BACKGROUND

CHAPTER 2

Background Information: Concepts, Overviews and Approaches

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CONTENTS

1 INTRODUCTION

This chapter serves as a reference for the subsequent chapters of the report by discussing key recurrent concepts related to the primary goals of the assessment. It also provides a brief review of the science associated with understanding past and future climate change, and an overview of the broad implications of climate change for Canada. Readers are encouraged to consult the additional sources referred to in this chapter for more detailed explanations. Finally, the chapter includes a description of the approaches used in this assessment, noting where these differ from other recent national- and global-scale assessments.

2 KEY CONCEPTS

Canadians are increasingly aware that climate change represents a fundamental challenge to our health and well-being, environment and economy. The vast majority of discussion at the public-policy level has focused on mitigation, the critically important response of reducing greenhouse gas emissions. Mitigation is essential to slow the rate, and ultimately to limit the magnitude, of climate change. There is, however, less awareness of the fact that, regardless of the success of global mitigation initiatives, further climate change and associated impacts are unavoidable (e.g. Intergovernmental Panel on Climate Change, 2007a). Even if greenhouse gas concentrations were stabilized, warming and sea-level rise would continue for centuries due to the nature of the climate system and feedbacks (Meehl et al., 2006; Intergovernmental Panel on Climate Change, 2007a). This assessment focuses on the need for adaptation in recognition of the reality that Canada's present climate is different from that of the recent past and will continue to change in future.

Adaptation actions undertaken by Canadian governments, industry, communities and individuals are, and will continue to be, based on implicit or explicit understanding of vulnerability. With respect to climate change, this involves considering how climate is likely to change, the probable impacts of these changes and the potential for adaptation. To understand vulnerability, authors of this assessment have drawn from a wide range of disciplines, ranging from the physical, biological and social sciences to economic analysis, and have integrated this information with other sources of knowledge, including local knowledge. Several key concepts that use terminology specific to the field, and convey explicit meanings that extend beyond the basic dictionary definitions, underlie this analysis. Rather than repeating explanations of these key concepts throughout the report, they are discussed in detail here. Note that a more extensive list of key terms in the field of impacts and adaptation is contained in the glossary to this report. For the remainder of Section 2 only, the first occurrence of words in the glossary is in bold italics.

2.1 ADAPTATION

Adaptation refers to any activity that reduces the negative ***impacts*** of ***climate change*** and/or positions us to take advantage of new opportunities that may be presented. Adaptation is needed to address the challenges of climate change, and represents a necessary complement to ***mitigation*** (reduction of ***greenhouse gas*** emissions; Box 1). Both the ***United Nations Framework Convention on Climate Change (UNFCCC)*** and the ***Kyoto Protocol*** include requirements for Parties (i.e. countries) to address adaptation. The goals of adaptation may include 1) alleviating current impacts (Füssel and Klein, 2006); 2) reducing ***sensitivity*** and ***exposure*** to climate-related hazards; and 3) increasing resiliency to climatic and non-climatic stressors (i.e. enhancing ***adaptive capacity***). Successful adaptation does not mean that negative impacts will not occur, only that they will be less severe than would be experienced had no adaptation occurred.

There are many different types of adaptation (Table 2). Adaptation includes activities that are taken before impacts are observed (anticipatory) and after impacts have been felt (reactive). Both anticipatory and reactive adaptation can be planned (i.e. the result of deliberate policy decisions), while reactive adaptation can also occur spontaneously (i.e. autonomous, without planning). Planned adaptation is an iterative process involving four basic steps: information development and awareness-raising; planning and design; implementation; and monitoring and evaluation (Figure 1; Klein

BOX 1

Adaptation and mitigation

There are two categories of response to climate change: mitigation and adaptation. In the climate change literature, these two terms have clear and distinct definitions, and there are fundamental differences between them (*see* Table 1). Mitigation refers to "***anthropogenic*** interventions to reduce the sources or enhance the sinks of greenhouse gases" (Intergovernmental Panel on Climate Change, 2001a). The goal of mitigation is to reduce or prevent changes in the ***climate system*** and, as such, mitigation focuses on the sources of climate change (Schipper, 2006).

TABLE 1: Characteristics of mitigation and adaptation (*compiled from* Füssel and Klein, 2006).

Characteristic	Adaptation to climate change	Mitigation of climate change
Benefited systems	Selected systems	All systems
Scale of effect	Local to regional	Global
Lifetime	Years to centuries	Centuries
Effectiveness	Generally less certain	Certain
Ancilliary Benefits	Mostly	Sometimes
Monitoring	More difficult	Relatively easy

Adaptation, on the other hand, is concerned with addressing the consequences of climate change (Schipper, 2006). Adaptation refers to activities aimed at reducing or preventing the impacts of climate change on human and natural systems.

Although the two terms are distinct, adaptation and mitigation are also codependent. Mitigation, through moderating both the rate and magnitude of changes in the climate system, affects both the demand for, and the potential success of, adaptation options. Greater magnitudes of change will require more extensive adaptation, and greater rates of change make adaptation more challenging. In addition, there are some activities that can be considered both mitigative and adaptive. For example, planting trees in urban areas both increases greenhouse gas sinks (mitigation) and acts to cool surrounding areas (adaptation to increased temperatures). This codependency between adaptation and mitigation indicates the need for climate change policies that address the two responses simultaneously (Mendelsohn, 2006).

While the distinction between adaptation and mitigation is well established in the climate change community, not all disciplines use these terms in this way. The natural hazards community, for example, has long used the term 'mitigation' to refer to activities that reduce the impacts of natural hazards. For example, land-use planning that limits development in floodplains would be considered a mitigation measure in the natural hazards community but an adaptation measure in the context of climate change.

et al., 1999). In most circumstances, anticipatory planned adaptations will incur lower long-term costs and be more effective than reactive adaptations. Nevertheless, there are risks involved in implementing adaptation options to deal with an uncertain future, including opportunity costs (the use of resources that could otherwise be used for competing priorities) and the potential for ***maladaptation*** (*see* Mendelsohn, 2006).

Many different groups, including individuals, organizations, industry and all orders of government, are involved in facilitating adaptation and in the choice and implementation of specific adaptation measures. Such measures are highly diverse, and may involve behavioural changes, operational modifications, technological interventions, and revised planning and investment practices, regulations and legislation. The role of governments includes the provision of information and ***tools***, and the establishment of policy frameworks, that promote adaptation action (Stern, 2006).

Many climate change impact studies provide lists of potential adaptations. Such lists help exemplify the diverse range of adaptation responses, and many examples of these are presented in the regional chapters of this assessment. Nevertheless, they represent only a starting point in analysis. Decisions regarding the most appropriate adaptation response to address a specific impact, or suite of impacts, require understanding of the process of adaptation and the related concepts of ***vulnerability***, adaptive capacity and ***resilience*** (*see* Sections 2.2–2.4). Adaptation will not take place in response to climate change alone, but in consideration of a range of factors with the potential for both synergies and conflicts. Attention must be paid to the feasibility, likelihood and mechanisms for adaptation uptake. Critical questions include the following (Smit and Wandel, 2006): "What can be done practically?", "Who will do it?" and "How will it be implemented?" Research on such questions is currently sparse in the field of climate change (Smit and Wandel, 2006).

2.2 VULNERABILITY

In the climate change literature, vulnerability refers to the degree to which a ***system*** is susceptible to, and unable to cope with, the adverse effects of climate change (Intergovernmental Panel on Climate Change, 2001a). The ***Intergovernmental Panel on***

TABLE 2: Different types of adaptation (*modified from* Smit et al., 1999).

ADAPTATION			
Based on	Type of adaptation		
Intent	Spontaneous	Planned	
Timing (relative to climate impact)	Reactive	Concurrent	Anticipatory
Temporal scope	Short term	Long term	
Spatial scope	Localized	Widespread	

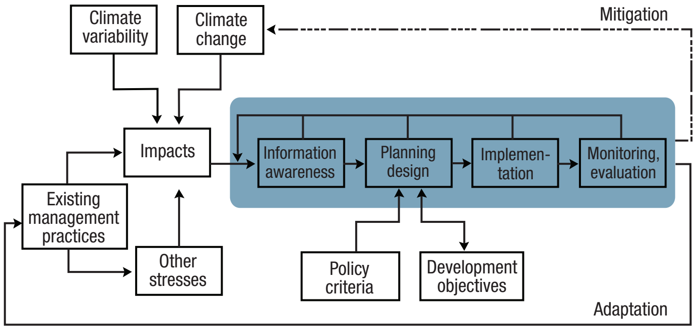

FIGURE 1: Conceptual framework showing (in the shaded area) the steps involved in planned adaptation to climate variability and change (*from* Klein et al., 2006).

Climate Change (2001a) states that "vulnerability is a function of the character, magnitude, and rate of ***climate variation*** to which a system is exposed, its sensitivity, and its adaptive capacity." As such, vulnerability integrates an external dimension, namely exposure to climate, as well as characteristics internal to the system under study (sensitivity and adaptive capacity; Füssel and Klein, 2006). It also necessitates an understanding of both biophysical and socioeconomic processes (Adger, 2006).

As an example, the vulnerability of an agricultural operation to climate change requires understanding of how climate is likely to change (e.g. increased temperatures, more frequent ***droughts***), the sensitivity of the system to that change (e.g. the relationship between crop yield and temperature and/or drought) and the potential for the system to adjust to the change (e.g. planting different crops, irrigation). Although this operation may be highly sensitive to climate change, in that crop yield is strongly controlled by temperature and drought, the system would not be considered highly vulnerable if effective adaptation measures, such as switching to more drought-resistant crops, are easy to implement.

The above example illustrates three other important aspects of vulnerability. First, by definition, vulnerability focuses on negative impacts — the "adverse effects of climate change" (Intergovernmental Panel on Climate Change, 2001a). It is well accepted, however, that climate change will bring benefits as well as negative impacts. In the example provided, increased temperatures may well lead to increased crop yields. Hence, adjusting activities so as to best capitalize on these benefits is also a recognized goal of adaptation. Second, the aspects of climate change most important for informing adaptation decision-making are rarely captured well in terms of the most commonly discussed climate parameters: changes in mean temperature and precipitation. In this example, more important considerations for crop yields may include the timing of precipitation, occurrence of extreme rainfall, growing degree-days and drought severity. Third, and most important, even if the vulnerability of a system is considered relatively low due to a high capacity to adapt, it may still incur significant impacts if adaptation actions are not implemented. In the example provided, if the operator continued to plant the same crop and made no other adjustments in the operation, they could experience severe negative impacts or would fail to benefit from new opportunities.

Recognition of the need to consider the ability of systems to adapt is what distinguishes vulnerability from sensitivity. Sensitivity does not account for the moderating effect of adaptation, whereas vulnerability can be viewed as the impacts that remain after adaptation has been taken into account. Although many early climate change impact studies focused primarily on sensitivity, it is now accepted that adaptation will strongly influence the magnitude of climate change impacts. Indeed, researchers have noted that "it is meaningless to study the consequences of climate change, without considering the ranges of adaptive responses" (Adger and Kelly, 1999). Most of the more recent climate change impact studies focus on assessing vulnerability, rather than sensitivity.

Assessing vulnerability requires consideration of the main stressors, both climatic and non-climatic, on a system or region, as well as the socioeconomic influences on adaptive capacity (see Section 2.3; Füssel and Klein, 2006). It is widely recognized that engagement of ***stakeholders*** represents a critical first step in assessing vulnerability (Lim et al., 2005). While impacts are frequently expressed quantitatively (e.g. percentage increase in productivity, dollar loss in revenue), vulnerability studies focus more on understanding the processes involved and influencing factors. The social and biophysical influences on vulnerability change readily over time and space (Adger, 2006). As a result, vulnerability is generally characterized, rather than measured, although advances in quantifying the concept are ongoing (*see* Adger, 2006).

2.3 ADAPTIVE CAPACITY

In the context of climate change, adaptive capacity is defined as the "potential, capability or ability of a system to adapt to climate change stimuli or their effects or impacts" (Intergovernmental Panel on Climate Change, 2001a). A system is a broad term, which encompasses all scales and types of units, including regions, communities, economic sectors, ***institutions*** and private businesses.

Adaptive capacity is a relatively new term in climate change research, first appearing in the scientific literature in about 1999 and not being cited frequently until 2003. The uptake and use of the term was likely spurred by the publication of the *Third Assessment Report of the Intergovernmental Panel on Climate Change* (2001), in which Chapter 18 ('Adaptation in the Context of Sustainable Development and Equity'; Smit et al., 2001) discussed the concept in detail. Adaptation and adaptive capacity are closely linked (Box 2), and enhancing adaptive capacity is a ***'no-regrets'*** adaptation option that brings benefits regardless of the changes in climate. As such, adaptation approaches that focus on enhancing adaptive capacity are an effective way of taking action, despite the uncertainties inherent in projections of future climate (Smit and Pilifosova, 2003). By increasing adaptive capacity, vulnerability to current climate, future climate and oftentimes other stressors are reduced.

To address adaptive capacity, two key questions must be considered: "Adaptive capacity of what?" and "Adaptive capacity to what?" (Smit et al.,1999). One may, for example, consider the adaptive capacity of a farm (system) to increased aridity (climate change), or the adaptive capacity of a community (system) to more frequent heat waves (climate change). Adaptive capacity is influenced by a number of location-specific determinants, which depend upon the social, economic and institutional state of the system or region being studied (Figure 2). These determinants act to either constrain or enhance ability to adapt (Kelly and Adger, 2000), and vary in both space and time (Smit et al., 2001).

Past experience clearly influences adaptive capacity. Canada's highly variable climate contributes positively to the capacity of Canadians to adapt to climate change. Single events can impact adaptive capacity both positively and negatively (Smit et al., 2001).

For example, lessons learned from a recent ***storm surge*** should lead to improved preparedness for future storms, thereby enhancing adaptive capacity. However, if recovery from that same event exhausted financial resources available to assist flood victims, adaptive capacity could be diminished until those resources are replenished. Past events also influence perception of ***risk*** at the individual and institutional levels, which in turn affects the likelihood of proactive adaptation (Grothmann and Patt, 2005).

Adaptive capacity is difficult to measure. Proxy indicators, such as per capita income, education level and population density, have been used for some of the determinants (Yohe and Tol, 2002), but others are more difficult to assess. In addition, although adaptive capacity is most meaningful as a local characteristic, data availability frequently means that it can only be assessed at the national or regional level (Yohe and Tol, 2002).

