IBC BAC | Insurance Bureau of Canada
Bureau d'assurance du Canada

TELLING THE WEATHER STORY

PREPARED BY

THE INSTITUTE FOR CATASTROPHIC LOSS REDUCTION (ICLR)

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1. EXECUTIVE SUMMARY

Public and private sector leaders need information about regional climate trends in order to adapt for the future.

There is increasing evidence around the world that the frequency and severity of severe weather is on the rise. In Canada, the recent spike in extreme weather-related events has resulted in social and economic consequences for individuals, governments, and home and business insurers around the country. Yet little research has been undertaken to investigate historical and projected changes in weather trends in this country at the regional level.

Adaptation

Adaptation refers to initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist (e.g., anticipatory and reactive, private and public, and autonomous and planned).

The purpose of this report is to provide a greater understanding, based on the best available peer-reviewed science, about how weather patterns have changed in the past and how they are expected to change in the future. In doing so, the report aims to provide decision makers with the information they need to better adapt public and private infrastructure to the realities of the changing climate, while allowing home and business insurers to plan for future claims scenarios.

This report has been prepared by Professor Gordon McBean and colleagues at the Institute for Catastrophic Loss Reduction (ICLR). It is mainly based on internationally reviewed climate science as summarized by the Intergovernmental Panel on Climate Change (IPCC). Canada-specific information has been added based on Environment Canada publications, reviewed articles and a special report prepared by James P. Bruce commissioned by ICLR (Climate Change Information for Adaptation). Regional projections are provided within specific ranges due to the varying availability of reliable historical weather data and the challenges associated with projecting future changes in weather at the local level.

Canada's climate is changing.

This analysis reveals that the warming of the world's climate system is unequivocal based on observed increases in global average air and ocean temperatures. The year 2010 ranked, together with 2005 and 1998, as the warmest on record.

In Canada, on average, temperatures warmed by more than 1.3°C between 1948 and 2007, a rate of warming that was about twice the global average. The national average temperature for the year 2010 was 3.0°C above normal, which makes it the warmest year on record since nationwide records began in 1948. Canada has also become wetter during the past half century, with mean precipitation across the country increasing by about 12%. On average, Canada now experiences 20 more days of rain compared with the 1950s. These changes to the climate are likely responsible, at least in part, for the rising frequency and severity of extreme weather events in Canada, such as floods, storms and droughts, because warmer temperatures tend to produce more violent weather patterns.

These weather trends are already affecting Canadians.

People around the world, including Canadians, are already seeing the impact of severe weather in terms of lost lives and injuries, families displaced from their homes, and towns that are devastated. The personal and social costs of these losses are incalculable.

Insurers have seen first-hand the financial impacts of severe weather, as insured losses from natural catastrophes have ranged between $10B and $50B a year internationally over the past decade. In Canada, catastrophic events cost roughly $1.6B in 2011 and almost $1B in each of the two previous years. The majority of these insured losses were caused by extreme weather events, but Canada's home and business insurers are also seeing an increase in claims resulting from smaller weather events that nevertheless result in significant property damage for consumers. These losses are driven in part by Canada's aging sewer infrastructure, which is often incapable of handling the new, higher levels of precipitation, while the fact that homeowners are investing more in costly basement upgrades also has an impact on claims. As a result, water claims have now surpassed fire as the number one cause of home insurance losses in many parts of the country.

The climate will continue to change, with varying impacts across Canada's regions.

The earth is projected to warm by another 1.5°C by 2050. This change in the climate is expected to have varying impacts on temperature, precipitation and extreme weather trends throughout Canada, depending on the region of the country and the season.

By 2050, northern Canada is expected to warm the greatest amount during the winter, while southwestern Canada is likely to warm the most during the summer. Over this same period, seasonal average precipitation is projected to decline over parts of western and Atlantic Canada in the summer, while average precipitation is likely to increase over all of Canada in the winter. Region-specific information on the projected weather trends is provided in the Regional Syntheses section of this report.

Severe weather is projected to increase over the next 40 years.

Future trends in the frequency and severity of extreme weather will have a significant impact on the ability of individuals, governments and insurance companies to prepare for future catastrophic events. This is a concern given that the IPCC has concluded that it is very likely that extreme weather such as hot extremes, heat waves and heavy precipitation events will become more frequent over the next 50 years.

The frequency with which Canada experiences events such as heavy rainfall of a given intensity (known as the return period), is projected to increase such that an event that occurred on average once every 50 years will be likely to occur about once every 35 years by 2050. Even in regions of the country where average rainfall is projected to decrease in the summer, the frequency at which severe precipitation events occur is expected to increase over the next 40 years.

Changes to Canada's climate will also have implications for climate effects other than changing precipitation patterns. The occurrence of forest fire activity is projected to increase by 25% by 2030, with major regional variations as certain parts of the country become hotter and drier than others. Recent observations have led to projections of global mean sea level rises of 1 metre or more over the next century, with tangible impacts for Canada's coastal regions. Where information is available, this report also provides projected changes to severe wind/thunderstorms, hail, and freezing rain events.

Canada must adapt to this new reality.

These historical and projected trends point to the need for Canada to adapt its existing infrastructure now in order to minimize the social and economic costs associated with severe weather. Given the real threat of climate change, governments, communities, and individual home and business owners can use the information contained within this report to help make targeted decisions about how to adapt existing public and private impacts to manage the risks associated with these events.

2. INTRODUCTION

Globally and in Canada, there is increasing evidence that the climate is changing. Every day, international news outlets publish stories about the impact of extreme weather around the world – from floods in Bangkok to drought in Sudan. In Canada, a recent spike in severe weather-related events – including severe rainstorms, tornadoes, flooding and forest fires – has resulted in social and economic consequences for individuals and governments across the country. As a result of these trends, water losses have now surpassed fire as the number one cause of home insurance claims in many parts of the country.

This increase in severe weather has raised questions among the public, governments and insurers about regional changes to the climate: How have weather patterns changed over the past 40 years, and how are they expected to change in the future? Little research has yet been undertaken to investigate regional changes in severe weather patterns and projected changes.

The purpose of this report is to tell the story of regional-specific changes in the frequency, severity and duration of weather events across Canada. This report focuses on both the observed trends in climate and severe weather over the past 30 to 50 years and projected trends for the next 40 years, until 2050. The goal is to provide consumers and governments with information to help them better adapt public and private infrastructure to the realities of the changing climate, while allowing home and business insurers to plan for future claims scenarios.

3. METHODOLOGY

This report is based on internationally reviewed climate science, generally as summarized by the Intergovernmental Panel on Climate Change (see IPCC description in box) and specifically its Fourth Assessment Report presented to governments in 2007[1] and its 2012 special report on climate extremes.[2] Since the IPCC produces global assessments, specific information on Canada and its regional variations has been added from publications of Environment Canada, reviewed scientific articles and a special report prepared by James P. Bruce[3] and commissioned by the Institute for Catastrophic Loss Reduction (ICLR).[4] A narrative summary for each of the seven regions across Canada is provided below in the Regional Syntheses section.

IPCC

The Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations Environment Program (UNEP) in 1988 and is responsible for assessing and compiling the most recent and best scientific research on climate change. The IPCC is considered the world authority on climate change information and periodically releases comprehensive change reports, which are used as the basis for climate change policy making worldwide. In 2007, the IPCC was jointly awarded the Nobel Peace Prize with Al Gore "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change."

Confidence

The level of confidence in the correctness of a result is expressed in the 2007 IPCC report, using a standard terminology defined as follows:

TERMINOLOGY	DEGREE OF CONFIDENCE IN BEING CORRECT
Very high confidence	At least 9 out of 10 chance of being correct
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

The rate of global climate warming for the next 25 years is projected to be approximately 0.2°C per decade under all scenarios. This rate of change is approximately the same as the observed global warming rate for the past 25 years of 0.18°C per decade, and is due to the slow response of the climate system to rising greenhouse gas concentrations. Through to 2050, the differences among the most likely scenarios of greenhouse gas emissions remain small, although the rate of global warming is projected to increase slightly as the accumulating emissions have more effect. There is a scientific basis for extrapolating potential changes in climate from past records where there is appropriate quality data – including changes to specific climate parameters, such as rainfall and sea level rise.

There are challenges with any approach that aims to provide specific projections of smaller-scale climate changes. These include limited past observations of relatively rare occurrences of extreme events, non-linearities in the climate system and the limited ability of climate models to provide small-scale details, due to their necessarily global nature. The sources of data and other information, as well as any specific limitations, are identified throughout this report.

4. CLIMATE CHANGE

4.1 Scientific background

Climate is a complex phenomenon with many facets and variations in both space and time. What is happening in one place may or may not be an indicator of what is happening in another. Similarly, last year's or month's climate may not be an indicator of the next. Current understanding of this complex climate system is based on centuries of scientific study, and the time scales of the climate system are important for understanding projected changes to the climate. The atmosphere adjusts quickly to changes, but the oceans respond very slowly, on a time scale of decades. These phenomena influence the response time and magnitude of change in the climate system as a whole when it is disturbed. Climate and climate change refer to changes averaged over decades, not year-to-year variations. For the purposes of this report, "normal" climate is defined as that over a 30-year period.

Climate

Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state of the climate system, including a statistical description.

Atmosphere

This is the gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1% of the volume) and oxygen (20.9%), together with a number of trace gases, such as argon (0.93%), helium and radiatively active greenhouse gases such as carbon dioxide (0.039%, which corresponds to 390 parts per million) and ozone. In addition, the atmosphere contains greenhouse gas water vapour, whose amounts are highly variable but typically present around 1% of volume. The maximum amount of water vapour that the atmosphere can hold, corresponding to 100% relative humidity, depends strongly on its temperature – warm air can hold more water vapour. The atmosphere also contains clouds (water in its liquid phase) and aerosols.

Weather

Weather includes short-term changes in the atmosphere, and can change over very short periods of time. Weather can change from minute to minute, day to day and month to month.

4.2 How is the climate changing globally?

The knowledge about climate change comes from careful analysis of literally thousands of observations from across the globe over decades, coupled with knowledge of how the climate system works. Figure 1 shows the global average temperatures since the mid-1800s to 2005. Over the last 100 years, the best linear fit to the data shows a warming of 0.074°C per decade. Around 1940, the globe was relatively warm, compared to this trend, and then cooled relative to the previous decades in the 1950s and 1960s due to a period of active volcanic eruptions.

Climate change

(a) The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings or to persistent anthropogenic changes in the composition of the atmosphere or in land use."

(b) The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

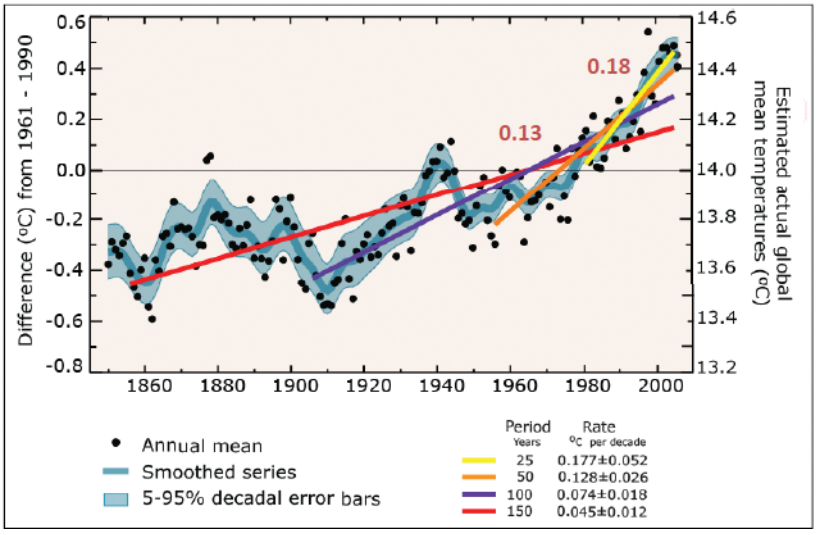

Figure 1. Annual global mean temperatures (black dots) with linear fits to the data. The left-hand axis shows temperature anomalies relative to the 1961 to 1990 average and the right-hand axis shows estimated actual temperatures, both in °C. Linear trends are shown for the last 25 (yellow), 50 (orange), 100 (magenta) and 150 (red) years. The smooth blue curve shows decadal variations with the decadal 90% error range shown as a pale blue band about that line. The total temperature increase from the period 1850 to 1899 to the period 2001 to 2005 is 0.76°C ± 0.19°C. The numbers in red show the linear trends in °C per decade for the past 50 years (0.13) and last 25 years (0.18).[6]

Over the past 50 years, the trend is higher than it was during the past 100 years, doubling to 0.13°C per decade, and for the last 25 years of the record, mean temperature rose by 0.18°C per decade. Note also that the trend is much more consistent when averaged over a few years, and the most recent rate of warming approaches being three times higher than over the century as a whole.

Based on this and other analyses, the IPCC in its 2007 full assessment concluded that the "*warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.*"[7]

The warming has not stopped. The World Meteorological Organization confirmed the Earth's significant long-term warming trend in noting that "*2010 ranked as the warmest year on record, together with 2005 and 1998*"... "*The ten warmest years on record have all occurred since 1998. Over the ten years from 2001 to 2010, global temperatures have averaged 0.46°C above the 1961–1990 average, and are the highest ever recorded for a ten-year period since the beginning of instrumental climate records.*"[8] But the rate of warming is not uniform over the globe (Figure 2). The Arctic is warming most rapidly, with northern land areas warming more than the tropics, and oceanic areas generally warming the least.

