Hard Choices: Climate Change in Canada

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Introduction

Jan Zwicky

WEATHER. WHEN I WAS A KID on the farm in Alberta, everything depended on it: what you put on in the morning and what you ate for breakfast; what you did at any given hour of the day and whom you did it with; my grandfather's, my mother's, and my own mood. And we talked about it constantly—"Did you notice? Clouding over in the west," "If it clears off now, she'll freeze," "It's already over 70° (in those days we still used Fahrenheit), gonna be a scorcher"—the hourly, sometimes minute-by-minute, warp on which our lives were strung. Much later in my life, my job often had me on the road late at night between Saint John and Fredericton. To keep myself awake, I listened to the radio. My favourite part was always the late-night marine forecast: although I'd never been in a fishing boat in my life, nor seen the straits, banks, and fans the reports named, there, alone in the dark on a New Brunswick highway, I felt profoundly at home—connected, through the significance of weather, to a life like my own.

Before the move to the Maritimes, I'd spent several years in southwestern Ontario, a region renowned for its muggy summer heat and slow-witted thunderstorms. One July afternoon in 1988, I was hanging out a load of laundry. It had been hot for days, temperature parked in the thirties, but around noon a breeze had sprung up and I figured we were in for a change. It was, in fact, downright windy by the time I got the clothes to the line—but, to my surprise, there wasn't a cloud in sight. There was a haze on the horizon, but I realized it was dust. As I pegged, struggling with the shirts and towels as they jerked in the wind, I was overcome with unease.

everything that is. But me, I'm with Herakleitos: "The things of which there is seeing, hearing, and perception, these do I prefer" (Diels, 1934, Fr. 55). I would be the last to deny the power of universal, atemporal being; it's just that because I'm human—that is, because I love and die—it's only half the story. "Nameless:" says the *Tao Te Ching*, "the origin of heaven and earth./ Naming: the mother of ten thousand things" (1993, chap. 1). Those ten thousand things are the other half of the story. They are the manifestations through which the mystery flows, without which it would be invisible, of which we are one. We hope because, quite apart from the philosophers, we have good reason to believe that beauty will be here: there will be trees and grass and rivers and, unless we are staggeringly stupid, a few humans around to appreciate them. We grieve because we also have reason to believe that this beauty—at least some among these copses, these grasslands, these shorelines—will not survive. That is what this book is about: the grounds for that hope, and that grief.

Notes

1 Herriot compares reports of three early European visitors to the region, noting differences in rhetorical style which may also have influenced the Canadian government's decision to promote European colonization. The three accounts in question are to be found in Palliser (1859), Hind (1971), and Macoun (1882).

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Part I

What's [Going to] Happen[ing]?

The Science of Climate Change

Andrew J. Weaver

Introduction

In January 2001, the United Nations Intergovernmental Panel on Climate Change (IPCC) released a report stating that there is now new and stronger evidence that most of the climate warming observed over the last 50 years is attributable to human activities. This powerful statement by the world's leading climate scientists sends a strong signal to governments that informed policy is urgently needed to determine a course of action for the future. To set this target, researchers must reduce uncertainty in climate projections and quantify the socio-economic impacts of climate change. They must also develop the policies and mitigation technologies that will most effectively achieve the appropriate levels of net greenhouse gas emissions and develop the adaptation strategies that will respond to the consequences resulting from those choices.

This chapter presents a review of the science of climate change, starting with a discussion of the 200-year history of the science leading up to our present-day understanding of global warming. Since much of the observational evidence and many future projections of climate change are derived from the IPCC Third Assessment Report, a brief review of the history behind the formation of the IPCC is given before this chapter turns to climate change detection and attribution: the search for an anthropogenic (human-induced) warming signature above a background of natural variability. A summary is given in section 7 and concluding remarks offered in section 8.

A common public misconception is that the IPCC working groups undertake their own independent research. This is not the case: they only provide an assessment of the peer reviewed literature, although they make reference to published technical reports. IPCC does not consider Web sites, or newspaper opinion pieces or editorials to have passed the standards set by the peer-review system, and so will not include these in the assessments.

There have now been three formal IPCC Assessments of Climate Change. The first, in 1990, led to the creation of the Intergovernmental Negotiating Committee for a UN Framework Convention on Climate Change by the UN General Assembly. The second assessment, in 1996, was formally used in the negotiations leading up to the adoption of the Kyoto Protocol to the UN Framework Convention on Climate Change at the Third Conference of Parties in 1997. The Kyoto Protocol requires Canadian greenhouse gas emissions to be 6% below 1990 levels in the period spanning 2008–2012. The third IPCC assessment was completed in 2001, and the fourth assessment will be completed in 2007.

While the IPCC assessments ultimately enter the political arena, the actual writing of the assessment itself is free from political interference. In the third assessment, for example, 120 of the world's leading climate scientists wrote the WGI document, with contributions from over 500 other climate scientists. The content of an individual chapter was chosen exclusively by the lead authors of that chapter, in consultation with the lead authors of other chapters (to ensure that there was no duplication). The final report underwent review three times by more than 300 experts in the field. This review process included an informal review by all lead authors; a review; by experts in the field; an additional expert review and government review. The third draft of the document was put together after the IPCC meeting in Victoria, British Columbia, and was sent to United Nations member states for approval in Shanghai in January 2001. Final changes were made to the "Summary for Policy-makers" in Shanghai as a consequence of feedback from UN member states.

As noted above, the formal charge of WGI is the assessment of available information on the science of climate change and on its association with human activities. More specifically,

> In performing its assessments WGI is concerned with: developments in the scientific understanding of past and present climate, of climate variability, of climate predictability and of climate change including feedbacks from climate impacts; progress in the modelling and projection of global and regional climate and sea level

> change; observations of climate, including past climates, and assessment of trends and anomalies; gaps and uncertainties in current knowledge. (IPCC—WGI, n.d)

In what follows, I will draw heavily from the assessment that arose from this IPCC WGI process. In particular, I will focus on the key findings of chapter 2, "Observed climate variability and change," in the next section. Then I will highlight the most important aspects of chapter 9, "Projections of future climate change," and chapter 12, "Detection of climate change and attribution of causes," respectively.

Observational Evidence of Climate Change

Radiative forcing of climate

The Earth is said to be in a global radiative equilibrium if the total amount of energy received from the sun, averaged over a few decades, equals the total amount of energy emitted by the earth to space. A change in the average net (incoming minus outgoing) radiation at the top of the atmosphere is defined as a *radiative forcing*. A positive radiative forcing acts to warm the Earth's surface, while a negative radiative forcing acts to cool it. That is, a radiative forcing is a disturbance in the balance between incoming and outgoing radiation, and, over time, the climate system (fig. 2.2) responds to try and re-establish global radiative equilibrium.

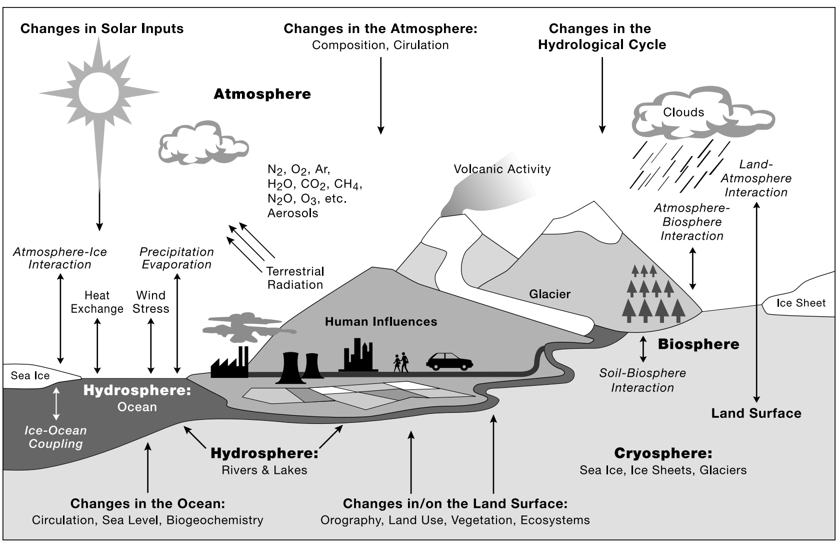


Figure 2.2. Schematic representation of the climate system *Source*: IPCC, 2001.

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are examples of greenhouse gases whose increase over the last 150 years has created a positive radiative forcing (fig. 2.3). Aerosols, which are tiny liquid or solid particles in the atmosphere, are most often considered to provide a negative radiative forcing (e.g., sulphate aerosols released in the combustion of coal). These and other aerosols affect the radiation balance of the Earth by both directly scattering incoming radiation back to space and indirectly affecting the formation, lifetime, and properties of clouds.

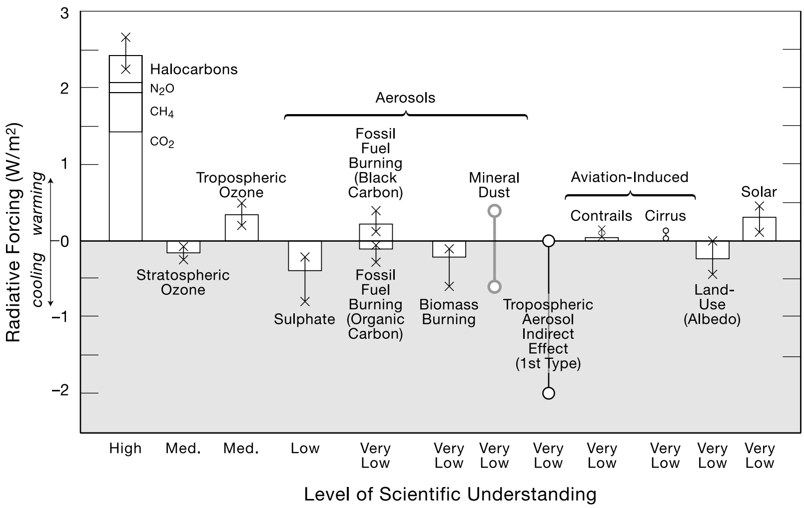


Figure 2.3. Global and Annual-Mean Radiative Forcing (W/m²) for Various Agents from Pre-industrial Times (1750) to the Present (late 1990s)

The height of the rectangular bar denotes a best-estimate value, while its absence denotes that no best estimate is possible. The vertical line about the rectangular bar with "×" delimiters indicates an estimate of the uncertainty range, for the most part guided by the spread in the published values of the forcing. A vertical line without a rectangular bar and with "0" delimiters denotes a forcing for which no central estimate can be given owing to large uncertainties. A "Level of Scientific Understanding" index is accorded to each forcing, with high, medium, low, and very low levels. This represents the subjective judgment about the reliability of the forcing estimate. The well-mixed greenhouse gases (e.g., carbon dioxide, methane, and nitrous oxide) are grouped together into a single rectangular bar. The sign of the effects due to mineral dust is itself uncertain. The indirect forcing due to tropospheric aerosols as well as the forcing due to aviation via their effects on contrails and cirrus clouds, is poorly understood. The forcing associated with stratospheric aerosols from volcanic eruptions is highly variable over the period and is not considered for this plot. It is emphasized that the positive and negative global-mean forcings cannot be added up and viewed a priori as providing offsets in terms of the complete global climate impact. *Source*: IPCC, 2001.

snow, and sea ice. Change is much smaller over the oceans than over land, and hence around Antarctica relative to the Arctic, due to the high heat capacity of the surrounding ocean. A warmer atmosphere holds more moisture so cloud coverage should increase, leading to a reduction in the diurnal temperature range. The hydrological cycle should also intensify, leading to enhanced precipitation at mid-to-high latitudes, with more extreme events and enhanced evaporation at low latitudes.

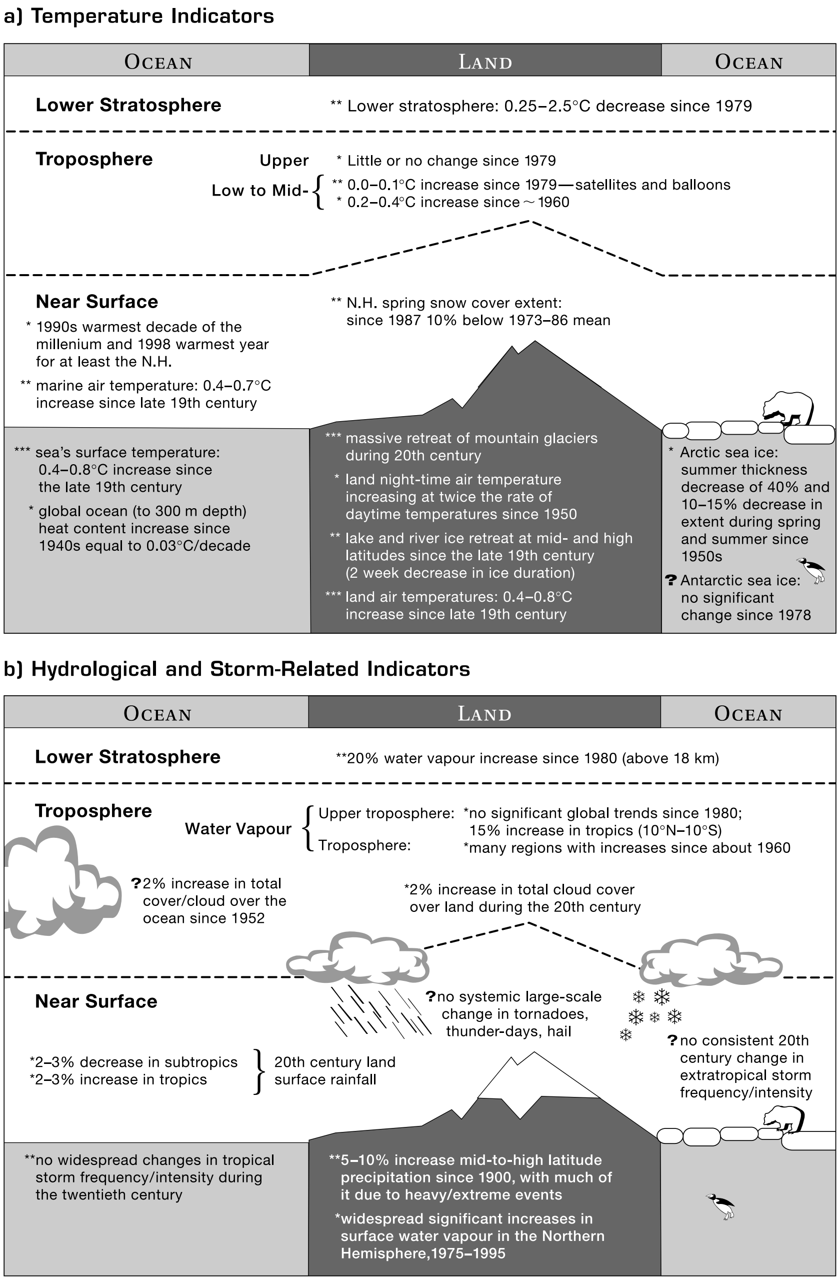
Figure 2.8 is particularly useful for comparison with Figure 2.15 (next section), which summarizes what a variety of coupled atmosphere–ocean general circulation models (GCMs) project for a future climate warmed through an increase in greenhouse gases. It will be evident that what has already occurred is consistent with what models suggest should have occurred, and also what these same models project will occur more noticeably in the future.