For this assessment, authors focused on characterizing the factors that influence adaptive capacity within their region, in some

BOX 2

Contrasting adaptation and adaptive capacity

Adaptive capacity and adaptation, although related, are distinct terms in the climate change literature. Adaptive capacity is an attribute of a system, which provides an indication of its ability to adapt effectively to change. A system with a high adaptive capacity would be able to cope with, and perhaps even benefit from, changes in the climate, whereas a system with a low adaptive capacity would be more likely to suffer from the same change. Adaptation, on the other hand, refers to a process and/or specific action.

Building adaptive capacity is a component of adaptation strategies (Brooks et al., 2005), and a system with many adaptation options generally has a higher adaptive capacity than a system with few or none (Yohe and Tol, 2002). Some suggest that adaptive capacity can be viewed as the potential for adaptation and, when adaptive capacity is used to adapt, vulnerability is reduced (Brooks, 2003).

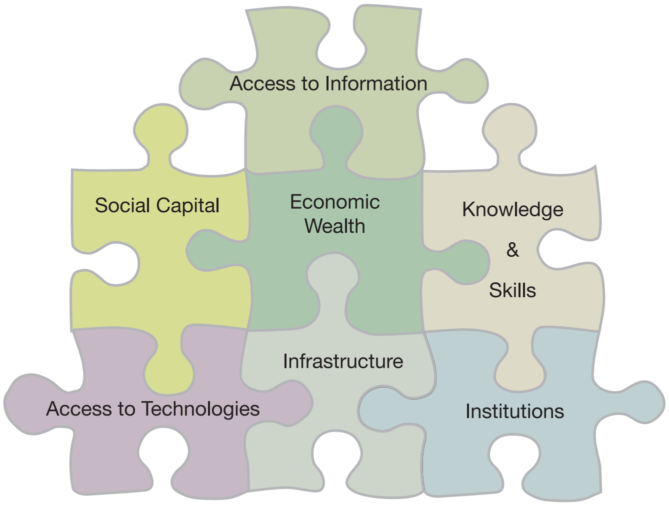

FIGURE 2: Determinants of adaptive capacity (*adapted from* Smith et al., 2003).

instances extending this characterization to the system level (subregions or sectors). Although discussion of adaptive capacity at the local level is rare in the climate change literature, there is considerable potential to learn lessons from analyses of other disciplines, including emergency preparedness, economic development/diversification and ***food security***. While generally beyond the scope of this assessment, such analysis represents a profitable direction for future impacts and adaptation research (*see* Chapter 10).

2.4 RESILIENCE

Resilience is defined as the "amount of change a system can undergo without changing state" (Intergovernmental Panel on Climate Change, 2001a). The term 'resilience' is not as commonly used in the climate change literature as 'adaptive capacity' or 'vulnerability'. Studies that do use the term tend to focus more on natural systems, rather than human systems, likely due to the term's roots in the field of ecology. Some researchers have modified the terminology for specific use in climate change studies, and now refer to 'eco-social resilience' or 'social-ecological resilience' (e.g. Adger, 2006).

As noted above, much of the terminology around impacts and adaptation continues to evolve. At times, 'resilience' has been used interchangeably with 'adaptive capacity'. Each term refers to an attribute of a system that relates to its ability to deal with external stressors, and both can be either constrained or enhanced by internal and external factors. However, as the definition of resilience implies an inherent characteristic of systems to remain at their current state and to provide the same function and structure (Walker et al., 2004), it does not necessarily align well with the goals of adaptation, where change is viewed as a necessary consequence of changing climate.

The definition of 'resilience' introduces two related concepts that are important for adaptation: ***'coping ranges'*** and ***'thresholds'***. 'Coping range' refers to the variation in climate that a system can absorb without incurring significant impacts. Adaptation actions will adjust the coping range, and similarly affect resilience (Figure 3). A 'threshold' is the point at which significant impacts are incurred (i.e. the coping range is exceeded) or the system undergoes a change of state (i.e. resilience is overwhelmed). Defining thresholds within natural systems is a key objective of many climate change impact studies (International Scientific Steering Committee, 2005), while understanding thresholds in human systems can be key to guiding adaptation decisions. Walker and Meyers (2004), however, have questioned whether thresholds can be defined before they are crossed, and found no examples in the published literature of thresholds being predicted before occurrence.

2.5 TECHNOLOGIES FOR ADAPTATION

Technology is frequently cited as a vital solution for the challenges presented by climate change. This is particularly true for mitigation, where a range of innovative new and developing technologies hold promise for providing alternative sources of

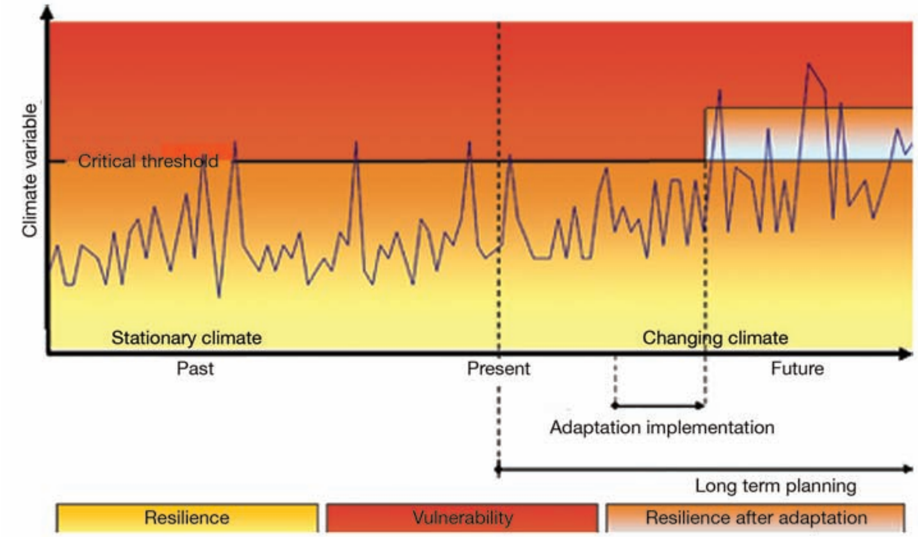

FIGURE 3: Adaptation will increase the coping range, making systems more resilient, and therefore less vulnerable, to climate change (*adapted from* Smit et al., 1999).

energy, enabling sequestration of greenhouse gases and enhancing energy efficiency. Technology will also play a role in adaptation (United Kingdom Climate Impacts Programme, 2005). Access to, and use of, technology is commonly cited as a determinant of adaptive capacity. For example, use of water conservation technologies may improve capacity to address climate change impacts on water supply (*see* Chapter 7). The goals of technologies for adaptation include improved resilience and flexibility, prevention of additional damage and reduction of costs.

Although relatively little research has focused on the actual role of technology in climate change adaptation, the concept of ***'technologies for adaptation'*** is explored in a comprehensive manner by Klein et al. (2006). The term itself (as opposed to 'adaptation technologies') indicates that many of the technologies that may be implemented for climate change adaptation represent existing technologies developed to address issues not directly related to climate change. While the focus in mitigation has been on the development of new technologies, greater emphasis in adaptation will likely be placed on the transfer of existing technologies that are then customized to meet local requirements. In the climate change literature, technology tends to be given a very broad definition, such as "a piece of equipment, technique, practical knowledge or skills for performing a particular task" (Metz et al., 2000), hence encompassing virtually every conceivable adaptation option. A distinction is generally made between hard and soft technologies, the former referring to physical products and the latter to practices and planning. Successful adaptation strategies will generally include both hard and soft technologies (Klein et al., 2006). Further distinctions can be made between traditional, modern, high and future technologies (Klein et al., 2006). In this assessment, the term 'technology' is generally limited to hard technologies.

2.6 SCENARIOS

Scenarios are "a coherent, internally consistent and plausible description of a possible future state of the world" (Parry and Carter, 1998). A scenario is not a prediction, since use of the term 'prediction' or 'forecast' implies that a particular outcome is most likely to occur. Rather, a scenario represents one of any number of possible futures. Both climate and socioeconomic scenarios provide input to analyses of impacts, vulnerability and adaptation measures. They provide a foundation to guide and explore the implications of adaptation and mitigation decisions, and to raise awareness of climate change issues. Scenarios define a range of possible futures that facilitate consideration of the ***uncertainty*** relating to different development pathways, with implications for future climate, social, economic and environmental change. For national and regional scenarios extending more than about 30 years into the future, significant attention has been paid to the development of ***climate scenarios***, whereas socioeconomic scenarios remain poorly developed despite the direct linkages between the two.

Climate Scenarios

Most climate scenarios are derived from ***climate model*** output, usually from ***Atmosphere-Ocean General Circulation Models*** (AOGCMs; *see* Box 3). Current standard practice in scenario development is to calculate the change between 30-year average AOGCM representations of the future (e.g. 2040–2069) and ***baseline*** (currently 1961–1990) conditions, and to apply these changes to observational data. These changes are generally expressed as simple differences for temperature, and in percentage differences for precipitation. Model output is averaged over thirty years for both the baseline and future time periods to ensure that the longer term climate change trend is captured. The AOGCM-derived changes are referred to as climate change scenarios, or sometimes as change fields. A climate scenario refers to the data that result from applying these change fields to observed climate data, and represents climate information for the future time period (e.g. the 2050s).

Owing to uncertainties involved in the projection of future climate (*see* Box 3), it is important that impacts and adaptation studies consider a range of climate change scenarios. The use of climate scenarios in this assessment is discussed in Section 5.3. Further information concerning scenarios can be found in Intergovernmental Panel on Climate Change Task Group on Scenarios for Climate Impact Assessment (1999).

Socioeconomic Scenarios

Social and economic conditions will not remain static as climate changes, and understanding the likely nature of these socioeconomic changes is important in characterizing vulnerability to climate change. Socioeconomic scenarios, which include information concerning population and human development, economic conditions, land cover and land use, and energy consumption, provide important information for understanding adaptive capacity. Global-scale socioeconomic scenarios extending to 2100 are the foundation of the emissions scenarios in the *Special Report on Emissions Scenarios* (SRES) of the Intergovernmental Panel on Climate Change (IPCC; *see* Box 3; Carter et al., 2001). It is unclear, however, whether these scenarios can be meaningfully downscaled for the purpose of impacts and adaptation studies. Socioeconomic forecasts at the national and regional scales may be more relevant for use in impacts and adaptation studies.

BOX 3

Climate modelling

Atmosphere-Ocean General Circulation Models (AOGCMs)[2]

The extreme complexity of the Earth's climate system, involving dynamic interactions between the atmosphere, the oceans, the ***cryosphere***, land surfaces and the biosphere, necessitates the use of sophisticated AOGCMs to project future climate change. These AOGCMs are three-dimensional mathematical representations of the large-scale physical processes of the Earth-atmosphere-ocean-land system, and provide a comprehensive and internally consistent view of future climate change. In AOGCMs, the Earth's climate system is divided into a gridded network of interconnected boxes, and the physical processes that control this system are represented by series of fundamental mathematical equations describing the conservation of momentum, mass and energy. ***Feedback*** effects in the climate system, such as those between snow and ice and the reflectivity of the Earth's surface ***(albedo)***, are included in the models, although some of these processes are incompletely specified and poorly quantified.

To project future climate, AOGCMs must be provided with information about future atmospheric composition. Future levels of greenhouse gas and aerosol emissions are dependent on a range of factors, including population growth, economic activity and use of energy and technology, so there is a wide range of possible emissions futures, referred to as ***emissions scenarios***. For its Third Assessment Report, the Intergovernmental Panel on Climate Change commissioned a Special Report on Emissions Scenarios (SRES), which describes about forty different emissions scenarios (Carter et al., 2001). Six of the ***SRES scenarios*** have been identified as 'marker scenarios' and are recommended for use by the climate modelling community, namely A1FI, A2, A1B, B2, A1T and B1 (presented in order of descending radiative forcing by 2100). At the extremes, the A1FI storyline describes a fossil-fuel-intensive world with very rapid economic growth, global population that peaks around 2050 and rapid introduction of new technologies. The B1 storyline describes a convergent world in which population also peaks about 2050, but with rapid economic changes towards a service and information economy and the introduction of clean and resource-efficient technologies (Carter et al., 2001). Best estimates and likely ranges of globally averaged temperature changes and ***sea-level rise*** for each of these marker scenarios are shown in Table 3.

TABLE 3: Influence of the scenario used on projected temperature change and sea-level rise. *Source*: Intergovernmental Panel on Climate Change (2007a).

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a]		Sea Level Rise[b] (m at 2090-2099 relative to 1980-1999)
	Best estimate	Likely range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations[c]	0.6	0.3 - 0.9	NA
B1 scenario	1.8	1.1 - 2.9	0.18 - 0.38
A1T scenario	2.4	1.4 - 3.8	0.20 - 0.45
B2 scenario	2.4	1.4 - 3.8	0.20 - 0.43
A1B scenario	2.8	1.7 - 4.4	0.21 - 0.48
A2 scenario	3.4	2.0 - 5.4	0.23 - 0.51
A1FI scenario	4.0	2.4 - 6.4	0.26 - 0.59

[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity (EMICs), and a large number of Atmosphere-Ocean Global Circulation Models (AOGCMs).

[b] Sea-level-rise estimates are based on observed flow rates from Greenland and Antarctica for 1993–2003. These rates may increase or decrease in the future. If they were to increase linearly with global mean temperature rise, the upper ranges shown in the table would increase by 0.1–0.2 m.

[c] Year 2000 constant composition is derived from AOGCMs only.

Uncertainty in projections of future climate increases with time. Emission scenarios represent one source of uncertainty related to future development pathways. Although this uncertainty cannot be avoided, it is noteworthy that emission scenarios only become an important source of uncertainty after about 2030 (Intergovernmental Panel on Climate Change, 2007a). A second source of uncertainty relates to differences between AOGCMs in the way physical processes and feedbacks are simulated. These differences result in the different AOGCMs simulating different global warming values per unit change of radiative forcing. New methods for dealing with this uncertainty have emerged since 2001 (Solomon et al., 2007).