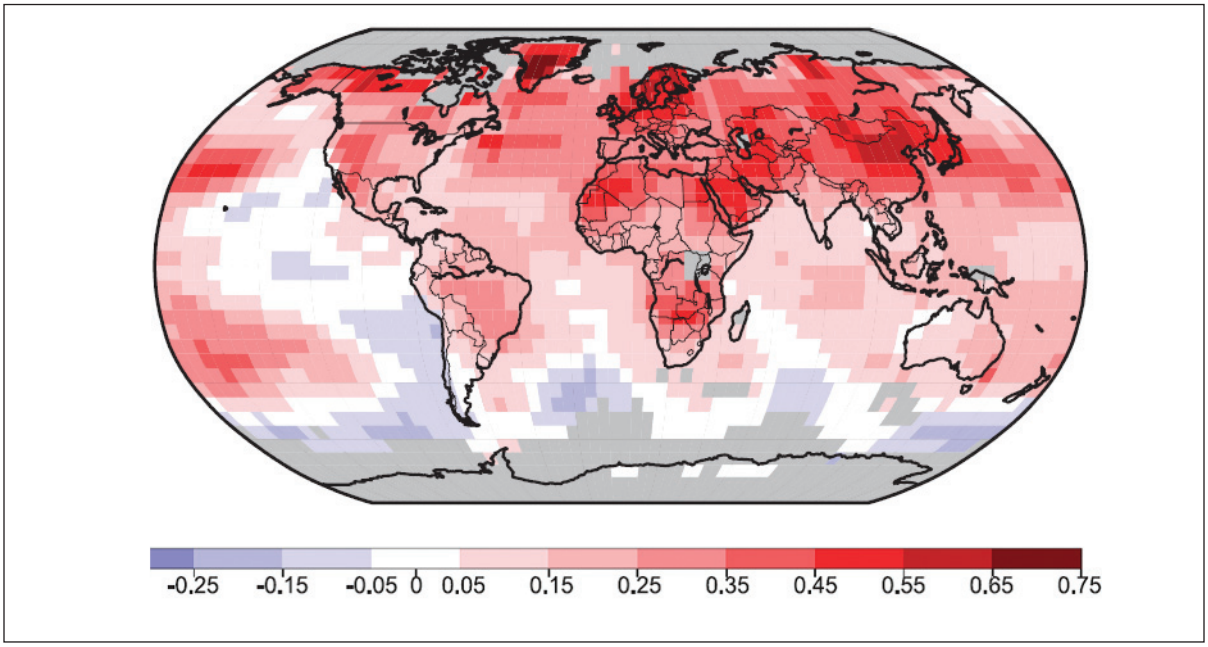

Figure 2. Patterns of linear global temperature trends from 1979 to 2005 estimated at the surface in °C per decade. Grey areas indicate incomplete data. [9]

4.3 How is the climate changing in Canada?

Over the period from 1948 to 2010, Canada warmed at an average rate of 0.24°C per decade, about twice the global average.[10] For the far north, the rate was up to three times faster. Over the past 25 years, the rate of change has approximately doubled (Figure 3 top). The winters are warming more than the summers although there is large variability from year to year and within a given year (Figure 3 bottom).

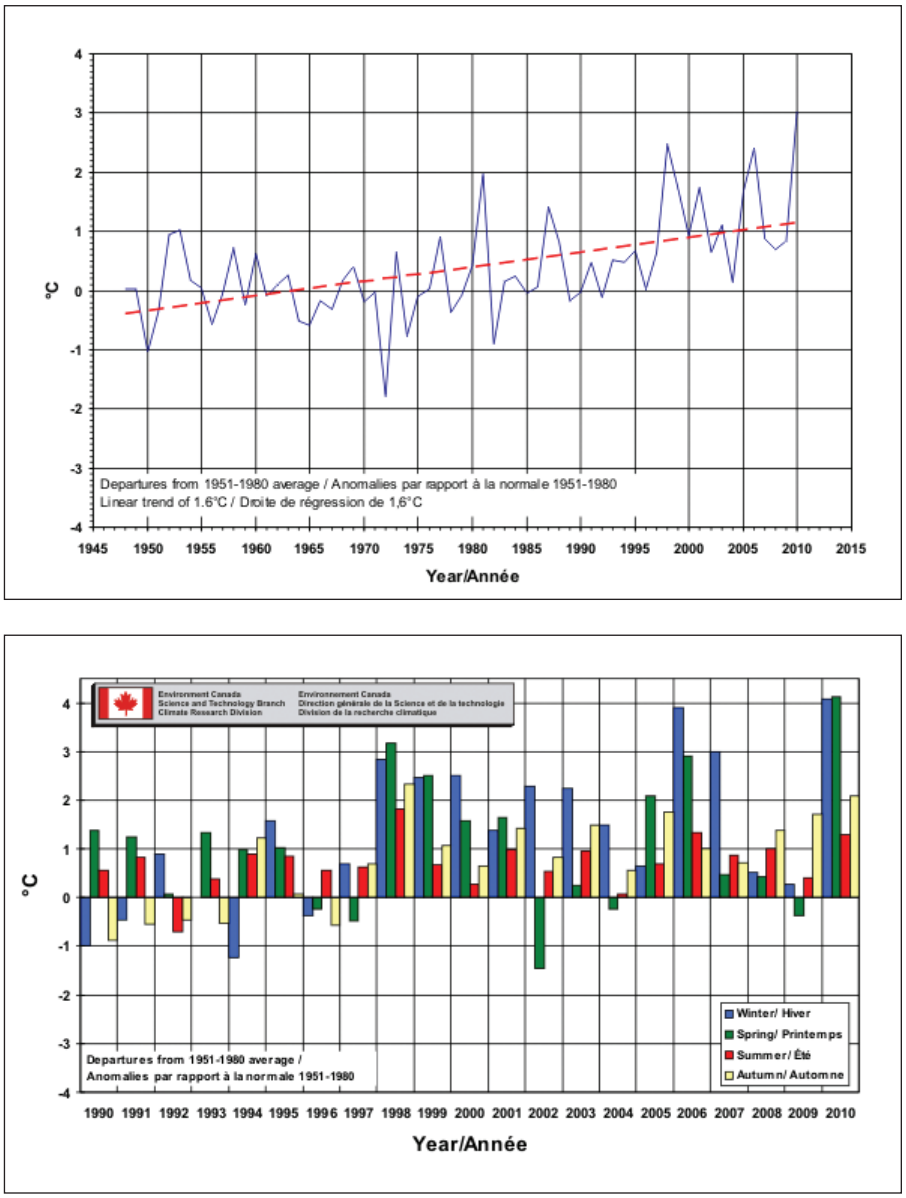

Figure 3.
Annual temperatures averaged over Canada, as departures from 1951–1980 average, from 1948 to 2010 (top). Seasonal mean temperatures from 1990 to 2010 (bottom).[11]

The national average temperature for the year 2010 was 3.0°C above normal, which makes it the warmest year on record since nationwide records began in 1948 (Figure 3 top and Figure 4 top). All of the country experienced above normal temperatures in 2010, with most of Nunavut and northern Quebec at least 4°C above normal.[12]

Variations in precipitation are much larger than those for temperature; in addition, there are inconsistencies in the data across the country and over time. In 2010, for example, there were significant variations in precipitation across the country (Figure 4 bottom). The variations in the extremes in temperature and precipitation, and some other variables, are discussed below in the Regional Syntheses section.

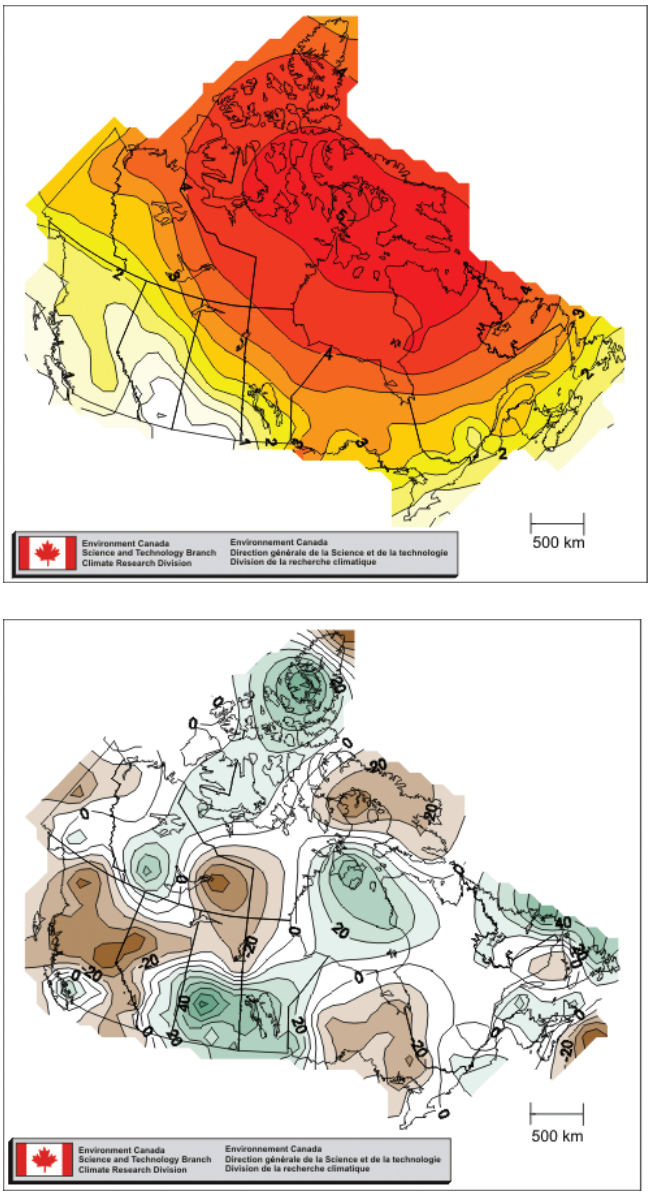

Figure 4. Spatial variations average in temperature (top) and precipitation (bottom) changes for 2010, as departures from 1951–1980 average.[13]

Nevertheless, it is clear that Canada has, on average, become wetter during the past half century, with mean precipitation across the country increasing by about 12%.[14] Annually averaged, the largest percentage increase in precipitation has occurred in the high Arctic, while parts of southern Canada, and particularly the Prairies, have seen little change or a decline. These trends have led to more transpiration, resulting in decreases in stream flows in southern Canada by about 8%.[15]

5. WEATHER/CLIMATE-RELATED HAZARDS AND DISASTERS AND THEIR IMPACTS AROUND THE WORLD

Exposure

Exposure refers to the people, property, systems or other elements present in hazard zones that are thereby subject to potential losses.

Vulnerability

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity.

For example, a flooded river, per se, is not a disaster. However, a disaster occurs when a flood interacts with a vulnerable system, such as an exposed community located in a flood plain.

The United Nations International Strategy for Disaster Reduction defines a hazard as a "*potentially damaging physical event, phenomenon and/or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.*"[16] Thus, a windstorm, flood or hot day may be defined as a hazard. A major impact occurs when the hazard affects an exposed and vulnerable community, structure and person, where vulnerability depends on the physical, social, economic and environmental factors or processes that together make the affected entity vulnerable.

Averaged over the past 10 years, there have been 785 natural catastrophes in the world per year. In 2010, there were a total of 950 natural catastrophes, nine-tenths of which were weather-related events such as storms and floods.[17] Munich Re defines a great natural catastrophe as any one or more of the following four situations: (1) number of fatalities exceeds 2,000; (2) number of homeless exceeds 200,000; (3) the country's Gross Domestic Product (GDP) is severely hit; and/or (4) the country is dependent on international aid.[18] As shown in Figure 5, over the past 25 years there has been an upward trend in the number of great natural catastrophes, with meteorological and hydrological events being the main drivers.

Climate change is likely responsible, at least in part, for the rising frequency and severity of extreme weather events, such as floods, storms and droughts, since warmer temperatures tend to produce more violent weather patterns.[19] As a result, weather events that used to happen once every 40 years are now happening once every six years in some regions in the country.[20]

M. Wahlström, the UN Assistant Secretary-General for Disaster Risk Reduction, stated in 2008, "*Over the last two decades (1988–2007), 76% of all disaster events were hydrological, meteorological or climatological in nature; these accounted for 45% of the deaths and 79% of the economic losses caused by natural hazards. The real tragedy is that many of these deaths can be avoided.*"[21] In this context, "hydrological, meteorological or climatological" events are climate

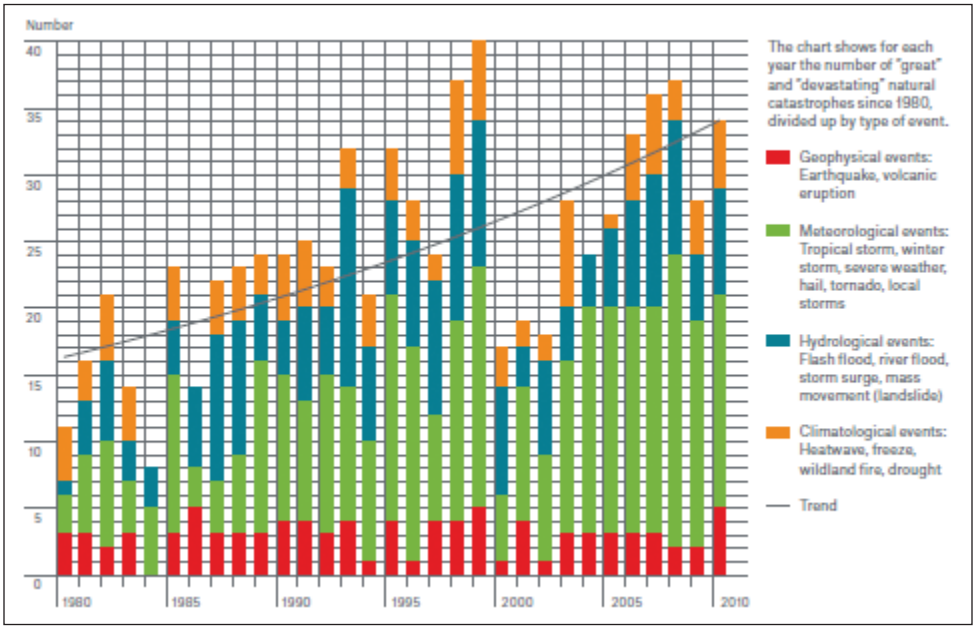

Figure 5. The number of "great" and "devastating" natural catastrophes (as defined by Munich Re) since 1980, indicated by type of event.

Extreme weather event

An extreme weather event is an event that is rare at a particular place and time of year. Definitions of "rare" vary, but an extreme weather event would normally have less than a 1 in 10 chance of occurring. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. Single extreme events cannot be simply and directly attributed to anthropogenic climate change, as there is always a finite chance the event in question might have occurred naturally. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).

and weather and related events (heat waves, freezes, wildland fires, drought, tropical storms, winter storms, severe weather, hail, tornado and local storms, flash floods, river floods, storm surges and mass movements/landslides).

Citizens rely on the property and casualty insurance industry to help carry the costs of property damage resulting from severe weather-related events. Over the past decade, global insured losses from natural catastrophes ranged between $10B and $50B a year.[22] Relative to climate risk and its disclosure by insurers, S. Leurig notes in a Ceres report, "*This changing climate will profoundly alter insurers' business landscape, affecting the industry's ability to price physical perils, creating potentially vast new liabilities and threatening the performance of insurers' vast investment portfolios.*"[23]

6. WEATHER/CLIMATE-RELATED HAZARDS AND DISASTERS AND THEIR IMPACTS IN CANADA

Within Canada, recent trends have seen an increase in property insurance claims resulting from catastrophic weather-related events. Catastrophic events over the past three years have cost roughly $1B a year. Most of these insured losses were caused by extreme weather events.