Projections of Climate Change with Applications to Canada

Coupled atmosphere–ocean GCMs have evolved considerably over the years and are continually being further improved, both in terms of resolution and through the inclusion of new, sophisticated, physical parametrisations. These models consist of an atmospheric component, developed through decades of research in numerical weather prediction around the world, coupled to interactive ocean and sea ice models. All GCMs include a land surface scheme, and some now allow the terrestrial vegetation to respond to a changing climate. Climate models are not used to predict weather but rather the slow mean change of average weather and its statistics. They are built on the physical principles that we believe govern the various components of the climate system. Before a climate model is deemed useful for future climate projections, it must be satisfactorily tested against the present-day and transient twentieth-century climate. GCM simulations of past climates (e.g., 6,000 and 21,000 years ago) are also used to evaluate a model's performance against paleo reconstructions. Model deficiencies found through this evaluation process are documented, and attempts are then made to reduce or eliminate them.

Scenarios of future emissions

Any projection of future climate change fundamentally requires assumptions about future emissions of greenhouse gases and aerosols. These in turn are determined by making assumptions about future economic and population growth, technological change, energy use, etc. Clearly, it is



Likelihood { *** Virtually certain (probability > 99%) ** Very likely (probability > 90% but ≤ 99%) * Likely (probability > 66% but < 90%) ? Medium likelihood (probability 33% but ≤ 66%)

Figure 2.8. Schematic Diagram of Observed Variations:

in a) Temperature; b) Hydrological and Storm-Related Indicators. *Source*: IPCC, 2001.

run their GCMs under a select number of these scenarios. The climate sensitivity (defined as the equilibrium warming for a doubling of atmospheric CO_2) and oceanic heat uptake, obtained from the coupled models, can also be used in simpler models to span the full range of scenarios and produce estimates of first-order quantities like global sea-level rise and surface air temperature changes over the next century. These simple models, however, do not allow projections of regional changes in climate.

Projections of future temperature change from simple models

As an initial illustration of the projected global mean surface temperature change over the twenty-first century, we provide Figure 2.10, derived from a simple climate model that uses the climate sensitivity and oceanic heat uptake from more complex models. Using the range of climate sensitivities from coupled GCMs and all emissions scenarios, we arrive at a range of projected 2100 warming, relative to 1990, of 1.4–5.8° C. This range, reported in the IPCC Third Assessment Report, is higher than the 1.0–3.5° C range

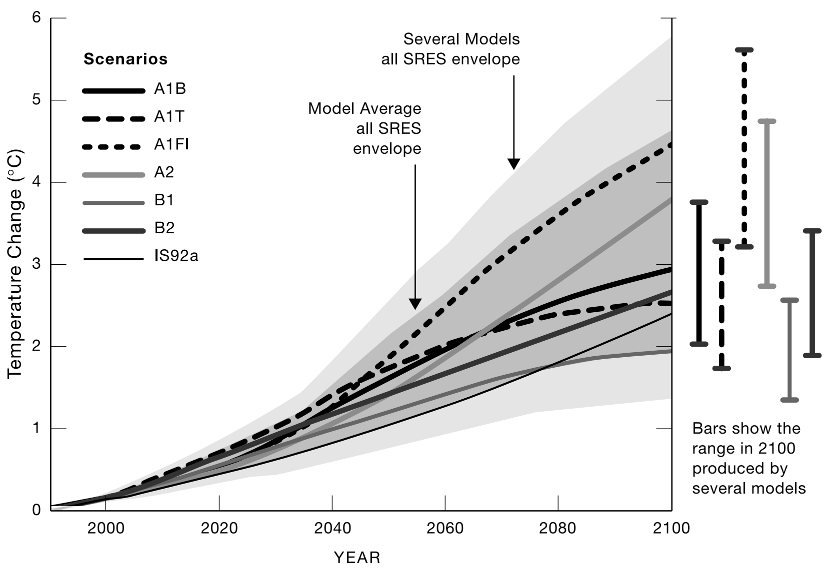


Figure 2.10. Simple Model Projected Global and Annual Mean Temperature Change Relative to 1990 under a Wide Range of Scenarios

The dark shading gives the range using all scenarios and the average model climate sensitivity. The light shading extends this range by calculating the spread from each model independently. Note that in all cases, warming is projected, even though in B1 emissions of CO_2 and CH_4 are assumed to drop substantially below 1990 levels (fig. 2.9). *Source*: IPCC, 2001.

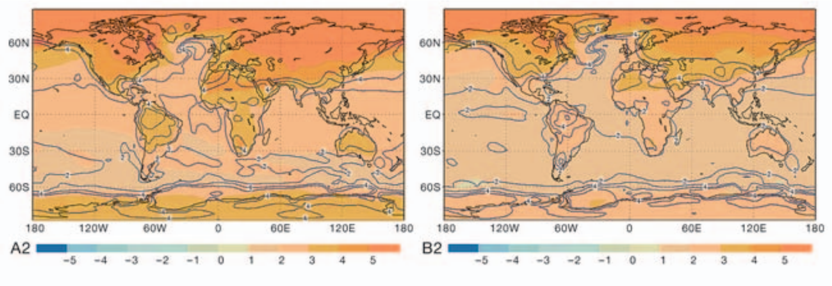


Figure 2.11. The Annual Mean Temperature Change (coloured shading) and Intermodel Range (contour lines) between the 2071–2100 and 1961–1990 Average Climates

Coupled atmosphere-ocean GCMs were driven by either Scenario A2 (left); or scenario B2 (right). All units are in °C. *Source*: IPCC, 2001.

latitudes tends to warm less than the east coast because the prevailing winds are from west to east and thus the west coast is more influenced by the ocean. Fourth, the high latitudes warm more than the lower latitudes due to powerful albedo feedbacks associated with retreating snow and sea ice. As noted above, the retreat of sea ice results in an additional positive feedback since the ocean is no longer insulated from the atmosphere and so can warm it from below. Fifth, the northern hemisphere warms more than the southern hemisphere as there is more land there.

Enhanced warming is also projected in the winter months relative to the summer months, as indicated in Figure 2.12 for the Canadian Centre for Climate Modelling and Analysis model integrated under the IS92a scenario. This particular simulation also reveals local cooling around the North

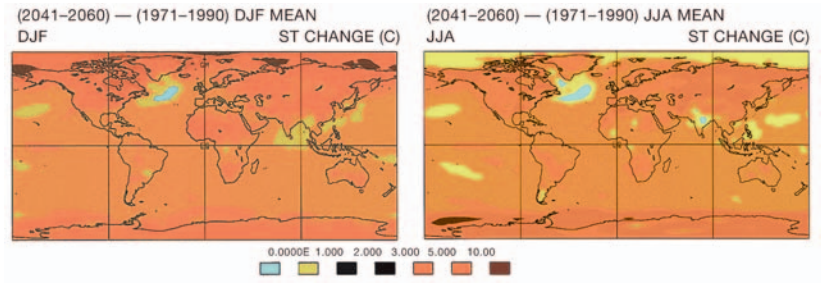


Figure 2.12. Mean Temperature Change between the Average Seasonal Climate in 2041–2060 and 1971–1990 under an IS92 Scenario

Left: Winter: December, January, February; Right: Summer: June, July, August. All units are in °C. *Source*: Dr. G. Flato, Canadian Centre for Climate Modelling and Analysis in Victoria, British Columbia.

Atlantic due to a weakening of the North Atlantic conveyor and subsequent reduction in northward ocean heat transport there. Figure 2.12 also shows other regions of little warming, or even slight cooling, around India and southeast Asia due to concentrated industrial activity and the local cooling effects associated with anthropogenic tropospheric aerosols.

Extreme events and the possibility of surprises

Extreme events

Extreme weather or climate events are important from a policy perspective as they cause the most stress on adaptation strategies for climate change. Adaptation strategies aimed exclusively at dealing with a slow mean change in climate could be ineffective if they do not also account for projected changes in climate and weather statistics associated with the projected mean climate change. In its Third Assessment Report, the IPCC undertook a systematic analysis of observed changes in extreme weather and climate events over the twentieth century and their projected change over the twenty-first century (summarized in Table 2.1, opposite).

Abrupt climate change

Rapid transitions between fundamentally different climate regimes have commonly occurred over the last 400,000 years (fig. 2.1; see Clark et al., 2002 for a review), inspiring scientists to try and grapple with their possible likelihood of future occurrence. Two specific climate change surprises have been given special attention. The first involves trying to determine the probability of a collapse of the West Antarctic ice sheet—an event that would lead to a 6-metre global sea-level rise over a relatively short period of time. The second involves assessing the likelihood of a complete shutdown of the North Atlantic conveyor—if this were to transpire, the global oceanic deep circulation would be reorganized and the amount of heat transported northward in the North Atlantic by the ocean would be substantially reduced; this would tend to affect the climate over land downwind of the ocean (i.e., Europe). In its Third Assessment Report (IPCC, 2001), the IPCC concluded that the collapse of the West Antarctic ice sheet was very unlikely (1–10% chance) to occur over the twenty-first century and noted that it was too early to determine whether an irreversible change in the conveyor is likely or not over this same period.

Most, but not all, coupled model projections of the twenty-first-century climate show a reduction in the strength of the North Atlantic conveyor with increasing concentrations of greenhouse gases (IPCC, 2001). Nevertheless, all coupled model simulations show that Europe continues to warm even in those simulations where the conveyor slows down. In those

Table 2.1 Estimates of Confidence in Observed and Projected Changes in Extreme Weather and Climate Events

Confidence in Observed Changes (latter half of the 20th century)	**Changes in Phenomenon**	**Confidence in Projected Changes (during the 21st century)**
Likely	Higher maximum temperatures and more hot days over nearly all land areas	Very Likely
Very Likely	Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very Likely
Very Likely	Reduced diurnal temperature range over most land areas	Very Likely
Likely, over many areas	Increase of heat index (a measure of human discomfort) over land areas	Very Likely, over most areas
Likely, over many northern hemisphere mid- to high latitude land areas	More intense precipitation events	Very Likely, over many areas
Likely, in a few areas	Increased summer continental drying and associated risk of drought	Likely, over most mid-latitude continental interiors (lack of consistent projections in other areas)
Not observed in the few analyses available	Increase in tropical cyclone peak wind intensities	Likely, over some areas
Insufficient data for assessment	Increase in tropical cyclone mean and peak precipitation intensities	Likely, over some areas

Source: IPCC, 2001.

Note: Virtually certain (> 99% chance that a result is true);
Very Likely (90–99% chance);
Likely (60–90% chance);
Medium Likelihood (33–66% chance);
Unlikely (10–33% chance);
Very Unlikely (1–10% chance);
Exceptionally Unlikely (< 1% chance).

simulations where the conveyor reduces in the short term, the ocean acts as a negative feedback to high latitude warming. A reducing conveyor reduces high latitude ocean heat transport and hence sea surface temperatures. This affects atmospheric surface temperatures directly and also affects them indirectly through feedbacks on ice areal extent. Over the longer term, most climate models find a re-establishment of the conveyor to present-day levels: during this re-establishment phase, the ocean conveyor would act as a positive feedback to warming in and around the North Atlantic. What is even less known, and still an outstanding question, is how the stability of the conveyor will change in a future climate warmed through anthropogenic greenhouse gases.

Projected climate change and Canada

Chapter 10 of the IPCC Third Assessment was charged with assessing regional climate information both in terms of the evaluation of regional climates and the projection of regional climate change. This chapter formally showed that the warming found in several coupled atmosphere–ocean GCMs driven by two illustrative scenarios (A2 and B2; see figs. 2.9 and 2.11), was 40% above the global average in the winter months at high northern latitudes (see fig. 2.13). The eastern North American (ENA), central North American (CNA), and western North American (WNA) regions, which include most of southern Canada, showed greater than average warming both in summer and winter in both the A2 and B2 scenarios. For the eastern Arctic/Greenland (GRL) region, which includes some of northern Canada, greater than average warming in the summer and much greater than average warming in the winter months are projected. The 1.4–5.8°C globally averaged warming projected by 2100 should be considered to be amplified over most of Canada (see figs. 2.11 and 2.12).

Similarly, there is intermodel agreement that the GRL and Alaskan (ALA) regions, which include much of northern Canada and all of the Canadian Arctic, will receive at least a 5%–20% increase in precipitation in summer and winter by the year 2071–2100 (fig. 2.14). Under the A2 scenario (figs. 2.9 and 2.11) greater than 20% increases are projected for these regions. Increases of 5%–20% in precipitation by 2071–2100 in the winter are projected for both the WNA and ENA regions, although in the summer as well as in the CNA region, intermodel differences are of inconsistent sign. The impact of these projected changes in regional precipitation will be discussed further in chapter 4.

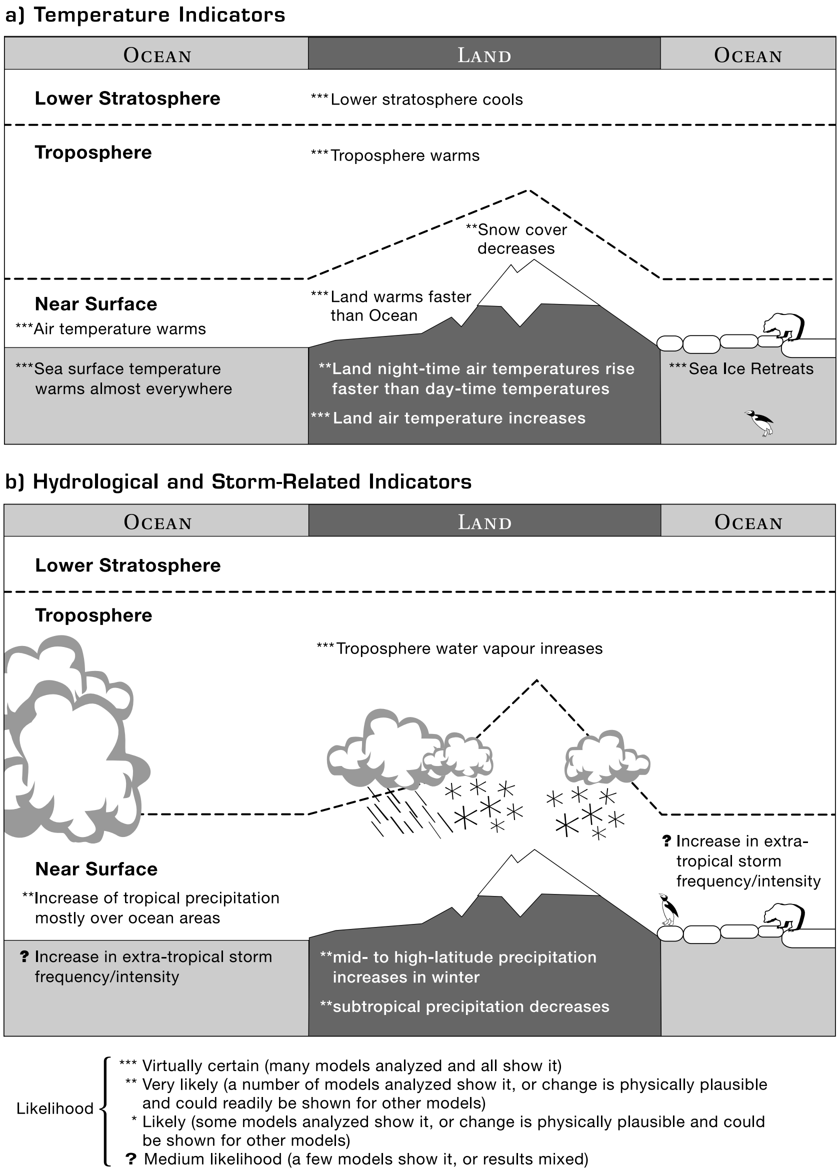


Figure 2.15. Schematic Diagram of Variations in a) Temperature; b) Hydrological and Storm-Related Indicators

Source: IPCC, 2001.

ocean solubility pump will be able to draw down. Nevertheless, uncertainties in natural carbon cycle feedbacks are large and are only just beginning to be examined by the scientific community.