Regional Climate Models (RCMs)

Regional Climate Models provide higher spatial resolution (i.e. more detailed) data than AOGCMs by nesting a high-resolution RCM within a lower resolution AOGCM. This means that RCMs are susceptible to any systematic errors present in the AOGCM used (Canadian Institute for Climate Studies, 2002). An advantage of RCMs is their ability to provide information that is more spatially detailed, and hence at a more appropriate scale for climate impact studies (Laprise et al., 1998). At present, however, RCM data are only available for a limited combination of AOGCMs and emission scenarios, and generally do not encompass a full range of plausible futures. Nevertheless, work in this field is evolving rapidly, with analysis and quantification of the confidence and uncertainty associated with RCMs a major area of research (cf. Caya, 2004; Déqué et al., 2005, Plummer et al., 2006).

In Canada, researchers have access to RCM data from the Canadian Regional Climate Model (CRCM) through the Canadian Centre for Climate Modelling and Analysis (CCCma; *see* http://www.cccma.ec.gc.ca/models/crcm.shtml); refer to Laprise et al. (2003) and Plummer et al. (2006) for discussions of model sensitivity and validation. The Ouranos Consortium provides support for the development of the CRCM and has utilized scenarios based on RCMs for analysis of climate change impacts (*see* Chapter 5).

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[2] *Also commonly referred to as Global Climate Models or General Circulation Models (GCMs).*

3 CLIMATE SCIENCE

Climate science is an intrinsic and important aspect of addressing vulnerability. Understanding why and how the climate is changing is critical to dealing with climate change. Each regional chapter of this assessment discusses the region's current climate, recent climate trends and future projections as input into analyses of sensitivity and vulnerability. This section complements material in the regional chapters by providing an overview of the causes of climate change, evidence for recent global climate change, and future changes in global climate. Climate change in Canada is discussed in Section 4.3. For more detailed information, readers are referred to the report *An Introduction to Climate Change: A Canadian Perspective* (Hengeveld et al., 2005), as well as the more technical reports prepared by Working Group I of the Intergovernmental Panel on Climate Change (2001c, 2007a).

3.1 CLIMATE CHANGE DRIVERS

Climate change drivers comprise both natural factors, such as solar orbit, sunspot cycles and volcanic eruptions, and anthropogenic factors, including emissions of greenhouse gases. These drivers influence the amount of energy that the Earth receives from the sun and the amount that is retained within the atmosphere and oceans, resulting in changes in all elements of climate, such as temperature, precipitation and atmospheric circulation.

Climate change drivers operate on a range of time scales, with changes in some factors (e.g. the orbit of the Earth around the sun) operating over tens to hundreds of thousands of years, whereas changes in others (e.g. atmospheric concentrations of greenhouse gases and volcanic aerosols) operate on shorter time scales. At timescales of decades to centuries, long-term drivers such as orbital variation are not as relevant. That is because, despite the large magnitude of related changes in climate when accumulated over many millennia, the rate of change on a century time scale is very small, on the order of 0.1°C/century or less.

Since the mid–twentieth century, human activities, including the burning of fossil fuels and changes in land-use patterns, have been the dominant cause of climate change (Intergovernmental Panel on Climate Change, 2007a). This trend is expected to continue through the present century and beyond, leading to rates of global warming that will exceed any experienced during the past several thousand years (Intergovernmental Panel on Climate Change, 2007a).

Paleoclimatic Change

During the past two and a half million years, the Earth's climate has been dominated by large fluctuations between glacial and interglacial conditions. Although average global surface temperatures during glacial periods were only about 4 to 6°C colder than during the warm interglacial periods, these changes were enough to alter Canada's landscape from one almost entirely covered with thick ice sheets to the hospitable biome of today. The last global deglaciation began about 20 000 years ago, and full interglacial conditions have dominated the Earth's climate for the past 10 000 years. The best analogue for the current interglacial, in terms of both climate forcing and the pattern of paleogeographic changes, may be the interglacial that took place some 400 000 years ago (European Project for Ice Coring in Antarctica community members, 2004). A comparison of the two periods suggests that the Earth's present climate, if allowed to evolve naturally, might last an additional 20 000 years or so before the conditions begin to slide back into the glacial part of the cycle.

Changes in solar insolation due to variations in the Earth's orbit around the sun are thought to be the primary driver of climate change across glacial-interglacial cycles. These variations include the 100 000 year cycle in the shape (eccentricity) of the Earth's orbit (from ellipse to circle and back again), the 42 000 year cycle in the angle (obliquity) of its axis of rotation with respect to the orbit, and the 22 000 and 19 000 year cycles in its wobble (precession). Reconstruction of past changes in atmospheric composition during the past 650 000 years from ice cores extracted from polar ice sheets indicates that the responsive changes in atmospheric concentrations of carbon dioxide, methane and nitrous oxide, three key natural greenhouse gases, significantly amplified the climatic effects of changes in solar insolation (Hutterli et al., 2005; Spahni et al., 2005).

Analyses of various proxy climate records extracted from polar ice cores, ocean sediments and other sources suggest that global temperatures have been remarkably stable during the past 10 000 years, a period referred to as the Holocene. These data also indicate, however, that this period has experienced some pronounced changes in regional climates, likely due to natural, internal climate variability. Such events involved a redistribution of heat within the climate system rather than a change in the total energy of the system (as in the case of the enhanced greenhouse effect).

Anthropogenic Forcings

Human activities, including greenhouse gas emissions (e.g. of carbon dioxide, methane and nitrous oxide), aerosol emissions (e.g. sulphate, carbon, nitrate and dust) and land-use change (e.g. deforestation, land development) are increasingly affecting global climate. Although natural factors can explain much of the global climate change that occurred during the first part of the twentieth century, the warming observed in the late twentieth century is primarily due to human activities that have led to increased atmospheric concentrations of greenhouse gases (Intergovernmental Panel on Climate Change, 2001c, 2007a; *see* Table 4). The effect of this anthropogenic radiative forcing on climate since 1950 has been approximately five times greater than the influence of solar output changes (Intergovernmental Panel on Climate Change 2007a; *see* Figure 4).

Although the rate of increase in the concentrations of human-induced nitrous oxide and methane are currently stable or declining, the rate of increase in carbon dioxide (the most important greenhouse gas with significant anthropogenic influence) emissions continues to rise (Intergovernmental Panel on Climate Change, 2007a). The predominant sources of carbon dioxide emissions are fossil fuels (production, distribution and consumption), cement production and land-use changes associated with forestry and agriculture.

TABLE 4: Current and pre-industrial concentrations of the main greenhouse gases (*compiled from* Intergovernmental Panel on Climate Change, 2007a).

Greenhouse gas	2005 concentration	Pre-industrial concentration
Carbon dioxide	379 ppm	~ 280 ppm
Methane	1774 ppb	~715 ppb
Nitrous oxide	319 ppb	~270 ppb

Atmospheric aerosols emitted by human activities also affect climate, both directly (by reflecting sunlight back to space) and indirectly (through effects on cloud properties). Although their effects are short lived (as they are removed by gravity and precipitation), they significantly affect radiative forcing at the continental to global scale. Aerosols have a negative radiative forcing (cooling effect) and are likely to have offset some of the warming during the twentieth century that would otherwise have been induced by greenhouse gases (Intergovernmental Panel on Climate Change, 2007a).

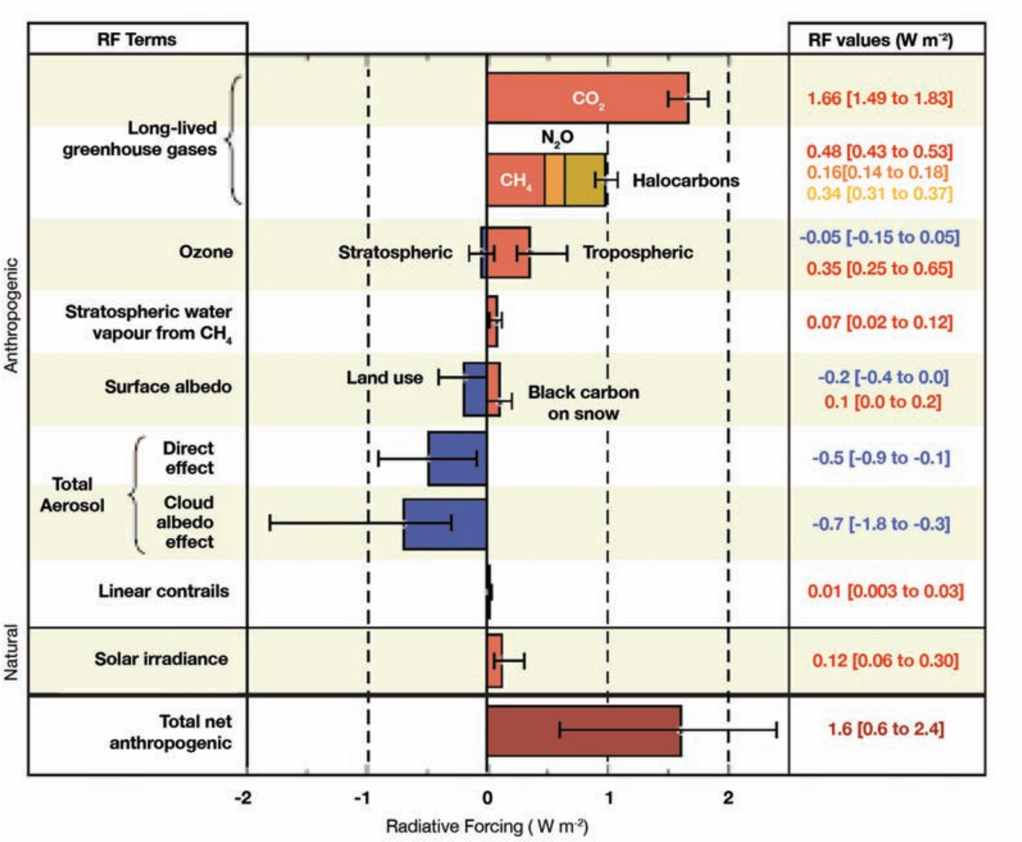

FIGURE 4: Global-average (2005) radiative forcing components of important agents and mechanisms. *Modified from* Intergovernmental Panel on Climate Change (2007a).

Feedbacks and Interactions

In addition to these primary drivers of climate change, there are numerous complex interactions and feedbacks in the climate system, at a variety of spatial and temporal scales, that either enhance or moderate climate change. Some of these feedbacks are positive (i.e. they amplify the magnitude of the original change) and others are negative (i.e. they moderate the original change). Particularly important feedbacks are the role of atmospheric water vapour (which also functions as a greenhouse gas) and clouds (which both reflect sunlight and absorb outgoing heat radiation). Rising temperatures increase both the rate of surface evaporation of water and the atmosphere's capacity to hold water vapour (a positive feedback). More water vapour also affects the distribution and properties of clouds in complex ways, providing both positive and negative feedbacks. Another important feedback is the change in the reflectivity of Earth's surface (albedo) that results from changes in the extent of snow and ice cover. The potential for release of large volumes of methane as a result of permafrost degradation, and subsequent decomposition of previously frozen organic material, is another example of a positive feedback that would enhance climate change (cf. Hyndman and Dallimore, 2001). A negative feedback is the potential for reduced Arctic sea-ice cover to allow arctic marine waters to absorb additional CO_2 from the atmosphere (Bates et al., 2006).

3.2 CLIMATE VARIABILITY

Interactions between the ocean and the atmosphere, and changes in associated circulation patterns, are the primary cause of climate variability. These changes are not directly related to changes in the global energy balance, although indirect interactions are likely. Much of this variability is natural, reoccurring at time scales that vary from months to decades and even longer. Because these oscillations change the flow of warm and cold air masses and alter storm tracks, they often cause trends in one region or location opposite to those in another, resulting in relatively small changes in large-scale climate. Nevertheless, their impact on regional climate in different parts of Canada can be quite significant.

Climate variations of particular importance to Canada include the following:

El Niño–Southern Oscillation (ENSO):

This well-known pattern of variability causes surface temperatures of the tropical Pacific Ocean to vary from El Niño conditions (abnormally warm temperatures in the eastern tropical Pacific) to La Niña conditions (much colder surface waters in the tropical Pacific) and back again about once every 3 to 7 years. In transition years, neither condition dominates.

The strength of the easterly trade winds in the tropics is closely related to ENSO behaviour. Strong El Niño and La Niña events, however, can also dramatically affect the flow pattern of winds and storm tracks over Canada, and hence temperature and precipitation patterns. These impacts are most evident in British Columbia, where El Niño events bring warmer and drier conditions than La Niña events (*see* Chapter 8). The impacts of ENSO are strongest in winter and spring, and are a significant factor in the country's year-to-year climate variability.

Pacific Decadal Oscillation (PDO):

This pattern of variability is most prominent in the North Pacific, and therefore has a large influence on the mid-latitude climates of North America, particularly that of western Canada. Its cause is not well understood, but it is likely linked to ocean circulation processes. Although the record is too short to determine whether the PDO is a persistent mode of variability, there have been two full cycles during the past century. The positive (warm) PDO phase is characterized by warmer coastal waters in the northeastern Pacific. In British Columbia, the positive PDO is associated with slightly higher winter and spring temperatures, and variable effects on precipitation, whereas the negative PDO phase is associated with cooler and wetter conditions (*see* Chapter 8). Hence this oscillation has been a significant influence on climate variability over much of Canada on multi-decadal time scales.

Arctic and North Atlantic Oscillations (AO and NAO):

The North Atlantic Oscillation is an indicator of atmospheric pressure differences between high and temperate latitudes of the North Atlantic Ocean. It is related to variations in the behaviour of the westerly winds of the Northern Hemisphere, so variations in the NAO affect the entire hemisphere. Alternatively, the Arctic Oscillation index (also known as the Northern Annular Mode, or NAM) describes variation in pressure patterns around the North Pole. The two appear to be closely linked. Variations in the NAO-AO significantly influence the monthly and annual variability of Northern Hemisphere climates, but also show significant long-term trends. There are indications that the anomalous behaviour evident in both indices during the 1990s may reflect human influences on the global climate circulation system (Hegerl et al., 2007).

3.3 OBSERVED AND PROJECTED CHANGES IN CLIMATE (GLOBAL[3])

Observed Changes

"*Warming of the climate system is unequivocal.*"
(Intergovernmental Panel on Climate Change, 2007a)

During the past century, the world has become warmer. This is evidenced by the increase in global average air and ocean temperatures, the rise in sea level and the decline in snow (Figure 5) and ice cover. Increased temperatures have been accompanied by a number of other observed changes in global climate (Table 5). For example, global sea level has risen an estimated 0.17 m (range 0.12–0.22 m) over the past century, with the rate of increase accelerating during the past decade (1993–2003; Intergovernmental Panel on Climate Change, 2007a).