In 2010 and 2011, storms in both summer and winter resulted in major claims for Insurance Bureau of Canada's (IBC's) member companies. For example:

- On June 5 to 6, 2010, the southern Ontario town of Leamington and surrounding areas experienced a wind and thunderstorm event that resulted in estimated insured losses of $120M to both residential and commercial properties.[24]
- From July 12 to 13, 2010, Calgary and other areas in southern Alberta were pummelled with a brutal thunderstorm in which homes, businesses and automobiles were damaged, resulting in estimated insured losses of $500M.[25]
- On September 20 to 21, 2010, strong winds and sewer backup from Hurricane Igor resulted in an estimated $70M in insured damage to Newfoundland and Labrador homes and businesses.[26]
- Over the month of December 2010, it is estimated that IBC's member companies paid a total of $50.7M in home, business and auto claims as a result of winter storms throughout Atlantic Canada.[27]
- In 2011, after a cool spring, much of Canada was under oppressive heat for most of the summer, with new record temperatures set in many locations. While arson is suspected to be the cause of the May forest fires in Slave Lake, Alberta, high temperatures may have contributed to the spread of the fire, which resulted in approximately $700M in insured losses.
- On August 21, 2011, an F3 tornado struck Goderich, Ontario, killing one, injuring 37 and costing insurers an estimated $110M in insured losses.[28]
- Between August 28 and 30, 2011, flooding and windstorms from Hurricane Irene resulted in insured losses estimated at approximately $130M in New Brunswick, Ontario and Quebec.[29]

Canada's home and business insurers are also seeing an increase in claims resulting from weather-related events that fall below the threshold for the definition of "catastrophe," but nevertheless result in significant property damage for consumers. For example, on March 5, 2011, Ontario and Quebec saw record rainfall. In the aftermath, Crawford & Company claims adjusters saw a 300% increase in claims volume for branches and local contractors.[30]

Infrastructure failure is linked to much of the damage caused to homes and businesses by these severe weather events.[31] A significant long-term deficit in infrastructure improvement has left sanitary/surface water systems vulnerable as, in some areas of the country, the storm and sanitary sewer infrastructure is simply unable to handle the increasing levels of precipitation.

7. WHY IS THE CLIMATE CHANGING?

There are many reasons why the climate can change, including variations in the Earth's orbit around the sun, which has been the principal cause of the ice ages of the past. Volcanic eruptions can cause short-term cooling of the climate, usually lasting a few years. Impact by asteroids from outer space can also change the climate. Within the climate system, there are variations, such as changes in ocean temperature, that can alter the climate for years or decades. The concern now is that human activities are aggravating changes to the natural greenhouse effect, which is a phenomenon that for the last 10,000 years or more has warmed our climate by about 33°C, allowing human life to develop as it has.

Greenhouse gases

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect (IPCC definition).

The main greenhouse gases are water vapour, carbon dioxide, nitrous oxide, methane and ozone.

The most important greenhouse gas is water vapour. The water content of the atmosphere is almost at capacity most of the time. If more water is added, it precipitates out. However, if the climate warms, the atmosphere can hold more water vapour, which increases the greenhouse effect, causing more warming; this is called a positive feedback effect. Carbon dioxide, the next most important greenhouse gas, is now less than 0.04% of the atmosphere. Carbon dioxide on Earth has, on average, a lifetime in the atmosphere of about 100 years (range: 50–200 years), with the oceans largely determining the amount and lifetime through their uptake, storage and release of carbon dioxide. Methane, the third most important gas, has a lifetime of about 10 years in the Earth's atmosphere. Because it takes only a few years for a greenhouse gas to mix around the globe, emissions in one location affect the global climate.

For most of the past 10,000 years, the atmospheric carbon dioxide concentration was about 280 parts per million (ppm) by volume. Human-generated greenhouse gases (mainly carbon dioxide and, to a lesser extent, methane) really started as land was cleared for agriculture, followed by urban development and industrialization, and the use of fossil fuels (coals, oil, gas) for energy beginning in the 1800s. The atmospheric concentration passed 300 ppm in 1900, reached about 325 ppm by the mid-1950s, and is now about 390 ppm. Atmospheric methane concentrations have more than doubled in the last 100 years. These additional greenhouse gases cause the climate to warm at a greater rate as it adjusts to the additional energy being retained. Because of the time it takes for the oceans to heat up, the atmospheric climate is always lagging behind the increased greenhouse concentrations. Global carbon

dioxide emissions, mainly from use of fossil fuels, are increasing now more rapidly than before: For the period 1990–1999, the average year-to-year increase was 0.9%. For the period 2000–2007, the rate of growth increased almost four fold to 3.5%.

Based on a careful analysis of climate of the past few decades and consideration of all possible causes for the changes, the IPCC (2007) concluded that "*Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic (man-made) greenhouse gas concentrations.*"[32] Variations in the sun and other "natural" occurrences do not explain the warming over the past few decades.

8. PROJECTING THE FUTURE

Section 4, Climate Change, described the past climate, and Section 7, Why is the Climate Changing?, described and explained the changes over the past 50 years. This section presents estimates for the future based on future emissions scenarios and projections from the historical trends. Plausible future emissions scenarios depend on future development of the activities that affect atmospheric concentrations of greenhouse gases (e.g., population growth, production, consumption of fossil-fuel-based energy and government policies to reduce the net emissions of greenhouse gases into the atmosphere). A range of such emissions scenarios was prepared by the Intergovernmental Panel on Climate Change and has been used in its reports to project future climate change.

Emissions scenarios

An emissions scenario is a plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change) and their key relationships. Four emissions scenario "family storylines" set out distinct directions for global development through the year 2100. The storylines and associated population, GDP and emissions scenarios – associated with the Special Report on Emissions Scenarios (SRES) – were developed by the IPCC to assist in climate change projections. Illustrations and key themes of the four family storylines are provided below.

A1: Rapid, globalized economic development; global population rising and peaking mid-century and subsequently declining; rapid introduction of new and more efficient technologies. Key themes: global, economic development. A commonly used variation on this scenario, called A1B, incorporates more aggressive assumptions with respect to the growth utilization of non-fossil fuels.

A2: Slower, regionally oriented economic development; continuously growing global population; slower per capita economic growth and technological change than in the other storylines. Key themes: regional, economic development.

B1: Same population scenario as in A1, but with a rapid shift toward service and information economies; reduced material consumption complimented with introduction of clean and resource efficient technologies; global emphasis on solutions to economic, social and environmental sustainability. Key themes: global, sustainable development.

B2: Continually increasing population, at a lower rate than A2; less rapid economic and technological development than in A1 and B1; emphasis on regional/local solutions to economic, social and environmental sustainability. Key themes: regional, sustainable development.

This report uses the IPCC scenarios described in the box above, coupled with historical trends, to discuss future climate projections for each of seasonal average temperatures, seasonal average precipitation, extreme events and other relevant climatic parameters. To the extent possible, scenario A2 is used as the basis for the projections, insofar as it appears to be the most realistic, in view of recent emissions increases and the lack of progress in negotiations to reduce the drivers of climate change.

The primary focus of the projections in this report is on the period to 2050, or the next 40 years of climate. Note that for some indicators, adjustments have had to be made to the available scientific analyses in order to fit within this time frame. The starting point for projections is 2010.

8.1 Projections of seasonal average temperatures

For the next two decades, a global warming rate of at least 0.2°C per decade is projected, regardless of the scenario, due to the slow response of the climate system. In fact, even if the concentrations of all greenhouse gases and aerosols are assumed to remain constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected.[33] For the A2 scenario, the globe is projected to be 1.5°C warmer in 2050 and 3.8°C in 2100, with a 2000–2050 warming rate of 0.3°C per decade.

The changes in temperature and other climate variables will not be uniform over the globe and will also change by season. The broad geographical patterns of change will be similar to those observed over the past several decades, with the warming greatest over land and at most high northern latitudes, and least over the Southern Ocean and parts of the North Atlantic Ocean.

Climate isotherms

Isotherms refer to boundary lines placed on a map to delineate between geographic areas that share average yearly temperatures. Climate isotherms provide the same function as contour lines on an elevation map. A poleward shift in mean climate isotherms means that northerly areas will experience warmer average temperatures that are normally associated with more southerly areas.

With the warming, there will be a general shift poleward in the mean climate isotherms (lines of the same temperature in full degrees Celsius), and by 2050, these isotherms will move about half the way northward toward the next northerly isotherm. This means that mid-latitude westerly weather flows will be displaced northward and strengthen, this being most pronounced in the autumn and winter. For most of Canada, the winters will warm more than summers, a trend that has already been happening. In the summer, southern Canada will generally warm more than the north, due to the cooling influence of the open waters of the Arctic regions. At this time of year, the largest warming will be centred in the U.S. west, extending north into southwestern Canada. In the winter, the opposite is true – northern Canada will warm more than the southern parts of the country.

8.2 Projections of seasonal average precipitation

The IPCC also stated that "*Increases in the amount of precipitation are very likely in high-latitudes, while decreases are likely in most subtropical land regions (by as much as about 20% in the A1B scenario in 2100...), continuing the observed patterns in recent trends.*"[34]

In the summer, there will be reductions in average precipitation in southwestern Canada and about the same in eastern Canada. In the winter, average precipitation will increase over all of Canada but more of it will fall as rain than snow. As a result of the warming, there will be changes in snow cover (Figure 6) such that over much of Canada the March snow cover will decrease by mid-century by over 50%. In the far north, the snow cover will increase due to the increased precipitation with warmer, but not above freezing, conditions.

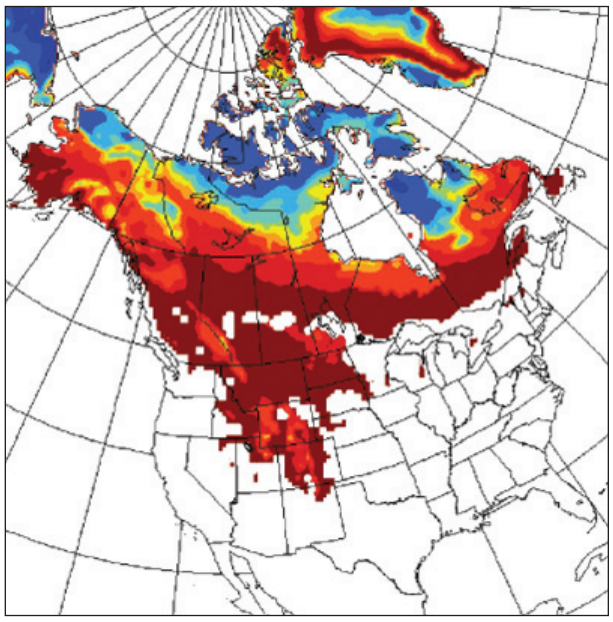

Figure 6. Percent changes in snow depth in March for mid-century (averaged over the period 2041 to 2070) under IPCC A2 emissions scenario, compared to the 1961 to 1990 period. The calculation is only done where climatological snow amounts exceed 5 mm of water equivalent. From IPCC.[35]

There will be more frost-free days as the winter shortens and the summer lengthens. Approximately half of the extensive permafrost regions in northern Canada are projected to disappear eventually with climate warming. Many areas of now permanent permafrost will shift to discontinuous permafrost.[36] These changes, along with increases in the number of freeze-thaw cycles, will have major impacts on roads, bridges and other infrastructure in the north, including the northern parts of many provinces.

8.3 Projections of changes in extreme events

Although changes in mean temperature are important, the changes in extremes are more important in consideration of severe events. The IPCC 2012 special report on climate extremes notes, "*A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events.*"[37] The possibility of "unprecedented" extreme events is important in terms of strategies for risk reduction. The report also concluded that "*The severity of the impacts of climate extremes depends strongly on the level of the exposure and vulnerability to these extremes*" and that "*Extreme and non-extreme weather or climate events affect vulnerability to future extreme events, by modifying resilience, coping capacity, and adaptive capacity.*"

With respect to extremes, note that even if there is no change in distribution of variations around the mean, the frequency of occurrence of values above a set threshold increases (Figure 7).

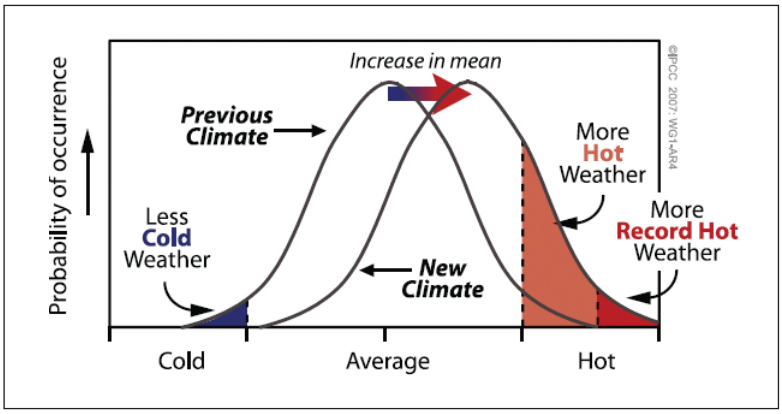

Figure 7. Schematic showing the effect on extreme temperatures when the mean temperature increases, for a normal temperature distribution. From IPCC.[38]

Based on scientific analysis of climate model projections, the IPCC assessed the likelihood of future trends in climate extremes (see Table 1) and concluded that "*It is very likely that hot extremes, heat waves and heavy precipitation events will become more frequent.*"[39]

PHENOMENON AND DIRECTION OF TREND	LIKELIHOOD THAT TREND OCCURRED IN 20TH CENTURY (TYPICALLY POST-1960)	LIKELIHOOD OF FUTURE TREND FOR 21ST CENTURY BASED ON PROJECTIONS USING IPCC SCENARIOS
Warmer and fewer cold days and nights over most land areas	Very likely	Virtually certain
Warmer and more frequent hot days and nights over most land areas	Very likely	Virtually certain
Warm spells/heat waves: frequency increases over most land areas	Likely	Very likely
Heavy precipitation events: frequency increases over most areas	Likely	Very likely
Area affected by droughts increases	Likely in many regions since 1970s	Likely
Intense tropical cyclone activity increases	Likely in some regions since 1970s	Likely
Increased incidence of extreme high sea level (excludes tsunamis)	Likely	Likely

Table 1. Climate extremes modified from IPCC Summary for Policy Makers.[40] In this table, recent trends, assessment of human influence on trends, and projections of extreme weather and climate events for which there is evidence of an observed late 20th-century trend are presented.

Notes: Changes in frequency of coldest and hottest days and nights refer to the coldest or hottest 10%. Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period. Changes in observed extreme high sea level closely follow the changes in average sea level.

8.4 Projections of changes in hot days and heat waves

A "return period," also known as a recurrence interval, is an estimate of the likelihood of events such as exceeding a maximum daily temperature. "Return values" are thresholds that will be exceeded on average once every return period.