Much as the Kyoto Protocol requires countries to consider the implications of their greenhouse gas emissions beyond their immediate national borders, reducing the uncertainties in the science of global warming requires scientists to transcend traditional disciplinary boundaries to meet the challenges raised in this chapter. Meeting these challenges will create new scientific opportunities, and from these opportunities we will determine what is an acceptable level of future change.

Notes

1 For example, in Global Warming: The Clouds Thicken, by Peter Foster, *National Post*, 19 August 2000; Global Warming Fears Cool Off. Why Impose Questionable Constraints on Economic Growth, by Peter Holle, *Winnipeg Free Press*, 27 January 2001.
2 For example: US National Academy of Sciences, National Research Council, *CO_2 and Climate: A Scientific Assessment* (1979) and *Changing Climate* (1983).
3 The albedo of a surface is defined as the percentage of incoming solar radiation hitting the surface that is reflected back to space.
4 *Hot, Hot Is the Range,* by Margaret Munro, 23 January 2001.
5 *Pace of Global Warming "Could Double,"* by Charles Clover, 25 January 2001.

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The Human Challenges of Climate Change

Steve Lonergan

Introduction

THE RAPIDLY CHANGING CLIMATE detailed by Andrew Weaver in the previous chapter has been the result of a broader human transformation of the natural environment. The human causes of this transformation are varied and have as much to do with institutional and cultural norms and practices as with economic and social ones. In this chapter on the human challenges of climate change, I introduce two types of activities that are primarily responsible for this transformation: (1) changing land use; and (2) increased fossil fuel consumption. Subsequently, I review the potential human consequences of climate change and outline the response options that have been developed and/or discussed to either mitigate the causes or adapt to the consequences. The remainder of the chapter discusses the social processes and driving forces that represent the true human challenges of dealing with climate change, with specific emphasis on equity, and offers some options for the future.

It is clear that the causes of climate change, the consequences, and the options for response vary widely over space. To date, developed countries have been largely responsible for the increase in atmospheric concentrations of carbon dioxide (CO_2). Since 1950, five countries (US, Russia, Germany, Japan, and the UK) account for well over 50% of the total CO_2 emissions globally (ORNL, 2001; Table 3.1). The US alone contributed almost 30% of the total emissions from fossil fuel combustion. Canada's contribution to total global emissions of CO_2 was only 2.1% in 1996, but it also exhibits one of the largest per capita emission levels in the Organization for Economic and Co-operative Development (OECD), behind only the US and

Australia (see fig. 3.1). Immediately, this brings into question issues of equity in dealing with the consequences of climate change and developing appropriate response options.

Table 3.1. Cumulative Emissions of CO_2 since 1950, Top 12 Countries

Country	**Cumulative CO_2 Emissions, 1950–1995 (1000 tonnes)**	**% of Total Emissions (since 1950)**
United States	180,245,575	27.31
Russia	66,694,682	10.11
China	54,030,802	8.19
Germany	41,784,828	6.33
Japan	29,736,951	4.51
United Kingdom	26,666,955	4.04
Ukraine	20,934,158	3.17
France	16,443,057	2.49
India	14,507,388	2.20
Canada	14,467,674	2.19
Poland	14,009,231	2.12
Italy	11,924,026	1.81

Source: ORNL, 2001.

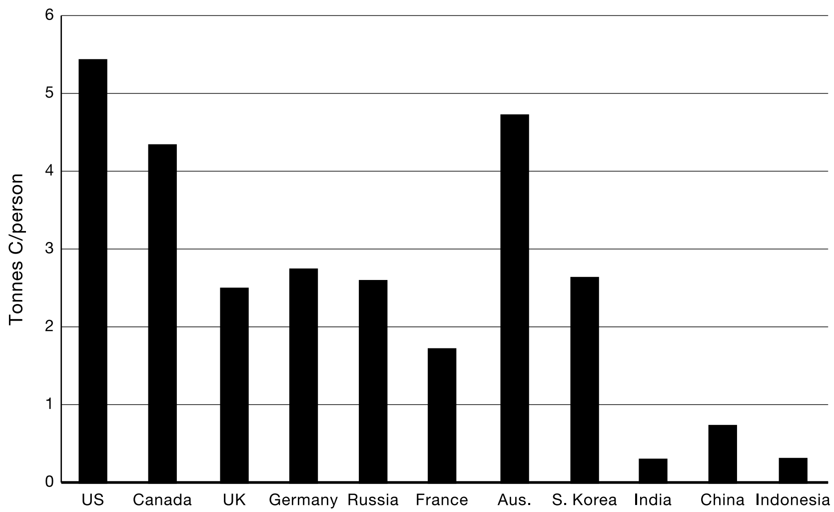

Figure 3.1. Per Capita Emissions of Carbon, 1998 (selected countries)

Source: ORNL, 2001.

While emissions of CO_2 and other greenhouse gases vary widely from country to country, so do the consequences of climate change. Developed countries may experience changes in water supply, biodiversity, and crop production, but the countries least able to accommodate a changing climate are the poorest countries of the South. The most recent report from the Intergovernmental Panel on Climate Change (IPCC) is very clear: "The impacts of climate change will fall disproportionately upon developing countries and the poor persons within all countries, and thereby exacerbate inequities in health status and access to adequate food, clean water, and other resources" (2001, p. 7). Poor economic conditions make these people and their communities vulnerable to any type of environmental disruption, and their ability to respond—part of their vulnerability—is extremely limited. The human challenges of climate change are closely tied to the inequitable distribution of causes, consequences, and response options available. Like the issue of sustainable development, equity is a key principle, and much of this book addresses this issue.

What Are the Major Human Causes of Climate Change?

Land use and land-cover change

The role of human activities in changing the land cover is central to the study of environmental change. Almost 20% of the world's forests have been converted to cropland and pastureland over the past 300 years (Richards, 1990). The alteration of the land cover and changes in the way land is used affect the biogeochemical cycles of the Earth, the level of atmospheric greenhouse gases, and other land surface characteristics (see Table 3.2).

Table 3.2 Changes in Land Cover, Globally, 1700–1980

Land Cover Type	Area in 1700 (millions of hectares)	Area in 1980 (millions of hectares)
Forest and Woodlands	6,215	5,053
Grassland and Pasture	6,860	6,788
Croplands	265	1,501

Source: Richards, 1990; National Research Council, 1999.

Changes in land cover are primarily the result of human use (Allen and Barnes, 1985; Turner et al., 1990). Human use of the land involves both the ways in which land is manipulated, and the intent underlying that nomic, technological, and social systems as well as to the institutional context that is presently being developed. Growth in energy consumption and CO_2 emissions is expected to be particularly rapid in China and South Asia, due to industrial expansion, population growth and urbanization, and increased per capita incomes. Exacerbating the problem is the fact that coal, which produces the highest CO_2 emissions of any fossil fuel, is the major source of electricity for China (70%) and South Asia (60%), and electricity demand in these regions is rising at close to 7% per year.

For some countries, such as Canada, the link between CO_2 emissions and economic growth was slightly "decoupled" during the late 1970s and early 1980s. Because of technological change, less carbon is emitted per dollar of economic output than was the case 40 years ago (from 1.2 tonnes of $CO_2/\$10^6$ of output in 1958 to approximately $0.8/\$10^6$ in 1998). Figure 3.2 shows the growth in CO_2 emissions along with the growth of the national economy. Before 1978, CO_2 emissions grew steadily with (and even more rapidly than) economic output. Over the succeeding 8 years, the relationship between emissions and GDP appears to have weakened (or been "decoupled"); but the past 15 years have seen a "recoupling" of CO_2 emissions and GDP, highlighting the difficulty Canada faces in reducing greenhouse gas emissions and maintaining economic growth. As well, the absolute level of CO_2 emissions continues to rise, despite the country's

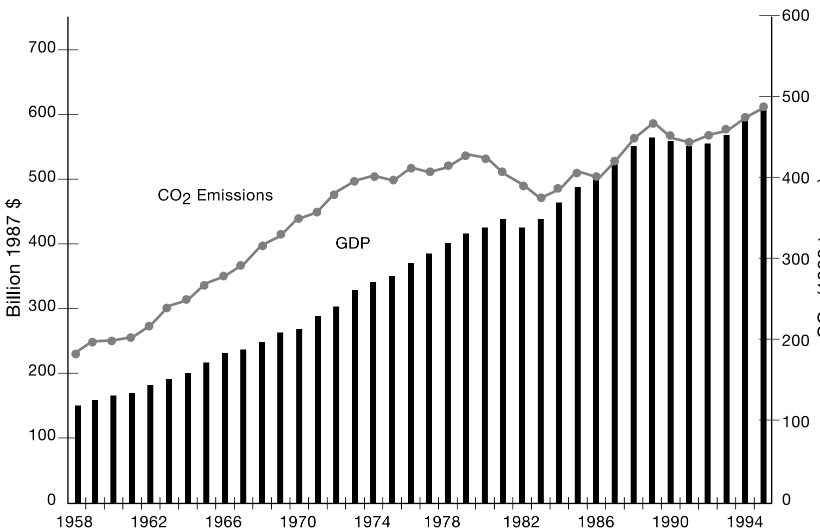

Figure 3.2. CO_2 Emissions and GDP for Canada, 1958–1995

Source: ORNL, 2001; Statistics Canada.

commitment under the Kyoto Protocol to decrease emissions by 6% (from 1990 levels) by the year 2012. One of the major human challenges of climate change will be to "decarbonize" the global economy, starting with developed countries. In other words, we need to find a way to maintain a reasonable level of global economic output while reducing our level of fossil-fuel energy consumption.

Canada signed the Kyoto Protocol in 1997 and ratified it in 2002, thereby agreeing to reduce its CO_2 emissions by 6% of 1990 levels. However, CO_2 emissions were 13.5% higher in 1998 than in 1990 (Environment Canada, 2000), and they continue to rise.

At present, two sectors in Canada account for more than half of the greenhouse gases: transportation and power generation (see fig. 3.3). Industry accounts for an additional 15% of emissions. Any attempt to reduce Canada's emissions will have to focus on these three sectors. However, meeting Canada's commitments to reduce greenhouse gas emissions through a reduction in domestic emissions is not politically palatable. Most Canadian reductions will occur by paying for efficiency improvements in other countries, through mechanisms incorporated into the Kyoto Protocol.

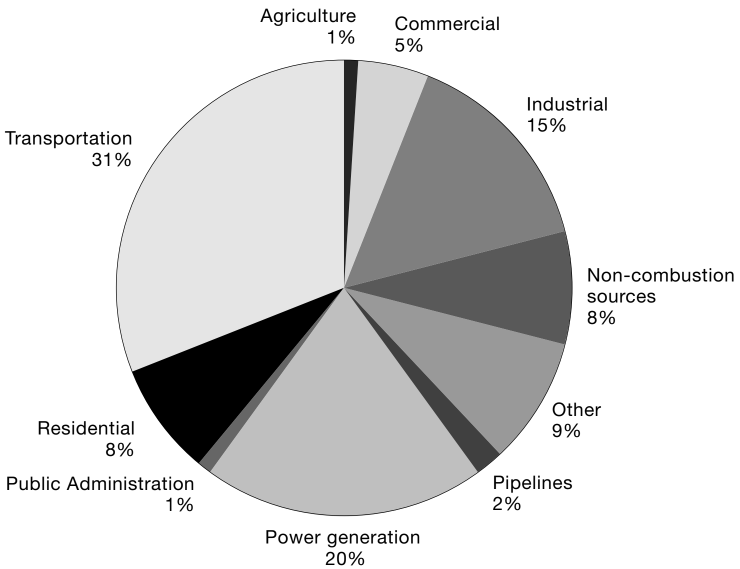

Figure 3.3. CO_2 Emissions in Canada, 1995, by Sector

Source: Environment Canada, 1998.

What Are the Human Consequences of Climate Change?

Introduction

A recent report by the Royal Society of Canada concluded that the greatest impacts of climate change on Canada would likely be on boreal forests (see chap. 5), water supplies, coastal ecosystems, and human health (Royal Society, 2001). Some of the problems include increased fire and pest outbreaks in our boreal forests, higher heat wave mortality in major cities, melting of large areas of permafrost, and disruptions in water supply in the Great Lakes and the Prairies. In the discussion below, I highlight impacts in four areas: human security, health, water resources, and food systems.

Human security

Resource scarcity and environmental degradation create inequities (or the perception of inequities) in resource distribution that often contribute to insecurity, and conflicts and tensions over natural resources such as energy and freshwater have been well documented (Westing, 1986; Homer-Dixon, 1991; Lonergan and Brooks, 1994). More difficult to determine, and possibly more devastating, are the long-term and somewhat diffuse impacts on national and human security that may result from climate change. Admittedly, the term “human security” is itself somewhat diffuse; but for our purposes, human security is achieved when and where individuals and communities

- have the options necessary to end, mitigate, or adapt to threats to their human, environmental, and social rights;
- have the capacity and freedom to exercise these options; and
- actively participate in attaining these options.

Human security is, accordingly, a term that encompasses many of the human dimensions of global change: health, resource availability, vulnerability to hazards, and environmental degradation (as well as crime, drugs, and assorted other problems). Climate change affects human security since it may have significant implications for resource availability, agricultural productivity, and economic output, and may lead to coastal flooding and the creation of “environmental refugees.” Sea-level rise, now projected to be between 0.2 and 0.6 metres under a scenario of doubling CO_2 levels, will have significant impacts on low-lying regions and countries such as Egypt and Bangladesh, where a large percentage of both the population and the productive capacity is located less than one metre above sea level. More disruptive to political stability, however, are the increasing magnitude and

Table 3.3 Climate Change and Disease Risk: Types of Diseases that Might Be Affected

Factor	Examples of Specific Factors	Examples of Diseases
Ecological changes (including those due to economic development and land use)	Agriculture; dams, changes in water ecosystems; deforestation/ reforestation; flood/drought; famine; temperature increases; precipitation increases	Schistosomiasis (dams); Rift Valley fever (dams, irrigation); Argentine hemorrhagic fever (agriculture); Hantaan (Korean hemorrhagic fever) (agriculture); hantavirus pulmonary syndrome, Southwestern US, 1993 (weather anomalies); malaria (climate), dengue (climate)
Human demographics behaviour	Population growth and migration (including environmental refugees and movement from rural areas to cities); war or civil conflict; urban decay	Introduction of HIV; spread of dengue; spread of HIV and other sexually transmitted diseases

Source: Adapted from Eyles and Sharma, 2001.