Shifts in precipitation patterns have also been observed. Some regions have seen increases in precipitation (e.g. northern Europe, northern and central Asia, and northern North America), while others have experienced declines (e.g. the sub-Saharan grasslands and southeastern Africa). In general, precipitation has increased at high latitudes and in the tropics, but decreased in the subtropics. Of greater concern than changes in annual precipitation for many regions is the increased frequency of heavy precipitation events that overload drainage systems, cause extensive flooding, trigger landslides and compromise drinking water and sewage systems, resulting in loss of lives and severe health and economic impacts (*see* Chapter 9).

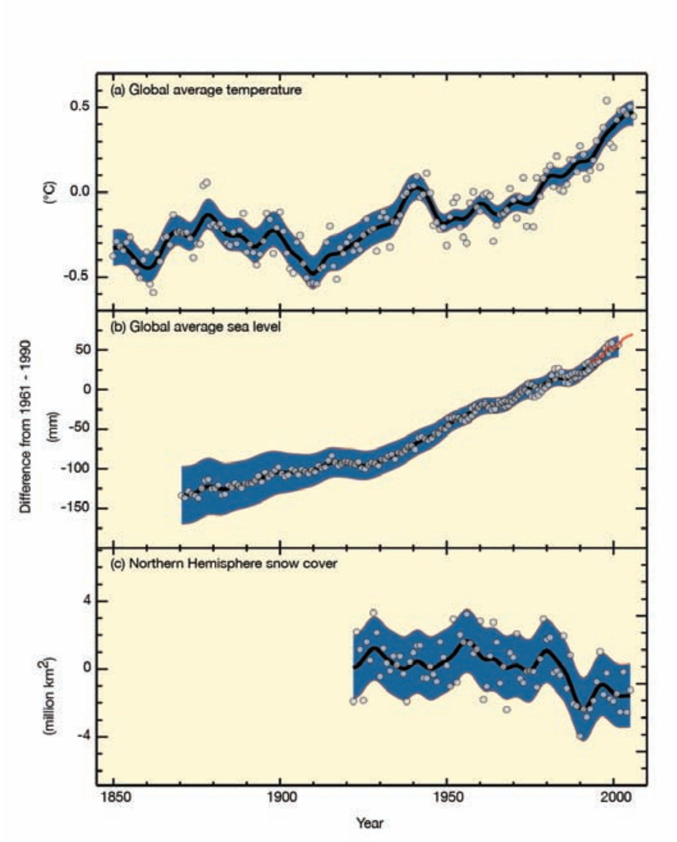

FIGURE 5: Observed changes (relative to 1961–1990) in global average surface temperature, sea level and Northern Hemisphere snow cover (Intergovernmental Panel on Climate Change, 2007a).

Climate Projections

Projections of climate are derived from climate modelling experiments (*see* Box 3) In many cases, future changes will involve a continuation, and often acceleration in the rate, of the observed trends of the twentieth century. The fourth assessment report of Working Group I of the Intergovernmental Panel on Climate Change (2007a; Meehl et al., 2007) discusses the key changes projected during the twenty-first century (Table 6). Significant advances in this report relative to previous IPCC assessments include greater confidence in model projections, improved projections of extreme events and stronger attribution of observed changes to anthropogenic forcing, all due to the advances in climate science and computer capacity, and longer observational periods.

TABLE 5: Observed changes in climate and weather indicators (*compiled from* Intergovernmental Panel on Climate Change, 2007a).

Indicator	Change	Comments
Air temperature	Increased 0.74°C Increased 0.13°C per decade	1906–2005 Rate (last 50 years)
Ocean temperature	Increased to depths of 3000 m	
Sea level	Rose 1.8 mm/a Rose 0.17 m	Rate (1961–2003) Total (1900–2000)
Snow cover	Declined	Northern Hemisphere
Mountain glaciers	Widespread retreat	Since 1900
Arctic sea-ice extent	Decreased 2.7% per decade	Rate (1978–2005)
Permafrost extent	Decreased by ~7%	Since 1900
Heavy precipitation events	Increased in frequency	
Droughts	Increased in intensity and duration	Since 1970s
Heat waves	Increased in frequency	
Tropical cyclones	Increased in intensity	Since 1970s

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[3] Observed and projected changes in Canada are presented in Section 4.3.

During the next two decades, IPCC-derived best estimates are that average global temperature will increase by 0.2°C/decade. Even if atmospheric concentrations of greenhouse gases were kept constant at year 2000 levels, global mean temperature would continue to increase by 0.1°C/decade (Intergovernmental Panel on Climate Change, 2007a) for the next two decades. Geographic variation in amount of warming is projected, with the greatest warming occurring over land and at high northern latitudes. Precipitation is also projected to increase more at high latitudes, and to decrease most in subtropical land regions. Sea level is projected to rise 0.18 to 0.59 m by 2100, depending on the scenario used (*see* Table 3).

Higher temperatures will be accompanied by continued reductions in snow cover, reduced extent and duration of Arctic sea ice, and an increase in the depth of permafrost thaw (Intergovernmental Panel on Climate Change, 2007a). Over longer time scales, the magnitudes of projected global temperature increase and sea-level rise are dependent on the assumptions inherent in the scenario used (Table 3), but it is important to note that the directions of such changes are consistent among the emission scenarios.

Changes in extreme weather, including hot days, cold days and heavy precipitation events, will accompany gradual warming (Kharin et al., 2007). Based on outputs of multimodel runs (12–14 models), Kharin et al. (2007) have projected that days of extreme heat in the summer will become hotter, winter cold extremes will warm substantially and heavy precipitation events will occur more frequently. Other studies suggest that tropical and winter cyclones may become more intense in the future due to rising sea-surface temperatures (Webster et al., 2005; Lambert and Fyfe, 2006).

Researchers acknowledge that there is also a real and finite risk of large and potentially cataclysmic surprises that are not captured by model simulations (Intergovernmental Panel on Climate Change, 2007a) but could have dire consequences. These include 1) the potential sudden reduction or shutdown of the Atlantic meridional overturning circulation that transports large quantities of heat from the equator to the North Atlantic, and without which Europe's annual temperature would be much cooler; 2) the disintegration of the west Antarctic ice sheet, which could cause global sea level to rise by 5 m; and 3) the abrupt release of large quantities of methane from frozen gas hydrates below the ocean floor, which would cause methane concentrations in the atmosphere to rise rapidly, resulting in further and more pronounced global warming. Although it appears very unlikely that such surprises will be fully realized within the next century, the irreversible processes that ultimately lead to them could be triggered before 2100. Paleoclimate records show that such surprises have occurred in the past, particularly during periods of rapid climate transition.

TABLE 6: Projected changes in climate (*compiled from* Intergovernmental Panel on Climate Change, 2007a).

Indicator	Change	Likelihood
Cold days and nights	Warmer and fewer	Virtually certain
Hot days and nights	Warmer and more frequent	Virtually certain
Heat waves	More frequent	Very likely
Hot extremes	More frequent	Very likely
Heavy precipitation events	More frequent	Very likely
Meridional overturning circulation of Atlantic Ocean	Slowdown (by 25%)	Very likely
Droughts	Increase in area affected	Likely
Tropical cyclones	More intense	Likely

4 OVERVIEW OF CLIMATE CHANGE IN CANADA

As outlined in Section 2, understanding the risks and opportunities that climate change presents for Canada requires knowledge of not only changes in climate but also the climate sensitivity of key aspects of the Canadian economy and social fabric, and the ability of Canadian governments, industry and individuals to undertake adaptation actions.

Canada is a vast country with great variability between and within regions in terms of climate, landscapes, communities and economy. This diversity is highlighted by contrasting the various regional chapters of this assessment. National-scale trends and projections provide important context for these regional analyses. Over the past half century, changes in climate have resulted in increased temperatures throughout much of Canada, altered precipitation patterns, reduced sea-ice cover, shifting hydrological conditions and changes in some extreme weather events. At the same time, Canada's economy has become dominated by the services sector, while the population has aged and become increasingly urban. In all cases, these trends are expected to continue, with implications for future vulnerability. For example, the services sector is likely less sensitive to changes in climate than the primary resource sector, and the elderly generally have a lower capacity to deal with extreme weather events, such as heat waves. Stronger economies also have more options for adaptation, and are therefore considered better able to adapt.

This section provides an overview of what climate change means for Canada, by examining current conditions, observed trends, and projections for our economy, demographics and climate. A recurrent theme is the importance of scale in assessing vulnerability to climate change. It highlights the fact that aggregate analyses at the national and global scale will inevitably understate the magnitude of the economic and social impacts that will be experienced at regional and local levels.

4.1 THE CANADIAN ECONOMY

Current State

The Canadian economy is large and diversified, with a national GDP of more than $1 trillion. It is mainly a tertiary economy: the services sector represents nearly 70% of GDP, whereas goods-producing industries make up about 30% (*see* Table 7). In the services sector, finance and insurance are main contributors, along with wholesale and retail trade, health care and public administration. Among the goods-producing industries, manufacturing (e.g. of automobiles, aircraft and pharmaceuticals) accounts for the largest share. Although natural resource–based industries, such as mining, agriculture, forestry, fishing and hunting, make up only a small percentage of GDP at the national scale (*see* Table 7), they remain a key component of Canada's economy. Historically, these industries played a large role in the development of the country and are still major contributors to foreign trade and the basis of Canadian wealth.

Trends and Projections

The strength of the Canadian economy during the past decade translated into continuous growth of production per capita through both a rising employment rate and growing labour productivity. This increase in productivity, largely attributed to technological development and capital building, should continue in the near and mid-future. Based on present trends, it is reasonable to foresee a sustained growth of the Canadian GDP and an increase in Canada's wealth.

TABLE 7: Gross domestic product at basic prices, by industry (Statistics Canada, 2007a).

	Millions of constant dollars (1997)				
	2002	2003	2004	2005	2006
Goods-producing industries:					
Agriculture, forestry, fishing and hunting	19 721	21 632	23 047	23 777	23 373
Mining and oil and gas extraction	36 345	38 287	39 469	39 750	40 157
Manufacturing	172 130	171 499	174 992	176 497	174 992
Construction industries	54 620	56 274	59 764	63 108	67 618
Utilities	26 982	27 221	27 366	28 562	28 042
Services-producing industries:					
Transportation and warehousing	46 638	47 176	49 494	51 403	52 792
Information and cultural industries	41 017	41 924	42 534	44 258	45 315
Wholesale trade	57 846	60 252	63 510	68 040	73 510
Retail trade	56 771	58 533	60 732	63 627	67 273
Finance and insurance, real estate, and renting, leasing and management of companies and enterprises	193 595	197 828	205 480	212 385	220 507
Professional, scientific and technical services	43 729	45 610	46 838	48 284	49 728
Administrative and support, waste management and remediation services	21 799	22 531	23 351	24 187	25 664
Public administration	56 346	57 882	59 084	59 902	61 527
Educational services	44 712	45 252	46 293	47 055	47 959
Health care and social assistance	56 933	58 369	59 477	60 305	61 572
Arts, entertainment and recreation	9 130	9 117	9 223	9 283	9 529
Accommodation and food services	23 063	22 533	22 983	23 223	24 143
Other services (except public administration)	24 496	25 065	25 529	26 015	26 628
All industries[1]	985 873	1 006 985	1 039 166	1 069 661	1 100 329

[1] North American Industry Classification Standard

Climate change will impact a rapidly evolving Canadian economy, in which demographic, commercial and technological changes will exert strong influences on future outcomes. The magnitude of the impacts of climate change on the Canadian economy is thus difficult to predict. Impact modelling suggests that, although overall economic impacts may be slightly positive in the short term at moderate degrees of warming, further warming and associated changes in climate will overwhelm systems, causing net economic losses (Stern, 2006). It must also be stressed that much of the research to date on the economic impacts of climate change considers only changes in mean conditions, rather than extreme events, despite the fact that natural disasters associated with extreme weather events frequently incur significant short- and longer term costs. Losses to regional and local economies from both extreme weather events and gradual, longer term changes in climate could be severe. At the local scale, communities that are reliant on climate-sensitive natural resources may be particularly vulnerable to climate change (*see* Box 4; Intergovernmental Panel on Climate Change, 2007b).

National-scale roll-ups, where losses or gains are expressed in terms of national GDP, tend to obscure the impacts in smaller provinces and territories. Consider, for example, the collapse of the northern cod fishery in Newfoundland in 1992. This had extreme provincial- and community-level repercussions, including the loss of up to 40 000 jobs (Mason, 2002), and yet was hardly reflected at the scale of national GDP.

Some of the key ways in which climate change will impact the Canadian economy are categorized as follows:

- **Impacts from extreme events and natural disturbances:** Economic losses from such events in Canada are often in the hundreds of millions of dollars (e.g. Hurricane Juan, Alberta hailstorms, British Columbia wildfires), and even in the billions (1998 Ice Storm, 1996 Saguenay flood; 2001–2002 national-scale drought). Insect damage to forests and crops may also be significant.
- **Impacts on buildings and infrastructure:** Included in this category are increased maintenance and protection costs, total loss or replacement costs, and loss of assets. Winter roads (*see* Chapters 3 and 7), coastal erosion (*see* Chapters 3, 4, 5 and 8) and permafrost degradation (*see* Chapters 3 and 5) are key concerns in Canada.
- **Impacts on the production and prices of, and the demand for, goods and services:** These costs will be manifest both within Canada and internationally (*see* Chapter 9), and will be both positive and negative.
- **Costs related to the impacts on public safety, health and welfare of populations:** These costs, although difficult to quantify and predict, may be high. Examples include the effect of vector-borne diseases, the long-term effects of flooding (e.g. mental health, mould issues and financial hardship), and impacts of changing climate on culture and traditional ways of life. Potential benefits may result from less extreme winter weather.
- **Impacts resulting from hydrological changes in lakes and streams:** Several economic sectors, including energy (e.g. hydroelectricity), tourism and recreation, freshwater fisheries, and transportation will be affected by changing water levels and supply.

Limited data are available on the sensitivity or vulnerability of the services sector in Canada, which now dominates our economy. In the short term, however, it is likely to be less sensitive to slow and/or moderate climate change than the renewable resources sector. For all sectors, continuing climate change means

BOX 4

Resource-dependent communities

Although agriculture, forestry, fishing and hunting account for only about 2% of national GDP (*see* Table 7), and a maximum of 7% of provincial GDP (Saskatchewan), they are vitally important for the economic well-being of many subregions and communities, where land- and resource-based activities are still the basis of economic life. For instance, more than 1600 Canadian communities are more than 30% reliant on one or more of these industries for their economic well-being (i.e. obtain 30% or more of their employment income from employment in these sectors; Natural Resources Canada, 2006). Of these, 808 communities are reliant on agriculture, 651 on forestry and about 200 on fishing. Note that these estimates do not capture smaller (population <250 people) resource-dependent communities.