The IPCC has projected that the number of hot days will increase. The projected return periods for the maximum daily temperature that previously was exceeded on average once during a 20-year period in the late 20th century (1981–2000) will decrease, implying that hot days will happen more frequently (Figure 8). For example, for western North America (region 3 on Figure 8), a hot day temperature that occurred only once in 20 years in the period 1981–2000, for the period 2046–2065 will occur every three to four years with an uncertainty of occurring between 1.5 and six years, depending on the emissions scenario.

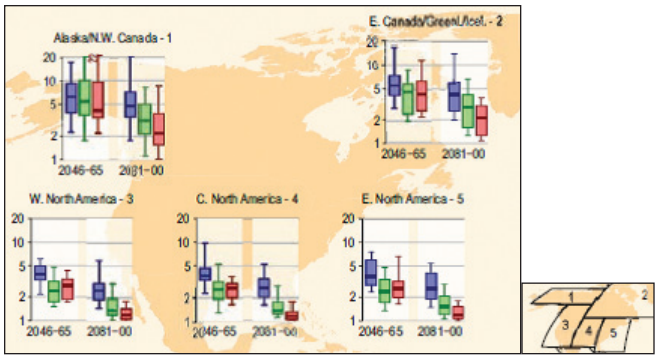

Figure 8. Projected return periods for the maximum daily temperature that was exceeded on average once during a 20-year period in the late 20th century (1981–2000). The box plots show results for regionally averaged projections for two time horizons, 2046 to 2065 and 2081 to 2100, compared to the late 20th century, and for three different emissions scenarios (from the IPCC's Special Report on Emissions Scenarios, or SRES) (B1, blue; A1B, green; A2, red). The boundaries of the regions are shown in the lower right. From IPCC.[41]

Environment Canada's Canadian Centre for Climate Modelling and Analysis has conducted scientific simulations of future climates. The number of hot days (days with a maximum temperature over 30°C) is projected to increase across Canada (Figure 9). For example, these model simulations show that Toronto would go from about 12 hot days in the period 1961–1990, to about 37 in the period 2041–2069, which implies that the increase in hot days will escalate over the period.

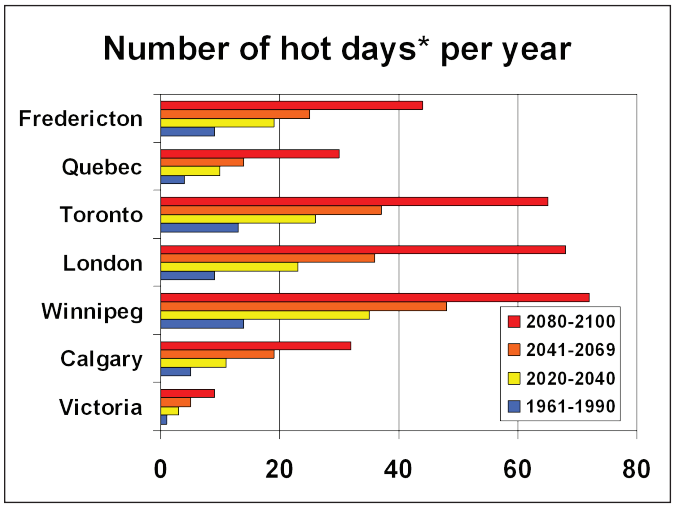

Figure 9. The number of hot days (days with a maximum temperature over 30°C) projected for several Canadian cities by Environment Canada.

8.5 Projections of changes in precipitation intensity

As it did for heat waves, the IPCC examined the projected changes in return periods for a daily precipitation event that was exceeded in the late 20th century on average once during a 20-year period (1981–2000) (see Figure 10). For example, for western North America (region 3), a daily precipitation event that occurred once every 20 years before is projected to occur every 12 years, with an uncertainty of 7 years to 17 years. Thus there will be less time between heavy precipitation events on average.

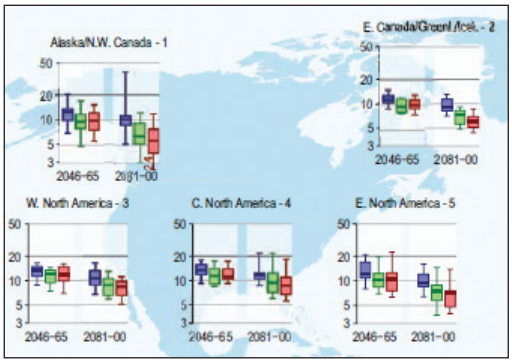

Figure 10. Projected return periods for a daily precipitation event that was exceeded in the late 20th century on average once during a 20-year period (1981–2000). The box plots show results for regionally averaged projections for two time horizons, 2046 to 2065 and 2081 to 2100, compared to the late 20th century, and for three different SRES emissions scenarios (B1, blue; A1B, green; A2, red). The boundaries of the regions are shown in the lower right of Figure 8. From IPCC. [42]

Return period

A return period is the average time between occurrences of a defined event. The return value is the highest (or, alternatively, lowest) value of a given variable, on average occurring once in a given period of time (e.g., in 10 years).

The Canadian Centre for Climate Modelling and Analysis has also conducted scientific simulations of projected changes in 24-hour extreme precipitation events (Figure 11) for the projections of the event recurrence time (in years) for events of a given magnitude.

This return period analysis is used to project changes in future return values of extreme rainfall events for a number of return periods. Scientific information on changes to future return values of extreme rainfall events is needed to be able to take into account climate change impacts on infrastructure and to develop adaptation strategies and policies. For example, the design criteria for storm water infrastructure are constrained by the largest precipitation event anticipated during a fixed design period (e.g., 20, 50 or 100 years).

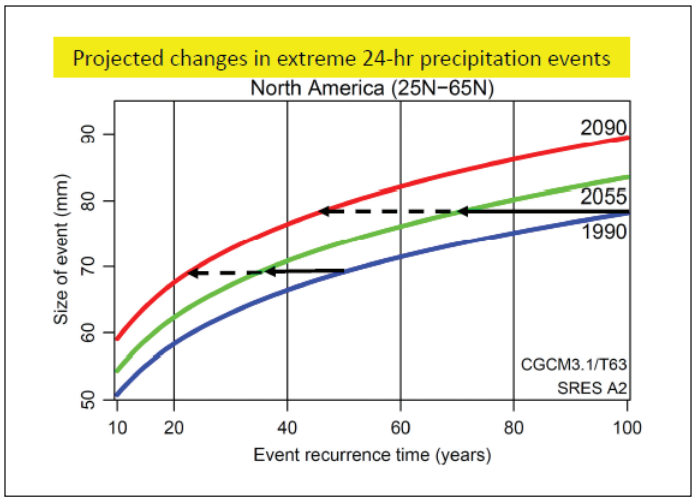

Figure 11. Projections of the event recurrence time (in years) for extreme precipitation events of a given magnitude (Environment Canada, based on the IPCC A2 scenario).

Figure 11 demonstrates that an event of, for example, 70 mm of rain over 24 hours (which has occurred on average about once every 50 years averaged across North America in the latitude band 25N to 65N) would occur statistically about once every 25 years by 2090.

A 2011 paper published in the *Journal of Climate* on projected changes in extreme precipitation characteristics over Canada found quite similar results in comparing two methods: the 20-year return level of one-day precipitation extremes for the 2041–2070 period increases between 3 and 10 mm when compared to the 1961–1990 period; and the 20-year return level of seven-day precipitation extremes increases between 9 and 20 mm. The conclusions of this paper include the statement that "*an increase in magnitude of short (i.e., 1-day) and longer (i.e., 7-day) duration precipitation extremes will have severe implications for various water resource–related development and management activities such as combined sewer systems, flood control in fast responding areas, and water storage systems, etc.*"[43]

8.6 Projections of changes in large-scale extreme winds

Because there have been few studies of storm-related extreme winds and because of the difficulty of simulating wind events in climate models, it is not possible to say with high confidence how extreme winds will change in the future. However, a new study projects average changes in the means of the daily averaged wind speeds (for the height of 10 m above ground) for the period 2081–2100 relative to 1981–2000, based on the results from 19 global climate models.[44] For the period December to February, winds are projected to increase by more than 10% along the west coast of British Columbia; across most of northern Canada; in areas across eastern Manitoba and northern Ontario; and extending south over parts of the Great Lakes and northwestern Quebec. For the June to August season, wind speeds are projected to increase across northwestern Canada, the upper Great Lakes, most of Quebec and Atlantic Canada.

An area where there is greater confidence is the mean tropical cyclone maximum wind speed, which appears *likely* to increase, although increases may not occur in all ocean basins. As the sea surface temperatures increase in the Atlantic Ocean, tropical cyclones – called hurricanes in the Atlantic oceanic areas – will likely gain in energy, bringing impacts on eastern and especially Atlantic Canada that are a concern.

8.7 Projections of changes to tornadoes, hailstorms and other small-scale extreme events

In Canada, tornadoes are currently observed (Figure 12) mainly in Ontario (19 per year), Saskatchewan (15) and Alberta (13),[45] with the most deaths coming from tornadoes in Ontario and Saskatchewan. The Maritime provinces rarely experience the severe types of thunderstorms that can spawn tornadoes, mainly because they don't have the dry conditions high in the atmosphere that are needed to create the necessary unstable conditions. Tornadoes are most common in flat terrain and in areas with little water. Mountainous terrain tends to break up the circulation that creates tornadoes, and the cooling effect of water tends to stabilize the atmosphere. The conditions that create tornadoes occur mostly during warm months, with more than three-quarters occurring in June, July and August.

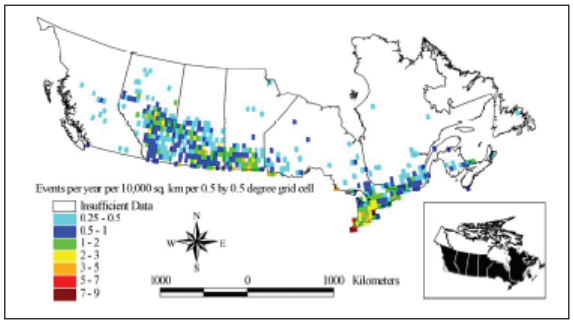

Figure 12. Observed tornado frequencies in Canada.[46]

In Canada, most tornadoes are relatively weak on the Fujita Scale (see table below) – over 50% are either in the F0–F2 range or of unknown scale because the scale can only be determined if the tornado impacts a structure or community. About 2% are F3 and 0.3% are F4; the first observed F5 tornado occurred in Elie, Manitoba, on June 22, 2007. The United States receives on average over 1,000 tornadoes each year and about 20 are F5 tornadoes.[47] The two tornado "alleys" in Canada – southwestern Ontario, and across the southern parts of the Prairies – are both extensions of tornado alleys in the United States.

Fujita Tornado Scale

RATING	EVENT TYPE	MAXIMUM WIND SPEED (KM/H)	TYPE OF DAMAGE DONE
F0	Gale tornado	64–116	Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; damages sign boards.
F1	Moderate tornado	117–180	The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	Significant tornado	181–252	Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light object missiles generated.
F3	Severe tornado	253–330	Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted.
F4	Devastating tornado	331–417	Well-constructed houses levelled; structures with weak foundations blown off some distance; cars thrown and large missiles generated.
F5	Incredible tornado	418–509	Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile-sized missiles fly through the air in excess of 100 metres; trees debarked; steel reinforced concrete structures badly damaged.

For small-scale extreme events such as tornadoes, hailstorms and thunderstorms, there are considerable difficulties in making specific projections. There are several reasons for this, including the fact that climate models do not simulate these small-scale phenomena, as well as competing physical processes that may affect future trends. As the IPCC 2012 special report concluded, "*There is low confidence in observed trends in small spatial-scale phenomena such as tornadoes and hail because of data inhomogeneities and inadequacies in monitoring systems.*"[48]

Reported tornado and thunderstorm occurrences in the United States over the past 50 years show an increasing trend, but this is thought mainly to reflect increased population density and increased numbers of people in remote areas[49,50] making it more likely that these storms will be observed. A warming climate creates unstable atmospheric conditions that lead to these kinds of extreme events, but it also reduces the pole-to-equator temperature gradient, somewhat offsetting this risk. As yet, the scientific literature has been limited in resolving these issues.[51]

Following a major tornado outbreak in April 2011, the U.S. National Oceanic and Atmospheric Administration issued a report that ends with the statement, "*So far, we have not been able to link any of the major causes of the tornado outbreak to global warming. Barring a detection of change, a claim of attribution (to human impacts) is thus problematic, although it does not exclude that a future change in such environmental conditions may occur as anthropogenic greenhouse gas forcing increases.*"[52]

In view of the deficiencies in the observational base and noting the concluding part of the preceding quote, it is appropriate to undertake a risk analysis of tornado risk in Canada in the context of a changing climate. This analysis leads to the conclusion that risk-management strategies should assume that there will be more frequent events in the future.[53]

In view of the distribution of tornadoes in Canada, it is important to note the impacts of tornadoes in the United States over the past 30 years in terms of their economic costs. Almost all the severe weather events where economic losses were greater than $1B (mostly tornados) have been located within a region from Texas–Oklahoma, across Kansas–Missouri and into Illinois. Although climate warming does not simply transfer weather elements poleward, translating this region of extreme events northward would put it into southwestern Ontario.

8.8 Projections of changes in wildland fires

As was tragically demonstrated this year in Alberta and Ontario, wildland fires can have great impacts on Canadians. Several studies have been conducted to project the changes in wildland fires across Canada. This section relies mostly on the most recent research by Wotton et al., 2010.[54] A wildland fire model was developed and tested with two global climate models, and then projections of future fire occurrence levels across Canada were made for 2030 and 2100 with the Canadian model, and for 2100 with the United Kingdom model. The study shows that most fires are started either by lightning or human activities. While fire activity increases across all of the studied forested regions in Canada, there are major regional variations. The Canadian simulations suggest an increase in overall fire occurrence of 25% by 2030 and 75% by the end of the century, while the United Kingdom model projected an increase of 150% by the end of the century. (See Figure 13.)

At present, through active forest fire management, fires in Canada are suppressed and, in most cases, kept to a very small size. Notably, it is the 3% of fires that escape initial containment and lead to large fires with area burned greater than 200 hectares that account for over 97% of the total area burned. Studies have shown that in Canada, there is approximately 100,000 km^2 more area burned per degree Celsius of temperature increase.

