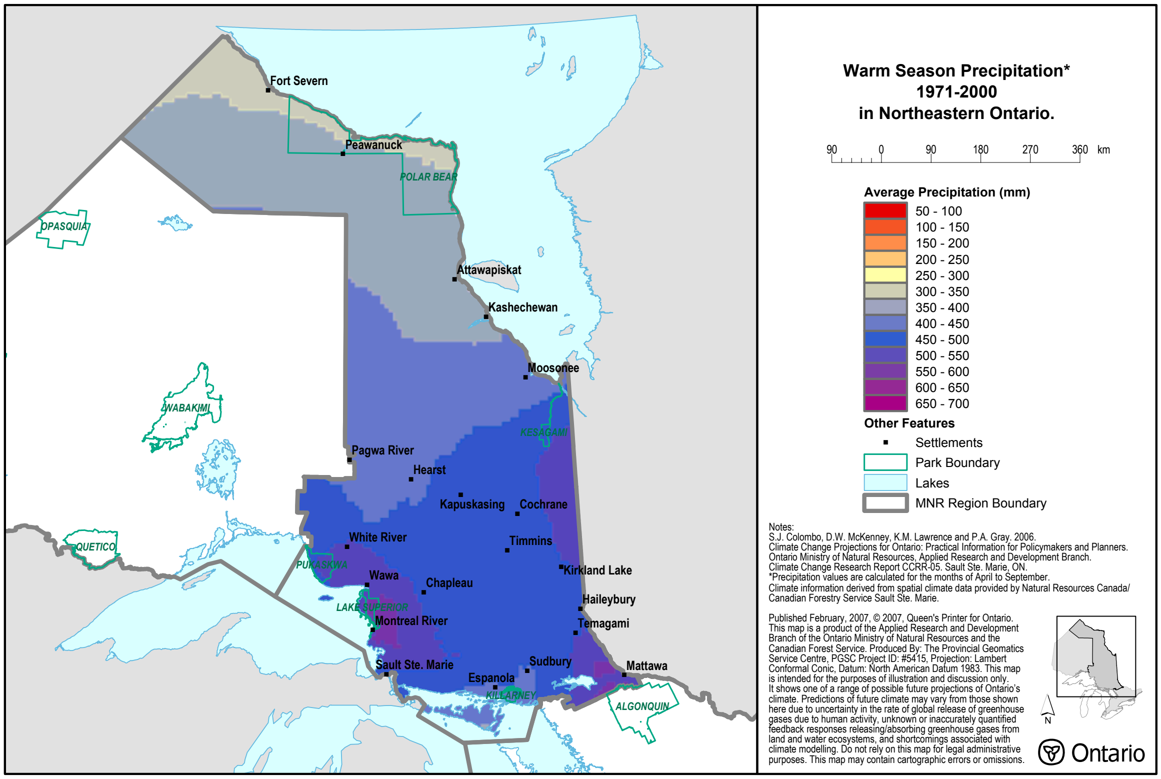


Figure 8c and d. Projected change in summer temperatures in northeastern Ontario for 2041-2070 and 2071-2100.



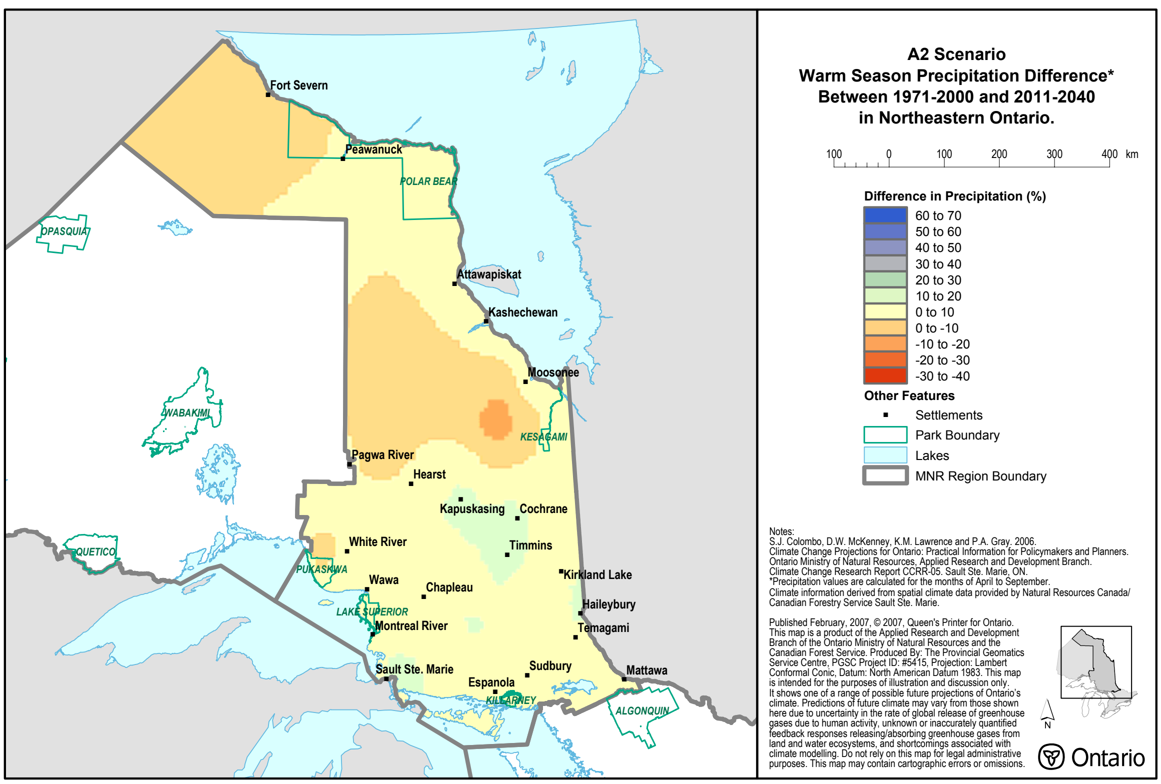
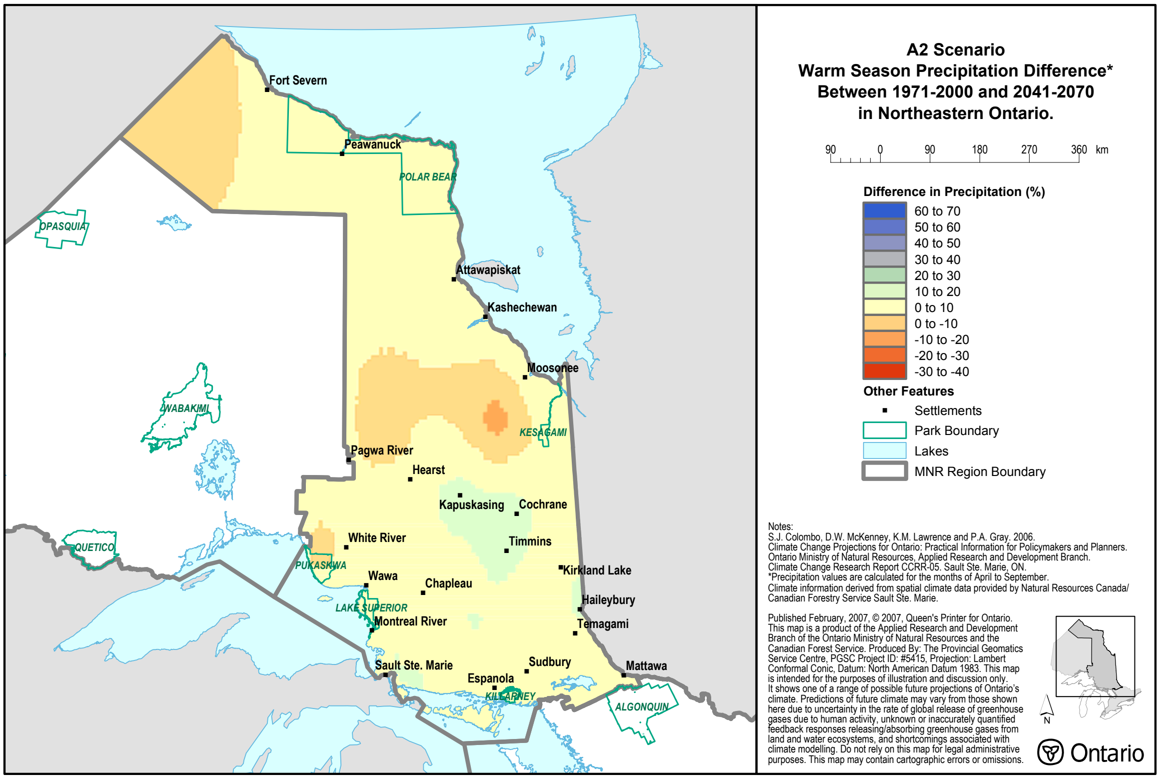


Figure 9a and b. Average warm season precipitation in northeastern Ontario for 1971-2000 and projected change in precipitation for 2011-2040.