Natural resources are also integral to many Aboriginal communities in Canada. The subsistence economy may constitute one-half to one-quarter of the total economy of these communities and be worth about $15 000 per household in the Arctic and half of that in the sub-Arctic (Berkes and Fast 1996; Centre for Indigenous Environmental Resources, 2006). These values, however, are not easily reflected in traditional economic accounting.

Several factors heighten the vulnerability of resource-dependent communities to climate change. These include the high climate sensitivity of many natural resources (agriculture, forestry and fisheries), as well as many factors related to lower adaptive capacity, including limited economic diversification, fewer economic resources available for adaptation, an aging population, and generally more restricted access to services (e.g. greater degree of isolation).

Overall, economic impacts at the community scale can be significant. Aggregate analysis tends to hide critical local impacts and imposed hardships.

increasing risk that critical thresholds will be reached, triggering long-term future feedbacks (Schneider, 2004) and catastrophic events that would be extremely costly (Stern, 2006).

4.2 POPULATION AND DEMOGRAPHICS

Current State

Canada has a population of 32.6 million (Statistics Canada, 2006), with a population density of 3.5 people/km^2, among the lowest in the world (Statistics Canada, 2007d). This number, however, is not representative of the regions where most people reside, since more than half of Canada's population lives in the densely populated Quebec City–Windsor corridor.

Trends and Projections[4]

Canada's population grew from 24.3 million in 1981 to 32.6 million in 2006 (Statistics Canada, 2006, 2007e). Two key trends have accompanied this population growth: urbanization and aging. Both of these trends are expected to continue into the future.

In 2001, approximately 80% of the Canadian population lived in cities, with the number of urban dwellers growing by about 50% since 1971. Urban population expansion has resulted both from cities being the preferential location for new immigrants and from the migration of rural residents to take advantage of job opportunities. This demographic is associated with growth in secondary and tertiary industries, but has also been accompanied by an expansion of the urban areas themselves. In 2001, the bulk of the urban areas in Canada were still found in Ontario and Quebec. Rapid expansion of urban areas is also occurring in Alberta and British Columbia.

The elderly are commonly identified as being among the most vulnerable to climate change, especially with respect to health-related impacts. The proportion of elderly persons (age 65 and over) in Canada increased 3% between 1981 and 2005 (from 10 to 13%), and will continue to increase until 2056 under all projection scenarios (Statistics Canada, 2005). Under medium-growth scenarios, the proportion of elderly is projected to almost double in the next 25 years and, by 2056, half the Canadian population would be over 47 years of age. The proportion of the oldest seniors (80 years and over) also increases sharply in every projection scenario. For example, in the medium-growth scenario, about one in 10 Canadians will be 80 years and over by 2056, compared with about one in 30 in 2005. Other populations considered more vulnerable to climate change include children, Aboriginal people, people with pre-existing health conditions and the poor (Health Canada, 2005).

Canada's population will continue to grow between now and 2056 under most scenarios analyzed by Statistics Canada (*see* Figure 6; Table 8). The medium-growth scenario would bring a 30% increase in the size of the Canadian population by 2056, whereas the high-growth scenario would yield a 53% increase from present. The low-growth scenario projects an increase to 2039, then a gradual decline to 2056. In all the scenarios considered, natural increase would become negative in the medium or long term and migration would become Canada's only source of population growth.

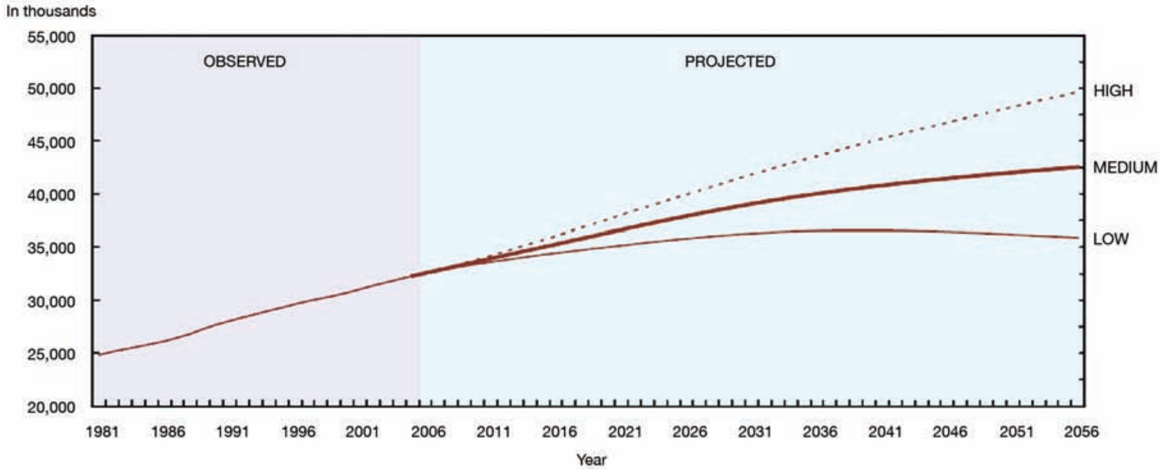

FIGURE 6: Observed (1981–2005) and projected (2006–2056) population of Canada according to three scenarios (Statistics Canada, 2005).

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[4] Further description of the projections presented in this section can be found in Statistics Canada (2005).

TABLE 8: Population projections for Canada under low-, medium- and high-growth scenarios to 2031 and 2056 (*compiled from* Statistics Canada, 2005).

Scenario	2031	2056
Low growth	36.3 million	35.9 million
Medium growth	39 million	42.5 million
High growth	41.8 million	49.7 million

Current population (2006): 32.6 million

The greatest rate of mean annual population growth is projected for British Columbia, followed by Ontario and Alberta (*see* Table 9). Certain provinces, namely Saskatchewan and Newfoundland and Labrador, are projected to see small declines in population. Population increases are projected to be concentrated largely in the major urban areas of the most populous provinces of Ontario, British Columbia, Alberta and Quebec. Further discussion of provincial and territorial trends is found in the regional chapters of this report. The projection results are more uncertain at the provincial/territorial level than at the national level due to interprovincial migration, which has been highly volatile in the past.

TABLE 9: Provincial growth projections for 2031 under a medium-growth, medium-migration trends scenario (*compiled from* Statistics Canada, 2005).

Province	Population (thousands)		Mean annual growth rate (rate per thousand)
	2005	2031	
British Columbia	4 254.5	5 502.9	9.9
Alberta	3 256.8	4 144.9	9.3
Saskatchewan	994.1	975.8	-0.7
Manitoba	1 177.6	1 355.7	5.4
Ontario	12 541.4	16 130.4	9.7
Quebec	7 598.1	8 396.4	3.8
Newfoundland and Labrador	516.0	505.6	-0.8
Prince Edward Island	138.1	149.5	3.1
Nova Scotia	937.9	979.4	1.7
New Brunswick	752.0	767.2	0.8
Yukon	31.0	34.0	3.6
Northwest Territories	43.0	54.4	9.1
Nunavut	30.0	33.3	4.0

4.3 CLIMATE TRENDS AND PROJECTIONS

Observed Trends — Temperature and Precipitation

The influence of anthropogenic climate change on Canada is evident in observed trends and temperatures simulated by global climate models (Zhang et al., 2006). These changes are already impacting human and natural systems (cf. Gillett et al., 2004). Observational data have been collected in southern Canada for more than a century and in other parts of Canada since the mid–twentieth century. These data, together with satellite data from the past 25 years or so, provide a detailed picture of how Canadian climate and associated biophysical variables have changed in recent decades. This section provides an overview of the observed changes; for more detailed discussion, readers are referred to Barrow et al. (2004) and Hengeveld et al. (2005).

On average, Canada has warmed by more than 1.3°C since 1948 (Figure 7), a rate of warming that is about twice the global average. During this time period, the greatest temperature increases have been observed in the Yukon and Northwest Territories. All regions of the country have experienced warming during more recent years (1966–2003; McBean et al., 2005), including the eastern Arctic, where there has been a reversal from a cooling trend to a warming one, starting in the early 1990s (Huntington et al., 2005a; Nickels et al., 2006).

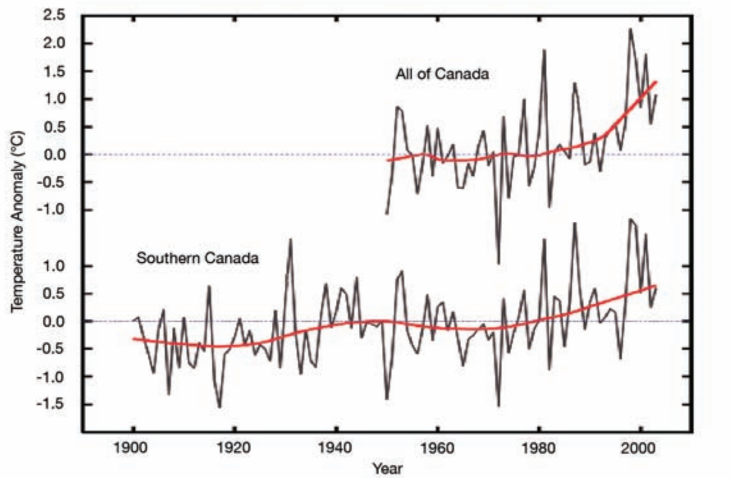

FIGURE 7: Annual national temperature departures and long-term trend, 1948 to 2006 (Environment Canada, 2006).

On a seasonal basis (Figure 8), temperature increases have been greater and more spatially variable during the winter and spring months. In northwestern Canada, winter temperatures increased more than 3°C between 1948 and 2003. During the same period, winter and spring cooling trends (up to –2.5°C) were observed in parts of the eastern Arctic. Summer warming has been both more modest and more uniform in space, whereas warming in the autumn period has been largely confined to Arctic regions and British Columbia (Figure 8).

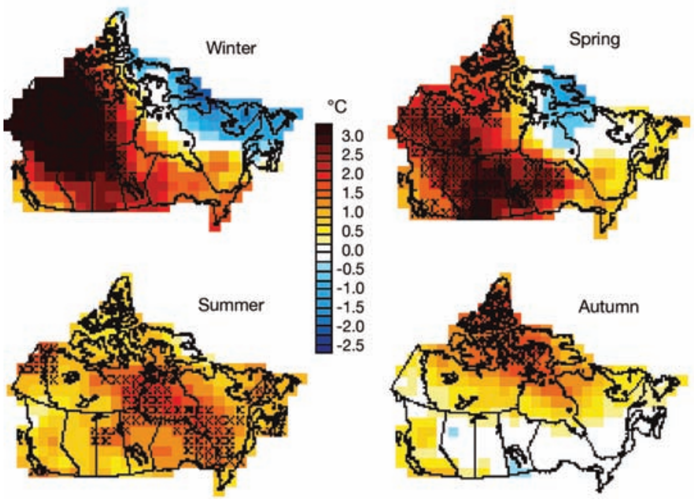

FIGURE 8: Regional distribution of linear temperature trends (°C) observed across Canada between 1948 and 2003, by season. The 'X' symbols indicate areas where the trends are statistically significant. *Source*: Hengeveld et al. (2005).

National trends in precipitation (Figure 9) are more difficult to assess, primarily because of the discontinuous nature of precipitation and its various states (rain, snow and freezing rain). Nevertheless, Canada has, on average, become wetter during the past half century, with mean precipitation across the country increasing by about 12 % (Environment Canada, 2003).

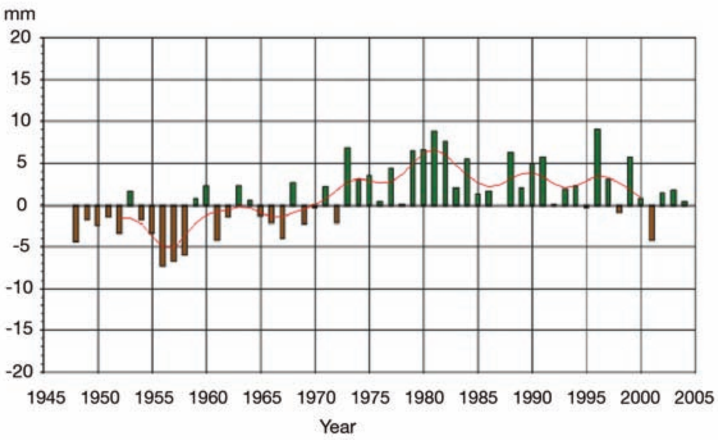

FIGURE 9: Trends in annual departures of average annual precipitation across Canada from the 1951 to 1980 normals, with weighted running mean. *Source*: Environment Canada.

Changes in precipitation have also varied by region and season (Figures 10, 11) since 1950. Annually averaged, the largest percentage increase in precipitation has occurred in the high Arctic, while parts of southern Canada (particularly the Prairies) have seen little change or even a decrease (Figure 10). For example, over most of Nunavut, annual precipitation has increased by 25 to 45%, whereas the average increase in southern Canada has been 5 to 35% (Environment Canada, 2003).

FIGURE 10: Regional distribution of linear annual precipitation trends (% change) observed across Canada between 1948 and 2003. The 'X' symbols indicate areas where the trends are statistically significant *Source*: Zhang et al. (2000), updated in 2005.

Seasonal trends since 1950 indicate that most of the Arctic has become wetter in all seasons. Southern British Columbia and southeastern Canada also show regions with significant increases in precipitation in spring and autumn. In contrast, most of southern Canada except the western part of southern Ontario, which has seen increased lake effect snow (*see* Chapter 6), has experienced a significant decline in winter precipitation.

Changes in the frequency of extreme temperature and precipitation events have been observed in Canada from 1950 to 2003, including (*from* Vincent and Mekis, 2006):

- fewer extreme cold nights,
- fewer extreme cold days,
- fewer frost days,
- more extreme warm nights,
- more extreme warm days,
- more days with precipitation,
- decrease in mean amount of daily precipitation,
- decrease in maximum number of consecutive dry days,
- decrease in annual total snowfall (southern Canada), and
- increase in annual total snowfall (northern and northeastern Canada).