As with many of the consequences of climate change, the distribution and spread of infectious diseases have a disproportionate effect on the poor. Poverty and the increased risk and incidence of infectious disease are mutually reinforcing. Again, the inequitable distribution of the consequences of climate change poses major challenges in planning future responses.

Water resources

The impact of climate change on water resources will vary widely from region to region. At present, almost 2 billion people, or one-third of the world's population, live in countries that are considered water stressed. The general notion of "water stress" and "water scarce" as developed (with different methods of measurement) by Falkenmark et al., (1989), Gleick (1996), and Ohlsson (1999) are widely used, but they are not particularly useful. Not only are there various forms of water stress and scarcity, but the level of stress is a function of many social, economic, and institutional factors, such as efficiency of use, level of national income, and level of agricultural development. Nevertheless, it is clear that as population grows, the num-

Table 3.4. Annex B Countries and Their Kyoto Targets.

Country	**Kyoto Target** (% change from 1990 emissions)	**Country**	**Kyoto Target** (% change from 1990 emissions)
Australia	+8	Poland	−6
Canada	−6	Romania	−8
EU	−8	Russian Federation	0
Hungary	−6	Switzerland	−8
Iceland	+10	Ukraine	0
Japan	−6	US	−7
New Zealand	0	Hungary	−6
Norway	+1		

Source: Kyoto Protocol to the United Nations Framework Convention on Climate Change.

ever, it will only come into effect as international law if either the US or Russia ratify, thereby surpassing 55% of global emissions.

The reduction of greenhouse gas emissions can be accomplished in two ways: either by reducing the rate at which CO_2 (and other greenhouse gases) is added to the atmosphere (this generally occurs through fossil-fuel combustion or biomass burning); or by increasing the rate at which CO_2 is removed from the atmosphere (by somehow storing additional carbon in the biosphere). The former could be accomplished through improved efficiency of energy production and end use, or by reducing the carbon content of fuels through a combination of decarbonization, fuel switching, and increased use of non-carbon energy systems (e.g., renewables and nuclear energy). The latter approach involves reducing net emissions through sequestering carbon by enhancing natural carbon sinks (e.g., increased forestation) or by capturing and storing CO_2 that has been emitted from fossil-based energy systems (e.g., in deep geologic formations or in the ocean). For economic and technological reasons, it is unlikely that Canada, the US, or a number of other countries can meet their CO_2 emission reduction commitments through improved energy efficiency and a decarbonization of their respective economies. However, it is conceivable, and even desirable, that these commitments could be met by the large-scale removal of carbon. The sequestration option has been broadly identified as land management activities, or Land Use, Land Use Change, and Forestry (LULUCF). LULUCF could include, for example, decreasing the

Driving forces

One key force driving greenhouse gas emissions has been the rapid globalization of economies and cultures—the major socio-economic change of the past century. The development of transnational corporations that wield considerable economic and political power, the emergence of global markets for goods, the increased mobility of capital and labour, and the conversion of socialist economies to a market-based structure have transformed the globe, with significant implications for the natural environment. This has resulted in both greater risks and improved opportunities to confront the issue of climate change. The rapid growth of fossil-fuel-based economies in India and China could dramatically increase the level of greenhouse gas emissions (fig. 3.4 shows the case for India; the graph for China has the same shape). Both countries—along with most other developing nations—have resisted international attempts to constrain their economies for the sake of the global environment. However, the development of multilateral environmental agreements, such as the UNFCCC noted above, has provided opportunities to address these risks while at the same time decreasing greenhouse gas emissions in developed countries.

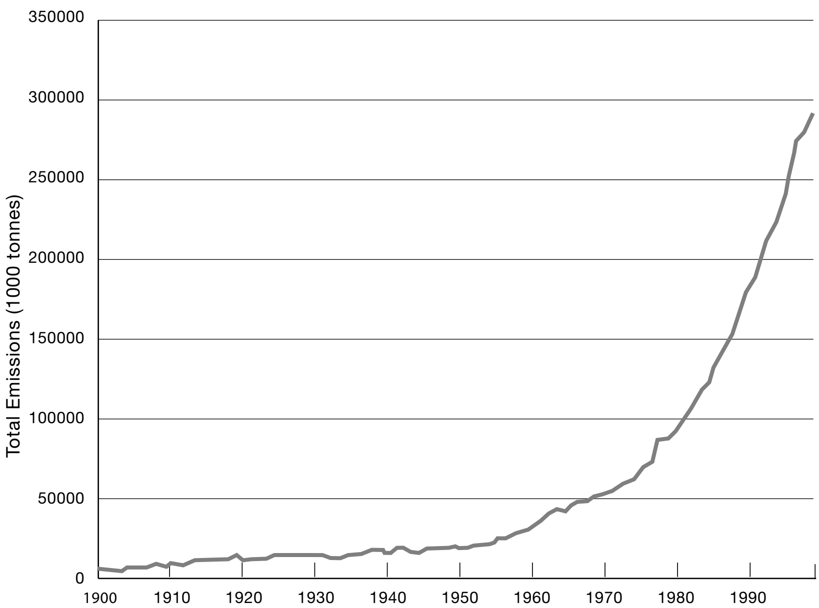

Figure 3.4. India CO_2 Emissions, 1900–1998 (from fossil fuels)

Source: ORNL, 2001.

Protocol. For example, one of the key components of the Kyoto Protocol is the Clean Development Mechanism, or CDM, as noted above. The CDM is a mechanism designed to facilitate the transfer of environmentally benign technology from the North to the South. In exchange, northern countries would get credit (toward their own emission reduction commitments) for reducing the emissions in the recipient countries. The CDM has two explicit objectives: first, to reduce the global emissions of greenhouse gases; and second, to promote sustainable development in the South. However, a cornerstone of sustainable development is—or should be—equity. International equity, intergenerational equity, and intra-generational equity are all aspects of equity that must be considered (Lonergan, 1993). Until equity becomes a cornerstone of a future climate change agreement, it is unlikely that we will achieve much-needed reductions in global greenhouse gas emissions or, for that matter, meet the goal of sustainable development that is explicit in the Kyoto agreement.

In the context of the climate change discussions, five aspects of equity must be considered (see Agarwal et al., 1999; Claussen and McNeilly, 1998; and Lonergan, 1993):

- responsibility for the problem;
- the distribution of impacts associated with the problem;
- the ability to pay to mitigate or adapt to climate change;
- the opportunities or options available to make changes; and
- the distribution of benefits from an agreement.

Unquestionably, one of the key challenges we face with respect to climate change is how to integrate these five components of equity.

Responsibility

The first issue is the responsibility for the present state of affairs with respect to greenhouse gas emissions. As noted above, five countries account for more than 50% of CO_2 emissions since 1950. Present emission levels—either in absolute terms or per capita—are similar, except that China now accounts for 12% of total emissions (ORNL, 2001). There is also concern about future responsibility for greenhouse gas emissions, as estimated by the average rate of growth of emissions by country (and taking into consideration the Kyoto targets). The conclusion from this cursory historical analysis is inescapable: developed countries have been primarily responsible for the emission of greenhouse gases into the atmosphere. The only change in this scenario in the future will be the growth of emissions in China and India, and the potential stabilization of emissions—and possibly their reduction—in developed countries.

The assumption here is that those who bear the responsibility for the environmental harm should also pay to remedy the problem (now commonly referred to as the "polluter pays principle" or PPP). While it seems clear that those who bear the responsibility for past CO_2 emissions should pay for both the removal of CO_2 and any damages, the complex nature of climate change (with multiple contributors, unknown damages and enormous emission reduction costs) considerably muddles this discussion.

Distribution of impacts

The uneven distribution of the effects of climate change constitutes a second aspect of the issue of equity. The impacts or consequences of climate change on human systems were outlined above. The most vulnerable to climate change—or any environmental stress for that matter—are the poor in developing countries and the developed world. In terms of the potential human toll, however, people in the South are much more at risk from such impacts as sea-level rise in low-lying island states, longer and more severe droughts in the Sudan, and flooding episodes in Bangladesh. While it is clear that the responsibility for climate change lies primarily with the North, the adverse consequences of climate change will fall disproportionately on the South.

Inequities in income and ability to pay

A third aspect of equity relates to the enormous gap in resources (economic, institutional, and other) between developed countries and developing countries. Per capita GDP figures highlight this difference. If the responsibility for CO_2 emissions falls primarily on the developed nations of the world, it is also clear that the ability or capacity to pay for any reduction in emissions is also highest for these same countries (with the exception of newly independent states, or NIX). There is enormous inequality in the standard of living among countries, and the gap between developed and developing countries is increasing (UNDP, 1998). However, regardless of who bears the responsibility for climate change, or who might be culpable in the future, climate change is global, and the consequences will be global as well as local. The costs of mitigation or adaptation must be borne by those who have the ability to pay.

Opportunities for emission reduction

A fourth aspect of inequity in climate change relates to the opportunities available to reduce greenhouse gas emissions. Inefficient economic sectors (in terms of CO_2 emissions per dollar of output) would be the first targeted for improvement. There are large variations in energy intensity across countries, from China, with 65.9 GJ/$ GDP in 1996, to Japan, which used only 6.7 GJ/$ in the same year (see Table 3.5). The implications of these variations could be enormous on economic and social levels, and within and between countries. Any long-term strategy to address CO_2 emissions reduction will involve a move away from fossil fuels. For energy intensive industries (and regions), this implies greater costs (for fuel substitution, for example) or even dislocation of industry. The present Kyoto Protocol does not require emission reductions from developing countries, so it is likely that, where possible, some energy intensive industries will move to developing countries to avoid the costs of operating in the North. Regions and countries that produce fossil fuels may also be impacted; resource-dependent places like Alberta in Canada or West Virginia in the US may experience negative economic impacts. This will also be true internationally. These differences will result in inequity in the cost of emission reduction, as developed countries face large economic costs, while inefficient industrial and transportation sectors in developing countries offer much cheaper emission reduction alternatives. This issue is recognized in the Kyoto Protocol, and mechanisms for emissions trading and joint implementation are built into the agreement. However, differing opportunities for emission reduction

Table 3.5 Energy Intensity of Selected Countries, 1980–1996 (in gigajoules of energy per dollar of GDP [1990 US$])

Country	**1980**	**1990**	**% Change 1980–1990**	**1996**	**% Change 1990–1996**
China	167.0	101.1	−39.5	65.9	−34.8
Germany	13.7	8.6	−37.2	7.2	−16.3
Egypt	33.2	31.8	−4.2	28.6	−10.1
India	60.4	49.6	−17.9	45.9	−7.5
Kenya	72.0	61.2	−15.0	57.6	−5.9
US	17.7	14.5	−18.1	14.2	−2.1
South Africa	30.3	36.8	+21.5	37.1	+0.8
Mexico	17.2	17.8	+3.5	18.1	+1.7
Brazil	12.1	13.0	+7.4	13.3	+2.3
France	8.3	8.0	+3.6	8.3	+3.8
Japan	7.7	6.4	−16.9	6.7	+4.7
Canada	27.3	22.7	−16.8	27.9	+22.9

Source: Agarwal et al., 1999.

Table 4.1 Climate Change Projections and Observations for Canada

	Projected	**Observed to Date (2000)**
Global Mean Temperature	1.4–5.8°C (1990–2100)	+0.6 or −0.2°C (20th century)
Canadian Mean Temperature	2–4°C (CGCM: 1975–95 to 2040–60)	>1°C (20th century)
Total Precipitation	(2040–2060) 0 to 20% more in north slightly less in mid continent in summer ($HadCM_3$)	1950–1998 ++ at high altitudes, + at mid latitudes Southern Prairies little change
Streamflow (or soil moisture) Mid-continent	30% by 2050 $2 \times CO_2$ (CGCM)	−10% Southern Prairies (1967–1996)
Date of Spring Breakup	Earlier	Earlier: 82% of basins (1967–1996)
Extreme Rainfall	Years between heavy rain events reduced by half (2090)	Up to 20% increase in heavy 1-day falls in US and SE Canada (early summer)
Water Vapour in Troposphere (lower atmosphere)	Increase	Statistically significant increase over N. America except NE Canada
Mean Sea Level Rise	40–50 cm (mean IPCC projections) 1990–2100	10–20 cm (1900–1999)
Arctic Sea Ice Extent	−21 to −27% by 2050	−3% per decade since 1978 (year round ice extent)
Snow Cover Extent Dec., Jan., Feb.	−15% by 2050 N. America (CGCM)	−10% (1972–2000) Northern Hemisphere
Late Season Snow Pack in Rockies—Apr. 1	Less (more melt over winter)	30% less since 1976 Fraser River Basin
Glacier Retreat South of 60° N e.g., Glacier National Park	None left in Park (by 2030)	2/3 reduction in numbers in Park (from 150 to 50) (1850–1990s)
Severe Winter Storms Frequency and Intensity	15% to 20% increase $2 \times CO_2$ (CGCM)	(1959–1997) • N of 60°N Increased frequency and intensity • S of 60°N Increased intensity

Source: Data from Akinremi et al., 1999; Angel and Isard, 1998; Boer et al., 2000; Carnell and Senior, 1998; Gregory et al., 1997; IPCC, 2001; Karl et al., 1995; Lambert 1995; McCabe et al., 2001; Mekis and Hogg, 1999; Moore, 1996; Ross and Elliot, 1996; Sarnko et al., 2002; Stone et al., 2000; Zhang et al., 2000; Kharin and Zwiers, 2000.

Notes: $HadCM_3$ = Hadley Centre (UK) Climate Model version 3
$2 \times CO_2$ = doubled pre-industrial level of CO_2 equivalent (by latter half of 21st century)
CGCM = Canadian Global Climate Model (CCCMA) (Environment Canada, University of Victoria)
++ = significantly more
+ = more

bears and seals dependent on the ice regime, and human communities dependent on hunting over ice-covered seas (Ashford and Castledon, 2001). The loss of sea ice means that larger waves impinge on the northwestern coast where permafrost thawing softens the shores, and rising sea levels compound the problems of coastal erosion affecting communities such as Tuktoyaktuk (Shaw et al., 1998).

Permafrost

Problems are developing in the maintenance of buildings, utilities, pipelines, roads, and railroads in the face of land slumps from the thawing of ice-rich permafrost. The greatest immediate risks are where permafrost is present in areas where air temperatures currently average higher than −2° C, for example in much of the Mackenzie River Basin south of Great Bear Lake. Both thawing of permafrost and coastal erosion require remedial action for existing infrastructure, and these factors must be taken into account in future building and planning (Cohen, 1997a, b).

Vegetation

Much of the Arctic has recently experienced warmer temperatures in winter and spring, resulting in a lengthening of the growing season. Future warming would continue this trend, and species are likely to shift to higher latitudes and elevations. Forest fire severity ratings are expected to increase with higher temperatures in southern Yukon and the Northwest Territories, signalling more frequent and extensive fires and a lengthening of the fire season. Impacts on wildlife (such as caribou) are more difficult to assess, but would likely be unfavourable for those that prefer cold climates (IPCC, 2001).

Transportation

Transportation is being affected in the Mackenzie Basin and other areas where northern community resupply depends upon trucks using winter ice roads. The period of reliable ice road travel has been shortening with the warming climate, reducing the usefulness of this transport mode. At the same time, the period of high enough water levels and flows on the Mackenzie River to carry extensive barge traffic is also getting shorter, with more frequent low flow periods in late summer and autumn (Cohen, 1997a). These observed trends will accelerate with further warming. Shipping through the Beaufort Sea and the Northwest Passage will become much easier with melting ice cover (see Human Adaptation below).