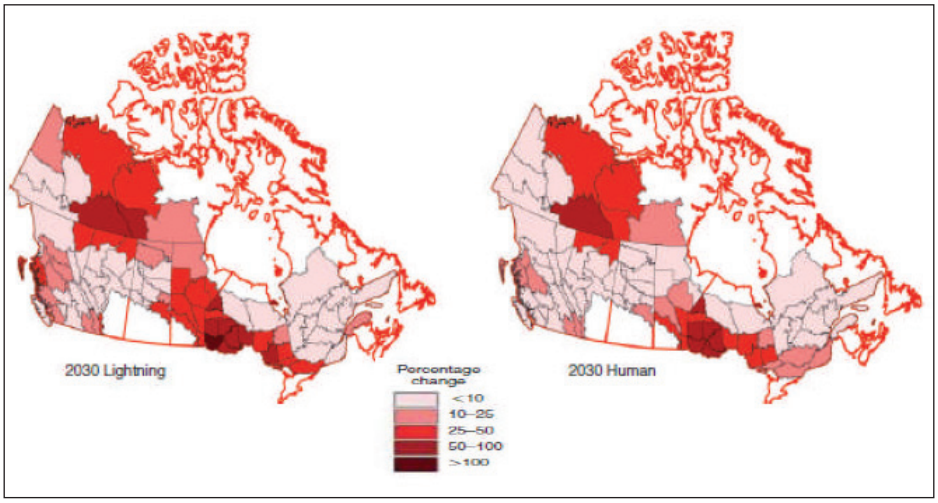

Figure 13. Relative change (% increase) in fire occurrence between future and baseline scenarios for the Canadian model due to lightning (left) and human activities (right). Relative change is given as the percentage increase in the number of fires predicted divided by the total number of fires in baseline. For the 2030 period, the largest percentage changes in the total number of fires are in Ontario and the Northwest Territories, both at 46%.

8.9 Projections of sea level rise

Since the IPCC 2007 Assessment Report, observations of sea level rise have been changing at even greater rates than were indicated by the IPCC projections (Figure 14). New observations of increasing loss of mass from glaciers, ice caps and the Greenland and Antarctic ice sheets have now led to projections of global mean sea level rises of 1 metre or more over the next century.[55]

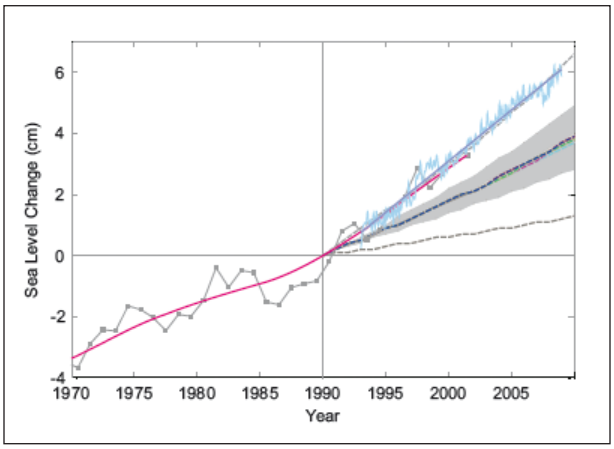

Figure 14. Change in sea level from 1970 to 2008, relative to the sea level at 1990.[56] The annual observations are shown by the dots connected by the light line. The light blue line from the mid-1990s to 2008 reflects new satellite observations. The solid red line represents the observations smoothed to remove the effects of interannual variability. The envelope of IPCC projections from 1990 is shown for comparison. The three short dash lines represent individual projections depending on the IPCC emissions scenario. The "most likely" scenario, based on analyses in 2000 is the middle scenario, which has shading around it to indicate the uncertainty. Note that the satellite observations follow along what was considered the upper limit of sea level rise for the period 2000–2010.

Canada is a country with very long coastlines and the projected rising of the seas as the climate changes will have a tangible impact here. A report of the British Columbia government is projecting that sea level rise will be both faster and higher than previously anticipated. For planning purposes they recommend using the following rates: for the next 25–50 years, 0.5 m; by 2100, 1.0 m; and for more than 100 years, 2.0 m.[57]

9. REVIEW

Based on international and national scientific assessments and on internationally peer-reviewed scientific papers, the climate is changing, human activities are the main cause and the changes in the decades to come will have impacts on Canada, Canadians and people around the world.

10. REGIONAL SYNTHESES

A narrative summary of past and projected weather trends for each of the seven Canadian regions is provided, building on the preceding information and the previously cited report Climate Change Information for Adaptation. These summaries focus on the most salient climate effects for each of the regions, applying the projected environmental changes to the regional level. Variations in the categories of information presented in these sections reflect the varying availability of reliable historical weather-related data for those regions on which to base projections. For example, in some cases data is available only for some provinces or municipalities due to limitations in weather monitoring.

These sections present projections based on the best available peer-reviewed climate science, and are not intended to be predictions of future climate changes. When projecting future changes in the weather, there is always the risk of inaccuracies. As the analysis gets down to the local level, the degree of certainty associated with the projections declines due to differential data quality and the challenges of applying macro-weather trends to diverse micro-climates.

10.1 Atlantic region

The four Atlantic provinces – New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador – have maritime weather and climates and are affected by storms both from the west on the continent and from marine systems moving from the south and occasionally the southeast. The Public Safety Canada Canadian Disaster Database shows that six hurricanes occurred in this region from 1990 to 2005.[58] The most frequent cause of losses was flooding, which resulted from 16 events. Winter storms, including snow storms and storm surges, resulted in 13 events, while no tornadoes occurred in Atlantic Canada over this same period.

The most costly weather events have been hurricanes, which usually hit the region as they are in the process of transforming into mid-latitude storms (see Table 2). Although these may be downgraded hurricanes in the usual definition, they can still have large impacts as the winds and rains can come together in intense sectors of the storm. The costliest event up to 2011 was Hurricane Juan, with insured losses of about $158M. The more recent Hurricane Igor, which struck Newfoundland in September 2010, also caused a lot of damage.

DATE	LOCATION	EVENT	INSURED LOSSES (ADJUSTED FOR INFLATION 2010 $M)
2003 Sept. 28–29	NS, PEI	Hurricane Juan	157.9
2010 Sept. 20–21	NL	Hurricane Igor	70
2010 Dec.	Atlantic provinces	Atlantic storms	50.7
2003 Mar. 30–Apr. 1	Atlantic provinces	Flooding	27.9*
1998 Jan.	NB	Ice storm	25.5
1999 Jul. 28	Atlantic provinces	Flooding	19.8

Table 2. The six most costly insured-loss weather-related events in Atlantic Canada in the period 1983 through 2011.[59]
*Figures are not available by province. Insured losses were likely lower for the province of New Brunswick.

Warm days exceeding 25°C are already increasing; see, for example, Figure 15 for Halifax. In Halifax, a well-defined upward trend is observed for days above 25°C. Over the 30-year period, the number of days above 25°C increased about 72%. The average number of days above 25°C during 2001–2010 increased by about 14 days compared to 1991–2000.

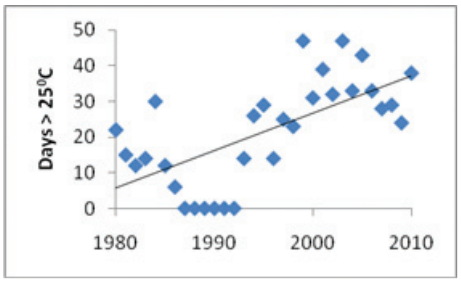

Figure 15. Trends of days with temperatures above 25°C during summer in Halifax, 1980–2010.

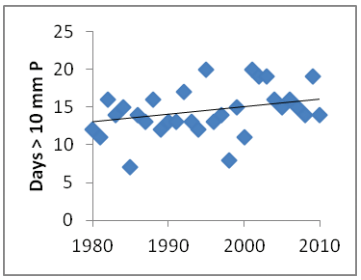

Figure 16. Trend of extreme precipitation days during winter in St. John's.

Based on this increasing rate, in 2040–2050 Halifax will face almost 74 days where summer temperatures will be above 25°C. Further, it is projected that there would be on average nine days with temperatures higher than 30°C in 2040–2050 compared to one day during 1981–1990. For St. John's, there is a more moderate increase of summer days above 25°C. The future projection shows that during 2041–2050 about 22 days will have temperatures higher than 25°C, which is approximately 46% higher than in the 2001–2010 period. Overall, with climate warming, there is projected to be warming of about 3°C across the Atlantic region in the winter, and 2–3°C in the summer by 2050.

Precipitation has also been on the rise in Atlantic Canada. For example, winter events of greater than 10 mm precipitation have increased in St. John's (Figure 16). Looking into 2050, overall changes in precipitation will not be large, with Newfoundland projected to see about a 10% increase in the winter by 2050, while other Atlantic provinces are expected to experience precipitation changes in the 0–10% range. There will be a reduction in snow to a total precipitation ratio of about 10%. Summertime precipitation changes will be generally smaller at 0–5%, with the possibility of decreases in New Brunswick and Prince Edward Island.

However, by 2050, intense precipitation will increase such that events now having a 20-year return period will occur about every 10 to 15 years, with the metric for Newfoundland being closer to 10 years. Given the impacts of hurricanes mentioned earlier, it is of concern that the IPCC (2007) projects an increase in intense tropical cyclone activity.[60] This will result from the warming of ocean temperatures. The risk of more intense hurricanes and winter storms, leading to more intense precipitation, adds to the risks for more flooding, which is already the most frequent disaster event in Atlantic Canada.

Wind disaster records from Public Safety Canada indicate that the frequency of storms with winds that are greater than 100 km/hour rose nationally by 16% from 1970 to 1990, mostly in coastal regions except for tornadoes.[61] With the mean sea level projected to rise 15–25 cm by 2050, there is a bigger risk that hurricanes or winter storms will result in significant storm surges.

Another concern is the projection that the occurrence of freezing rain events in Newfoundland will increase by 50%, with a smaller increase of about 20% projected for the Nova Scotia, New Brunswick and Prince Edward Island areas. Freezing rain increases the risk of road accidents and also can cause major power outages and have other impacts with great societal costs, as was shown by the eastern Canada ice storm of 1998.

10.2 Quebec

The province of Quebec is characterized by wide variations in both climate and population density. Most people live along the St. Lawrence or Ottawa rivers, or nearby in southern Quebec. The weather for most areas is continental, with four seasons varying from hot summers to cold, snowy winters. Central Quebec has longer, colder winters and shorter, cooler summers, whereas in the far north there is a severe Arctic climate with freezing winter and continuous permafrost. Any change in the climate pattern will strongly influence the population, natural and built environment, and socio-economic activity of the region.

Over the past 30 years, the five most expensive events in Quebec from an insured loss point of view (Table 3) occurred in southern Quebec, where the major concentrations of insured assets are located. The most costly event, and the most costly in Canada's history, was the January 1998 ice storm centred over Montreal and surrounding areas. The insured losses were over $1.6B, and the total economic costs are estimated in the $5B to $7B range. Generally, flooding and wind/hail events have constituted the next most costly events in the province.

DATE	LOCATION	EVENT	INSURED LOSSES (ADJUSTED FOR INFLATION 2010 $M)
1998 Jan.	Southern QC	Ice storm	1,652
1996 Jul. 19–20	Saguenay	Flooding	271.5
2011 Apr. 27–28	ON, QC	Wind and thunderstorm	210*
2011 Aug. 28–30	ON, QC, NB	Wind and thunderstorm event remnants of Irene	130*
2008 Jun. 10	Several regions, QC	Hailstorm	127.6
1996 Nov. 9	Montreal and Quebec City	Flooding	99.6

Table 3. The five most costly insured-loss weather-related events in Quebec in the period 1983 through 2011.[62]
*Figures are not available by province. Insured losses were likely lower for the province of Quebec.

In winter, northern Quebec along the shores of Hudson Bay and around Ungava will have warmed by about 5°C by 2050; central Quebec will have warmed less, and in Montreal and Quebec City and along the St. Lawrence the winter warming will be in the range of 3–4°C. In the summer, the overall warming will be less, around 2–3°C in the south, lowering to about 2°C near the northern waters. In Montreal, the number of days with temperatures lower than –10°C and –15°C has declined over the past 30 years, and will decline further by 2050.

With the warming of seasonal temperatures will also come a lengthening of the growing season and increase in the number of frost-free days. There will also be more hot days. For example, Quebec City, which had about five days per summer over 30°C in the period 1961–1990, will have about 15 such hot days per summer by mid-century. Montreal had about eight hot days in the same period, and this is projected to increase 60% by 2050. Climate models project that the 20-year return values of annual maximum of the daily temperature will increase by 2–3°C in southern Quebec and by about 2°C in central and northern Quebec by 2050.

Montreal had about seven to eight days of heavy precipitation (more than 10 mm per day) averaged over the period from 1970–2006 in each season. By 2050, there will be about a 40% increase in heavy precipitation in the summer and about 17% in the winter. In terms of return period, the heavy precipitation event that has been a one in 20-year occurrence should become a one in 10-year occurrence by 2050.

Wintertime precipitation will also increase considerably, about 50% along Hudson Bay and by 10–15% in the south of the province. The ratio of snow to total precipitation will decline by 15% in the winter. There will be reduced ice coverage on the bay and in the north of the province, which will contribute to more sea-effect precipitation, much of it still snow in the north. Summertime precipitation will generally increase, but only in the 0–10% range.

Recognizing the potentially huge impact of freezing rain events, it is important to note that the projections for the Ottawa–Montreal–Quebec City region show an increase in the number of freezing rain events of more than four hours by about 50% by 2050. Events of more than six hours are projected to increase by close to 80% by 2050. Further north in the province where there have been fewer hours of freezing precipitation, the number of freezing rain events of more than four hours are projected to increase by 70% during the period December–January–February. Overall, there will be significant increases in freezing rain events across the province in January.

With the changing climate will come an increased frequency of forest fire occurrences in the Gaspé region, mainly due to lightning, and near the St. Lawrence River. The increases could be over 100% by the end of the century, and somewhat less in 2050.

10.3 Ontario

Over the past 30 years, the 10 most expensive events in Ontario, from an insured loss point of view (Table 4), occurred in southern or eastern Ontario, where the major concentrations of insured assets are located. Most of the events occurred in the spring or summer, and the majority involved wind or water damage.

DATE	LOCATION	EVENT	INSURED LOSSES (ADJUSTED FOR INFLATION 2010 $M)
2005 Aug. 19	Southern ON	Wind/rainstorm	642.4
2009 Jul. 24–28	Southern ON	Wind and thunderstorm	218.9
1998 Jan.	Eastern ON	Ice storms	216.9
2011 Apr. 27–28	ON, QC	Wind and thunderstorm	210*
2000 May 12	Southern ON	Storm	156.5
1985 May 31	Barrie	Tornado	155.2
1999 Jan.	Southern ON	Snow storm	150.5
2011 Aug. 28–30	ON, QC, NB	Wind and thunderstorm event remnants of Irene	130*
2002 Mar. 9	ON	Windstorm	129.3
2010 June 5–6	Leamington and surrounding areas	Wind and thunderstorm	120.0

Table 4. The 10 most costly insured-loss weather-related events in Ontario for the period 1983 through 2011.[63]
*Figures are not available by province. Insured losses were likely lower for the province of Ontario.