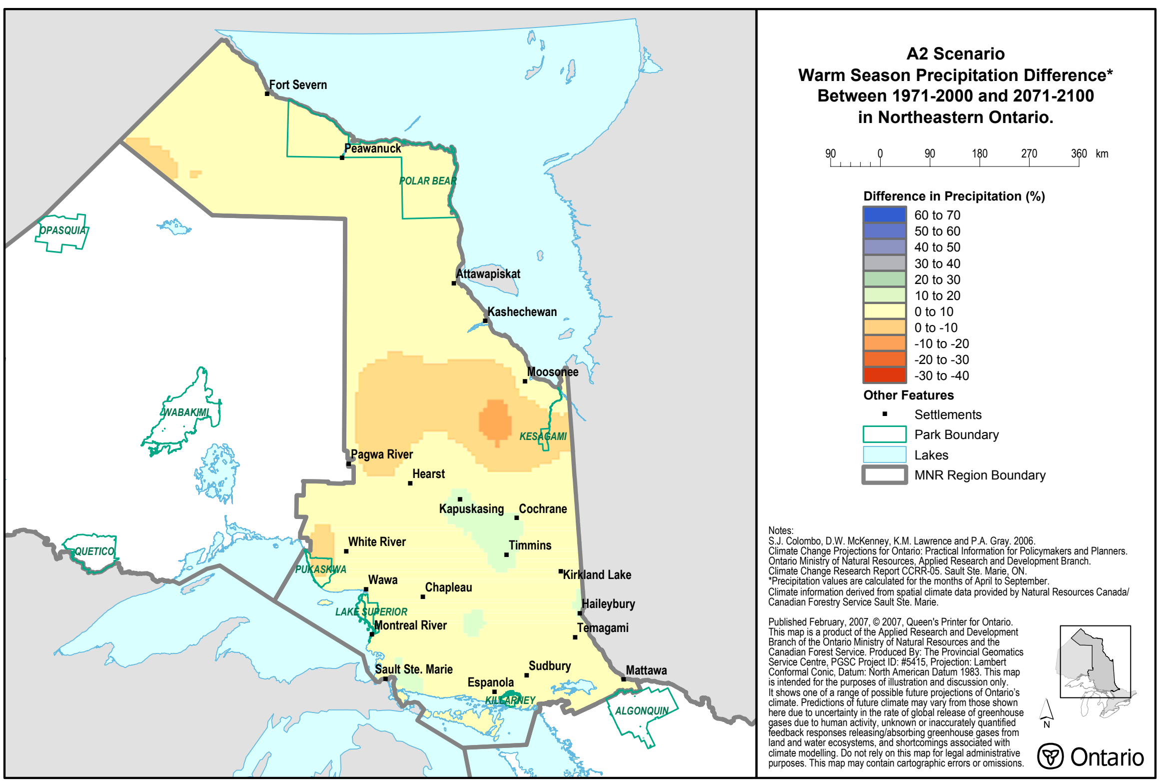
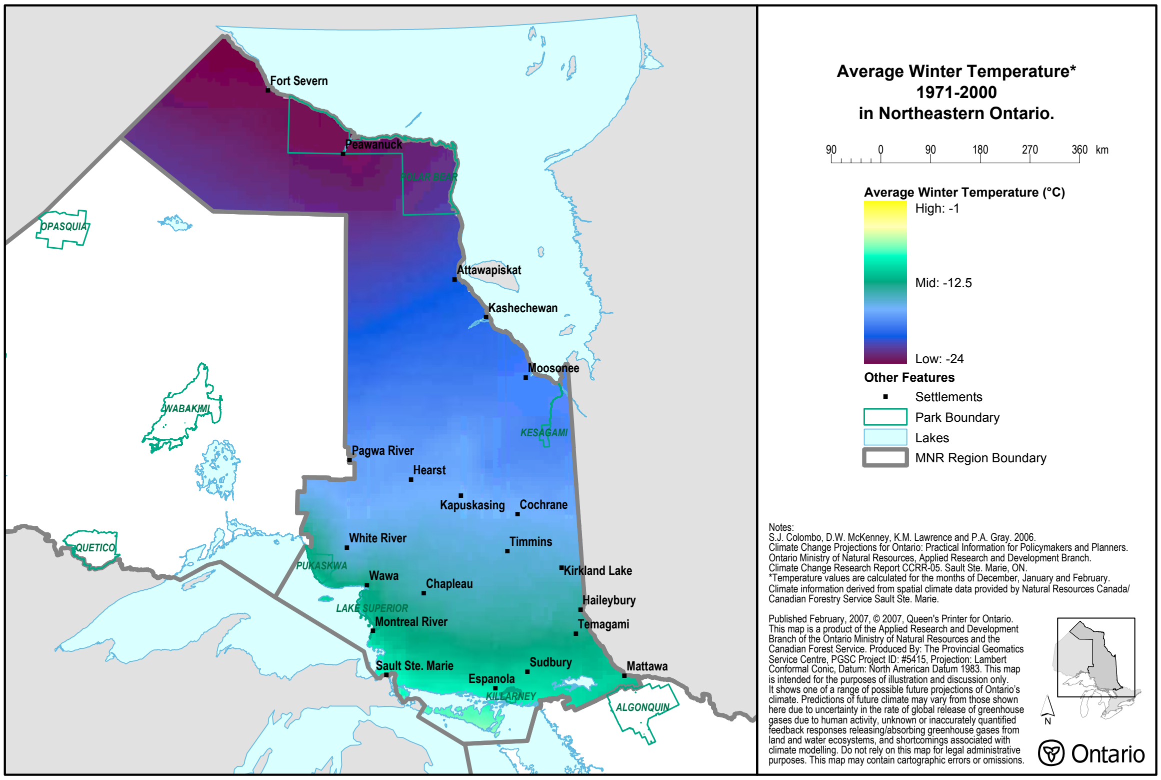


Figure 9c and d. Projected change in warm season precipitation in northeastern Ontario for 2041-2070 and 2071-2100.



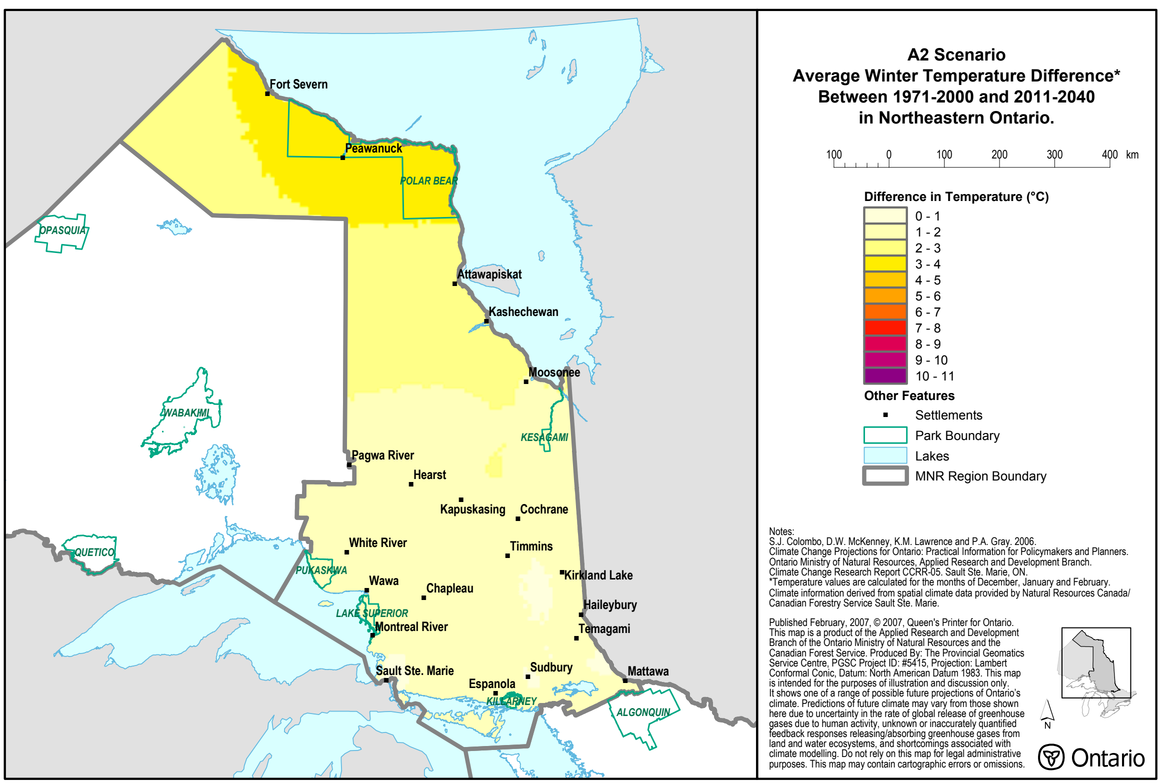
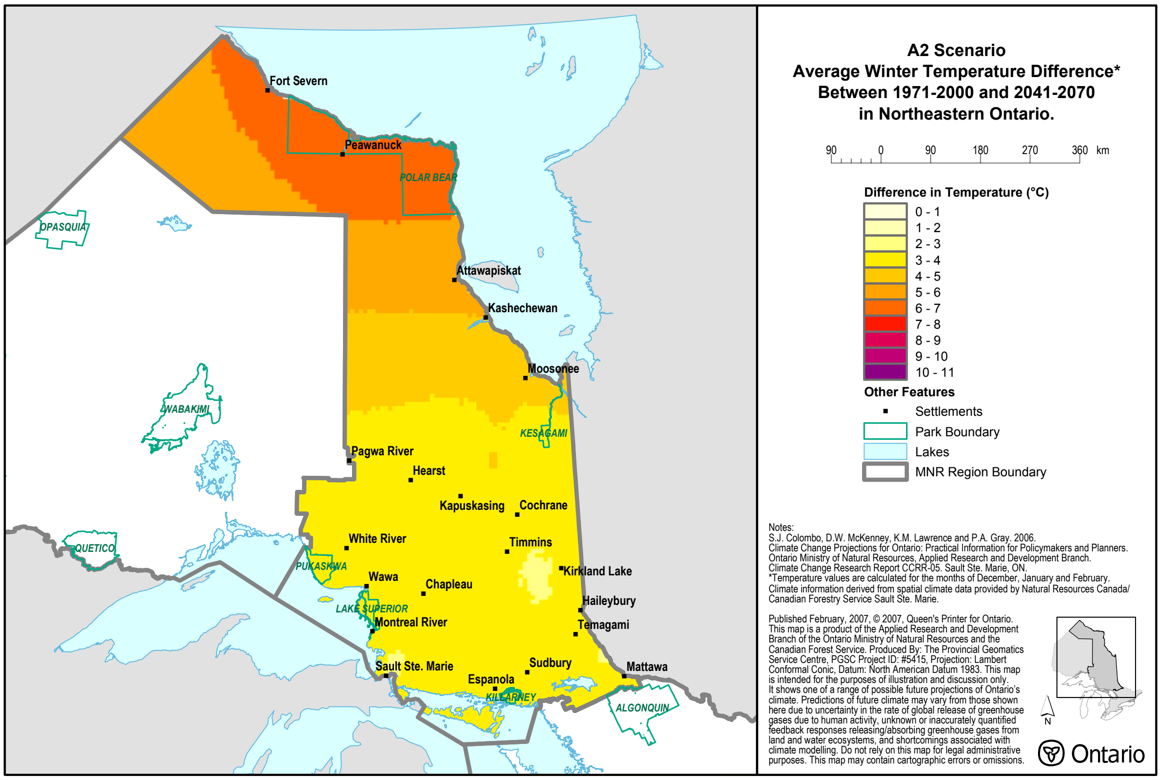


Figure 10a and b. Average winter temperatures in northeastern Ontario for 1971-2000 and projected change in winter temperatures for 2011-2040.