Nunavut: Eastern Arctic

It should, at the same time, be noted that little or no warming has occurred in much of eastern Nunavut or elsewhere in northeastern Canada. This is consistent with atmosphere-ocean climate model results, which show much less rapid warming or even cooling in future in northern Quebec, Labrador, Baffin Island and Baffin Straits due to changes in ocean circulation and ice patterns (Boer et al., 1998).

Toxic contaminants

An environmental issue that affects all of the Canadian Arctic and Subarctic is contamination by toxic chemicals. For the most part, these originate in the industrial regions of the northern hemisphere and are transported, mainly by the atmosphere, onto Arctic waters and land. Many such contaminants, both toxic metals and organic compounds, are first deposited in water bodies to the south, such as the Great Lakes. In warm water conditions, they re-volatilize[2] to the atmosphere to be transported further until they reach regions where the water remains cold all year. There, in the Arctic and Subarctic, they bioaccumulate and become a hazard to the health of creatures at the top of the food chain, including humans. Long-lived organochlorines, like PCBs and DDT, persist in the Arctic long after their use was banned in many countries. Coal-burning power plants and municipal waste incinerators are substantial sources of Arctic mercury, which also reaches unhealthy levels in blood of some indigenous people. There is little research on the impact climate change will have on the transport of these contaminants into the Arctic. However, several scientists have pointed out that, as southern water temperatures rise to the point where volatilization occurs more frequently, these southern waters will tend to cleanse themselves more rapidly at the expense of greater deposition in the still relatively cold waters of the North.

Storms

Throughout the area north of 60°N severe winter storms have been increasing in both frequency and intensity over the past three to four decades putting hunters and travellers far from home base at ever more serious risk (McCabe et al., 2001). This trend is projected to continue (Carnell and Senior, 1998).

Human adaptation

What all this means for Canada's northern communities is that the North will be faced with additional climate-related challenges superimposed on rapid changes in northern economies and institutions (Cohen, 1997a, b; Ashford & Castledon, 2001). In the last decade, we have seen the creation of Nunavut in the eastern Arctic, the growth of tourism, and the onset of diamond mining. There are growing pressures to expand oil and gas exploration. Expanded wage-based activities may not be as vulnerable to climate change as traditional harvesting, although ice and permafrost instability will lead to problems for buildings, winter roads, and perhaps mines. Traditional indigenous lifestyles may also be disrupted by these changes, and national sovereignty will be an increased concern as Arctic waters become more accessible.

Dialogue on climate change is expanding in this region as communities and governments consider their development goals and various choices for meeting them. The West Kitikmeot Slave Study (WKSS) on the regional effects of expanded mining north of Great Slave Lake includes observations of the ways recent warming has been changing ice conditions, snowmelt, and vegetation patterns (WKSS, 2001). The community of Sachs Harbour on Banks Island has also observed these changes (Ashford and Castledon, 2001). However, the impact of these and future changes will vary regionally, and there is a belief that any damages or benefits that may accrue from climate change will be influenced by development and lifestyle choices (Table 4.2). The Manitoba Climate Change Task Force's inclusion of Northern issues in its report (2001), the establishment of the Northern Climate Exchange in Whitehorse Yukon (NCE, 2001), inclusion of Northern concerns in emergency preparedness planning within the Quebec government (Jaimet, 2002), and the initiation of the Arctic Climate Impact Assessment by the Arctic Council (2003), illustrate the growing interest in developing a Northern capability to learn more about climate change impacts and potential responses.

The Inuit, Dene, and Métis have shown themselves to be very resilient to fluctuations in climate and resource availability, but many are becoming dismayed by the longer-term changes they are experiencing and by the physical and social impacts on their hunting and fishing-based communities. Successful adaptation will require these communities to go beyond the experience of their elders and their practical knowledge of the land, sea, and ecological systems (Ashford and Castledon, 2001). As temperatures warm, exploitation of northern resources of oil, gas, and minerals, and potentially much greater use of Arctic waters for transportation, will become increasingly viable. These activities must be carried out in a manner sensitive to protection of the existing environment and communities of the North.

Table 4.2 Opinions of Residents of Aklavik Regarding Future Regional Impacts of Climatic Change within Different Visions of Lifestyles

Impact	**Continued Reliance on Subsistence Activities**	**Greater Reliance on Wage Economy & Economic Development**
Greater flooding	–	–
Muddy road conditions	?	–
Insulation of buildings	+	+
Easier water delivery	?	+
Less time spent waiting out cold conditions	+	+
Outdoor meat storage	–	–
Uncomfortably hot in summer	–	–
Increased summer insects	–	–
Shorter winter road season	?	?
Longer water shipping season	?	+
Mode of transport	?	?
Infrastructure of camps	–	?
Location of camps	–	?
Changes in wildlife habitat	–	?
Increased sediment loading	–	–
Thinner ice	–	–
Greater snowfall	?	–
Variability in timing & consistency of break-up & freeze-up	–	–
Longer ice free season	?	+
Shoreline erosion & lowland flooding	–	–
Greater variability in decisions/perceptions	–	?

Source: Aharonian, 1994, p. 419.

Notes: + =positive impact; − = negative impact; ? = impact is indeterminate. See text referring to Table 4.2 on page 78.

doubled CO_2 predicts that the average interval between heavy rain events will be reduced by 50%, e.g., a heavy rain equalled or exceeded only once in 20 years over a long period of time (a 20-year return period rain) becomes a 10-year return period event (Kharin & Zwiers, 2000). In the Great Lakes–St. Lawrence Basin and Atlantic Canada, high rain intensity events in spring and early summer have shown significant increases from 1950 to 1995 (Stone et al., 2000). A recent study indicates that a 6–7% increase in urban and suburban runoff volumes occurs for every 5% increase in rain intensity. This poses a dilemma for municipalities—do they accept an increased frequency in the overflow and flooding of storm sewers, or do they enlarge sewer capacity at substantial cost? Storm-water storage in combined storm and sanitary sewer systems would have to be increased by 11–16% for a 5% increase in rainfall intensity in a 100-year storm in order to prevent overflows and discharge of sanitary wastes.

Agriculture

Increased frequency of heavy rains also increases episodes of surface runoff from agricultural lands, with potential for, and tragic experience with, farm chemicals and E. coli from animal waste entering rivers and groundwater supplies. Soil erosion is expected to increase, but, in general, longer growing seasons should benefit most agricultural production in the Great Lakes–St. Lawrence Region (Bruce et al., 2000).

Urban air pollution

Smog episodes will be longer and more intense in this region. An estimated 1900 premature deaths per year occur at present in Ontario from smog and air pollution, with additional cases in the Montreal area and southern Quebec. More intense and prolonged heat waves will make this an even more serious public health issue, when both air pollution and high heat stress affect vulnerable populations of asthmatics and the elderly. Remedial actions are urgent. Reducing dependency on fossil fuels can reduce local air pollutants and contributions to greenhouse gas forcing of climate at the same time.

Recreation

Winter snow-based recreation in southern Quebec and southwest Ontario will have shorter seasons in future, although snow amounts could increase at ski resorts to the east of Lake Huron and Georgian Bay with a longer period of lake-effect storms. A longer summer recreation season is expected.

suggest that terrestrial vegetation and soils take up only about 40% of global CO_2 emissions from human activities. As a result, carbon is accumulating in the atmosphere at an annual rate of about 3 Gt (fig. 5.1). However, there is considerable uncertainty and controversy surrounding estimates of global and regional carbon stocks and fluxes (rates of carbon exchange between the surface and the atmosphere). This is due to global differences in measurement methodologies and the difficulty in making reliable, consistent, and meaningful spatial and temporal measurements.

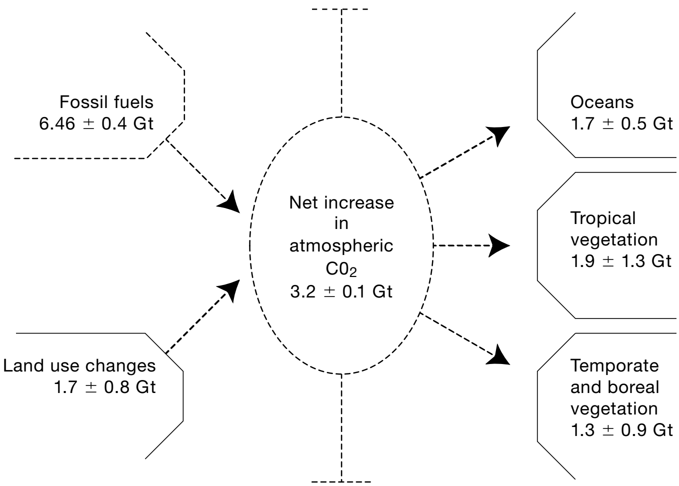

Figure 5.1. Carbon Flows to the Atmosphere from Fossil Fuel Emissions and Land Use Changes, and from the Atmosphere to Land and Ocean Sinks

Source: Royal Society, 2001.

The atmosphere contains approximately 760 gigatonnes of carbon (Gt C). This is about a third of the total amount of carbon held in vegetation (550 ± 100 Gt) and soils (1750 ± 250 Gt). Most of the carbon stored in terrestrial ecosystems is in forest soils and vegetation. For example, tropical and boreal forests (and soils) account for almost 40% of the carbon reservoir. By contrast, croplands account for only 5% of the total stored carbon. It takes approximately 10 years for all atmospheric CO_2 to exchange with land surfaces, but the net exchange is in disequilibrium because of natural climatic variability and the direct and indirect effects of human activity (including changes in land-use practices).

Carbon is taken up by plants through the process of photosynthesis—the largest-scale synthetic process on earth. Almost 50% of the total global photosynthesis is accomplished by marine organisms. However, when photosynthesis is expressed on a per unit area basis, the productivity of terrestrial ecosystems is much higher than that of marine ecosystems. The photosynthetic process (with the exception of photosynthetic bacteria) involves converting the conversion of light energy captured by pigments (the principal class of which are chlorophylls) into the chemical energy of organic molecules, primarily carbohydrates, using CO_2 and water from the environment: molecular oxygen is subsequently released. Energy is gained in the chemical bonds of the carbohydrates and is stored in high-energy compounds such as adenosine tri-phosphate (ATP). In the process of respiration, energy captured by photosynthesis is used to synthesize and maintain plant tissue, releasing CO_2 and consuming oxygen. The breakdown and utilization of plant tissue by microbial organisms in the soil also releases respiratory carbon.

Terrestrial carbon uptake by photosynthesis is estimated at 120 Gt per year, and plant respiration (carbon loss) is about half that value (fig. 5.2). The combined release of carbon through fires (4 Gt) and decomposition of soil organic matter (55 Gt) is also about 60 Gt per year. The net land carbon sink is about 3.2 Gt per year, which is rather small relative to the constituent

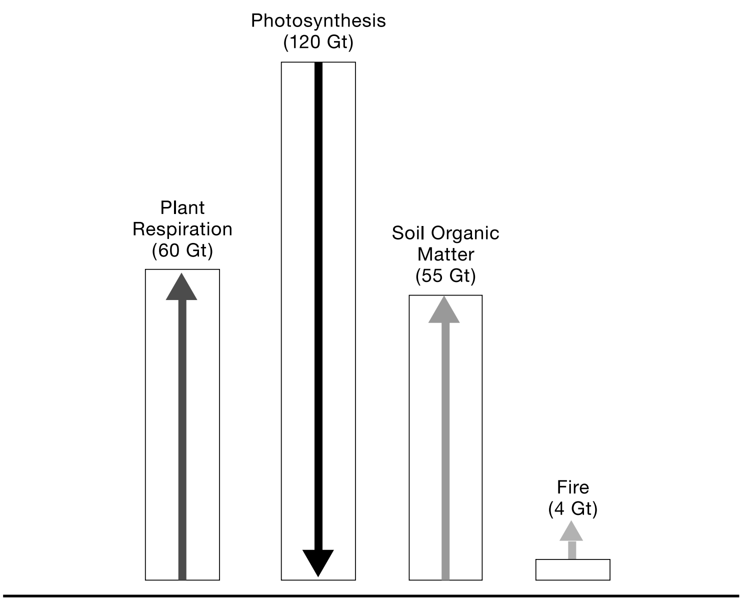

Figure 5.2. Estimates of Carbon Exchange in Gigatonnes of Carbon per Year between the Atmosphere and the Terrestrial Ecosystems

Arrows pointing away from the surface indicate a net loss of carbon to the atmosphere. *Source*: Royal Society, 2001.

Table 5.1 Carbon Content of Biomass, Various Tropical Forests and Regions

Country/Forest	Wet Tropical	Dry Tropical
Africa	187 t C ha^{-1}	63 t C ha^{-1}
Asia	160 t C ha^{-1}	27 t C ha^{-1}
Latin America	155 t C ha^{-1}	27 t C ha^{-1}

Source: Papadopol, 2000.

Table 5.2 Depletion of Soil Carbon Following Tropical Forest Conversion to Agriculture

Region	Soil C in Forest	New Land Use	Soil C Loss with New Land Use
Semi-arid	15–25 t C ha^{-1}	Shifting cultivation (arable agriculture)	30–50% loss in 6 years
Subhumid	49–65 t C ha^{-1}	Continuous cropping	19–33% loss in 5–10 years
Humid	60–165 t C ha^{-1}	Shifting cultivation pasture	40% loss in 5 years 60–140% of initial soil C

Source: Adapted from Paustian et al., 1997.

Table 5.3 Total Carbon in Tropical Ecosystems by Sink[a]

Land Use	Tree %	Understory %	Litter %	Root %	Soil %
Original forest	72	1	1	6	21
Managed & logged-over forest	72	2	1	4	21
Slash & burn croplands	3	7	16	3	71
Bush fallow	11	9	4	9	67
Tree fallow	42	1	2	10	44
Secondary forest	57	1	2	9	32
Pasture	<1	9	2	7	82
Agroforestry & tree plantations	49	6	2	7	36

Source: Woomer et al., 1999.

Note: [a]Average of Brazil, Indonesia, and Peru.

tillage, reduced summer fallow, and more set-asides), and grazing management (manipulation of the amount and type of vegetation and livestock produced) are activities that lead to enhanced soil organic carbon and/or more carbon stored in biomass. The problem with carbon stored by prevention of forest degradation and enhanced agricultural sinks is that these changes are likely ephemeral, and carbon flux is difficult to measure.