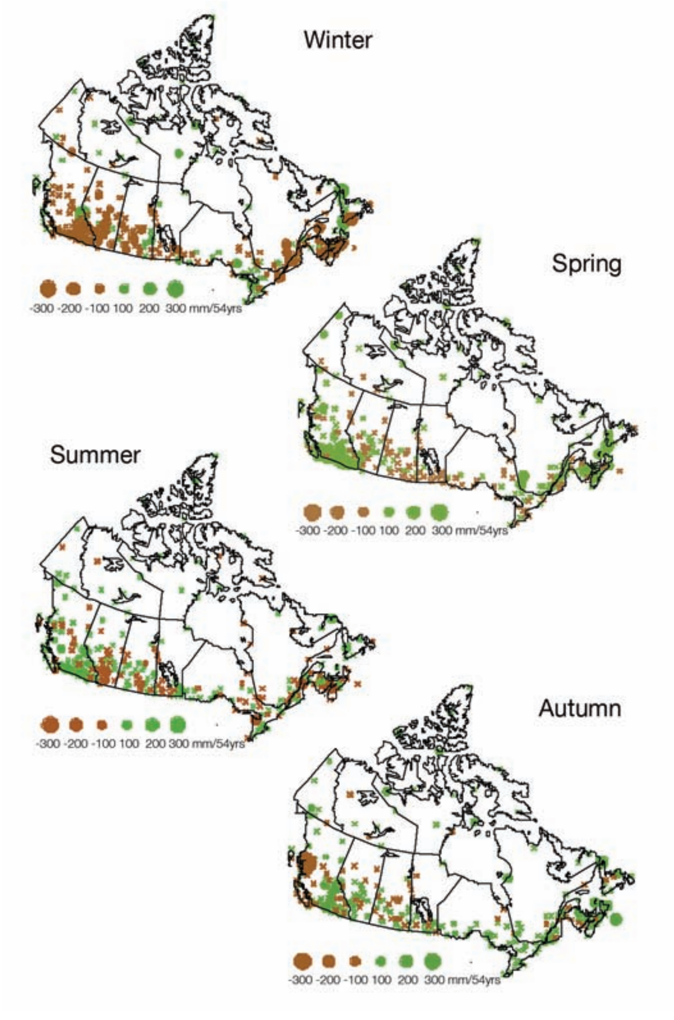

FIGURE 11: Changes in precipitation since 1950, by season. Data are presented as total change over the full 54 years of data, expressed in mm. The magnitude of change is indicated by the size of the circle, with green indicating an increase and brown a decrease. The crosses denote areas where trends are not statistically significant.
Source: Environment Canada.

Accompanying these changes has been a significant decline in the number of heating-degree days. There are also significant changes at the regional scale in the numbers of intense precipitation events. On average, the fraction of precipitation falling as intense events (the upper 10%) has been decreasing in southern Canada but increasing in northern Canada, particularly in the northeast. Also, more of the precipitation is falling as rain rather than snow.

Other Observed Changes

Changes in temperature and precipitation during the past 50 to 100 years have led to changes in other variables, including sea ice, snow cover, permafrost, evaporation and sea level. These changes, as well as their implications for the environment, the economy and society, are discussed in detail in the regional chapters of this report. This section simply highlights key observations.

The cryosphere has responded to observed warming. For example, the extent of Arctic sea ice during the late summer season has decreased by 8% since 1979 (Figure 12). Snow-cover duration, on average, has decreased by about 20 days in the Arctic since 1950 (Figure 13). Annual total snow amount has increased in some Arctic regions (Taylor et al., 2006), however, because

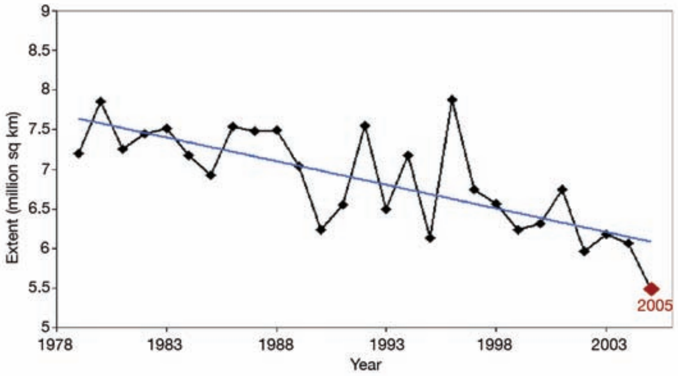

FIGURE 12: Trends in minimum (September) Arctic sea-ice extent from 1978 to 2005, as recorded by NASA satellites. The trend from 1979 to 2005, now showing a decline of more than 8% percent, is shown with a straight blue line. *Source*: National Snow and Ice Data Center (2005).

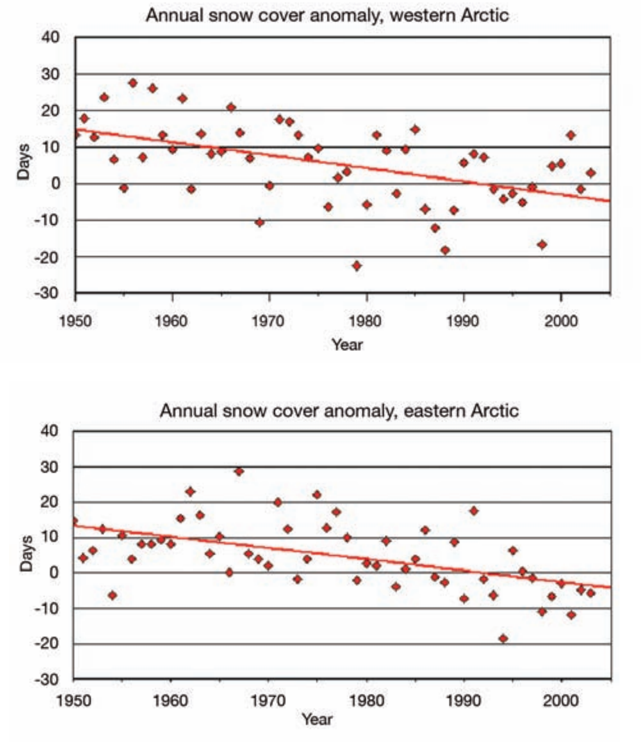

FIGURE 13: Trends in Canadian Arctic snow-cover duration, measured as change in days relative to 1990. *Source*: Ross Brown, Environment Canada, pers. comm., 2007.

higher temperatures induce higher humidity, which results in more precipitation. A general increase in thaw depth was observed through the 1990s across the Canadian permafrost regions (e.g. Brown et al., 2000; Nixon et al., 2003; Smith et al., 2005). Shallow permafrost temperatures increased during the last two to three decades of the twentieth century by 0.3 to 0.5°C per decade in the Canadian high Arctic (Taylor et al., 2006), and ranged from no change to almost 1°C per decade in the western Arctic (Smith et al., 2005).

Recent declines in the volume of glacial meltwater in western Canada (Demuth et al., 2002), and precipitation changes and increased evaporation elsewhere (linked to higher temperatures), have altered water resources across much of Canada (Shabbar and Skinner, 2004). Actual evapotranspiration rates (AET) have, on average, increased in most regions of the country during the last 40 years (Table 10), although the trend is weak or inconsistent in some areas (Fernandes et al., 2007) due to limited availability of water to evaporate. For example, evapotranspiration rates have decreased slightly in the dry regions of the Prairies, where water (to evaporate) is already limited throughout much of the year (Huntington, 2006; Fernandes et al., 2007). Although many areas of the country are expected to experience an increase in precipitation (*see* Figure 14), this may not be sufficient to offset the AET increase due to temperature rise. In the Great Lakes area, for example, a 1°C increase in mean annual temperature was associated with a 7 to 8% increase in AET (*see* Fernandes et al., 2007), resulting in a decrease in water availability.

Water levels in lakes across Canada have varied considerably over time, and recent trends toward lower levels in the upper Great Lakes, in association with higher temperatures, have been quite dramatic (Mortsch et al., 2006). Water levels in the Great Lakes are generally projected to continue to drop in the future (*see also* Chapter 6; Moulton and Cuthbert, 2000; Mortsch et al., 2006; Figure 15).

During the past century, global ocean levels have risen an estimated 0.17 m (range 0.12–0.22 m; Intergovernmental Panel on Climate Change, 2007a). The magnitude of relative sea-level rise along Canadian coastlines depends upon whether the coast is experiencing crustal (glacioisostatic) rebound or subsidence as a result of the deglaciation that took place thousands of years ago. For example, in some parts of Canada, such as around Hudson Bay, land has continued to emerge despite increasing global sea levels. However, regional land subsidence in other regions, including most of the Atlantic coastline, has doubled the rate of

TABLE 10: Trends and changes in actual annual evapotranspiration rates over 40 years by Canadian climate zone (*data from* Fernandes et al., 2007).

Region	ET trend	ET change
	mm/yr	mm over 40 yrs
Pacific Coast	1.16	46.40
South BC	1.24	49.68
Yukon	0.06	2.24
Prairies	0.03	1.12
Mackenzie	0.24	9.80
Northwest forest	0.22	8.80
Northeast	0.75	30.00
Great Lakes	0.69	27.56
Atlantic	1.04	41.48
Tundra	0.16	6.48

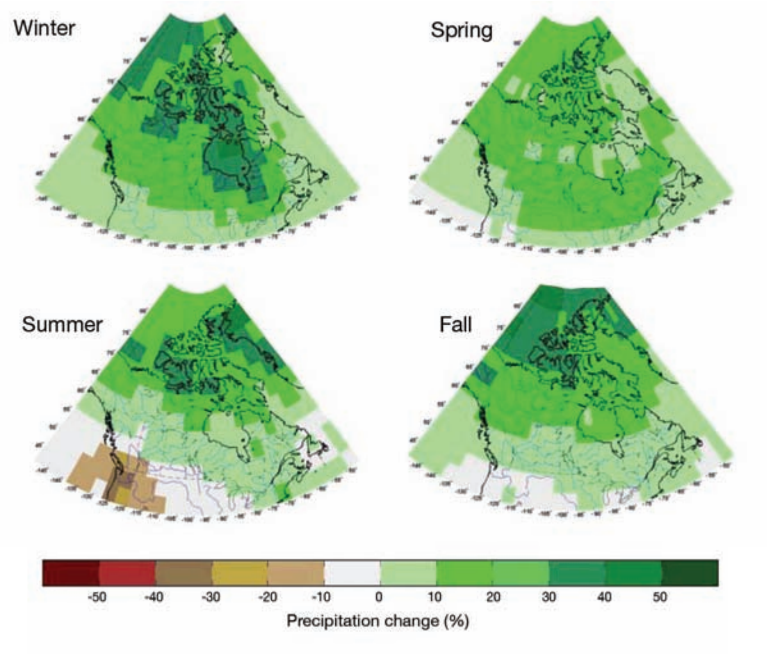

FIGURE 14: Seasonal change in precipitation by the 2050s (relative to 1961–1990), based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

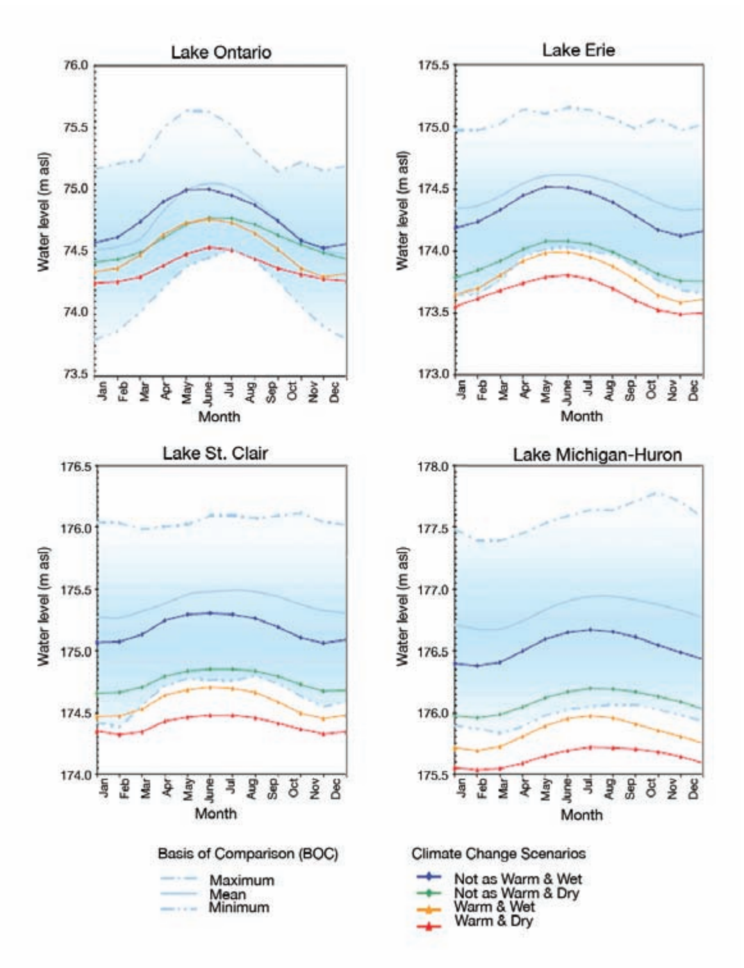

FIGURE 15: Projected changes in water levels for the Great Lakes (Mortsch et al., 2006).

local sea-level rise in some areas (McCulloch et al., 2002). In Charlottetown, for instance, relative sea level rose 32 cm over the twentieth century (Forbes et al., 2004). Additional geophysical factors influencing relative sea-level changes in Canada include tectonic activity along the Pacific coast and subsidence due to extensive sediment deposition, particularly in the Fraser River and Mackenzie River deltas. Along the west coast, relative sea-level change has been lower, with sea level rising by 4 cm in Vancouver, 8 cm in Victoria, 12 cm in Prince Rupert and dropping by 13 cm in Tofino over the twentieth century (British Columbia Ministry of Water, Land and Air Protection, 2002). In the north, the Yukon coast and the directly adjacent Northwest Territories coast are subsiding, making relative sea-level rise in these regions greater than along most of the Arctic coast (Barrow et al., 2004).

Projections — Temperature and Precipitation[5]

All of Canada, with the possible exception of the Atlantic offshore area, is projected to warm during the next 80 years. In most cases, future changes in climate will involve a continuation of the patterns, and often an acceleration of the trends, discussed above. Therefore, amounts of warming will not be uniform across the country (*see* Figure 16). During the present century, temperature increases will be greatest in the high Arctic, and greater in the central portions of the country than along the east and west coasts (Figure 16). Regional differences in temperature projections are also illustrated in Figure 17, which shows historical and projected change in temperature for six cities across Canada.