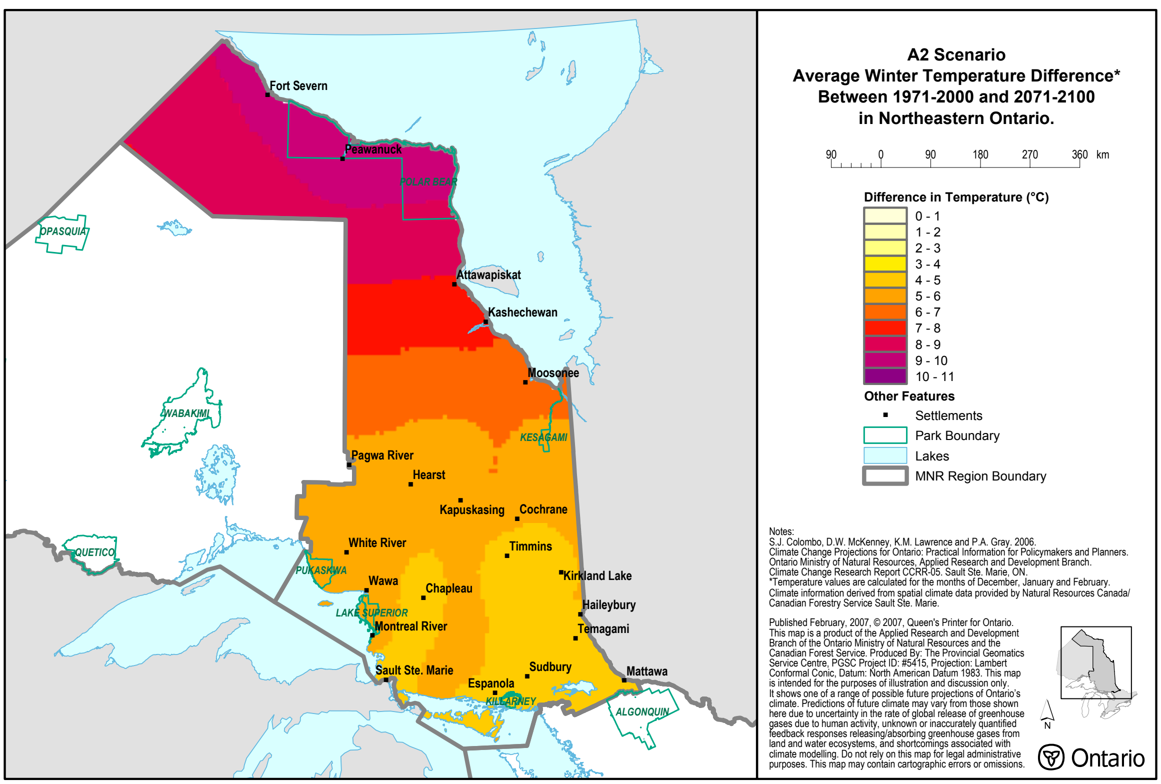
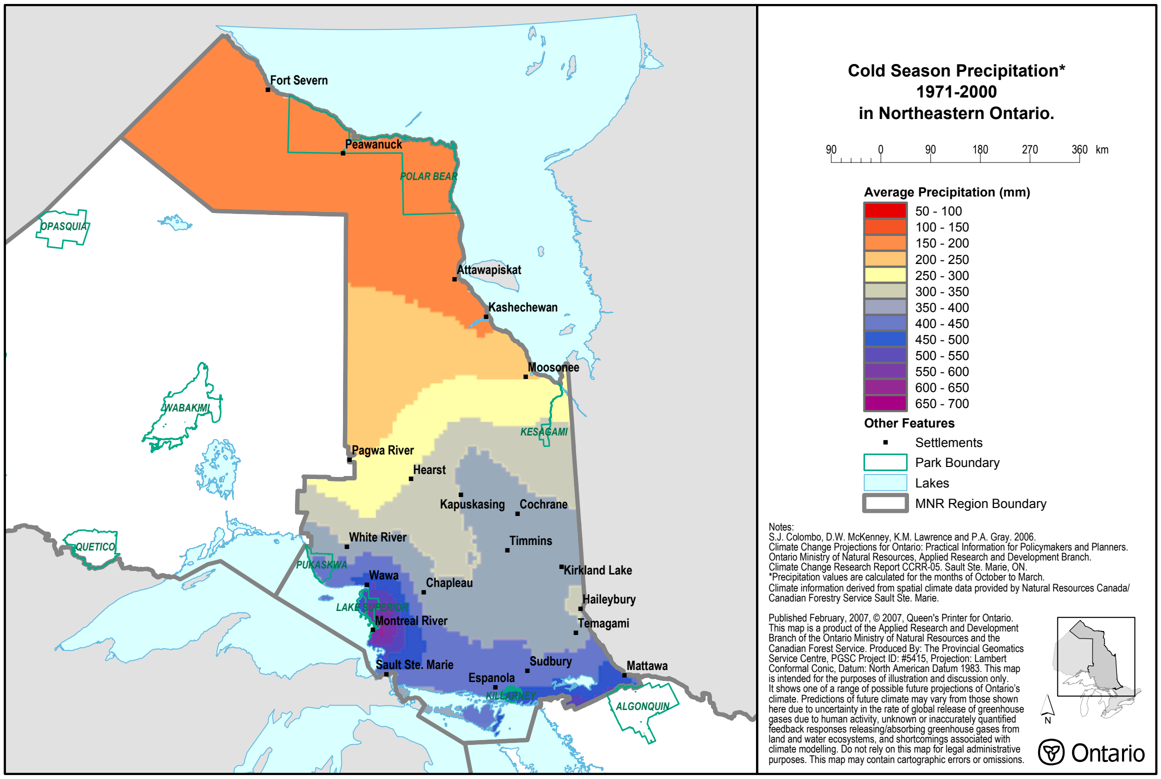


Figure 10c and d. Projected change in winter temperatures in northeastern Ontario for 2041-2070 and 2071-2100.



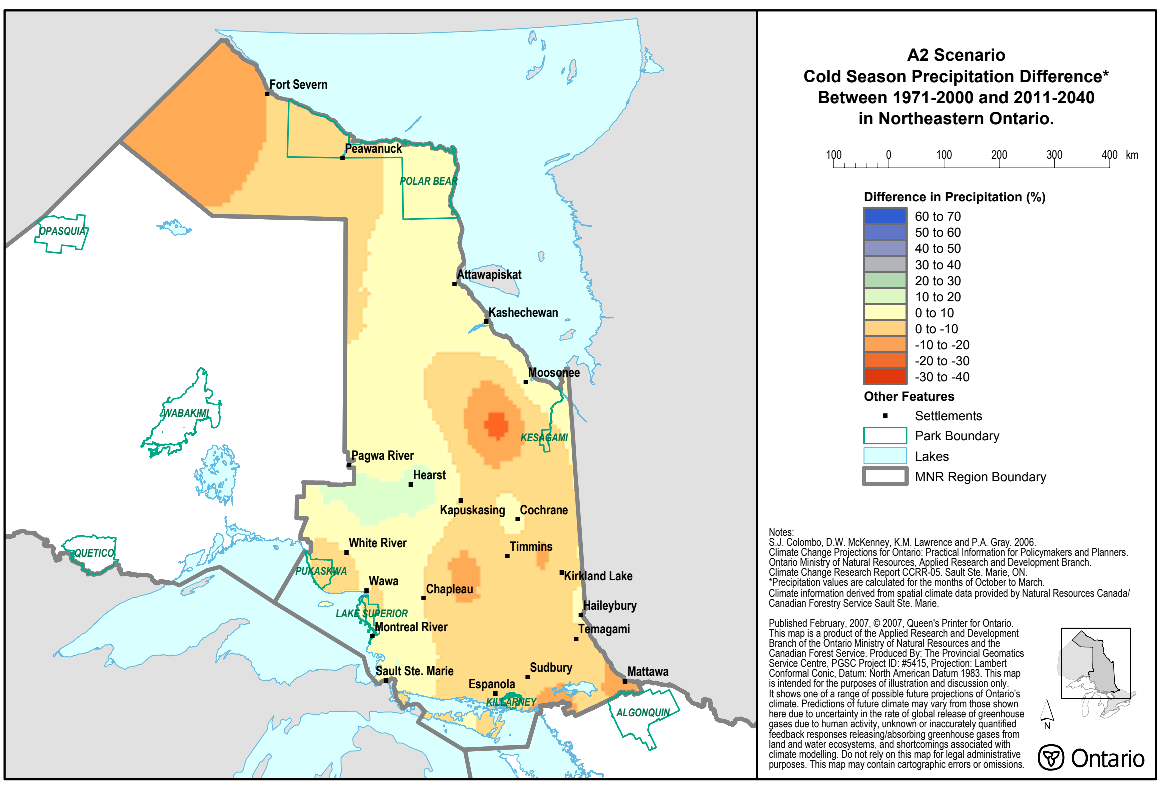
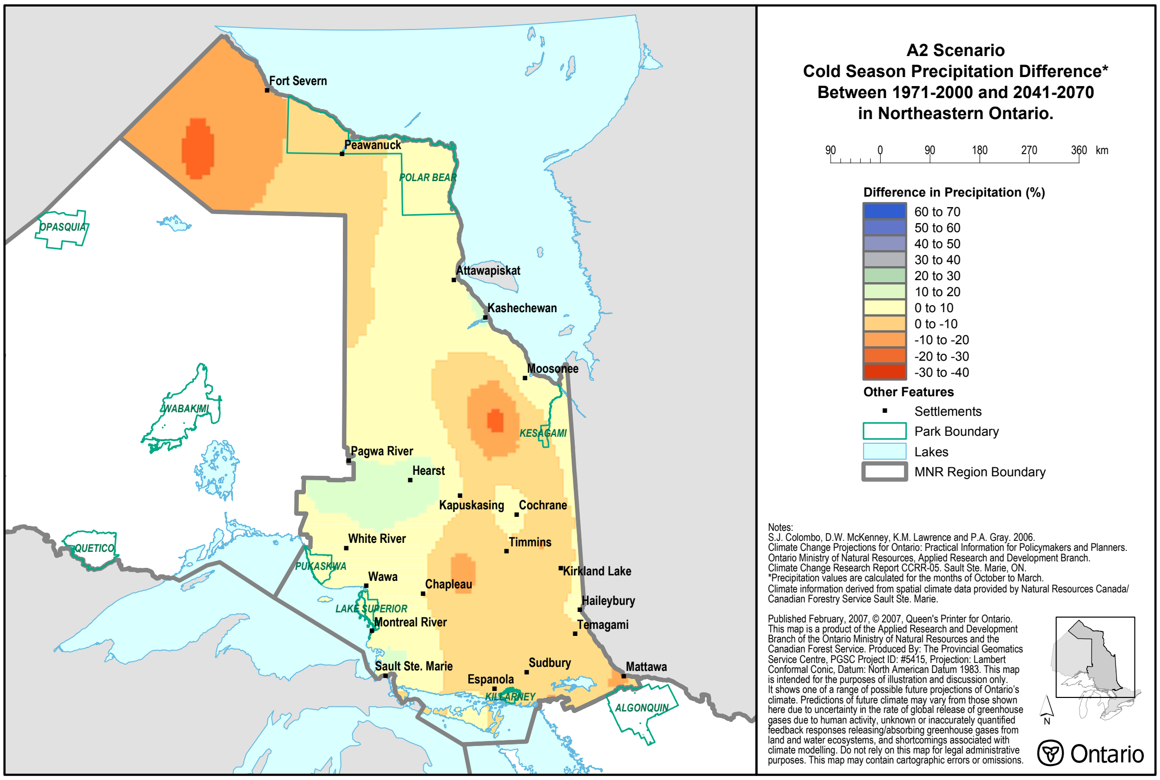


Figure 11a and b. Average cold season precipitation in northeastern Ontario for 1971-2000 and projected change in precipitation for 2011-2040.