Estimates of the effects of both improved land-use management and changes in land use on net terrestrial carbon uptake are provided in Table 5.4. This table gives estimates of the potential of these activities for mitigating climate change; but it also demonstrates how current land uses have resulted in the release of C over time. For example, cultivation alone has

Table 5.4 Effects on Potential Net Carbon Storage of Land Use Activities, Excluding Afforestation and Reforestation[a]

Activity	Potential Area (10^6 ha)	Rate of C Gain (t C ha^{-1} yr^{-1})	Potential (Mt C yr^{-1}) 2010	2040
1. Improved Management of a Land Use	1,289	0.34	125	258
Cropland: reduced tillage, improved management of crop rotations, cover crops, etc.	(45.7%)		(60%)	(51%)
Rice paddies: better irrigation, improved residue management	153 (2.6%)	0.10	8 (<10%)	13 (<7%)
Agroforestry: better management of trees on cropland	400 (20.8%)	0.28	26 (46%)	45 (38%)
Grazing land: better management	3,401 (38.1%)	0.77	261 (36%)	523 (36%)
Forest land: enhanced silviculture, reduced degradation	4,051 (46.9%)	0.41	170 (59%)	703 (72%)
Urban land: tree planting, improved wood product management & waste management	100 (505)	0.30	2 (50%)	4 (50%)
2. Land Use Change				
Agroforestry: conversion of poor crop/grassland to agroforestry	630 (0%)	3.1	391 (0%)	586 (0%)
Restoring severely degraded land: to forest, crop or grass land	277 (4.3%)	0.25	4 (<20%)	8 (13%)
Grassland: converting cropland to grassland	1,457 (41.3%)	0.80	38 (63%)	82 (59%)
Wetland restoration: converting drained land back to wetland	230 (91.3%)	0.40	4 (100%)	14 (93%)
Global Total			**1,029 (39%)**	**2,236 (44%)**

Source: IPCC, 2000.

Note: [a]Contribution by developed countries provided in parentheses.

As shown in Table 5.6, energy from wood residues can compete with fossil fuels and purchased electricity. This conclusion needs careful scrutiny, however. First, wood residue prices are based on average and not marginal costs, and are only available for small-scale operations where wood is easy to come by. At a larger scale, one would expect much higher raw material (wood) costs. Second, wood fibre prices vary significantly by region depending on environmental regulations and residue surpluses or shortages. Regional values are not currently available for comparison (Forest Sector Table 1999). If fast-growing plantations are included, estimated costs are $2.82 per gigajoule (GJ), which is more expensive than fossil fuels but still cheaper than purchased electricity.

Table 5.6 Energy Price Comparisons for British Columbia, Canada ($1997)

Wood Residues	
(assumed conversion factor = 18 GJ per dry tonne)	
Wood residue from pulp and paper mills	\$ 1.0 GJ^{-1}
Wood residue from wood industry	\$ 0.56 GJ^{-1}
Wood waste plus plantation wood	\$ 2.82 GJ^{-1}
Fossil Fuels	
(based on natural gas, boiler efficiency of 85%, C emission factor of 0.050 t GJ^{-1})	
Fuel price	\$ 1.73 GJ^{-1}
Electricity	
(at \$0.039 per kWh)	\$10.84 GJ^{-1}

Source: Forest Sector Table, 1999, and own calculations.

Fossil-fuel substitution on a global scale, using 10% of an estimated 3,454 million ha of forested area as a source for biomass energy, would replace an average of 2.45 Gt C per year. This figure is based on 7 t C ha^{-1} yr^{-1}, while the average carbon capture rate can vary from less than 0.5 to 12 t C ha^{-1} yr^{-1} depending on the type of forestry being practiced—conventional or plantation. This amounts to some 40% of global fossil-fuel emissions of carbon in 1990. In Canada, the high capital cost of infrastructure, regulation of the electricity market, and the relatively low cost of fossil fuels restrict the economic viability of substituting biomass for fossil fuels in power generation. When we consider global climate change, future energy requirements, availability of supply, and social and environmental values, we find that the benefits of renewable energy sources such as wood biomass outweigh the costs in some, but not all situations.

line to operate. Even the bland surface of the pencil, that exemplar of "appropriate" low technology, conceals the logging operations, graphite mines, and castor oil refineries required to produce it. Our technological services are unbreakably linked to large-scale energy use, and these in turn rely for the most part on the combustion of hydrocarbon fuels. The question facing us at the beginning of the twenty-first century is whether the link between energy and climate change is as unbreakable as that between technology and energy use. Can we wean ourselves from hydrocarbon energy sources without crippling the world economy—a prospect as deadly as any climate change scenario?

All of society's services—among them heat, light, information, transportation, nutrition and hygiene—are provided by the technologies that comprise these sectors. Figure 6.1 shows a breakdown of global energy use by energy source. In 1999, the world consumed about 402 exajoules (1 EJ = 10^{18} J) of commercial energy, of which over 85% was due to the combustion of petroleum, coal, and natural gas (EIA 2002). Only 58.4 EJ (14.5%) came from carbon-free sources, and of these, renewable sources (comprising geothermal, solar, wind, wood and waste technologies) contributed just 3.0 EJ, 5% of the carbon-free sources and 0.7% of total energy consumption. Nuclear fission and hydroelectric generation made the largest contributions among the carbon-free technologies, generating 26.6 EJ and 28.8 EJ respectively.

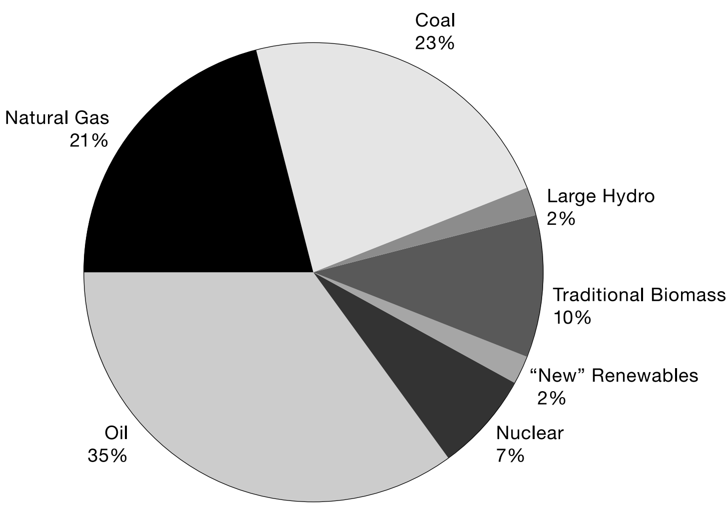

Figure 6.1. Global Commercial Energy Supply by Source

Source: IEA (2000).

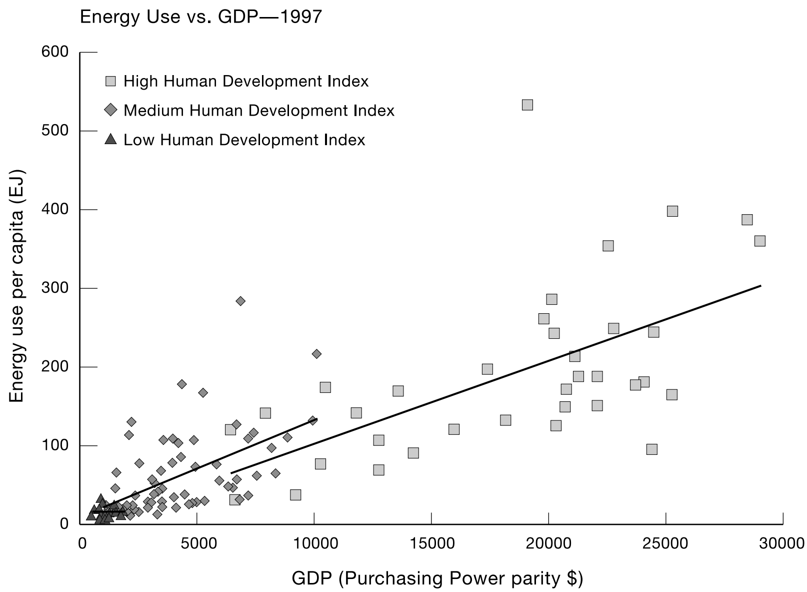

Figure 6.2. Comparison of Energy Use Per Capita and Gross Domestic Product (1997)

Source: UNDP (2001), IEA (2000).

oped, and they will surely demand the technological services we have come to take for granted. Barring unprecedented breakthroughs in the efficiency with which services are supplied, there is simply no question that worldwide energy demand will continue to increase. The International Energy Agency has considered a number of scenarios of future global development, and has come to the conclusion that global energy consumption will increase at a rate of about 2% per year for the foreseeable future. By 2020, the world will use over 640 EJ of commercial energy, a 60% increase over today's levels. In the developed world, energy demand is expected to grow at a slightly slower rate of around 1.7%; the developing countries, containing the majority of the world's population, will grow at about 2.7% (IEA, 2000). It is important to note that *all* the scenarios considered in this study featured a considerable increase in worldwide energy use over today's levels, including those based on strong conservation and efficiency measures.

Energy efficiency and conservation measures are often mentioned as having huge potential to reduce greenhouse gas emissions, but in almost all cases the actual potentials are far lower than commonly supposed. In 1999, Canada developed the National Options Tables Exercise in order to assess the potential efficiency and conservation mechanisms to achieve

Services	Service Technologies	Services	Transformer Technologies	Sources
Transportation	Automobile	Gasoline	Drilling rigs & oil refineries	Coal
Communication	Telephone	Natural gas	Dams & hydraulic generators	Sunlight
Illumination	Light bulb	Electricity	Uranium mines & nuclear power plants	Oil
Health care	Health Care	Methanol	Photovoltaic cells	Geothermal
Potable Water	UV Purification	Hydrogen	Windmills	Natural gas
Refrigeration	Refrigerator	Diesel		Wind
Entertainment	Television	Jet-A		Uranium
Heating	Heat pump			Tides
				Biomass
What people want	What technology and industry provide (what ESVic works on)			What nature provides

Figure 6.3. The Architecture of the Energy System

Source: Service Energy Linkages. Institute for Integrated Energy Systems, University of Victoria (IESVic).

practice, this is achieved by using stored hydrocarbon currencies (such as diesel or natural gas) in generators with fast time response to augment slow-response baseload capacity. It is much more difficult to recover the excess energy that is dumped when demand suddenly decreases. This would require the ability to re-store the excess energy, and unfortunately hydrocarbons provide a one-way flow of energy only. They are not reversible: gasoline can be converted into electricity, but electricity cannot be converted into gasoline. Unfortunately, none of the candidates for carbon-free energy production discussed in the previous section can provide an easy path to currencies that store energy. They all generate electricity (or heat) only. To create a long-term sustainable energy system that can use the energy offered by carbon-free energy technologies, we require an energy currency that allows energy to be stored, and that can be created from both electricity and heat. If it were possible to create an energy currency from electricity that could be stored, transported, and distributed in different forms, we would begin to have a truly viable alternative to hydrocarbon currencies. Such a currency would begin to usher in a post-combustion age.

Fortunately, there is such a currency: hydrogen. It has the highest energy density by weight of any fuel. Hydrogen can be made from any energy source, using thermal, chemical, biological, or electrolytic processes.

It can do work through direct combustion or (much more efficiently) through electrochemical conversion to electricity in a fuel cell. There are large technical and economic barriers to a hydrogen-based energy system, but hydrogen is the only alternative for the future that will allow us to continue developing both stationary and transportation energy services without increasing the risk of large-scale environmental damage. Hydrogen is source-independent and, together with carbon-free electricity, it can provide all the services we enjoy today in an environmentally benign manner. While it is unlikely that we will ever drive wind-powered cars, it is most likely that we will drive hydrogen-fuelled cars, with the hydrogen produced from wind-generated electricity.

Since hydrogen can be produced from any energy source, it makes sense to integrate energy production for both stationary and transportation services to produce the dual currencies of electricity and hydrogen synergistically. Figure 6.4 provides a schematic block diagram of this emerging system. Using this approach, many of the difficulties identified with carbon-free energy technologies can (at least in principle) be addressed.

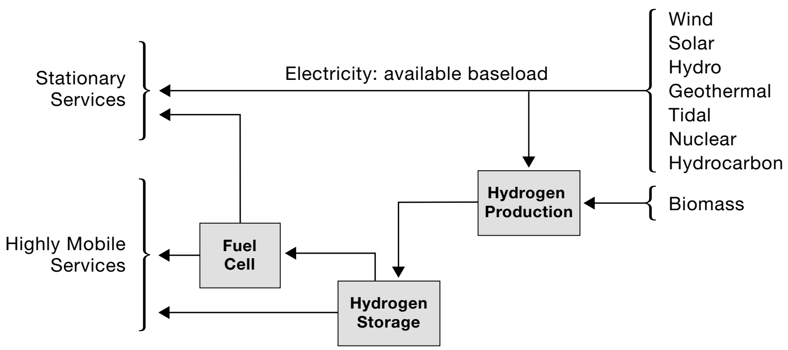

Figure 6.4. The Emerging Energy System

Source: Institute for Integrated Energy Systems, University of Victoria (IESVic).

Current nuclear power plants, as mentioned, can only output constant levels of electricity. In this case, hydrogen production can be used as a buffering element: the nuclear plant would be designed to produce an oversupply of electricity, and the excess would be used for hydrogen production and storage. The process would be controlled to provide the dynamic characteristics required for load following electrical service supply. Instead of trying to store the produced electricity, the plant would produce a mix of both electricity and hydrogen, with the rate of hydrogen production being controlled to "throttle" the electrical output.

The results in Tables 7.1 and 7.2 are idealistic in the sense that they assume no policy failure (except that revenues are recycled in lump-sum fashion rather than used to reduce distortionary taxes elsewhere in the economy). However, in countries where CO_2 taxes have been introduced, some sectors have been exempted or taxed at a different rate, thereby substantially increasing economic costs relative to a policy that involves uniform taxes (IPCC, 2001, p. 56).

Table 7.1 Energy Modeling Forum Main Results: Marginal Abatement Costs to Achieve 2010 Kyoto Target (in 1990 US$/t C)[a]

	No Trading					
Model	**USA**	**OECD Europe**	**Japan**	**Canada, Australia New Zealand**[b]	**Trading Only among Annex B Countries**[b]	**Full Global Trading**[b]
Energy-Technology Models						
Administration	154	43	18	n.a.	n.a.	n.a.
EIA	251	110	57	n.a.	n.a.	n.a.
CETA	168	46	26	n.a.	n.a.	n.a.
Funds	14	10	n.a.	n.a.	n.a.	n.a.
GRAPE	204	304	70	44	n.a.	n.a.
MERGE3	264	218	500	250	135	86
RICE	132	159	251	145	62	18
POLES	136	135	195	131	53	18
Econometric Models						
Oxford	410	966	1074	224	123	n.a.
CGE Models						
ABARE-GTEM	322	665	645	425	106	23
AIM	153	198	234	147	65	38
G-Cubed	76	227	97	157	53	20
MIT-EPPA	193	276	501	247	76	n.a.
MS-MRT	236	179	402	213	77	27
SGM	188	407	357	201	84	22
WorldScan	85	20	122	46	20	5
Average	**187**	**248**	**303**	**186**	**78**	**29**

Source: IPCC, 2001, Table TS.4, and calculation.

Notes: [a] To convert to $ per t CO_2, multiply the figures in the above table by 12/44 as 1 t C = 44/12 t CO_2.
[b] n.a. indicates not available.