On a seasonal basis, warming is expected to be greatest during the winter months (Figure 16), due in part to the feedback effect that reduced snow and ice cover has on land-surface albedo. Winter warming by the 2050s is expected to be most pronounced in the Hudson Bay and high Arctic areas, and least in southwestern British Columbia and the southern Atlantic region. A decrease in the winter diurnal temperature range across the country indicates that winter nights will likely warm more than winter days (Barrow et al., 2004). This pattern was not found for the other seasons. Rates of warming will be lower in the summer and fall, and summer warming is projected to be more uniform

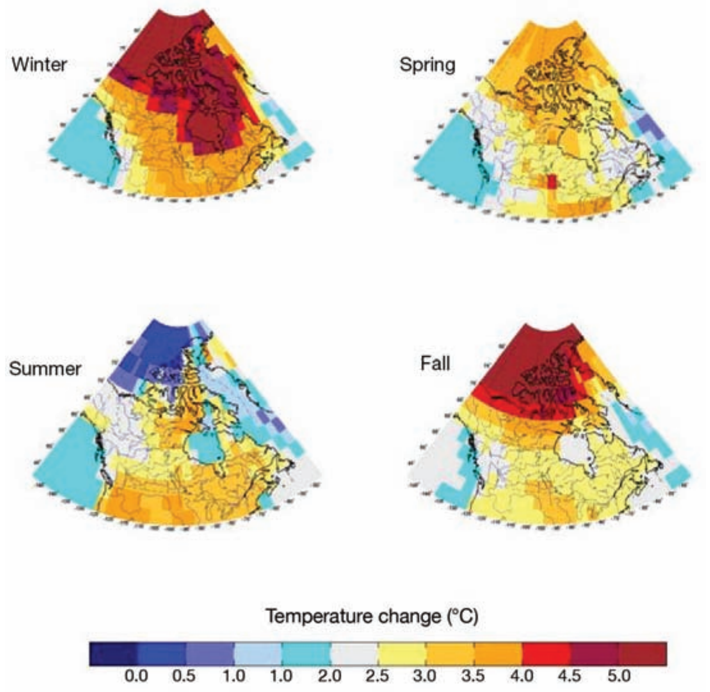

FIGURE 16: Seasonal change in temperature across Canada by 2050 (relative to 1961–1990), based on the median of seven global climate models and using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

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[5] Much of the material in this section is abstracted from the Barrow et al. (2004) report *Climate Variability and Change in Canada: Past, Present and Future.*

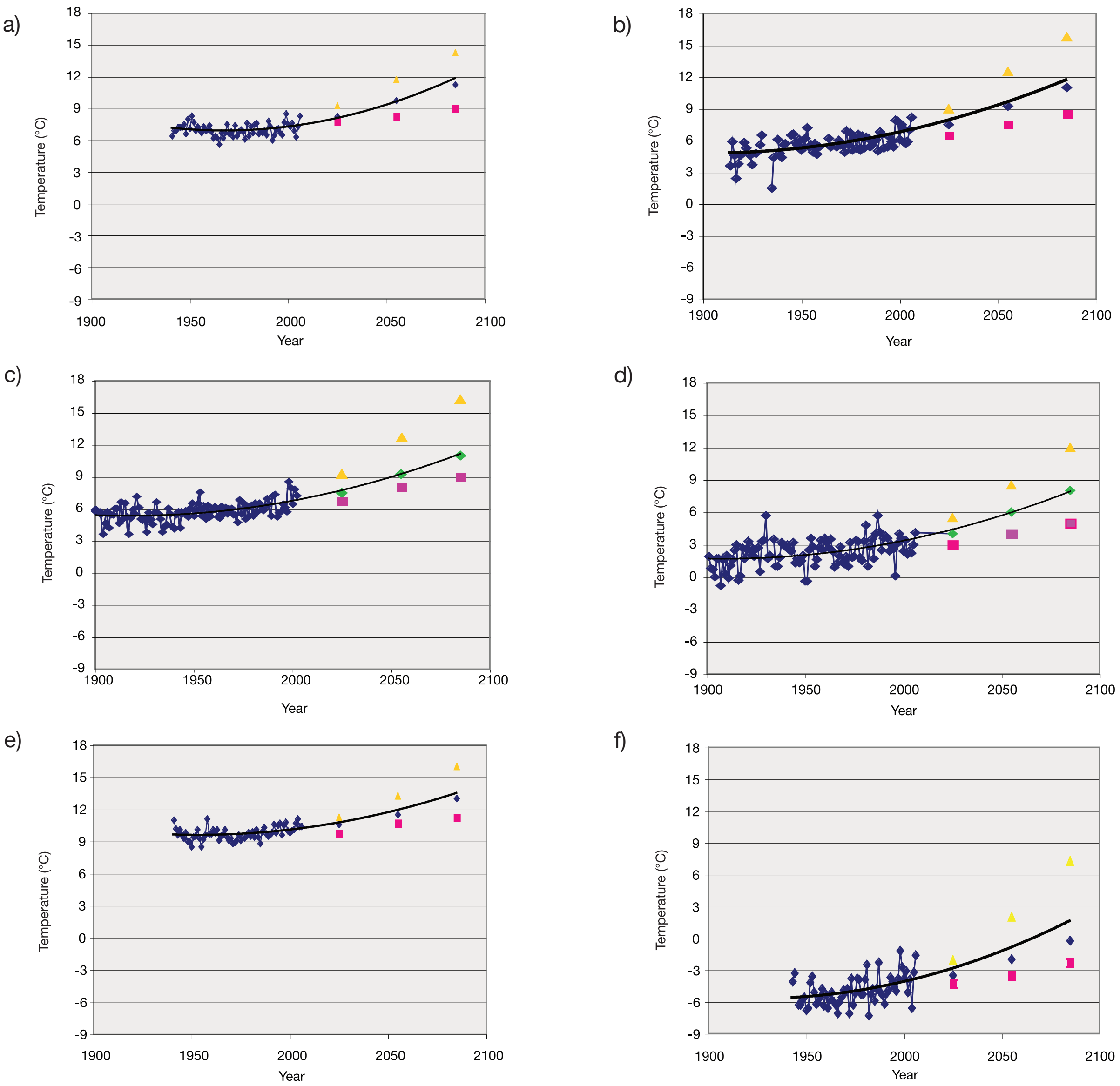

FIGURE 17: Historical trends (blue diamond) and projected maximum (yellow triangle), median (green diamond) and minimum (pink square) annual mean temperature scenarios for the 2020s, 2050s and 2080s for six cities across Canada: a) Yarmouth, NS; b) Drummondville, QC; c) Ottawa, ON; d) Regina, SK; e) Victoria, BC; and f) Yellowknife, NT. Note historical data presented are limited by data availability, and projected changes are derived from a range of global climate models using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

across the country. These patterns are consistent with the observed trends presented above.

The frequency of extreme warm summer temperatures (exceeding 30°C) is expected to increase across Canada (*see* Figure 18; Kharin et al., 2007). Heat waves are projected to become more intense and more frequent. The health impacts of extreme heat, as well as effective adaptation measures to deal with heat waves, are discussed in several of the regional chapters (e.g. Chapters 5, 6 and 7). At the same time, extreme cold days are projected to decline significantly (Kharin et al., 2007), resulting in an overall reduction in the climate severity index (Barrow et al., 2004).

Future precipitation is more difficult to project, and changes are generally of lower statistical significance, than changes in temperature (Barrow et al., 2004). This is reflected in the wide range in model results for projected precipitation (*see* Figure 19). Annual total precipitation is projected to increase across the country during the current century. By the 2080s, projected

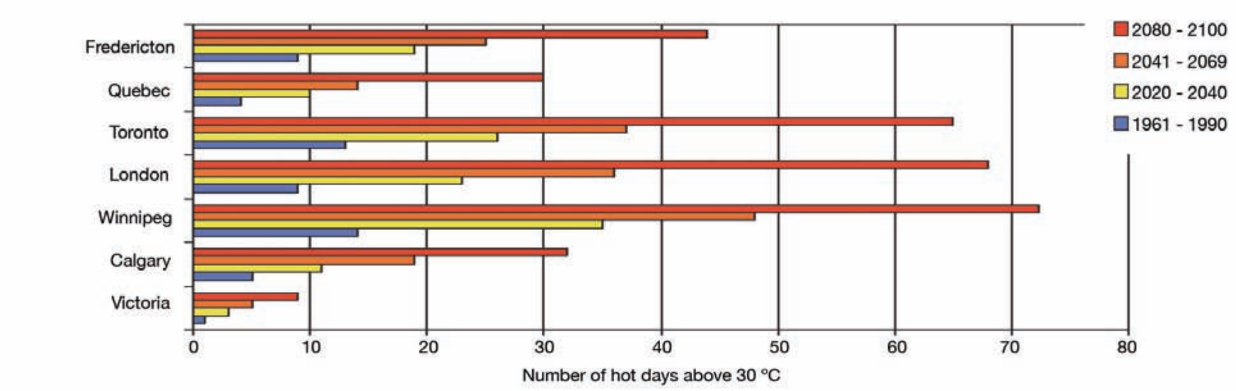

FIGURE 18: Number of days with temperatures exceeding 30°C, during observed (1961–1990) and future (2020–2040; 2041–2069; and 2080–2100) time periods (Hengeveld et al., 2005).

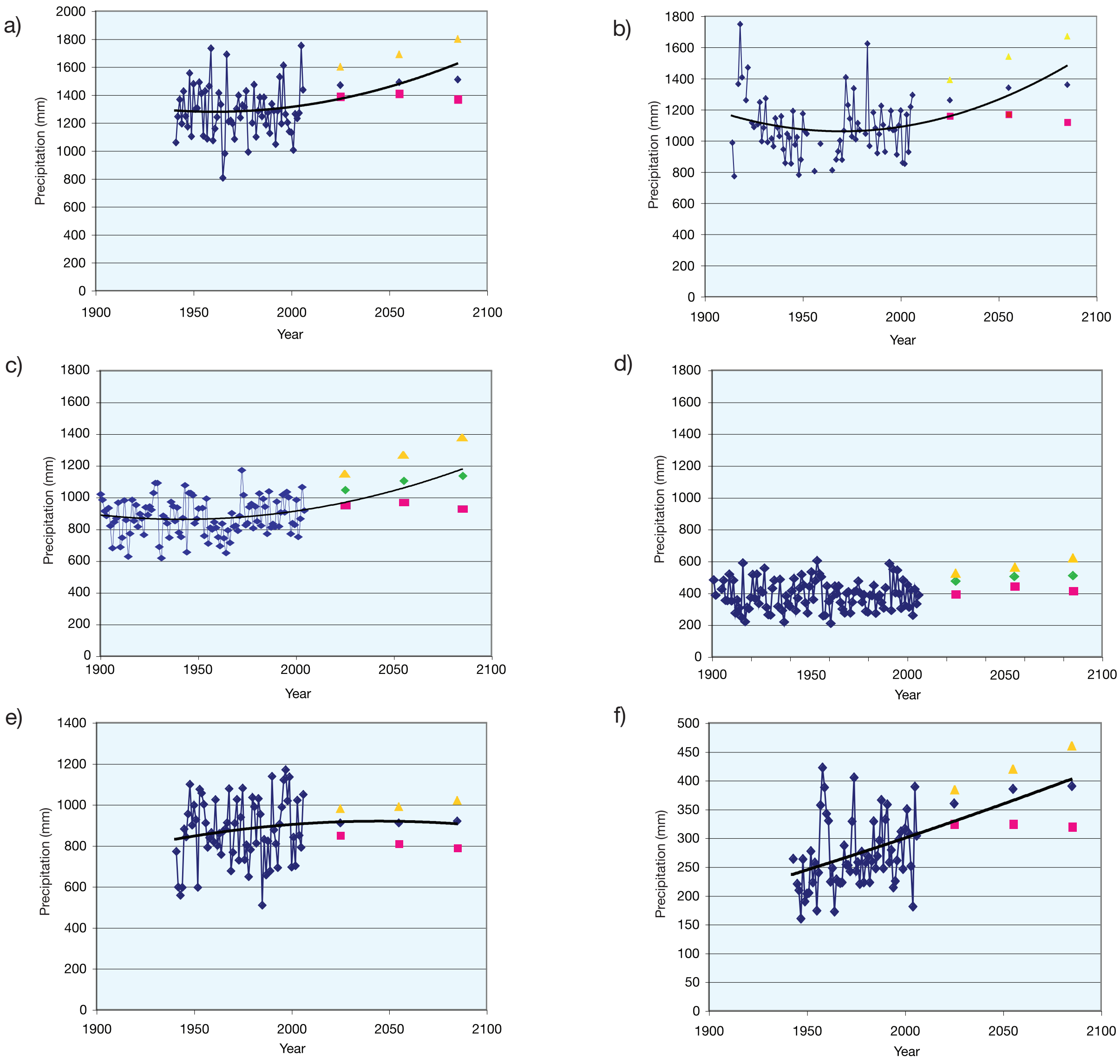

FIGURE 19: Historical trends (blue diamond) and projected maximum (yellow triangle), median (green diamond) and minimum (pink square) total annual precipitation scenarios for 2020s, 2050s and 2080s for six cities across Canada: a) Yarmouth, NS; b) Drummondville, QC; c) Ottawa, ON; d) Regina, SK; e) Victoria, BC; and f) Yellowknife, NT. Note historical data presented are limited by data availability, and projected changes are derived from a range of global climate models using the emissions scenarios of the *Special Report on Emissions Scenarios* (SRES).

precipitation increases range from 0 to 10% in the far south up to 40 to 50% in the high Arctic. Due to enhanced evapotranspiration, driven by higher temperatures, many regions will experience a moisture deficit despite greater amounts of precipitation.

Seasonal changes in precipitation will generally have greater regional-scale impacts than the annual totals. Throughout most of southern Canada, precipitation increases are projected to be low (0–10% by the 2050s) during the summer and fall months. In some regions, especially the south-central Prairies and southwestern British Columbia, precipitation is even expected to decline in the summer (Figure 14). This means less available precipitation during the growing season in important agricultural regions. Other important changes in precipitation include an increase in the percentage of precipitation falling as rain rather than snow, and an increase in extreme daily precipitation (Figure 20; Kharin and Zwiers, 2000).