Over the last 30 years, the number of days with a maximum temperature above 30°C in the summer at Toronto Pearson Airport increased (Figure 17), and although there is considerable variation from year to year, these increases reflect a statistically significant trend. Based on this trend, the average number of days with a maximum temperature above 30°C in the summer will increase from about 15 in 2005 to about 28 in 2050. In the climate model simulations shown earlier (Figure 11), the number of hot days in Toronto is projected to go from about 12 hot days in the 1961–1990 period to about 37 in the period 2041–2069.

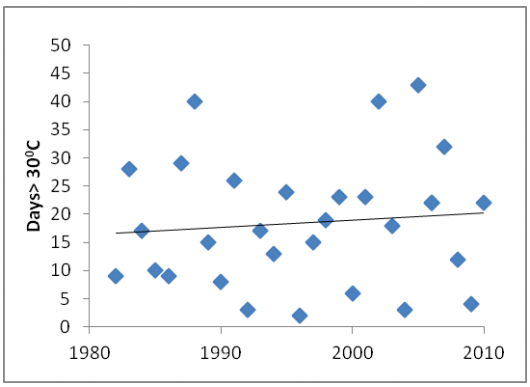

Figure 17. Number of days in the summer where the maximum temperature at Toronto Pearson Airport was above 30°C.

As we look to 2050, Ontario will be warmer on average throughout the year compared to the present. In the north, near Hudson Bay, winter temperatures will be about 4.5°C warmer. In the south the warming will be less, about 3°C along the southern Great Lakes. Overall, summertime warming will be a little less than 2–3°C across the province. The number of frost-free days is expected to double in winter 40 years from now. The number of days below –15°C and –20°C both showed decreasing trends from 1970–2006 and are expected to decrease greatly in next 40 years.

Another way of looking at the effects of climate change in this province is to consider the 20-year return values of annual maximum daily temperature. These values are projected to increase by 2–3°C in southern Ontario and by 2°C in northern Ontario by 2050. The hot days are likely to be accompanied by more smog and associated health impacts of heat and air pollution. As the mean shifts upward, there could be summers with over 50 hot days by mid-century. In some places near the upper Great Lakes, there will be little change, or possibly declines in the number of hot days with a maximum temperature greater than 30°C due to cooler waters of the lakes in spring and summer.

By 2050, wintertime precipitation will be higher by 20% near Hudson Bay with more rain, compared to snow, than at present. In the south, precipitation will increase by about 10% in winter. In the summer the precipitation changes will be much smaller, about 5% increase in the north and a little smaller change in the south. The ratio of snow to total precipitation will decrease by 5–10% over most of the province, and possibly decrease by 15% in the Ottawa Valley. However, in northern Ontario around the upper lakes, the warming with reduced ice cover will keep the lakes ice-free later into the fall, resulting in more snowfall near the lakes as the water temperatures cool. With warmer atmospheric temperatures, there will be generally more evaporation, so lakes, soils and vegetation will lose water. Generally, the Great Lakes (and other lakes) will see a marked decrease in wintertime ice cover, becoming close to zero for the southern lakes.

In terms of severe precipitation, there were seven flood-producing heavy rain events in the Toronto area with intensities exceeding the expected return period value (the highest precipitation value on average occurring once in a 20-year period) during the period of 1987–2007. The rain intensities have shown the greatest seasonal increase over southern Ontario in the spring. The record observed short-duration rain intensities have included Tobermory Cypress Lake, 112 in 60 min and 118 mm in two hours in 2003; Toronto North York, 66 mm in 15 min, 90 mm in 30 min and 132 mm in two hours in 2005; Upper Grand River basin, more than 200 mm in one day in 2004; and Peterborough (Trent University), 240 mm in one day in 2004. For North Bay, an interesting trend is observed. While the days with greater than 10 mm precipitation remained unchanged, the number of days with higher precipitation, above 30 mm, has moderately increased with warmer temperature, which has the capability to hold more moisture; this trend is projected to continue. Projecting forward for Ontario, the annual maximum 24-hour precipitation rate that at present occurs once every 20 years, will occur more often and become a once every 12–14 year event. Meanwhile, in northern Ontario the occurrence rate will lower from once every 20 years to closer to once every 10 years. With more heavy precipitation events over Ontario, there will be an increased risk of flash floods.

A study of April–November rainfall extremes of four selected river basins (Grand, Humber, Rideau and Upper Thames) showed large percentage increases in future three-day accumulated rainfall extremes with a warming climate.[64] The 20-year return values of annual maximum three-day accumulated rainfall totals are projected to increase by 30% to 55% for the period 2026 to 2075. Since the observed annual maximum three-day accumulated rainfall totals are about 80 mm, these are larger changes (25–45 mm) than the average projected for Canada as a whole. There are uncertainties in all these projections, but they all show significant increases in the intensity of extreme precipitation events.

Hail is not as costly a hazardous event in Ontario as in the Prairies, but on September 24, 2006, a windstorm-hail event in the Oshawa region cost about $4.6M in insured losses. A study of hail events over the last two decades showed an ever-increasing frequency of severe hail events.[65] The analysis showed that severe hail frequency is closely linked with atmospheric convective instability and that high hail event years are associated with warmer air temperature than low hail event years. It is concluded, therefore, that severe hail events would occur more frequently in the warming climate.

With warming winters and increasing precipitation, eastern Canada, including Ontario, is also projected to have more freezing rain events in the future than was historically experienced during the period 1958–2007.[66] The increase in the number of freezing rain events could be progressively greater from south to north, or from southwest to northeast across eastern Canada. For example, the percentage increase for severe freezing rain events (lasting six hours per day or longer) is projected to be about 35% in southwestern Ontario and around the lower lakes, and about 80% in eastern Ontario around the Ottawa Valley, extending to Sudbury by the period 2081–2100. In northern Ontario the increases would be between 80% and 100%.

Summer days with more than 50 km/hour winds have shown a significant increasing trend in Toronto, where the windy days increased on average by three times after 2000. This indicates an increased frequency of more severe damaging winds in the decades to come.

Also, with the shift in wind patterns, it is projected that there will be an increase in intense winter storms affecting all of Ontario. Global climate models project wintertime wind increases over northern Ontario and extending south over parts of the Great Lakes of nearly 10% by 2050, relative to 1981–2000.[67] During the summer, the highest wind increases, also about 10%, will occur over the Great Lakes. The trend toward reduced ice cover and stronger winds over the Great Lakes will increase the incidence of damaging storm surges.

As shown previously, in Figure 13, the warming conditions will lead to very large increases in the occurrence of wildfires – 50% to 500% – with the highest increases over northwestern Ontario.

10.4 Manitoba and Saskatchewan

The five largest insured weather-related events in Manitoba and Saskatchewan have resulted from flooding, wind, hail and thunderstorms (Table 5). As the climate changes, fluctuating precipitation regimes, wind and wildfire will present considerable risks across Manitoba and Saskatchewan.

DATE	LOCATION	EVENT	INSURED LOSSES (ADJUSTED FOR INFLATION 2010 $M)
1993 Jul. 25–Aug. 14	Winnipeg	Flooding	251.6
1996 Jul. 16	Winnipeg	Flood, hailstorm	192.4
2008 Sept.	SK	Hailstorm	134.8
2010 Jul. 1–3	South of Swift Current, Wynyard and Hudson Bay region (SK)	Wind and thunderstorm	100.0
2009 Aug.13–15	Southern MB, from Winnipeg to Steinbach	Wind and thunderstorm	84.5

Table 5. The five most costly insured-loss weather-related events in Manitoba and Saskatchewan in the period 1983 through 2011.[68]

As in the rest of Canada, Manitoba and Saskatchewan will experience rising average annual and seasonal temperatures and changing precipitation regimes by 2050 as a result of the changing climate. However, drought and water scarcity are of particular concern for the Prairie Provinces, where historically large loss events for the insurance industry have resulted from different hazards.

In southern regions of Manitoba and Saskatchewan, annual average temperatures could rise by 2–4°C by 2050, compared to 2010. Temperature increases will be greatest in the winter and spring, with possible 3–4°C average increases during these seasons. Thus, in Winnipeg, winter temperatures could increase by 3–4°C, summer average temperatures may increase by 2–4°C, and autumn averages may increase by 1–2°C by 2050. Increasing average temperatures are also expected in the northern regions of Manitoba and Saskatchewan. By 2050, yearly average temperatures could increase by 2–4°C in the north, with winter and spring seasons experiencing the greatest potential increase (3–4°C per season).

In southern Manitoba and Saskatchewan, winter precipitation is likely to increase by 3–10% by 2050. Average precipitation for the summer months is projected to decrease in southern Saskatchewan and southeastern Manitoba by a few percent, while average precipitation will remain unchanged or increase slightly across the middle of the provinces. Further north within the provinces, the winter precipitation will increase more, reaching 15% in the northwest part of the region and closer to 20% in the northeast part near Hudson Bay. Summer precipitation will also increase in the northern regions but in the 5–10% range.

In the Prairie Provinces, drought has historically been the most frequent cause of natural disasters. While average precipitation values could increase or decrease under changing climate conditions, a recent Natural Resources Canada report on climate change impacts suggests that water scarcity resulting from a greater number of dry years is a likely climate change outcome for the Prairie Provinces.[69] Between 1900 and 2005, the Canadian Disaster Database recorded 35 drought disasters in Saskatchewan and 33 in Manitoba. Drought and water scarcity are likely to be a growing climate risk throughout the Prairie Provinces.[70] Thus, decreases in average precipitation in southern areas could have serious implications in both provinces.

While average precipitation amounts are likely to decrease in some parts of the two provinces, extreme precipitation events are expected to increase in frequency. In northern Saskatchewan and Manitoba, historical one in 20-year rainfall amounts could increase by 10 mm by 2050. A 5–10% increase in severity of rainfall would result in a doubling of the expected frequency of one in 20-year rainfall events, such that rainfall amounts that were historically associated with one in 20-year return periods will be associated with one in 10- to 15-year frequencies.

Flooding has historically been the second most common cause of disasters in both Saskatchewan and Manitoba. Between 1900 and 2005, the Canadian Disaster Database recorded 19 flood disasters in Saskatchewan and 28 flood disasters in Manitoba.[71] As a result of the changing nature of extreme events resulting from climate change, flooding may continue to be a common cause of disaster events in the provinces, particularly in urban areas,

which are susceptible to high costs from extreme rainfall events.[72] Further, while average annual, maximum and minimum daily stream flows are expected to decrease throughout Manitoba and Saskatchewan, increasing severe rainfall events may increase flood risk along the Red River through Winnipeg. As well, increasing sea levels have implications for northern Manitoba. Sea level observations indicate a historical (1993–2007) rise of 3.2 cm per decade, suggesting that the Hudson Bay coastline in northern Manitoba may be subject to a sea level rise of 20 cm by 2050.

The proportion of precipitation that falls as snow will decrease over most of Manitoba and Saskatchewan by 2050 during the winter, spring and autumn seasons. The greatest decrease in snowfall proportions will be experienced in spring throughout the provinces, where spring snowfall proportions could fall by 10% in northern areas and 15% in southern areas. In the northern regions, the provinces will experience a snowfall decrease of 5% in the winter by 2050.

While wildfire has not historically resulted in significant insured losses in Manitoba and Saskatchewan, there have been several historical disaster events associated with wildfire. Between 1900 and 2005, there were three wildfire disasters in Manitoba and seven wildfire disasters in Saskatchewan. Wildfire occurrence and area burned is expected to increase in Manitoba and Saskatchewan as a result of climate change, and the occurrence of wildfires caused by lightning is expected to increase considerably, with a more moderate increase in human-caused wildfire events.[73] By 2050, a 50% increase in area burned by wildfires is expected in the northern regions of Manitoba and Saskatchewan.

Wind represents a significant hazard in Manitoba and Saskatchewan. In 2007, Elie, Manitoba, a few miles west of Winnipeg, was home to Canada's first recorded F5 tornado. Several other severe tornado events have occurred in Manitoba, including an F4 tornado in Birtle in 1994 and an F4 in the Rosa-St. Malo area in 1977, which caused three deaths. One fatality resulted from an F2 tornado in Gull Lake in 2006.[74] Regina was the site of Canada's most deadly tornado, with 28 deaths in 1912, and a southeastern Saskatchewan tornado in 1920 killed four.[75] While reporting of tornado events in the United States has resulted in a larger number of recorded tornadoes, trends in actual tornado occurrence over time are unclear.[76] However, an 8–15% increase in intense winter storms is expected for all of Manitoba and Saskatchewan by 2050.

Hail results in considerable insured losses in the Canadian Prairies. Research on trends in hail occurrences and the impacts of climate change on hail in Canada and the Canadian Prairies is limited. However, studies from other jurisdictions indicate increases in historical hail event frequencies and possible climate change implications. For example, as discussed earlier, a 2008 study of Ontario revealed an increasing frequency of hail events over the past two decades,[77] and a 2008 Australian study argued that hail events will increase as a result of climate change.[78] Similarly, a 2001 ICLR study found a statistically significant increase between 1977–1982 and 1983–1993 in the frequency of hail events in Alberta.[79] As discussed in the Ontario section, hail is associated with warmer temperatures and is thus likely to increase as a result of climate change.

10.5 Alberta

The costliest disaster event for Alberta has been the very recent Slave Lake fire, where current estimates put insured losses at $700M. While the cause of this event is now suspected to be arson, it is likely that the strong winds and extended dry spell in that region of the province contributed to the large scale of losses experienced. Prior to this, the major insured loss events were wind and hailstorms, with flooding and tornadoes also being significant (Table 6).

DATE	LOCATION	EVENT	INSURED LOSSES (ADJUSTED FOR INFLATION 2010 $M)
2011 May 14–15	Slave Lake	Wildfire	700.0
2010 Jul. 12–13	Calgary and other areas in southern AB	Wind and thunderstorm	500.0
1991 Sept. 7	Calgary	Hailstorm	482.2
2009 Aug. 1–3	Southern AB	Wind and thunderstorm	361.5
2005 June 6–8, 17–19	AB	Flooding	326.6

Table 6. The five most costly insured-loss weather-related events in Alberta in the period 1983 through 2011.[80]

Over the past few decades, there has been an increasing trend in hot summer days (days above 25°C and 30°C) and a decreasing trend in very cold (below –20°C) winter days in Calgary (Figures 18 and 19).