Table 7.2 Reduction in GDP in 2010 as a Result of Meeting Kyoto Protocol Targets (% of GDP)

	No Trading				Annex B Trading				Full Global Trading			
Model	USA	OECD-Eur	Japan	CANZ	USA	OECD-Eur	Japan	CANZ	USA	OECD-Eur	Japan	CANZ
ABARE-GTEM	1.96	0.94	0.72	1.96	0.47	0.13	0.05	0.23	0.09	0.03	0.01	0.04
AIM	0.45	0.31	0.25	0.59	0.31	0.17	0.13	0.36	0.2	0.08	0.01	0.35
CETA	1.93	n.a.	n.a.	n.a.	0.67	n.a.	n.a.	n.a.	0.43	n.a.	n.a.	n.a.
G-Cubed	0.42	1.5	0.57	1.83	0.24	0.61	0.45	0.72	0.06	0.26	0.14	0.32
GRAPE	n.a.	0.81	0.19	n.a.	n.a.	0.81	0.1	n.a.	n.a.	0.54	0.05	n.a.
MERGE3	1.06	0.99	0.8	2.02	0.51	0.47	0.19	1.14	0.2	0.2	0.01	0.67
MS-MRT	1.88	0.63	1.2	1.83	0.91	0.13	0.22	0.88	0.29	0.03	0.02	0.32
Oxford	1.78	2.08	1.88	n.a.	1.03	0.73	0.52	n.a.	0.66	0.47	0.33	n.a.
RICE	0.94	0.55	0.78	0.96	0.56	0.28	0.3	0.54	0.19	0.09	0.09	0.19
Average	**1.30**	**0.98**	**0.80**	**1.53**	**0.59**	**0.42**	**0.25**	**0.65**	**0.27**	**0.21**	**0.08**	**0.32**

Source: IPCC 2001, Table TS.5, and calculation.
Note: n.a. = not available.

Mitigation cost estimates for Canada

In 1990, Canada generated 607 Mt of CO_2-equivalent emissions (165.5 Mt C); thus Canada's Kyoto commitment requires a reduction of emissions to 571 Mt CO_2 (155.7 Mt C) by 2008–2012. By 2000, after a period of economic expansion, Canada's GHG emissions had increased by 19.6% to 706 Mt CO_2 (192.5 Mt C) (Olsen et al., 2002). Business-as-usual emissions are projected to reach 802 Mt CO_2 (218.7 Mt C) annually by 2010, some 40% above Canada's Kyoto commitment to reduce emissions 6% below 1990 levels by 2008–12. Canada must reduce emissions by 240 Mt CO_2 per year below business-as-usual emissions. Several studies have sought to address the costs of complying with Kyoto targets. The main results of these studies are summarized in Table 7.3, but these hide a fair amount of detail.

Table 7.3 Summary of Costs of Attaining Kyoto Protocol Targets at 2010, Canada

Item	No Emissions Trading	Global Emissions Trading
Required Carbon Tax (US$/t c)	150–835	11–114
Welfare loss (% of GDP)	0.9–2.2	0.2–0.6

Source: Wigle, 2001, pp. 6–7.
Note: Not including studies by AMG (2000) and Wigle (2001).

over the course of the twenty-first century, as populations increase, pressures on land and water resources become more serious, and global economies become more integrated?

As we consider Canada's adaptation prospects, it is important to keep in mind the country's previous experiences with weather and climate variations and trends, as well as current and anticipated trends in economic development. Death rates from extreme weather events and vector-borne diseases have declined during the twentieth century, but weather-related costs have increased dramatically. Insurance costs have also increased, both in Canada and in the United States. In the following sections, we offer several vignettes illustrating Canada's vulnerabilities to current climate, potential implications of scenarios of future climate change, and an assessment of adaptation options.

Canada's Unique Vulnerabilities to Today's Climate

The Canadian climate has always exhibited considerable variability, and Canadians have coped with this. Transportation, housing, recreation, and commercial activities endeavour to align themselves with the opportunities and challenges presented in the climatic conditions found in different regions at various seasons of the year. Adaptation to the current climate, however, comes at a price. Many examples of recent extreme weather events also demonstrate our vulnerabilities. One particular case, the 1998 Ice Storm, is described below, along with a description of how governments and the private sector have used insurance and relief programs in an effort to cope with extreme weather events.

The 1998 Ice Storm: A cautionary tale

In January 1998, an intense ice storm hit eastern Ontario, southern Quebec, and parts of the Maritime Provinces, as well as portions of New York and New England. This was actually a series of three storms that deposited more than 80 millimeters of freezing rain in less than six days. States of emergency were declared in 41 US counties, 3 Canadian cities, and 23 Canadian rural townships and communities (Abley et al., 1998; Harris, 1998). The storm caused power outages that lasted over a week in most areas and much longer in some rural communities. Loss of electric power affected about 4.7 million people. The cities of Montreal and Ottawa were especially hard hit. Indeed, it was fortunate that one grid line remained intact, supplying power to the city of Montreal. Had this failed also (as it easily might have done) the magnitude of the disaster would have increased manyfold.

Did this ice storm occur because of climate change? Increased intensities of winter storms are anticipated for mid-latitude regions as the climate warms (see chaps. 2 and 4), but our purpose is not to suggest that the 1998 storm or other recent weather events have occurred because of human-induced climate change. Such attribution of individual events cannot be determined. What is clear, however, is that there are major forces in society that tend to make us more vulnerable to weather and climate, and that we need to develop better adaptation strategies to deal with them. This case therefore represents an opportunity to learn about climate-related impacts and vulnerabilities in the Canadian context as extreme weather events may occur more often in a warmer future.

How significant were the impacts of the 1998 storm? The total economic impacts have been estimated at C$4.2–C$5.1 billion. This is higher than estimates of insured losses (Table 8.2). Although agriculture and the maple sugar industry were affected, all communities and sectors that relied on electricity suffered. The power loss lay at the heart of the impact. The grid that carried electricity to the city of Montreal suffered massive damage (fig. 8.1). In Quebec, the hardest-hit province, 3,000 km of the distribution system, 16,000 poles, 150 pylons, 4,000 transformers, and 3,000 other structures were damaged. For a province that meets 41% of its total and 68% of its residential energy needs through electricity, this was a catastrophe (Kerry et al., 1999).

Figure 8.1. Damage from the 1998 Ice Storm near Drummondville, Quebec.

Source: Ministry of Environment, Province of Quebec.

There has been some argument about whether the electrical distribution system was or was not designed and maintained to a sufficient level. It certainly lacked resilience. No redundancy or fail-safe designs were incorporated, and when failure occurred, recovery was slow. The weather created additional problems due to an extended freeze period, which made emergency response difficult. This disaster highlighted the vulnerability not only of the energy system but also of our socioeconomic system. This was a major

Table 8.2 Estimated Damages from the 1998 Ice Storm

Type of Loss	Canada	United States	Total
Insured losses	Cdn $1.44 billion	US $0.2 billion	US $1.2 billion
Insurance claims	696,590	139,650	835,240
Deaths	28	17	45
Customers without power	4,700,000 (1,673,000)	546,000	5,246,000
Electricity transmission towers/distribution poles toppled	130 / 30,000	?	?
Electric transmission system damage	Cdn $1 billion	?	?
Manufacturing, transportation, communications, and retail business losses	Cdn $1.6 billion	?	?
Forests damaged	?	17.5 million acres	?
Loss of worker income	Cdn $1 billion	?	?
Dairy producers experiencing business disruption	5,500	?	?
Loss of milk	Cdn $7.3 million	US $12.7 million	US $18 million
Agricultural sector (poultry, livestock, maple syrup)	Cdn $25 million	US $10.5 million	US $28 million
Quebec & Ontario Governments	Cdn $1.1 billion		

Source: Adapted from IPCC 2001a.

Note: Based on an analysis conducted by the Canadian Institute for Catastrophic Loss Reduction and the US-based Institute for Business and Home Safety, both insurance industry organizations (Lecomte et al., 1998). Losses as of October 1, 1998 (1 CDN$ = 0.7 US$).

failure of technology. The storm resulted in restrictions to the actual distribution of power. The interruption in the power system disrupted the lives and routines of individuals whose day-to-day functions are based on the use of technology and power.

Over time, we have become increasingly reliant upon technology. This has created a system that is much more efficient under normal circumstances than it was in the past, but suffers to a greater extent when failure occurs. This experience illustrates the need to consider various changes in, for example, design specifications, building codes, and energy distribution systems, in order to meet a changed climate regime. This could actu-

Over time, the cost of insurance payouts has increased both within Canada and globally. This is evident in Figures 8.2 and 8.3, which show trends of premium-to-loss ratios for the insurance industry. Disaster relief payments from the federal government to the provinces were actually declining during 1970–1994, but rose sharply during 1995–1999 (fig. 8.4). In addition, recent government crop insurance payments have varied between \$50 million in 1996 and \$1 billion in each of 1988 and 1989, which were years of major drought. Payments for droughts in 2001 and 2002 were \$570 million and one billion, respectively (Bonsal et al., 2003). The drought of 2003 may result in payments of similar magnitude.

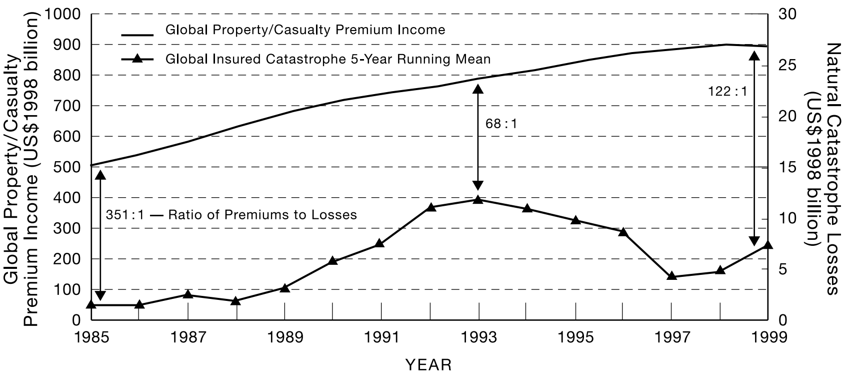

Figure 8.2. Global Insured Weather-Related Catastrophe Losses vs. Property/ Casualty Premium Income

Source: IPCC, 2001a.

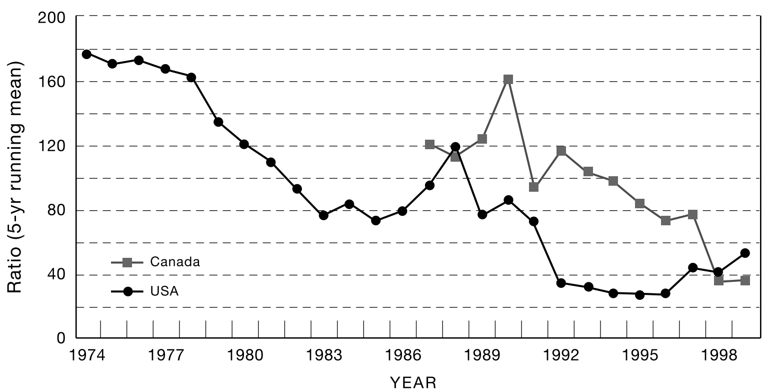

Figure 8.3. Ratio of Property/Casualty Premiums to Insured Weather-Related Catastrophe Losses in Canada and the US

Source: IPCC, 2001a.

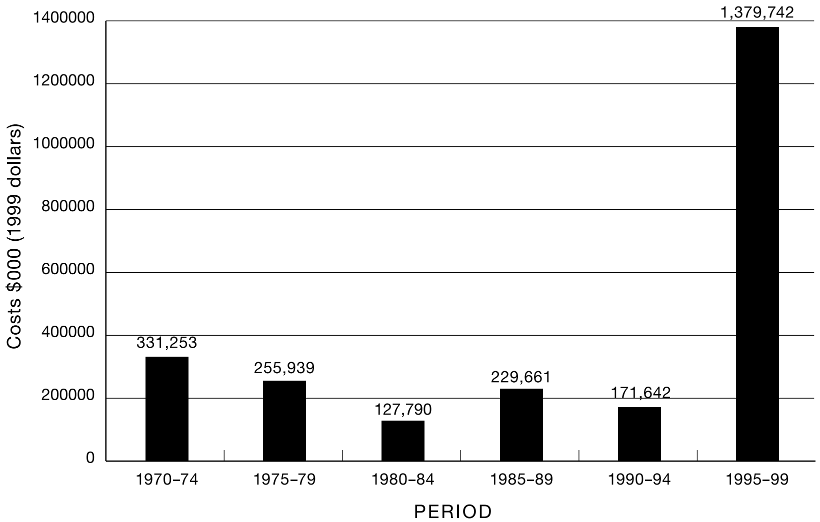

Figure 8.4. Audited Totals of Claims Made under Disaster Financial Assistance Arrangements (DFAA)

Source: Data from Office of Critical Infrastructure Protection and Emergency Preparedness.

Note: These figures do not include costs of provincial assistance to sub-DFAA threshold events (i.e., less than $1 per capita provincial population).

Both public and private sectors are now considering how better to mitigate their losses in the future, by creating more disaster-aware and resilient communities. In Canada, the main process by which the insurance industry works towards this goal is through research and lobbying efforts by the Institute for Catastrophic Loss Reduction (www.iclr.org), which held a series of workshops across Canada in 1998 in order to develop a national mitigation strategy (ICLR, 1998). The following principles underlie their approach to mitigation:

- The threat of severe weather is increasing; nevertheless, sustained action can reduce catastrophic losses. Hazard assessment and risk identification are cornerstones of catastrophic loss mitigation.
- Solid, applied research provides an essential foundation for effective action to reduce future losses.
- Those who knowingly choose to assume greater risk must accept an increased degree of responsibility for their choice.
- Communication with the public before a peril strikes is an important means of reducing losses.

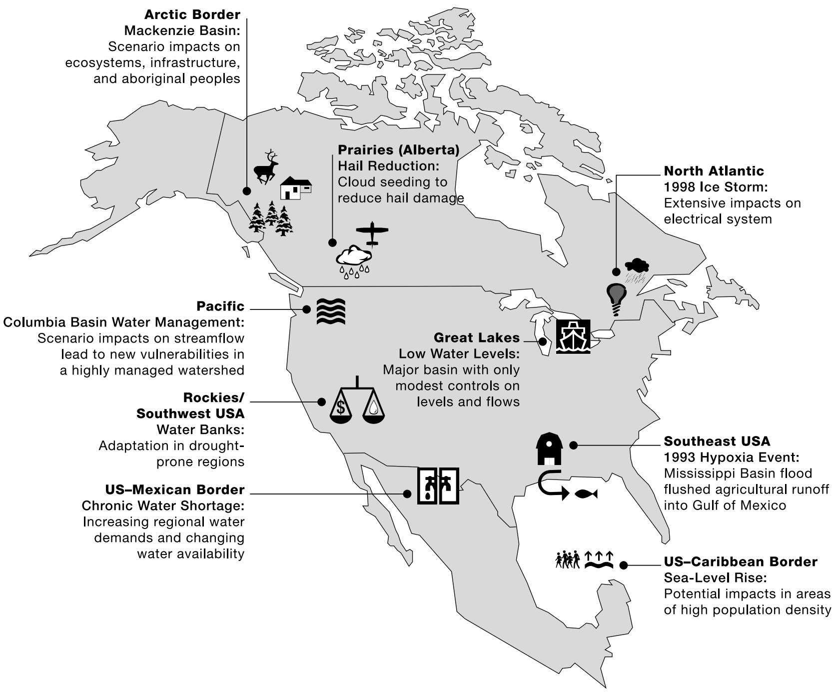

Figure 8.5. North American Impacts and Adaptation Cases
Source: IPCC, 2001a.