Other Projected Changes

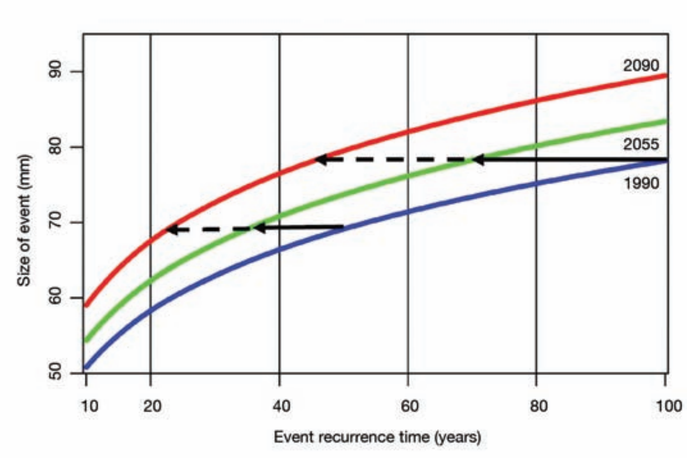

FIGURE 20: Projected changes in extreme 24-hour precipitation events, North America between latitudes 25°N and 65°N (based on Kharin and Zwiers, 2000). *Source*: Environment Canada.

Sea level will continue to rise during the current century, with global projections of 0.18 to 0.59 m by 2100 (Intergovernmental Panel on Climate Change, 2007a). Relative sea-level changes in Canada will continue to exhibit similar patterns to those observed during the twentieth century. Therefore, regions of rebound (e.g. Hudson Bay, parts of the British Columbia coast and the Labrador coast) will generally experience lesser impacts as a result of sea-level change than areas that are currently subsiding (e.g. Beaufort Sea coast, much of the Atlantic coast and the Fraser River delta). The influence of sea-level rise on coastal communities and activities such as shipping and tourism are discussed in detail in Chapters 3, 4, 5 and 8.

As sea level rises, the risk of storm-surge flooding increases. Such flooding will likely occur more frequently in the future, particularly in areas already impacted by these events. For example, storm-surge flooding in Charlottetown, which occurred six times between 1911 and 1998, is likely to occur every year by 2100 unless significant adaptation measures are implemented to protect the city (McCulloch et al., 2002).

There is not a simple direct relationship between sea ice and temperature because complex interactions, associated with changes in atmospheric and ocean circulation patterns (e.g. the Arctic and North Atlantic oscillations), strongly influence sea-ice patterns (Barrow et al., 2004). Patterns of sea-ice reduction will therefore continue to vary locally and regionally, as they have during the past century (Barrow et al., 2004). Arctic sea-ice extent will, however, decrease during the twenty-first century, and summer ice extent will change more than winter ice extent (Intergovernmental Panel on Climate Change 2007a; Anisimov et al., 2007). Although climate models vary in estimating the rate of ice decline (*see* Chapter 3), several scenarios indicate that large areas of the Arctic Ocean will be seasonally ice free before the end of the twenty-first century (Solomon et al., 2007).

Sea-level rise, storms and decreases in sea ice will all increase the rate of coastal erosion (*see also* Chapters 3 and 4; Manson et al., 2005). In northern regions, permafrost degradation will make coastal areas further susceptible to erosion.

4.4 CONCLUSIONS

Canada's climate is changing, and projections show that it will continue to change in the future. In addition to gradual shifts in average temperature and precipitation, changes in temperature and precipitation extremes, sea level, storm surges, sea ice and other climate and climate-related parameters have been both observed and projected. These changes will continue to occur across a backdrop of social and economic changes, which will greatly influence net impacts. Regional differences in projected climate, sensitivity and factors influencing adaptive capacity (e.g. access to economic resources, population demographics) mean that vulnerability varies greatly across the country, both within and between regions. These differences are highlighted throughout the regional chapters of the report.

5 APPROACHES USED IN THIS ASSESSMENT

5.1 SYNTHESIS

This assessment is a critical analysis of the existing body of knowledge concerning the risks and opportunities that climate change presents for Canada. This process required consideration of historical climate trends, projected climate change, climatic sensitivity of key systems, and current and future adaptive capacity. New studies and research were not commissioned for the purposes of the assessment.

Authors were directed to draw from three main sources:

1) **Peer-reviewed published literature**: Peer-reviewed published literature was the primary source of material for the assessment. There is a large and growing body of climate change literature focused specifically on Canada, and international papers of relevance to understanding Canada's vulnerability. In addition, there is a wealth of peer-reviewed information relevant to climate change impacts and adaptation outside climate change journals. The authors were therefore encouraged to draw from other fields of research, such as natural disasters, land-use management, political economics and planning.

2) **Grey literature**: Grey literature, including government reports, non–peer-reviewed papers in a variety of publications, workshop reports and consultant reports was also used as reference material. Such sources contribute significantly to understanding vulnerability to climate change, and often are the only place to access the most recent and locally relevant information. Authors' discretion was used to evaluate the quality and suitability of the grey literature.

3) **Local/practitioner knowledge**: This assessment recognizes that local knowledge, frequently obtained through communication with practitioners, complements that obtained from scientific sources. Given the applied nature and local scale of many adaptation measures, direct experience is rarely captured in the scientific literature. For this reason, the report occasionally cites personal communications to capture and attribute this knowledge.

As noted in Chapter 1, the scientific information presented in this assessment includes traditional (Aboriginal) knowledge. This knowledge is captured in all three sources described above. Material included in each chapter broadly reflects the scope of information available through the sources noted above. The volume of material available on a specific topic, however, does not necessarily reflect the relative significance of that issue at a regional or national level. Indeed, there is only very limited information available on some important aspects of impacts and adaptation, such as economic analyses. Hence, assessment of the significance of available knowledge reflects the expert judgement of the lead and contributing authors of each chapter, in their areas of specialization. The authors were also asked to identify key knowledge gaps. General guidance documents addressing scope, goals and key concepts were provided to the writing teams, but decisions on how information on any given region could be most effectively presented was left to the authors. Peer review by both science and policy experts in academia and government helped to guide the final version of this report.

5.2 LIKELIHOOD AND CONFIDENCE

Uncertainty is an inherent component of any climate change analysis. While it may be possible to identify the major sources of uncertainty (e.g. in climate change projections), full quantification is rarely possible. This is particularly true for impacts and adaptation studies, which typically involve multiple steps, each introducing uncertainties that are propagated through the study (i.e. cascading uncertainties). Uncertainties related to socioeconomic factors, which influence both future emission pathways and adaptive capacity, are especially difficult to assess (Manning et al., 2004). These uncertainties make it challenging to reach strong conclusions on the likelihood of an outcome being realized, or to determine the confidence that should be associated with a particular statement.

Many science assessments, including the Arctic Climate Impact Assessment (ACIA) and those of the Intergovernmental Panel on Climate Change (IPCC), adopt a probability-based nomenclature for expressing likelihood and/or confidence. Assignment of a particular term (e.g. likely, very likely) is based upon expert evaluation of the volume and agreement of the scientific literature, drawing from multiple lines of evidence that include observed trends, experiments, model simulations and theory (Huntington et al., 2005b).

For this assessment, it was deemed neither practical nor meaningful to adopt a probability-based terminology. When undertaking analysis at the regional or sub-regional level, the generally small volume of information available on any specific topic dictates that statements of likelihood and confidence will dominantly reflect expert judgement, and are necessarily qualitative. Authors were encouraged to focus on communicating both the likelihood and confidence of their conclusions using common-sense language rather than prescribed expressions. Authors were generally able to express greater confidence when the quantity and quality of research available on the issue was high. Expressions of likelihood are strongest where projections are consistent with historical trends and/or well-established climate-system relationships, and supported by independent modelling analysis.

5.3 USE OF SCENARIOS

Climate Scenarios

This assessment does not focus on any particular climate scenario or set of scenarios in the discussion of future climate change. As an integration and analysis of previous studies that took different approaches to the issue of climate scenarios and related assumptions, it tries to place the results of those studies in the context of a complete range of plausible climate futures.

Each regional chapter includes a section describing projected climate change for the region, which have been derived from climate change experiments undertaken with seven global climate models (GCMs), using an illustrative scenario from each of the six emissions scenario groups in the *Special Report on Emissions Scenarios* (SRES). These were the most recent scenarios available at the start of this assessment process (2005), and have been constructed in accordance with the recommendations of the IPCC Task Group on Data and Scenario Support for Impact and Climate Assessment (IPCC-TGICA). The GCMs selected for use conform to this group's recommendations, and the scenarios indicate the climate changes (with respect to 1961–1990) for the 2020s, 2050s and 2080s, the three future time periods recommended for study. Scenario results were provided to the authors of each chapter as scatterplots, maps and box-and-whisker plots (Appendix 1). The decision regarding which of these graphic formats appear in the published chapters was left to the lead authors. Some chapters present additional climate scenario information, in which case the models and emission scenarios used are specified.

Socioeconomic Scenarios

Long-term socioeconomic scenarios suitable for climate change impacts and adaptation studies do not exist for all regions of Canada. As a result, authors of each chapter were encouraged to use whatever relevant data was available. Extensive data on demographic and socioeconomic historical trends are available from Statistics Canada at various scales (e.g. national, provincial, census metropolitan area). Examples of trends of relevance to vulnerability assessment include rural to urban migration, changing age distributions, and trends in income level and gross domestic product (*see* http://www41.statcan.ca/ceb_r000_e.htm). Statistics Canada also provides projections of future population totals and age distributions by sex for the years 2011, 2016, 2021, 2026 and 2031. Other sources of socioeconomic data are referenced in individual chapters of this assessment.

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APPENDIX 1

GRAPHICAL PRESENTATION OF CLIMATE SCENARIOS

Scatterplots (Figure A-1)

The scatterplots provide a quick visual summary of changes in mean temperature and precipitation averaged over the study region. The number of grid boxes contained within an individual chapter region is GCM-dependent, since the spatial resolution varies between climate models. Each coloured symbol represents a different climate change scenario, identified in the associated legend. Also illustrated on the scatterplots are grey squares that indicate the representation of 'natural' climate variability by the second-generation coupled global climate model (CGCM2) of the Canadian Centre for Climate Modelling and Analysis. This has been derived from a long control run undertaken with this GCM in which there is no change in forcing over time.

Where there is overlap between the coloured symbols and the grey boxes, the scenarios concerned lie within the range of 'natural' climate variability. No overlap indicates that the scenarios lie outside of this range and potentially represent conditions that have not previously been experienced.

The blue lines on the scatterplot represent median changes in mean temperature and precipitation, derived from the suite of climate change scenarios illustrated on the scatterplot. These lines effectively divide the plot into four quadrants, allowing the identification of those scenarios that exhibit cooler, warmer, drier or wetter conditions than are indicated by the majority of scenarios. Thus, it also provides a means of identifying those scenarios that exhibit the most 'extreme' changes.

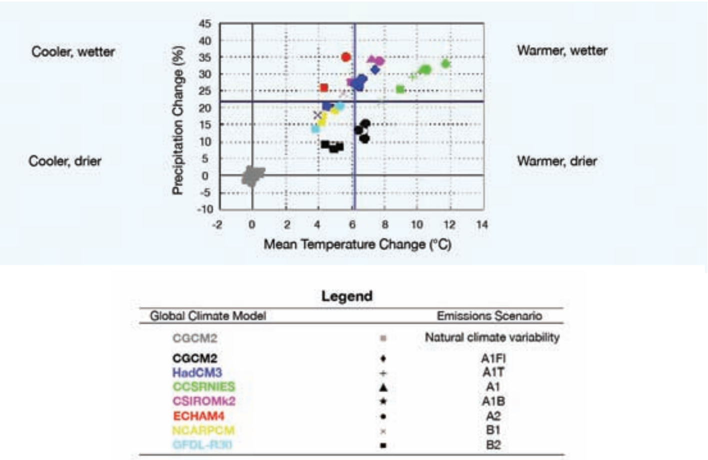

FIGURE A-1: Example of a scatterplot and the legend for the scatterplots presented in this report. The colours represent the global climate model, and the symbols represent the emissions scenarios.

Scenario Maps (Figure A-2)

The scenario maps summarize all the GCM-derived scenarios of climate change illustrated on the scatterplots. All scenarios have been interpolated onto the CGCM2 grid and then the minimum, median and maximum changes have been calculated and plotted. Hence, the values in each grid box are not necessarily from the same scenario.

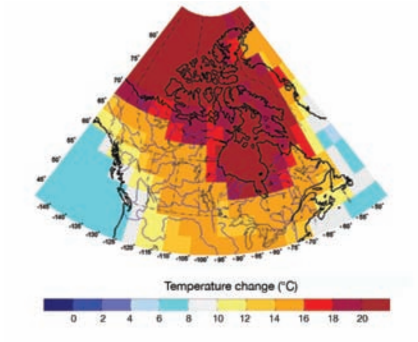

FIGURE A-2: Example of a scenario map for an ensemble scenario. This is the maximum annual temperature change projected for Canada by the 2080s.

Box-and-Whisker Plots (Figure A-3)

A box-and-whisker plot is a means of providing summary information about a data sample. The box has lines at the lower quartile, median and upper quartile values, and the whiskers are lines extending from each end of the box to show the extent of the rest of the data. The box represents the central 50% of the data sample. The whiskers indicate the maximum and minimum data values if there is a dot located on the lower whisker. If there are outliers in the data, indicated by '+' symbols, then the whisker length is 1.5 times the interquartile range. The box-and-whisker plot illustrated in Figure A-3 indicates that, for the 2050s and 2080s, the whiskers represent the maximum and minimum data values. For the 2020s there is an outlier at the upper end of the data values, indicated by the '+' symbol. In this case, the whisker represents 1.5 times the interquartile range.

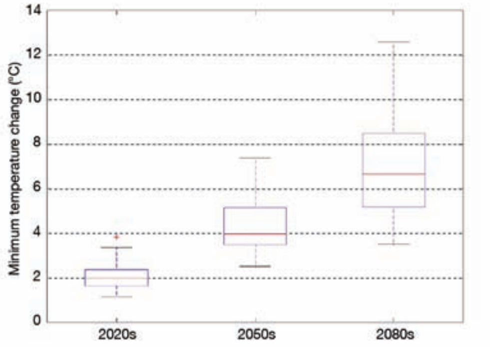

FIGURE A-3: Example of a box-and-whisker plot.