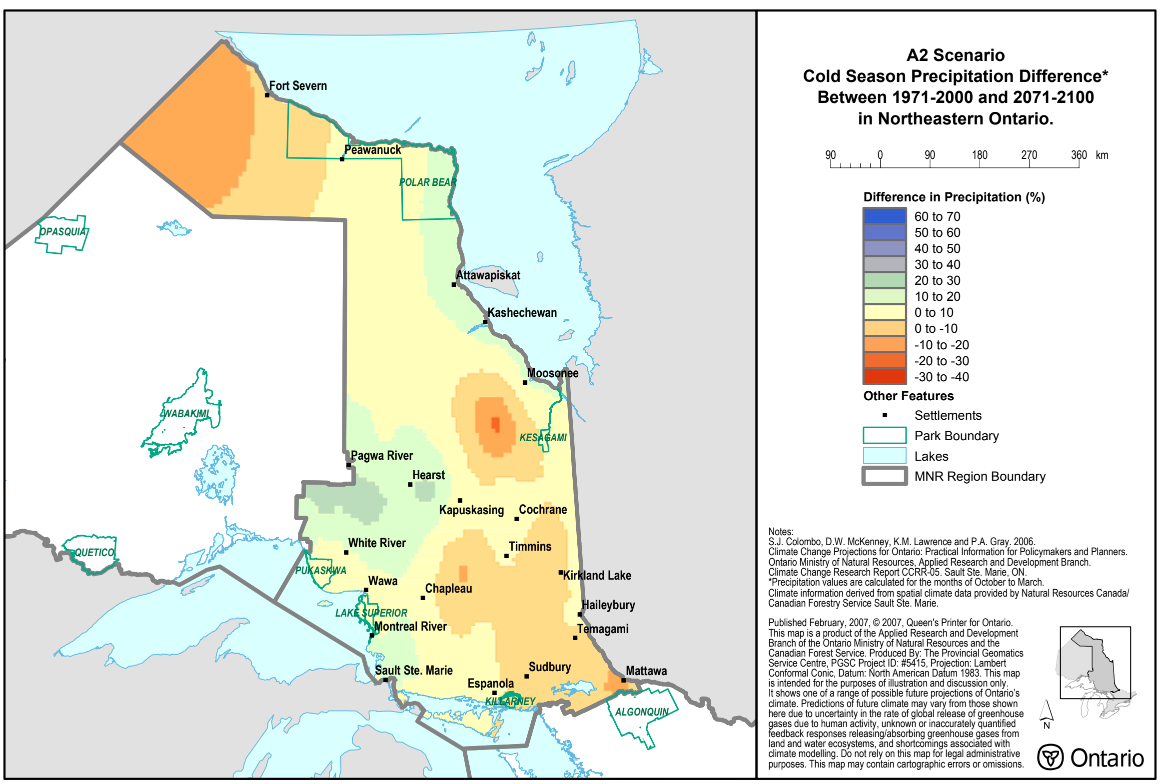


Figure 11c and d. Projected change in cold season precipitation in northeast Ontario for 2041-2070 and 2071-2100.

Northwestern Ontario

Summer climate

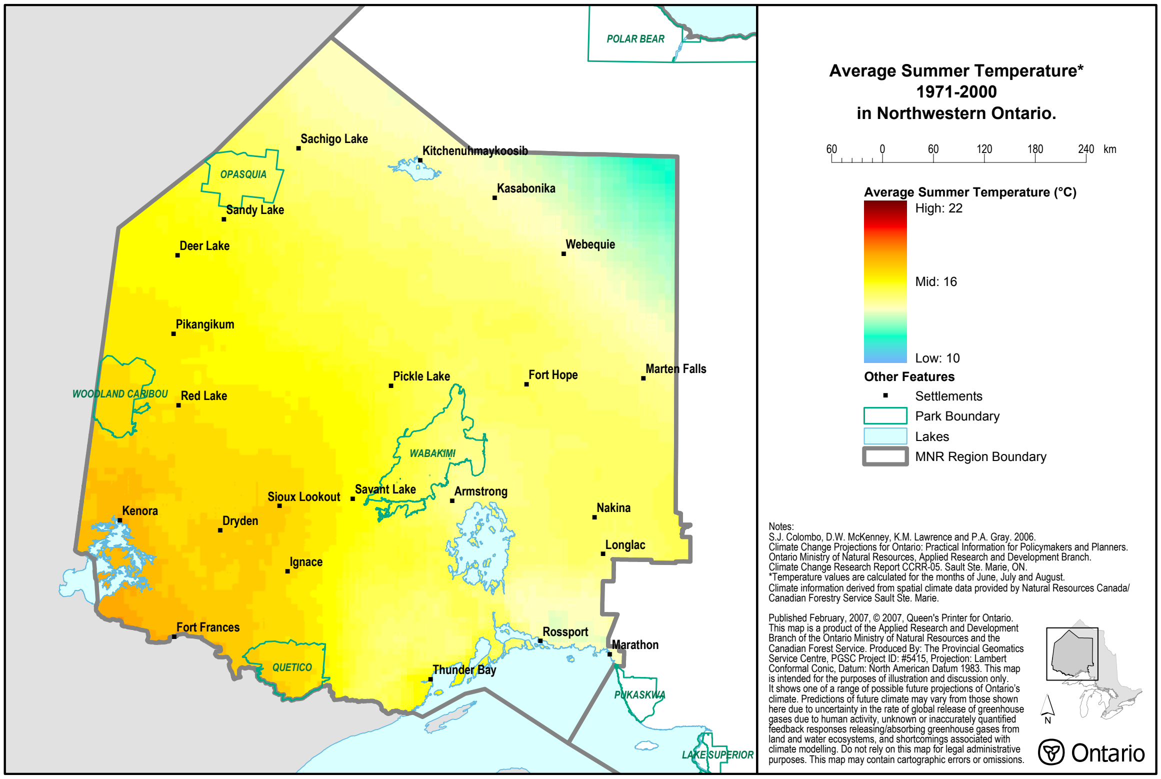
In northwestern Ontario during 1971-2000, average summer temperatures ranged from 11 to 12°C in the north near Kasabonika and Webequie to about 18°C in the southwest near Fort Frances and Kenora (Figure 12a). In the A2 greenhouse gas scenario, summers will warm by 1 to 2°C as early as 2011, (Figure 12b). Commencing about 2041, people in northeastern parts of the region such as Fort Hope and Marten Falls will see summers 3 to 4°C warmer compared with 1971-2000, while warming of 2 to 3°C will occur in southern parts of the region such as Red Lake, Sioux Lookout, and Thunder Bay (Figure 12c). As a result, by 2041, people living south of Ignace and Kenora will experience summer temperatures similar to present-day Nebraska and Arkansas. Between 2071 and 2100, summer temperatures in an A2 world will continue to get warmer, with 5 to 6°C increases further north in the region and 4 to 5°C increases further south (Figure 12d).

Warm season precipitation in southern parts of the northwestern region has historically ranged between 450 to 500 mm, with northern and western parts of the region being drier (Figure 13a). Beginning in 2011, forest fire-prone parts of northwestern Ontario, such as Red Lake, Kenora, Kasabonika, and Sachigo Lake, are projected to receive up to 10% less precipitation (Figure 13b). By 2071 in an A2 world, almost the entire western half of the region will receive up to 10% less precipitation (Figure 13d). When combined with higher temperatures, the projected decrease in precipitation in the western half of the region will result in soils that are considerably drier and forests much more at risk from fire.

Winter climate

In 1971-2000, people in northwestern Ontario experienced winter temperatures ranging from about -24°C in the north to -14°C in the south (Figure 14a). In an A2 world, by 2071, people in southern parts of the region will experience winters that are 5 to 6°C warmer (Figure 14d), making temperatures in Thunder Bay more like those found in Peterborough, in southern Ontario, during 1971-2000. However, warming in the region will be much greater for people and ecosystems north of Webequie, Kasabonika, and Kitchenuhmaykoosib, with winter average temperatures there increasing 8 to 9°C before the end of the century (Figure 14d). This will expose people in northern parts of the region to winter temperatures comparable to those found about 300 to 400 km further south in 1971-2000.

In northwestern Ontario, cold season precipitation has historically been greatest near Lake Superior, decreasing with distance from the lake (Figure 15a). By 2011 in an A2 world, most areas within about 100 km of Lake Superior will get up to 10% more cold season precipitation (Figure 15b). However, people in most of the region will get up to 10% less cold season precipitation compared with 1971-2000, and people living north of Pikangikum and west of Kitchenuhmaykoosib will receive up to 20 to 30% less precipitation (Figure 15b). By mid-century a significant north-south split in the region will emerge; northern areas will receive less cold season precipitation and the south will receive more (Figure 15c). By 2071, cold season precipitation in an A2 world is projected to increase in about three quarters of northwestern Ontario, especially to the south and east of Savant Lake and Nakina (Figure 15d). However, the A2 world will also see Sachigo Lake and Sandy Lake remain the centre of a zone of reduced cold season precipitation affecting many northwestern Ontario First Nations communities (Figure 15d).