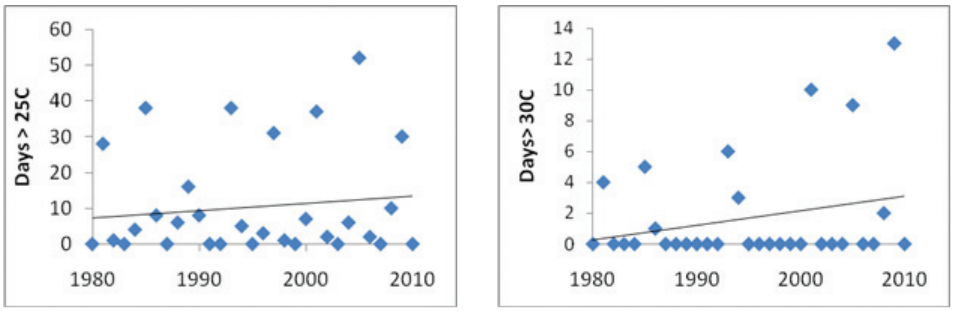

Figure 18. Summer days with temperatures above 25°C (left) and 30°C (right) in Calgary.

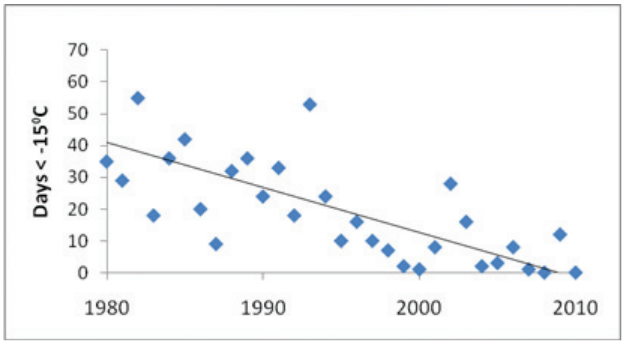

Figure 19. Winter days with temperatures below –15°C in Calgary.

Similar to the other Prairie Provinces, Alberta will be greatly affected by drought and water scarcity under changing climate conditions, and can expect potential increases in hail, storm and wildfire events. By 2050, average annual temperatures are expected to increase by 2–4°C across Alberta. The winter season will see the greatest average temperature increase over the next 40 years, at 3–4°C, while the province can expect average summer temperature increases of 2–3°C. Average spring temperatures may increase in the north and south by 2–4°C and in central regions by 3–4°C. Autumn temperatures may increase by 2–3°C in southern and central regions, and 1–2°C in northern regions.

Annual and seasonal precipitation averages will shift across Alberta by 2050, with expected precipitation decreases in summer and increases in other seasons. Decreases in summer precipitation will be the greatest in southern Alberta, at 5–10% by 2050. Winter precipitation will increase in southern, central and northern Alberta, with the southern and northern areas experiencing the greatest increases of 10–15% by 2050. Spring precipitation may increase by 5–15% in southern areas and 10–15% in central and northern areas.

Decreases in seasonal precipitation under climate change conditions are a significant concern in the Canadian Prairie Provinces. Drought conditions in Alberta could have serious implications for the agricultural economy, as demonstrated by the 2002 Prairie drought, which severely affected crops and resulted in livestock feed shortages.[81] Historically, drought has been the most common cause of disasters in Alberta, where 35 drought disasters occurred between 1900 and 2005.[82] A 2008 climate change report from the Government of Canada stated that increases in water scarcity resulting from climate change presents the greatest risk to the Prairie Provinces, including Alberta.[83] Changing precipitation patterns could result in lower summer stream flows, falling lake levels, retreating glaciers, decreasing soil-water content and a greater number of dry years. Retreating glaciers and stream flows may create difficulty in providing potable water to Alberta's rapidly increasing population, and water scarcity may constrain Alberta's economic development.[84] In particular, Calgary could be subject to water scarcity issues, as water levels in the Bow and Elbow rivers are expected to decline under changing climate conditions.

Flooding has been the second most frequent cause of disasters in Alberta. Public Safety Canada reported 34 flood disasters in the province from 1900–2005. Flooding in southern Alberta in 2005 resulted in approximately $300M in insured payouts – one of the largest loss events recorded by IBC between 1983 and 2005.[85] These large losses occurred despite the fact that residential property insurance policies typically do not provide coverage for flooding in Canada, while they often do provide coverage for losses from sewer backup.

While drought and low stream flow conditions may become more severe in the future, the changing nature of extreme precipitation events will likely result in continued flood risk throughout Alberta. Heavy rainfall events causing flash flooding in small catchment areas could be a particular concern, as extreme precipitation events are expected to increase in severity across Alberta by 2050. One in 20-year events, which from 1958 to 2007 resulted in an average of 25–50 mm in 24 hours in southern and northern Alberta, could increase in

severity by 10–15% by 2050. A 15% increase in the severity of these events would result in historical one in 20-year events occurring once every 10 years. By extension, historical one in 20-year events could increase in severity by 5–10% in central Alberta in the next 40 years.

The ratio of precipitation that falls as snow will decrease across Alberta by 2050. This trend will be notable in southern Alberta, where average annual ratios will drop by 15%. In the spring, the amount of precipitation that falls as snow will drop by 20%, while the winter months will see a 10% decline. In the north, the annual amount of precipitation that falls as snow will decline by 10% in the spring and 5% in the winter. Annually, ratios in this area will fall by 10% by 2050. Central regions will experience an annual decline in the amount of precipitation that falls as snow of 15%, with a decline of 15% in the spring season and 10% in the winter. Reduced snowfall could result in changes to river flood regimes in spring and may exacerbate water scarcity issues. Annual, maximum and minimum daily stream flow is also expected to decline across the province, which also has implications for water scarcity.

Historically, Alberta has suffered a greater proportion of large hail events than any other province in Canada. IBC data from 1983 to 2005 indicates that seven of the eight hail events in Canada that resulted in $50M or more in insurance payouts occurred in Alberta. Eighteen of the 26 large payout hail events that occurred in Canada between 1983 and 2005 occurred in Alberta.[86] A 2001 ICLR study found that Alberta had experienced a statistically significant increase in hail frequency by 1983–1993 when compared to 1977–1982.[87] Studies from other jurisdictions indicate increases in historical hail event frequencies and possible climate change impacts, including an increasing trend in hail events over the past two decades in Ontario[88] and a link between climate change and increasing frequency of hail events in Australia.[89] Hail events are associated with warmer temperatures and are thus likely to increase as a result of climate change.[90] However, historical drought periods have seen less frequent hail in some parts of Alberta.

Alberta has been subject to several wildfire disasters, including the recent Slave Lake wildfire. While it is now thought that arson ignited the fire, it is likely that extreme dry conditions were an important contributing factor to the amount of damage ($700M estimated) caused at Slave Lake. Lightning flash density could increase by 20% in southern and northern Alberta by 2050, which has implications for wildfire. In central regions, the area burned by wildfires could increase by 15% by 2050. Average temperature changes that result in earlier onset of spring- and summer-like conditions will also lengthen the wildfire season and increase wildfire risk.[91]

Alberta has been subject to many storm and wind events, and central Alberta is particularly tornado prone. Some historical tornado events have resulted in significant impacts. Of note was the Black Friday tornado that struck Edmonton on July 31, 1987.[92] Insured damages from this event were estimated to be over $200M, and total losses were estimated to be approximately $330M.[93] Twenty-seven people were killed and 600 were injured as a result of this tornado.[94] Twelve people were also killed in the Pine Lake tornado of April 2000. From 1980 to 2010, there was an increasing trend in the occurrence of reported tornadoes in the

province. While reporting of tornado events in the United States has resulted in a larger number of recorded tornadoes, trends in actual tornado occurrence over time are unclear due to changes in public awareness and technology, which may have increased the reporting of tornadoes.[95] However, storminess and extreme weather are expected to increase as a result of climate change in the Prairie Provinces.[96] Alberta was subject to six winter storm related disasters from 1900–2005, and an 8–15% increase in intense winter storms by 2050 is expected for the province.

10.6 British Columbia

British Columbia is home to the greatest variability in weather found in Canada. Prince Rupert is the wettest city in the country, while Ashcroft is the driest. Victoria has the mildest winter and the least snowfall, while Mount Fidelity has the most snowfall. Kamloops has the hottest summers, on average, while Fort Nelson has experienced the coldest weather in southern Canada. Kelowna is the least windy city in the country, while Cape Saint James has experienced some of the strongest winds recorded in Canada.

The 2003 Okanagan Mountain Park wildfire was the largest loss event in British Columbia, as measured by homes destroyed and damage claims paid by insurance companies: 27,000 people were forced to evacuate their homes and businesses, the largest evacuation in the province's history; 239 properties were destroyed; and insurance companies paid more than $210M in damage claims (adjusted for inflation). After Slave Lake, Alberta, this is the most damaging wildfire to have occurred in Canada.

The province has also experienced a number of damaging wind and severe rainfall events. (See Table 7.) The most severe, in terms of property damage, was in 2006 when a large storm resulted in extensive damage across British Columbia, Washington and Oregon. There had been a number of rainfall events over the previous month, so the region was particularly vulnerable when strong winds and heavy rainfall struck. The most visible damages from the storm were 1,000 trees felled in Stanley Park and extensive damage to trees around the Lower Mainland. Canada's insurers paid over $142M in damage claims (adjusted for inflation),[97] while insurers in the United States paid a further $220M.[98] Millions of dollars were also spent to rebuild infrastructure and parks. After the storm, more than 250,000 homes and businesses in British Columbia were without power.[99]

DATE	LOCATION	EVENT	INSURED LOSSES (ADJUSTED FOR INFLATION 2010 $M)
2003 Summer	BC	Forest fires	226.7
2006 Nov. 15–Dec. 15	BC	Storm	142.1
2008 Dec.	BC	Winter storm	61.3
2001 Dec. 14	Southwestern BC	Windstorm	32.2
2007 Jan. 5	BC	Storm	17.0

Table 7. The five most costly insured-loss weather-related events in British Columbia in the period 1983 through 2011.[100]

There has been significant warming across the province over the past 50 or 60 years, with the temperature rising by 1°C to 1.5°C since 1950. As shown in Figure 20, the number of days with temperatures over 25°C has increased in Vancouver from 1980 to 2010.

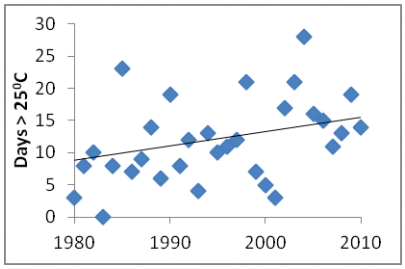

Figure 20. Observed trends of hot summer days in Vancouver.

Warming was greatest in the southern interior, moderate in the northern interior, and least in coastal communities. Warming across the province was greatest in the spring and least in the fall, and was greater in terms of reductions in evening low temperatures than in terms of increases in daytime high temperatures.

Looking ahead to 2050, this warming is expected to accelerate, at a rate almost twice that of the past 50 or 60 years – warming by a further 1.5°C on average over the period. Although British Columbia should continue to experience a wide range of weather, most of the province is likely to be warmer and wetter. The snowpack in the mountains is expected to decline, disappearing in some locations, with important consequences for those dependent on these snows for a source of water. The frequency and severity of wildfires may also increase.

Since 1950 there has been a 20–30% increase in rainfall in coastal British Columbia, a 5–10% increase in the northern interior, and an annual change in rainfall of –10% to +25% in the southern interior. The large variation in these projections is due in part to the potential for large spatial variation that can occur in mountainous regions and interior plateaus. A 5–10% increase in precipitation is expected over the period through 2050, with the largest increase

occurring in coastal areas and the northern interior. Increased precipitation is expected across the province in the winter, but rainfall should decrease in the summer, particularly in the southern interior. There is high confidence that there will be a 10–15% increase in intense rainfall events.

The incidence of severe wildfires are expected to increase significantly throughout BC's forests, perhaps increasing by 50% or more over the period through 2050. There is high confidence in this forecast.

Tornadoes are possible but rare in British Columbia. Only five tornadoes have been reported since 1900. Each was weak, at a likely magnitude F0 or perhaps F1, and resulted in little damage. There has never been hurricane damage in British Columbia. Cool ocean waters prevent Pacific storms from building into hurricanes, and Atlantic hurricanes that bring intense rainfall into the continent never extend as far as British Columbia. While the province does not experience damaging tornadoes and hurricanes, British Columbia does experience damaging wind events, such as the 2006 storm (see Table 7 above). There is little research to anticipate whether the risk of damaging winds is changing in British Columbia as temperatures are rising.

10.7 The North

For this report, the North is defined as the vast region of Canada that includes the Yukon, the Northwest Territories and Nunavut. The North has experienced the greatest warming in Canada over the past 40 or 50 years; indeed, its warming has been among the greatest in the world. This trend is expected to accelerate through 2050. The North also appears to have experienced the greatest increase in precipitation in Canada, particularly winter snowfall. Significant further increases in snowfall and rain are anticipated. Moreover, there has been a dramatic decline in sea ice cover, as well as increasing coastal erosion in many areas.

There is considerable variation in climate conditions across Canada's North. Summers are cool and brief, influenced by ice-filled polar waters. Winters are cold and long. Nunavut is mostly Arctic tundra, and can be subject to strong winds. In contrast, most of the Yukon and the Northwest Territories is covered in forest, with the forest density greatest in the southern parts, making wildfires a risk throughout the region. Several of Canada's largest fires have been in the North.

There are few weather stations in the North. Accordingly, there is relatively little regional data measuring weather history. In particular, there is little data recording climate extremes. The weather station in Iqaluit, Nunavut, provides some limited information about the increase in extreme weather events in the North. For example, there have been 99 days over the past 35 years when the temperature was above 25°C, and almost 60% of these were in the past decade. An even greater percentage difference was reported in the decline in the number of very cold days, when the temperature fell below –40°C (Figures 21 and 22).

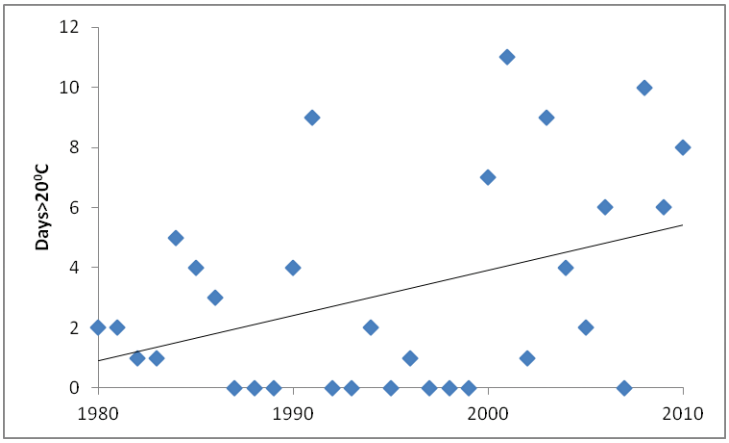

Figure 21. Trends in hot summer days in Iqaluit.