Canada's national park system is predicated on natural regions defined in part by vegetation classification. Using results from equilibrium global vegetation models driven with multiple climate change scenarios, Scott et al., (2002) examined potential changes in biome representation in Canada's national parks. Regardless of the vegetation-modelling scenario used, substantial changes in biome representation occurred in the national park system. In five of six vegetation scenarios, a novel biome type appeared in over half of the national parks (e.g., grasslands developing in a park dominated by boreal forest). The proportional representation of biomes in the national park system also changed, with diminishing representation of northern biomes (tundra, tundra/taiga, and boreal forest) and additional representation of more southerly biomes (temperate evergreen and temperate mixed forests in particular). Although equilibrium vegetation modeling results can only indicate the magnitude and probable trajectory of vegetation change, and cannot predict the eventual future distribution and composition of biomes in Canada, these and other vegetation modelling results (Neilson, 1998; Cramer et al., 2001) demonstrate that a reassessment of the system plan is necessary to consider contingencies for climate change.

Policy and planning sensitivities also exist at the individual park level. For example, the stated purpose of Riding Mountain National Park (RMNP) is to "Protect for all time the ecological integrity of a natural area … representative of the boreal plains and mid-boreal uplands." As Figure 8.6 illustrates, the park's mandate would be untenable in the long term as vegetation modelling projects the eventual loss of boreal forest in the park.

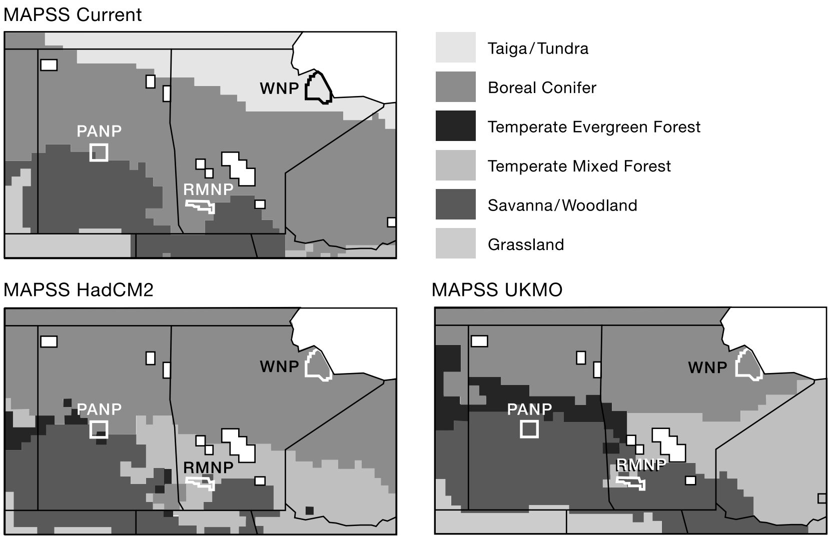

Figure 8.6. Implications of Potential Biome Shifts in Canada's National Parks

Riding Mountain National Park (RMNP), Prince Albert National Park (PANP), and Wapusk National Park (WNP). MAPSS global vegetation model (Neilson, 1995) run with current climate conditions and forced with Had CM_2-ghg and UKMO doubled-CO_2 climate change scenarios (see Scott et al., 2002 for details).

Source: Scott et al., 2002.

Superimposed on the projected biome distribution change would be a range of other regional climate change impacts that will also affect the ecological integrity of the national parks (see Scott and Suffling, 2000, for a summary). For example, of the nine national parks with coastal areas on the Atlantic Ocean, seven were rated as highly sensitive or moderately sensitive to physical changes resulting from projected sea level rise, including coastal erosion and salinity changes that could possibly degrade some key marine, dune, tidal pool, salt marsh, and estuary habitats. In Canada's Arctic parks, projected changes in growing season, permafrost, insect regimes,

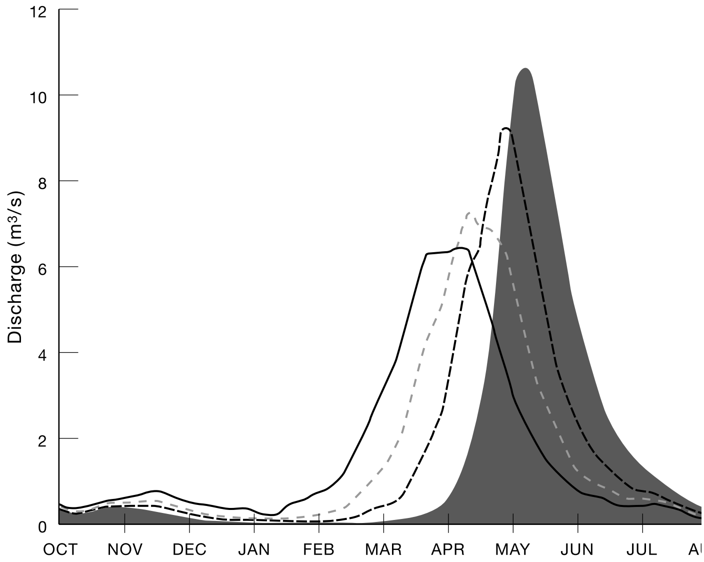

Figure 8.7. Impacts of Climate Warming on Discharge (cubic metres/second) at Dave's Creek, Okanagan Region, British Columbia

Based on IS92a emissions scenario and resulting climate change projection from the Canadian climate model CGCM1. POR = Period of record. Emissions scenarios are described in chapter 2.

Source: Hamilton, 2001.

peak flows and reduced annual flows, which would affect the reliability of the water management system to meet various goals, including provision of irrigation services, firm energy production, flood control, and "biological flow" to support fish habitat. Despite a high level of development and management in the basin, vulnerabilities would still exist and impacts could still occur (Cohen et al., 2000).

A dialogue on adaptation challenges and opportunities in the Columbia Basin has recently been initiated by the University of Washington (Miles et al., 2000) and the Sustainable Fisheries Foundation (SFF, 2002). A case study on adaptation in the Okanagan region is also focusing on dialogue with regional water interests as a way of bringing researchers and stakeholders together to share knowledge and generate new ideas about ways to adapt to the uncertainty of climate change. In the Okanagan, the prospects of an earlier spring snowmelt accompanied by a longer growing season and lower minimum streamflow present a challenge. Preliminary discussions with Okanagan stakeholders have revealed a wide array of views about how the region might adapt to climate change, with a preference synoptic classification method (Kalkstein et al., 1998) that associates air mass types with elevated mortality (relative to normal or average daily mortality for that location). Heat *alerts* are issued by the Medical Officer of Health when an oppressive air mass is forecast and the probability of excessive mortality is greater than 65%; the Mayor declares a heat *emergency* when a 90% or greater probability of excess deaths is predicted (City of Toronto, 2002).

The new, synoptic-based alert system was piloted during the summer of 2001. Four alerts were issued, covering a total of six days in June, July, and August, and a heat emergency was declared for three additional days in August (City of Toronto, 2002). The alert/emergency days are shown in Figure 8.8 together with Environment Canada humidex advisory days and temperature data for a downtown Toronto observing station. Between May 1 and September 30, daily maximum temperatures reached or exceeded 30° C and corresponding minimum temperatures failed to drop below 20° C on 15 days. From August 6–9 the daily maximum temperature exceeded 35° C.

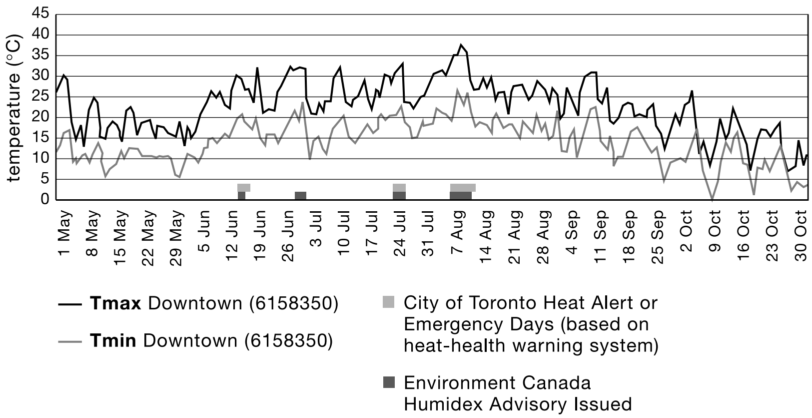

Figure 8.8. City of Toronto Heat Alert/Emergency Days, Environment Canada Humidex Advisory Days, and Temperature Data for a Downtown Toronto Observing Station (MSC-6158350) May–October 2001

Source: Authors.

Media reports identified heat as a contributing factor in five deaths in or near Toronto (Jones, 2001a, 2001b). Over 500 calls to the Red Cross heat information hotline were received during the alert and emergency days—21 of these led to patients being transported to hospital emergency departments by Toronto Emergency Medical Services (City of Toronto, 2002).

Over 1,000 people took advantage of the four cooling centres that were opened during the August 7–9 heat emergency (City of Toronto, 2002).

The heat-health warning system was deemed a success given that the actual death toll appeared to fall below the predicted excess four to five deaths per day during the heat emergency (Jones 2001b). Media reports suggested that the lack of increased demands for hospital emergency room services during the June and July alerts and again during the final two days of the August 7–9 heat emergency—relative to the first day—also indicated the program's success and people's willingness to adopt protective measures (Jones, 2001a, 2001b). While the anecdotal reports in the media are positive and useful feedback, it is important that rigorous evaluations be completed using hospital records and other data over several years to demonstrate the utility of this adaptive strategy.

Green Roof

Urban areas are sensitive to extremes of precipitation and extreme heat. Extreme precipitation events can result in flooding but more commonly in a strategy called combined sewer overflow (e.g., using the sewage system to handle the overflow runoff from storms, flushing pollutants from sewage into a receiving water body). Extreme heat in the summer can increase the rate of smog formation, triggering respiratory problems, heat stress, and increased consumption of electricity for air conditioning, which, if generated by coal or oil, will increase fossil-fuel emissions and air pollution. The sensitivities result from the replacement of vegetation with surfaces that are impervious to moisture and absorb more solar energy than plants, thus re-radiating more energy as heat.

Figure 8.9. Green Roof, Toronto City Hall
Source: photo by The Cardinal Group, Inc.

Green roof infrastructure provides an opportunity to replace part of the vegetation surface (fig. 8.9). Using green roof infrastructure to reduce the urban heat island is important for several reasons. Rooftops provide additional space for vegetation to complement urban forestry, and in high-density commercial areas roofs may provide far more surface than is available for trees at ground level. Roof and pest resistant (a contentious strategy given environmental and food-safety concerns), and greater reliance on a mix of crops that includes livestock, also featured prominently as adaptation strategies. Interestingly, greater use of chemical fallow was more likely to be adopted than increased tillage fallow as an adaptation strategy for conserving soil moisture. Farmers indicated they would be unlikely to rely more on irrigation, likely because irrigation is not generally practiced in Canada's grain belt (with the exception of southern Alberta). Somewhat surprisingly, farmers indicate that they would not increase plantings of crops grown in the US Corn Belt, despite its projected shift towards the north and west into Canada (fig. 8.10)

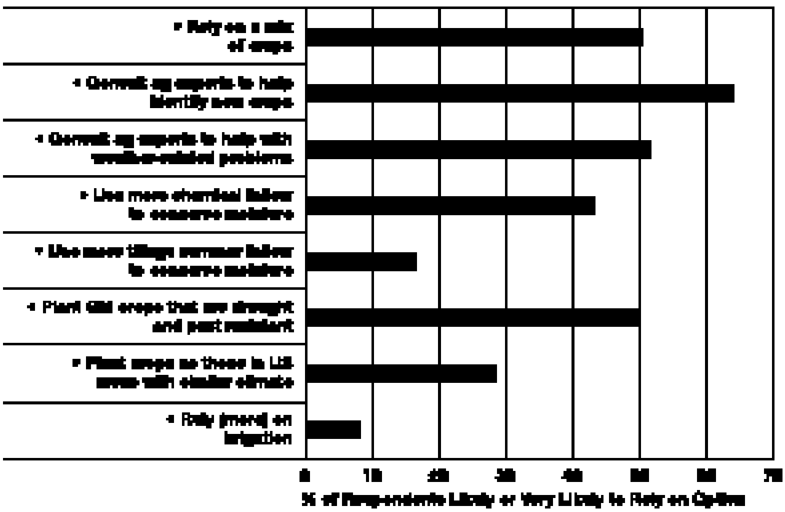

Figure 8.10. Results of Prairie Agriculture Adaptation Survey
Source: Suchánek, 2001; van Kooten et al., 2002.

Can Adaptation Play on Canada's Climate Change Team?

The ultimate objective of any response to climate change is the avoidance of "dangerous anthropogenic interference" with the atmosphere. Reduction of greenhouse gas emissions has attracted much of the attention of decision makers and the public, and there are a number of opportunities and challenges associated with successfully reducing emissions. Any definition of "dangerous" is a value judgment that will vary according to the context of individual places, societies, and economies. Through the vignettes presented in this chapter, we have tried to show that vulnerabilities and develop and demonstrate new technologies that promote sustainable development, with initial emphasis on technologies that mitigate, substitute, or sequester greenhouse gas emissions.

Conclusions

As the emission reduction policy debates continue, significant climate change impacts are appearing in Canada, consistent with climate models' projections of changes due to increasing levels of greenhouse gases in the atmosphere. Some of these observed and projected changes, and their impact in Canada, most severely in the Arctic and Prairies, are documented in chapter 4. It is recognized that Canada's emission reductions alone will have only a very minor impact on rates of climate change. However, it is also increasingly accepted that working together with other countries under international agreements, the Framework Convention and Kyoto Protocol, can begin to make a difference.

Kyoto is only a first small step towards stabilizing both greenhouse gas concentrations in the atmosphere and global climate. However, successful environmental agreements, on ozone layer depletion, acid rain, pollution of the Great Lakes, among other issues, have all started with a small step and expanded as needed. The first step is often the most difficult, and this is proving especially true for the issue of anthropogenic climate change since actions affect the energy base of the world's economy.

Notes

1 As of September, 2000.
2 Article 3, UN Framework Convention on Climate Change [1992].
3 For the Kyoto Protocol to become internationally binding law (i.e., enter into force), two conditions must be met: at least 55 countries need to ratify the Protocol (done) and the countries that have ratified must represent at least 55% of the developed countries' emissions. This second condition has not yet been met.
4 Canada ratified the Kyoto Protocol on 17 December 2002, after a Parliamentary vote.
5 Russia, along with other countries whose economies are in transition to a market-based economy, suffered a decline in economic production in the 1990s and, by virtue of the agreements related to Kyoto will be a net seller of carbon allowances for the first commitment period (2008–2012).
6 kt CO_2 equiv. is 1000 tonnes of CO_2 or other greenhouse gases with global warming potentials (expressed as CO_2 equivalents).
7 The National Secretariat until May 2002 was co-chaired by the province of Alberta and the federal government. Following the May 2002 meeting of min-

isters, which rejected Alberta's proposal to have its alternative plan included formally as part of the pre-ratification discussions, Alberta resigned its position as co-chair of the National Secretariat.

8 Targets that reduce the amount of GHG emitted per unit of production. These rate-based targets can contribute to reducing emissions intensity but may not reduce total emissions if production continues to rise.

9 Six economic models, including Norwegian (CICERO), Australian (ABARE), and US (MIT and Yale) models, show that with the US out of the Protocol the projected price of CO_2 emissions per tonne in 2010 would fall from a range of $15–44 US to as low as <$1–$23.

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