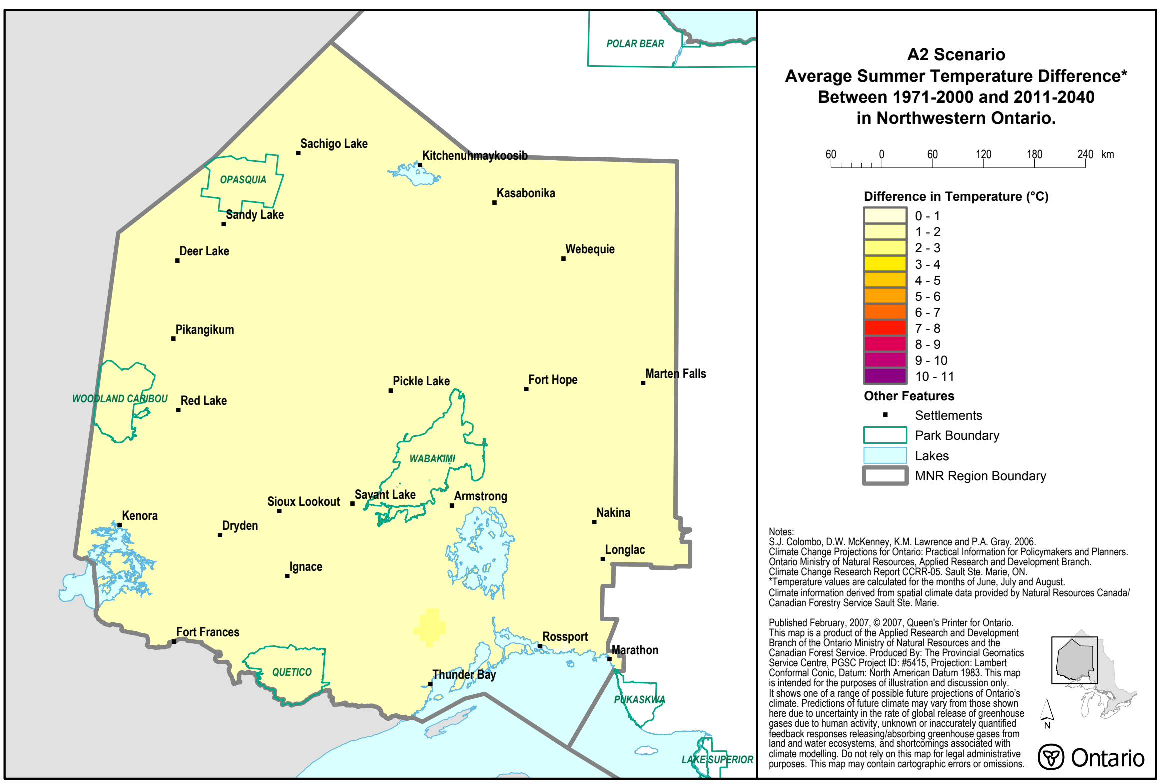
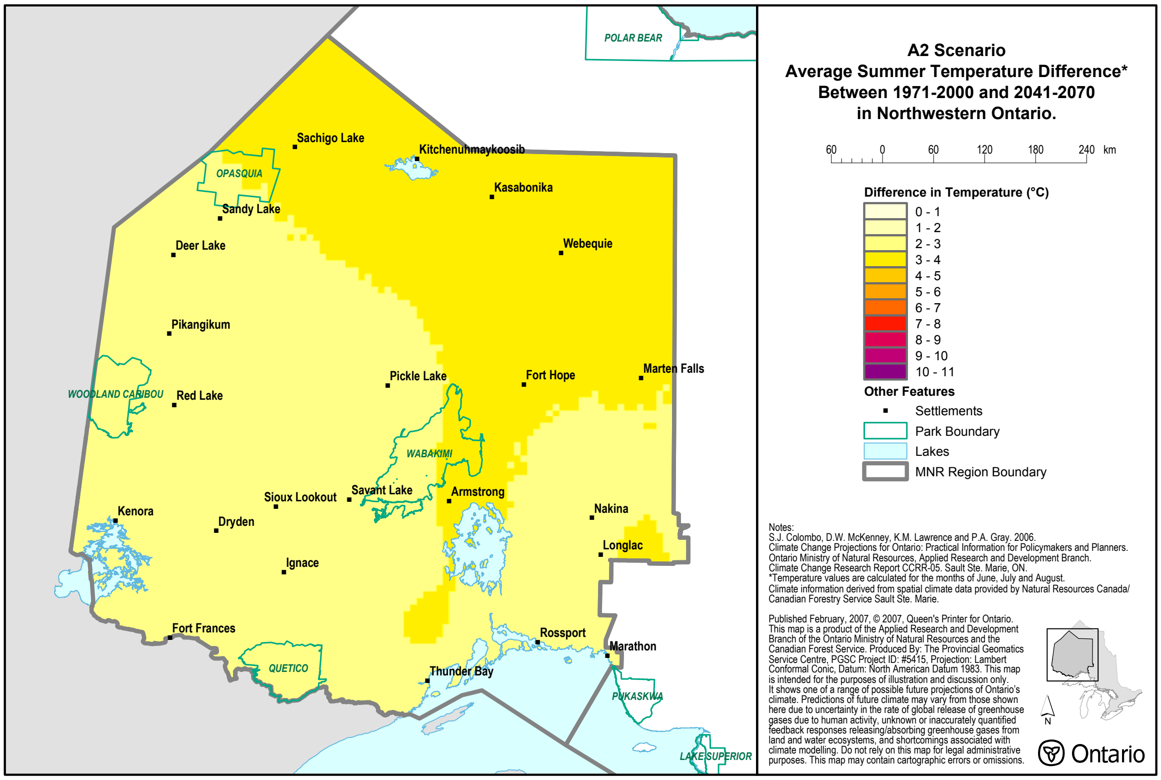


Figure 12a and b. Average summer temperatures in northwestern Ontario for 1971-2000 and projected change in summer temperatures for 2011-2040.



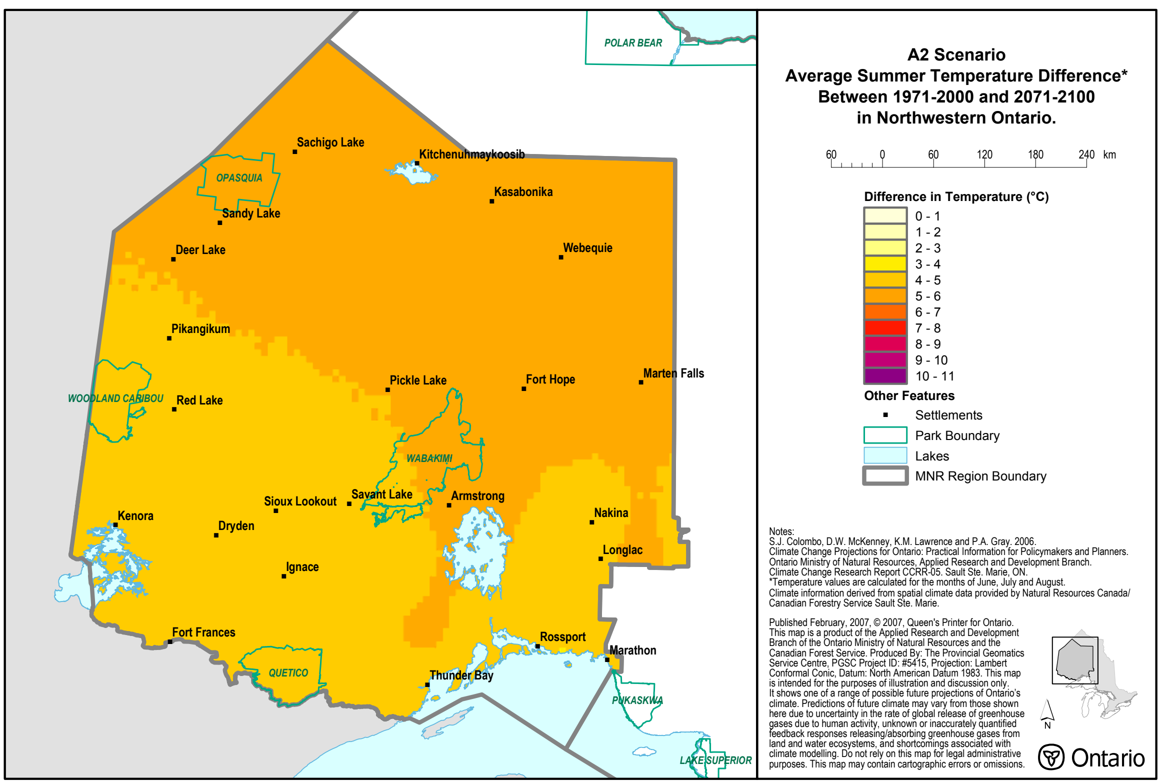
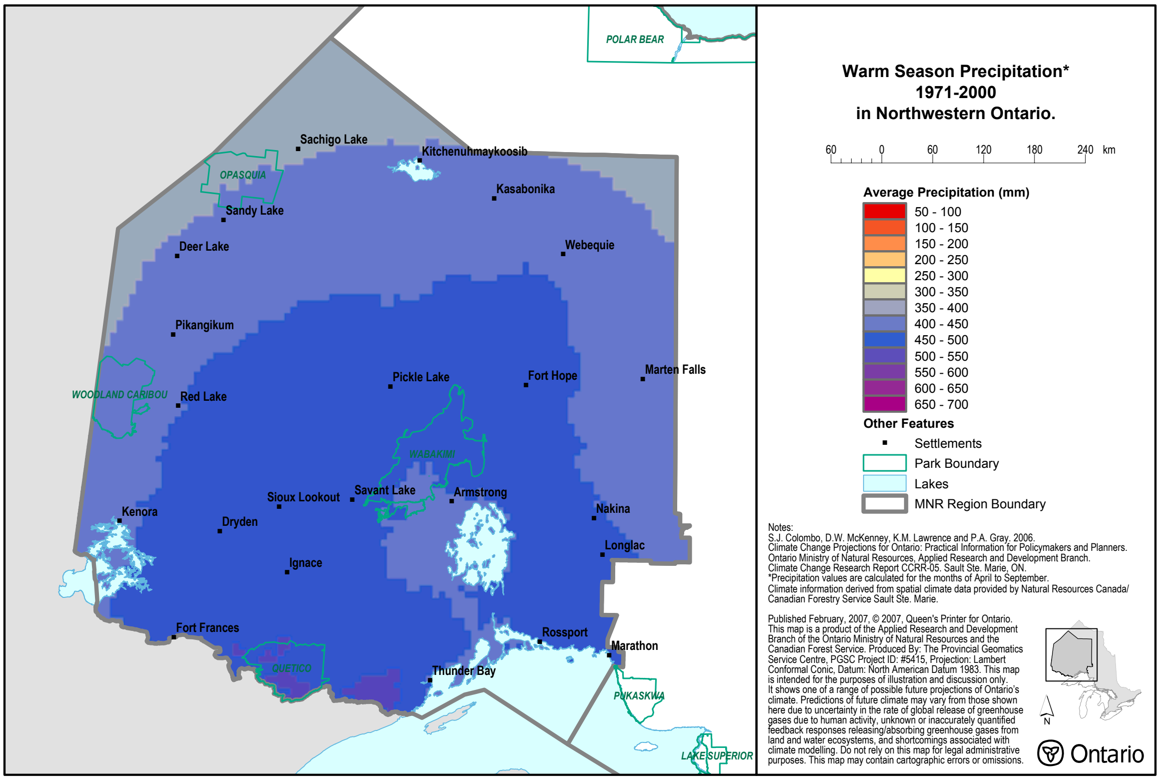


Figure 12c and d. Projected change in summer temperatures in northwestern Ontario for 2041-2070 and 2071-2100.



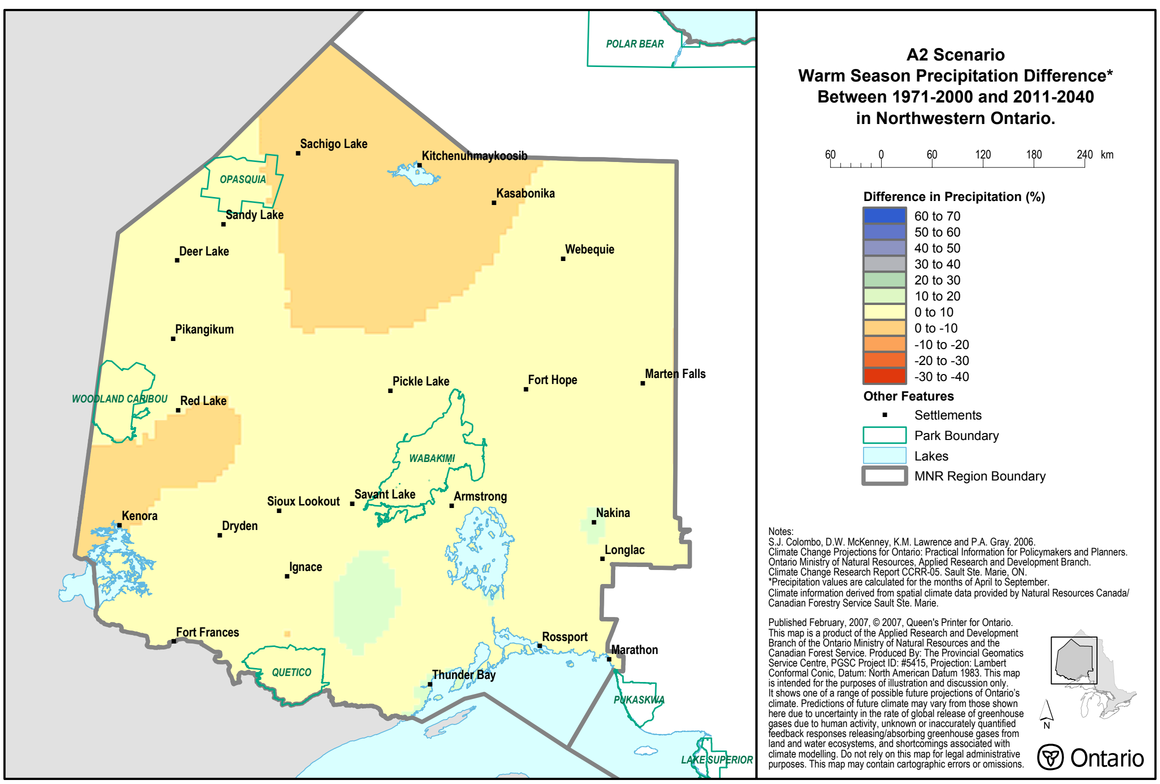


Figure 13a and b. Average warm season precipitation in northwestern Ontario for 1971-2000 and projected change in precipitation for 2011-2040.