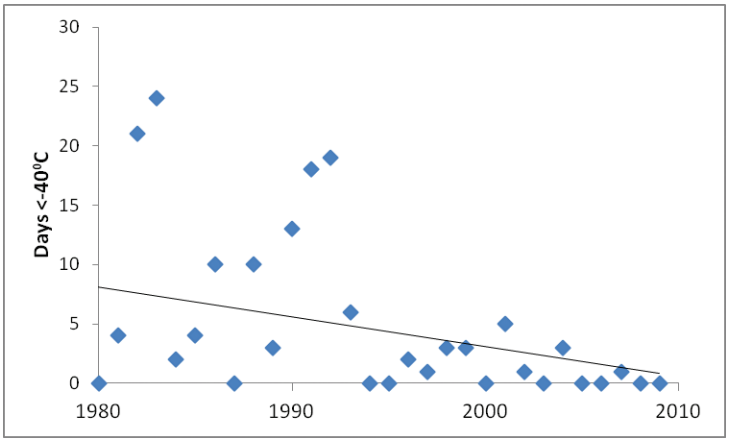

Figure 22. Trends in extreme cold on winter days in Iqaluit.

Temperatures are expected to increase by 2°C to 4°C through 2050. This is among the fastest rates of warming in the world. The warming in the autumn and winter is expected to be 2°C greater than during the summer, and is expected to follow a similar pattern across the Yukon, the Northwest Territories and Nunavut. By 2050, the likelihood of the temperature in Iqaluit exceeding 25°C could be five times greater than during the 1980s.

Precipitation in the North is projected to increase by 10–25% through 2050, with the largest increases happening in the winter. In northern areas of the North, a significant increase in winter snowfall of up to 40% is expected. In southern areas, there may be an increase in rain events relative to the increase in snow events. The limited data available that track the number of thunderstorm, hail and intense precipitation events include few observations and no statistically significant trends.

The number and severity of wildfires increased in the Yukon and the Northwest Territories over the past few decades and should rise further. This is because the fire season will likely lengthen by 10 days by 2050, increasing the frequency of evacuations and the risk of property destruction.

Across Nunavut and the Yukon, sea levels have been rising at an average rate of 3.2 cm per decade. By 2050, sea levels could be 15–25 cm higher. Rising sea level and reduced ice cover have increased the rate of coastal erosion in the North.

11. CONCLUSION

Based on the analyses conducted by the Intergovernmental Panel on Climate Change, the global climate is warming. Canada's climate is also warming, with winters generally warming more than summers. Recent trends in Canada have seen an increase in property claims resulting from extreme weather-related events. For the next two decades, a global warming rate of about 0.2°C per decade is projected, with a faster rate of warming in Canada, particularly in the North averaged over the year. In the winter, northern Canada will warm more than the southern parts, and in the summer, the opposite will be true. Average precipitation will increase over all of Canada in the winter. In the summer, there will be reductions in precipitation in the south over western Canada, and precipitation will remain about the same in eastern Canada.

Of major concern are the projections of increases in both hot days and heavy precipitation events. The projected return periods for the maximum daily temperature that previously was exceeded on average once during a 20-year period in the late 20th century (1981–2000) will decrease, implying that hot days will happen more frequently. For much of Canada, the recent once-in-20-years hot day will by mid-century be occurring every three to five years. For precipitation events, the daily precipitation event that was exceeded in the late 20th century on average once during a 20-year period will by mid-century be occurring about every 10 to 12 years – almost twice as often. Winds in winter larger-scale storms will also increase. Because of their small scale, it is not possible to project with confidence changes in tornado occurrences, but a risk analysis perspective indicates that a policy based on assumptions of more tornadoes is appropriate.

With the warming and changes in heavy precipitation events, presumably associated with lightning, increases in wildland fires are projected, reaching over 100% in northwestern Ontario by 2030.

On Canada's coasts, increasing sea level rise will make the impacts of storms and associated storm surges more dangerous.

This report has looked at the variations of these past and projected affects across Canada and raises overall concerns about the needs for strategies to reduce vulnerability and exposure in view of the increasing risks of more extreme hazards.

APPENDIX: GLOSSARY OF TERMINOLOGY

Adaptation

Adaptation refers to initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g., anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, and the substitution of more temperature-shock resistant plants for sensitive ones.

Adaptation benefits

Adaptation benefits refer to the damage costs avoided or the benefits accrued following the adoption and implementation of adaptation measures.

Adaptation costs

Adaptation costs refer to the costs of planning, preparing for, facilitating and implementing adaptation measures, including transition costs.

Anthropogenic

This word describes things that result from or are produced by human beings.

Atmosphere

The atmosphere is the gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1% of the volume) and oxygen (20.9%), together with a number of trace gases, such as argon (0.93%), helium and radiatively active greenhouse gases such as carbon dioxide (0.039%, which corresponds to 390 parts per million) and ozone. In addition, the atmosphere contains greenhouse gas water vapour, whose amounts are highly variable but typically present around 1% of volume. The maximum amount of water vapour that the atmosphere can hold, corresponding to 100% relative humidity, depends strongly on its temperature – warm air can hold more water vapour. The atmosphere also contains clouds (water in its liquid phase) and aerosols.

Carbon dioxide (CO_2)

Carbon dioxide is a naturally occurring gas fixed by photosynthesis into organic matter. A by-product of fossil fuel combustion and biomass burning, it is also emitted from land-use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured.

Climate

Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state of the climate system, including a statistical description.

Climate change

(a) The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings or to persistent anthropogenic changes in the composition of the atmosphere or in land use."

(b) The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Climate change commitment

Due to the thermal inertia of the ocean and slow processes in the biosphere, the cryosphere and land surfaces, the climate would continue to change even if the atmospheric composition was held fixed at today's values. Past change in atmospheric composition leads to a "committed" climate change, which continues for as long as a radiative imbalance persists and until all components of the climate system have adjusted to a new state. The further change in temperature after the composition of the atmosphere is held constant is referred to as the committed warming or warming commitment. Climate change commitment brings other future changes, for example in the hydrological cycle, in extreme weather events and in sea level rise.

Climate (change) scenario

A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships and assumptions of radiative forcing, typically constructed for explicit use as input to climate change impact models.

Climate isotherms

Isotherms refer to boundary lines placed on a map to delineate between geographic areas that share average yearly temperatures. Climate isotherms provide the same function as contour lines on an elevation map. A poleward shift in mean climate isotherms means that northerly areas will experience warmer average temperatures that are normally associated with more southerly areas.

Climate model

A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity (i.e., for any one component or combination of components, a hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented, or the level at which empirical parameterisations are involved. Coupled atmosphere/ocean/sea-ice general circulation models (AOGCMs) provide a comprehensive representation of the climate system.

More complex models include active chemistry and biology. Climate models are applied, as a research tool, to study and simulate the climate, but also for operational purposes, including monthly, seasonal and interannual climate predictions.

Climate prediction

A climate prediction or climate forecast is the result of an attempt to produce an estimate of the actual evolution of the climate in the future, e.g., at seasonal, interannual or long-term time scales. See also climate projection and climate (change) scenario.

Climate projection

A climate projection is the calculated response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based on simulations by climate models. Climate projections are distinguished from climate predictions in that the former critically depend on the emissions/concentration/radiative forcing scenario used, and therefore on highly uncertain assumptions of future socio-economic and technological development. Climate predictions do not rely on models of future changes as contributing factors but rather are most influenced by the initial conditions. For example, a weather prediction that tomorrow will be stormy is based on the state of the atmosphere today and/or in the recent past.

Climate sensitivity

Climate sensitivity describes the equilibrium temperature rise that would occur for a doubling of carbon dioxide concentration above pre-industrial levels.

Climate system

The climate system is defined by the dynamics and interactions of five major components: atmosphere, hydrosphere, cryosphere, land surface and biosphere. Climate system dynamics are driven by both internal and external forcing, such as volcanic eruptions, solar variations or human-induced modifications to the planetary radiative balance, for instance via anthropogenic emissions of greenhouse gases and land-use changes.

Climate threshold

The point at which external forcing of the climate system, such as the increasing atmospheric concentration of greenhouse gases, triggers a significant climatic or environmental event that is considered unalterable or recoverable only on very long time-scales, such as widespread bleaching of corals or a collapse of oceanic circulation systems.

Climate variability

Climate variability refers to variations in the mean state and other statistics (such as standard deviations, statistics of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability) or to variations in natural or anthropogenic external forcing (external variability). See also climate change.

Confidence

The level of confidence in the correctness of a result is expressed in the 2007 IPCC report, using a standard terminology defined as follows:

TERMINOLOGY	DEGREE OF CONFIDENCE IN BEING CORRECT
Very high confidence	At least 9 out of 10 chance of being correct
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

Disaster

A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, that exceeds the ability of the affected community or society to cope using its own resources. Disasters occur when hazards and vulnerabilities interact.

Drought

The phenomenon that exists when precipitation is significantly below normal recorded levels, causing serious hydrological imbalances that often adversely affect land resources and production systems.

Emissions scenario

An emissions scenario is a plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change) and their key relationships. Four emissions scenario "family storylines" set out distinct directions for global development through the year 2100. The storylines and associated population, GDP and emissions scenarios – associated with the Special Report on Emissions Scenarios (SRES) – were developed by the IPCC to assist in climate change projections. Illustrations and key themes of the four family storylines are provided below.

A1: Rapid, globalized economic development; global population rising and peaking mid-century and subsequently declining; rapid introduction of new and more efficient technologies. Key themes: global, economic development.

A2: Slower, regionally oriented economic development; continuously growing global population; slower per capita economic growth and technological change than in the other storylines. Key themes: regional, economic development.

B1: Same population scenario as in A1, but with a rapid shift toward service and information economies; reduced material consumption complimented with introduction of clean and resource efficient technologies; global emphasis on solutions to economic, social and environmental sustainability. Key themes: global, sustainable development.

B2: Continually increasing population, at a lower rate than A2; less rapid economic and technological development than in A1 and B1; emphasis on regional/local solutions to economic, social and environmental sustainability. Key themes: Regional, sustainable development.

Exposure

Exposure refers to the people, property, systems or other elements present in hazard zones that are thereby subject to potential losses.

Extreme weather event

An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally have less than a 1 in 10 chance of occurring. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. Single extreme events cannot be simply and directly attributed to anthropogenic climate change, as there is always a finite chance the event in question might have occurred naturally. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).

Feedback

An interaction mechanism between processes in the climate system is called a climate feedback when the result of an initial process triggers changes in a second process that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it. An example of a positive feedback process is melting sea ice, where climate change (first process) causes sea ice melt (second process) and sea ice melt intensifies climate change, due to loss of the ability of the sea to reflect a portion of the sun's energy back into space.

Fujita Tornado Scale

RATING	EVENT TYPE	MAXIMUM WIND SPEED (KM/H)	TYPE OF DAMAGE DONE
F0	Gale tornado	64–116	Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; damages sign boards.
F1	Moderate tornado	117–180	The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.
F2	Significant tornado	181–252	Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light object missiles generated.
F3	Severe tornado	253–330	Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted.
F4	Devastating tornado	331–417	Well-constructed houses levelled; structures with weak foundations blown off some distance; cars thrown and large missiles generated.
F5	Incredible tornado	418–509	Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile-sized missiles fly through the air in excess of 100 metres; trees debarked; steel reinforced concrete structures badly damaged.

Greenhouse effect

Greenhouse gases effectively absorb infrared radiation emitted by the Earth's surface, by the atmosphere itself due to the same gases and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus, greenhouse gases trap heat within the surface-troposphere system. This is called the greenhouse effect. Thermal infrared radiation in the troposphere is strongly coupled to the temperature at the altitude at which it is emitted. In the troposphere, the temperature generally decreases with height. Effectively,

infrared radiation emitted to space originates from an altitude with a temperature of, on average, –19°C, in balance with the net incoming solar radiation, whereas the Earth's surface is kept at a much higher temperature of, on average, +14°C. An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called enhanced greenhouse effect.

Greenhouse gases

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. The main greenhouse gases are water vapour, carbon dioxide, nitrous oxide, methane and ozone.

Gross Domestic Product

Gross Domestic Product (GDP) is the monetary value of all goods and services produced within a nation.

Hazard

A hazard is an event or phenomenon that has the potential to cause loss of life or injury, damage to property, social and economic disruption, or environmental degradation. Hazards may include windstorms, tornadoes, floods and heavy rainfall events.

Hydrographic events

Hydrographic events alter the state or current of waters in oceans, rivers or lakes.

Hydrological systems

These are the systems involved in movement, distribution and quality of water throughout the Earth, including both the hydrologic cycle and water resources.

IPCC

The Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations Environment Program (UNEP) in 1988 and is responsible for assessing and compiling the most recent and best scientific research on climate change. The IPCC is considered the world authority on climate change information and periodically releases comprehensive change reports, which are used as the basis for climate change policy making worldwide. In 2007, the IPCC was jointly awarded the Nobel Peace Prize with Al Gore "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change."

Likelihood

The likelihood of an occurrence, an outcome or a result, where this can be estimated probabilistically, is expressed in IPCC reports using a standard terminology defined as follows:

TERMINOLOGY	LIKELIHOOD OF THE OCCURRENCE/OUTCOME
Virtually certain	>99% probability of occurrence
Very likely	>90% probability
Likely	>66% probability
More likely than not	>50% probability
About as likely as not	33 to 66% probability
Unlikely	<33% probability
Very unlikely	<10% probability
Exceptionally unlikely	<1% probability

Methane (CH4)

Methane is one of the six greenhouse gases to be mitigated under the Kyoto Protocol and is the major component of natural gas and associated with all hydrocarbon fuels, animal husbandry and agriculture. Coal-bed methane is the gas found in coal seams.

Permafrost

Perennially frozen ground that occurs where the temperature remains below 0°C for several years.

Return Period

A return period is the average time between occurrences of a defined event. The return value is the highest (or, alternatively, lowest) value of a given variable, on average occurring once in a given period of time (e.g., in 10 years).

Scenario

A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a "narrative storyline." See also climate (change) scenario and emissions scenario.

Sea level rise

An increase in the mean level of the ocean. Eustatic sea level rise is a change in global average sea level brought about by an increase in the volume of the world ocean. Relative sea level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land level subsidence. In areas subject to rapid land-level uplift, relative sea level can fall.

Sensitivity

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise).

Snowpack

A seasonal accumulation of slow-melting snow.

Threshold

The level of magnitude of a system process at which sudden or rapid change occurs. A point or level at which new properties emerge in an ecological, economic or other system, invalidating predictions based on mathematical relationships that apply at lower levels.

Uncertainty

An expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour.

Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgement of a team of experts). See also confidence and likelihood.

Vulnerability

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity.

For example, a flooded river, per se, is not a disaster. However, a disaster occurs when a flood interacts with a vulnerable system, such as an exposed community located in a flood plain.

Weather

Weather includes short-term changes in the atmosphere, and can change over very short periods of time. Weather can change from minute to minute, day to day and month to month.

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