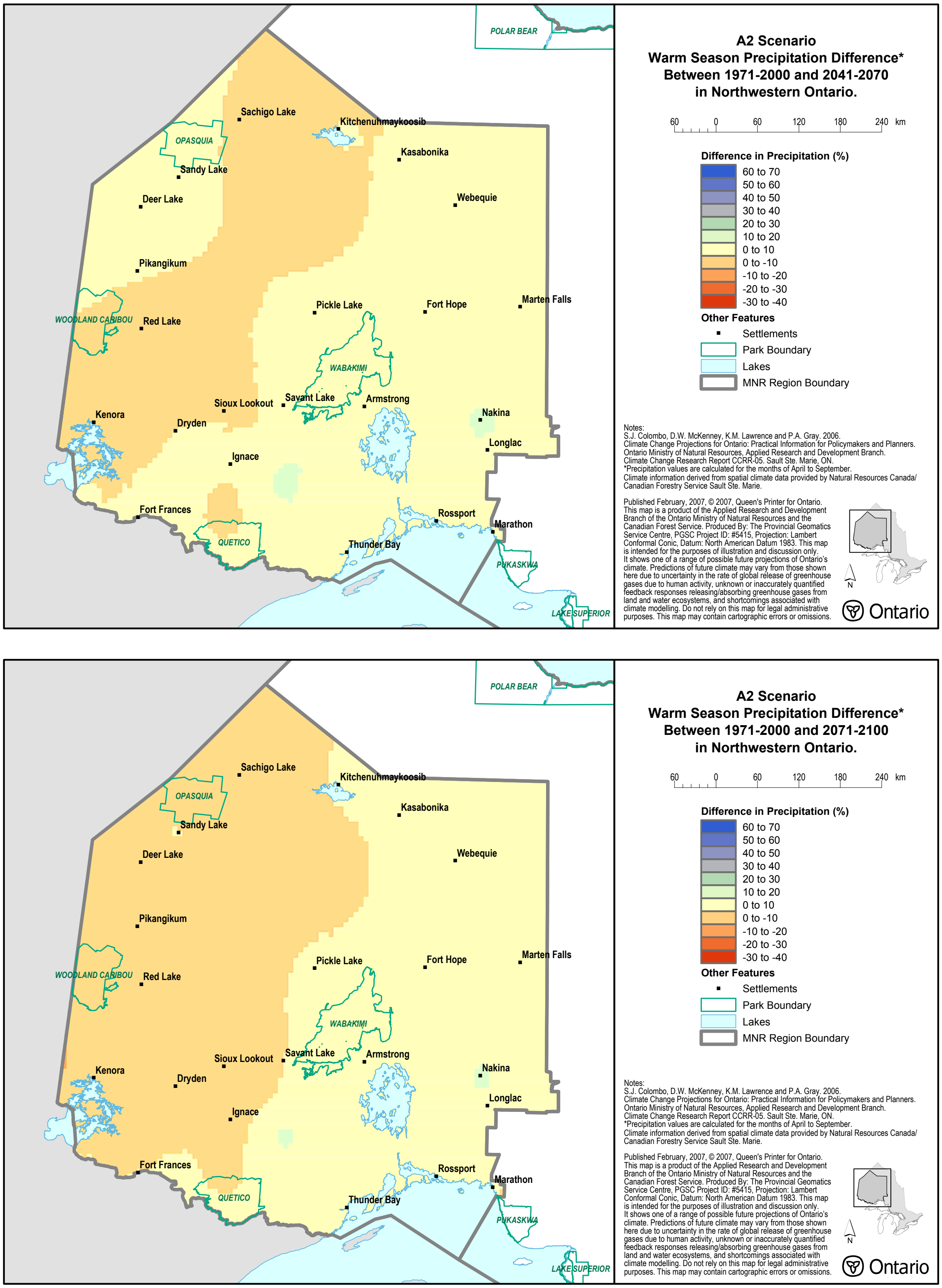
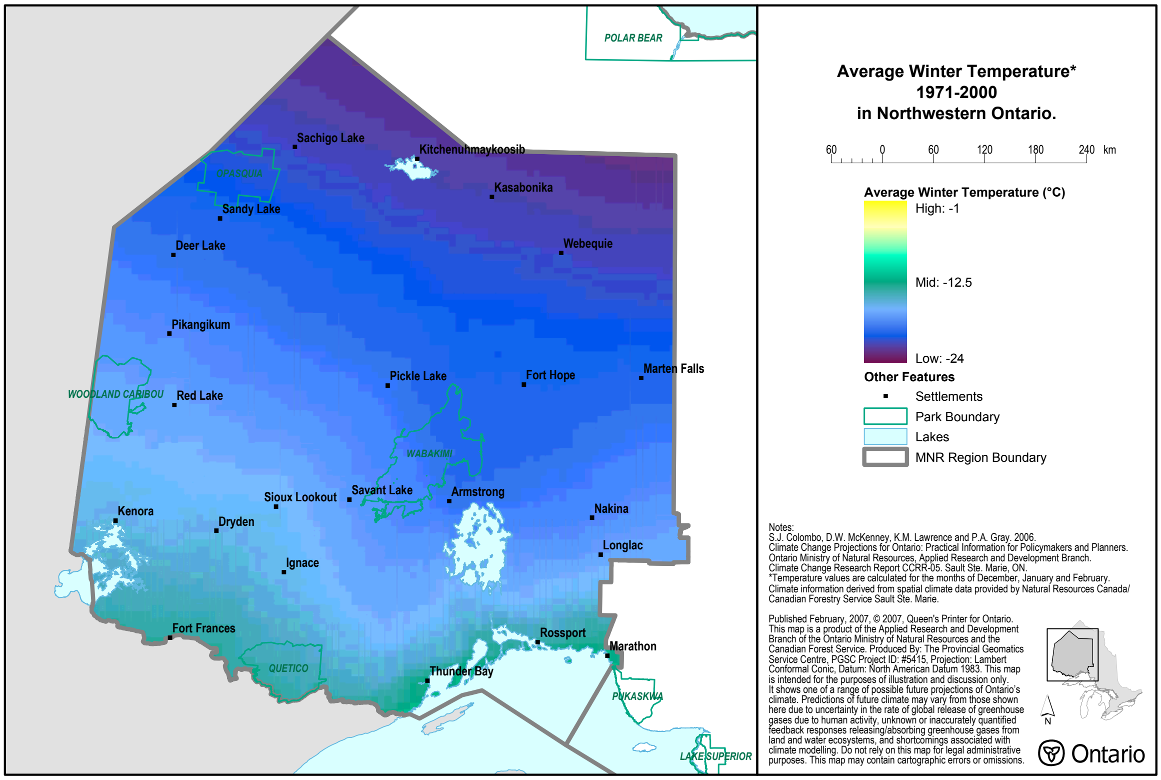


Figure 13c and d. Projected change in warm season precipitation in northwestern Ontario for 2041-2070 and 2071-2100.



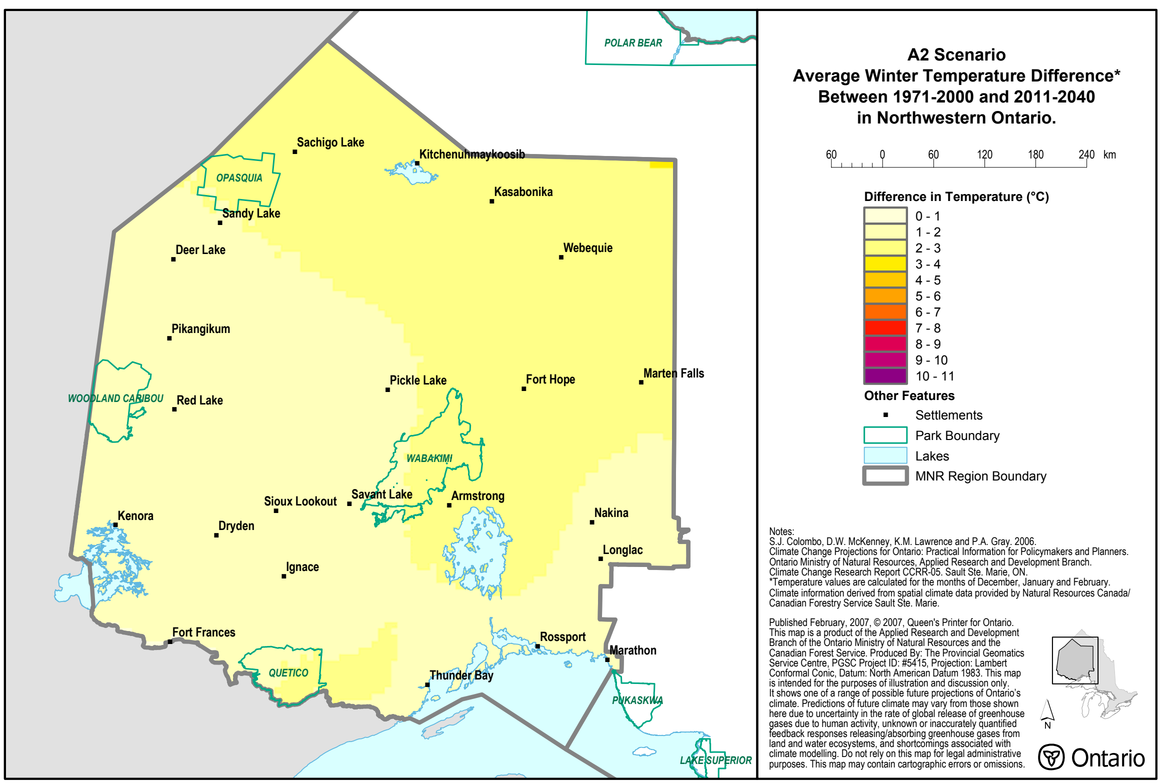
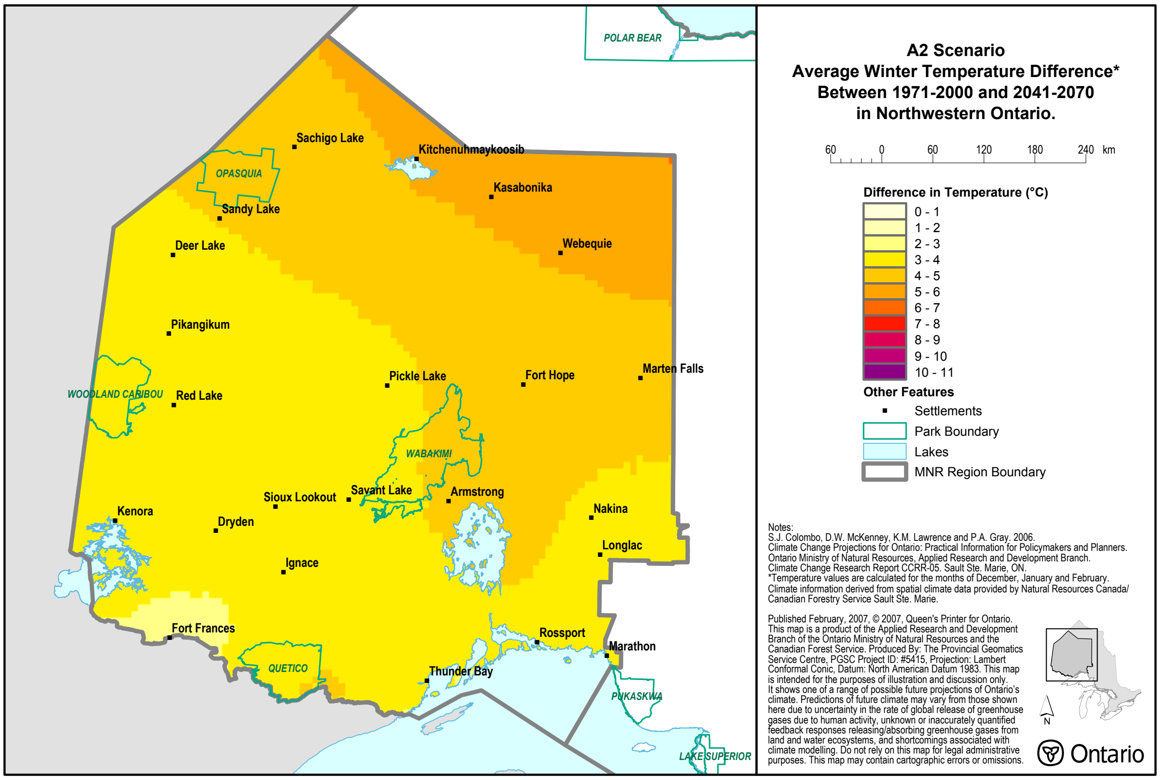


Figure 14a and b. Average winter temperatures in northwestern Ontario for 1971-2000 and projected change in winter temperatures for 2011-2040.



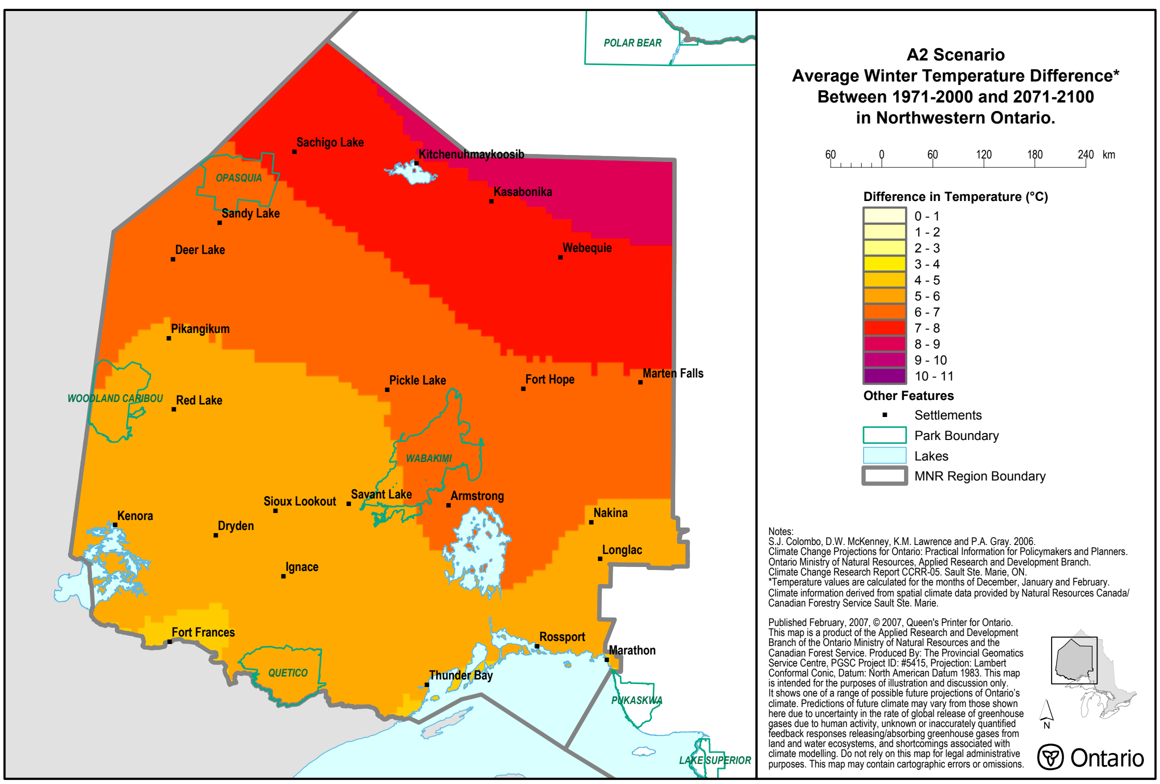
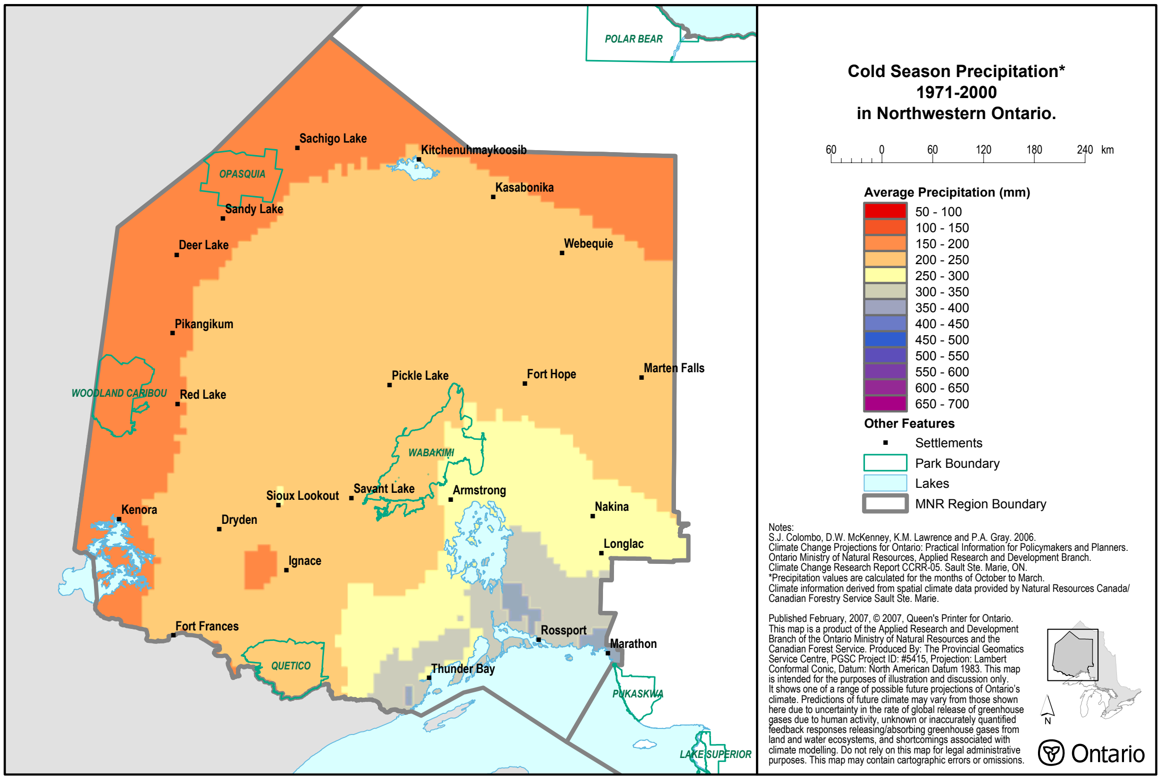


Figure 14c and d. Projected change in winter temperatures in northwestern Ontario for 2041-2070 and 2071-2100.



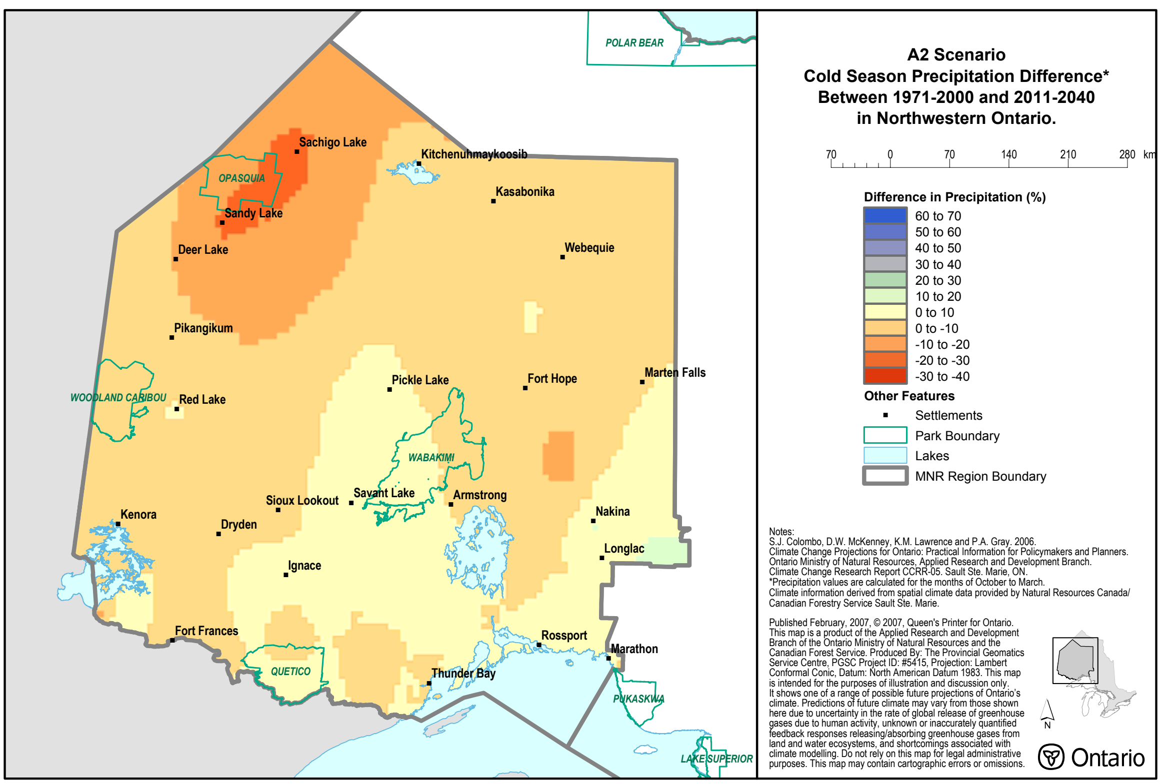


Figure 15a and b. Average cold season precipitation in northwestern Ontario for 1971-2000 and projected change in precipitation for 2011-2040.

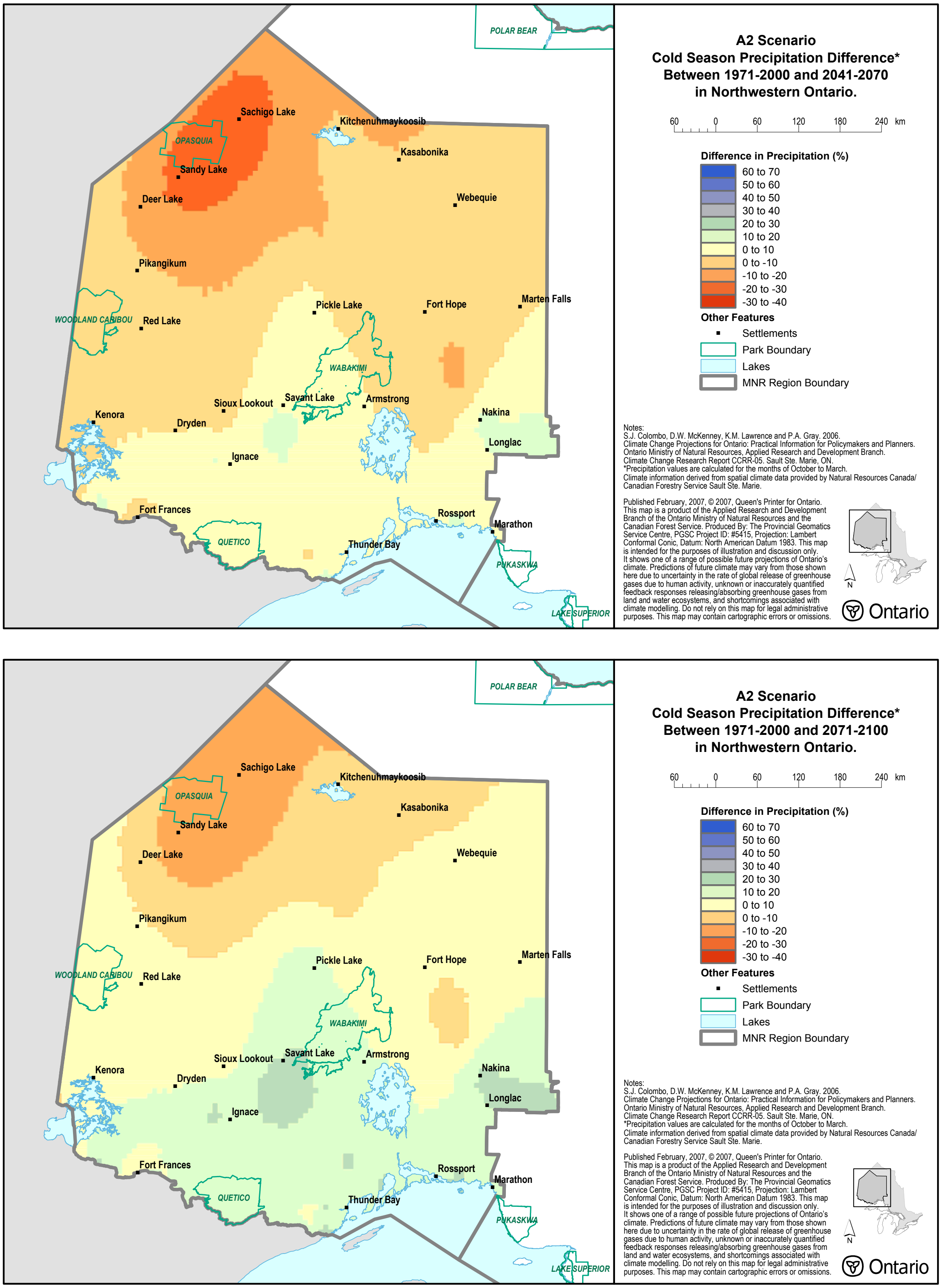


Figure 15c and d. Projected change in cold season precipitation in northwestern Ontario for 2041-2070 and 2071-2100.

Discussion

Most people in the world, including most Ontarians, behave as though past climate will prevail in the future. However, most climatologists believe that the Earth is entering a period of rapid climate change that will last beyond the 21st century. While the timing and extent of climate change are uncertain, significant changes now taking place in Canada's north are evidence that it is underway and changing the lives of people and ecosystems (Flannery 2005). Ontarians can address climate change in two ways: 1) Mitigation to reduce greenhouse gas emissions and increase carbon sequestration in forests and other carbon sinks, and 2) Adaptation to reduce the negative impacts of climate change on natural and human systems. The maps in this report were prepared to help readers contribute to informed decisions about mitigating climate change and adapting to its impacts.

Climate change will affect many aspects of human health, community infrastructure, and ecosystem composition and function (Table 1). While individuals, companies, and governments around the world are in some cases working to reduce greenhouse gas emissions, emission rates are nevertheless increasing (Jones 2006). Whether or not action will be widespread enough to stabilize greenhouse gas emissions in the atmosphere sometime this century remains unclear. Will the rates of greenhouse gas emissions in Canada and elsewhere continue to increase, resulting in larger changes in climate, or will efforts to reduce emissions be successful and the extent of climate change kept to a level that is still significant but less drastic?

In spite of these difficulties, enough information now exists to discuss the potential impacts of changes in Ontario's climate. Adaptive actions that will be beneficial for Ontario in both the short and long terms can also be considered, regardless of whether the climate changes more or less drastically. Understanding the timing and nature of climate change enables policymakers and planners to examine what future actions may be warranted to preserve or improve the social, economic, and environmental values that are important to Ontarians.

The possible timing and extent of climate change vary depending on which of the more than 20 climate models and 40 greenhouse gas scenarios are considered because each provides a different picture of what the future might hold (IPCC 2001). Some combinations project minor change while others project extreme change. We have chosen the A2 and B2 scenarios and used them in the Canadian Coupled Global Circulation Model to illustrate 2 views of Ontario's possible future climate. The maps illustrate the effects of intermediate increases in atmospheric greenhouse gas concentrations and therefore predict neither the greatest nor the least potential changes in temperature and precipitation. Policymakers and planners may elect to use these climate projections as a starting point in developing initial evaluations of the potential impacts and levels of risk resulting from climate change.

Some readers may want to explore what the future climate of Ontario may be like based on other climate scenarios and using additional climate models. The Hadley model (developed in the United Kingdom), for example, projects that summer temperatures will be even warmer than those projected by the Canadian CGCM. Users can examine climate change projections from other climate models online at the Canadian Forest Service's Geo-spatial Tools and Economic Analysis webpage (http://glfc.cfsnet.nfis.org).

Our maps depict average changes in temperature and precipitation over 30-year periods. These averages do not indicate the likelihood or extent of extreme weather events during each time interval (e.g., drought or very high intensity rainfall). However, it is often extremes in climate that can jeopardize human health and safety and disrupt ecosystems. A Statistical Tool for Extreme Climate Analysis is available to support this kind of investigation (http://www/cics.uvic.ca/scenarios/index.cgi?Other_Data#steca).

Developing a mechanism to make timely decisions concerning climate change in Ontario requires a cyclic process of (1) climate projection, (2) impacts assessment, and (3) adaptation of policies, planning, and infrastructure. This cycle will need to be repeated as climate models are improved and climate scenarios updated. In this way, policymakers and planners in the public and private sectors can use climate projections to improve their understanding of the effects of climate change. Doing so will reduce the risk that climate change will harm Ontario's people, infrastructure, and natural environments.

Table 1. Examples of key Ontario ecological, infrastructure, and social values likely to be affected by climate change.

Area	Climate change impacts
Agriculture	- reduced productivity where temperature rises without a compensatory increase in precipitation - change in crops that can be grown - less suitable climate to produce ice wine in southern Ontario - longer growing season - expansion of agriculture into new areas of northern Ontario where soils are productive
Environment	- changes in the biodiversity of species and ecosystems - increased difficulties for species currently at risk to survive or maintain their status - new species at risk because of disequilibrium with climate - increased opportunity for natural migration of invasive species to Ontario - loss of plants and animals for which some protected areas were established
Forestry	- increased frequency and more area burned by forest fires, placing stress on firefighting infrastructure and increasing the number and length of shutdowns of bush operations - regional changes in timber supply (some may increase while others decrease) - less access for forestry operations due to late freeze-up and mid-winter thaws - opportunities to plant faster-growing, less cold hardy tree species - migration of mountain pine beetle from Alberta threatening old-growth pine forests
Human health	- fewer winter cold alerts but more summer heat alerts - more SMOG days - appearance of new insect-borne diseases - increased water quality issues due to less total precipitation but more extreme rainfall events
Northern communities	- threats to northern communities by forest fires will be more frequent - soil instability and shifting of houses and other structures due to melting permafrost - increased community isolation and higher cost of living due to shortened winter road season
Power generation	- higher maximum summer power requirements due to increased summer temperatures - lower winter maximum power requirements due to warmer winters - reduced hydroelectric power generation due to lower stream/river flow and lower lake levels - more risk to power transmission lines from ice storms
Tourism and recreation	- fewer winter outdoor recreation opportunities in southern Ontario (e.g., less reliable skiing, snowmobiling, ice fishing, and outdoor ice skating) - longer warm weather outdoor recreation season (e.g., boating, camping, and golf)
Transportation	- shorter road snow-clearing season - greater risk of freezing rain and need for road de-icing in southern Ontario - longer Great Lakes shipping season - more shipping disruptions and channel/harbour dredging due to lower Great Lakes water levels

Conclusions

This report provides projections of Ontario's future climate that can be used for adapting to climate change. Understanding the timing and extent of climate change and its potential effects can help governments and private enterprise decide when to act, what actions to take, and whether it is better to be proactive or to react to changes as they occur. However, the changes in climate need not be as great as projected, if concerted efforts are made to reduce greenhouse gas emissions.

The maps in this report and the accompanying CD-ROM provide two intermediate scenarios of global atmospheric greenhouse gas concentrations. However, while these are intermediate scenarios, the projected changes in Ontario's climate are significant. The largest changes in climate are projected for Ontario's far north, where winter temperatures in 2071-2100 will increase by 9 to 10°C and precipitation will fall by as much as 30%, compared with the years 1971-2000. Compared with this, by 2071, people living in densely populated southern Ontario, will see a 4 to 5°C increase in average summer temperature making it similar to summers in present day Virginia. Given that precipitation is not expected not to increase significantly, higher summer temperatures will potentially result in moisture stress affecting many aspects of life in Ontario, including reduced hydroelectricity generation, decreased agriculture productivity, and altered natural environments. Reducing greenhouse gas emissions but planning for such changes and impacts, instead of carrying on with business-as-usual approaches, will help Ontarians adapt to their future climate.

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