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An Introduction to Climate Change

A CANADIAN PERSPECTIVE

Canada

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An Introduction to Climate Change

A CANADIAN PERSPECTIVE

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Introduction

TO THE BEST OF OUR KNOWLEDGE, Earth's atmosphere is unique in its ability to support life. It provides the oxygen, water vapour, and carbon dioxide needed to sustain the biological processes within the Earth's surface ecosystem. It contains a protective high-level ozone layer that acts as a screen against harmful ultraviolet radiation from the sun. Moreover, its constituents include gases that serve as an insulating blanket around the planet, keeping surface temperatures within the range necessary for the presence of liquid water and, hence, life as we know it. Each of these factors is essential to the presence of living things, and all have persisted for millions of years.

Scientists have long recognized the importance of the earth's atmosphere. However, it was not until the late 1960s that we were presented with the first stunning images of Earth from space. These showed a remarkable oasis of blue and white within the broad expanses of a lifeless cosmos – an oasis protected by a thin, fragile mantle of gases. It was a gripping reminder that Earth may indeed be unique and irreplaceable. Various astronauts in the Apollo flights have noted that, from the lunar distance, the Earth's atmosphere appears so thin that it is virtually unobservable – a resource that humans need to learn to conserve and use wisely.

If these observations about the Earth's atmosphere were timely forty years ago, they are even more relevant now. The scientific evidence is increasingly clear that the Earth's atmosphere is undergoing major changes. These changes have in some respects already exceeded the limits of the natural atmospheric fluctuations of at least the past 100 000 years, and they are projected to become significantly larger with time. They appear to be directly linked, not to some external changing force at work upon the planet but to a global-scale geophysical experiment unwittingly commenced from within by humankind, an uncontrolled experiment that could change the global ecosystem beyond anything the Earth has experienced for the last several hundred thousand years.

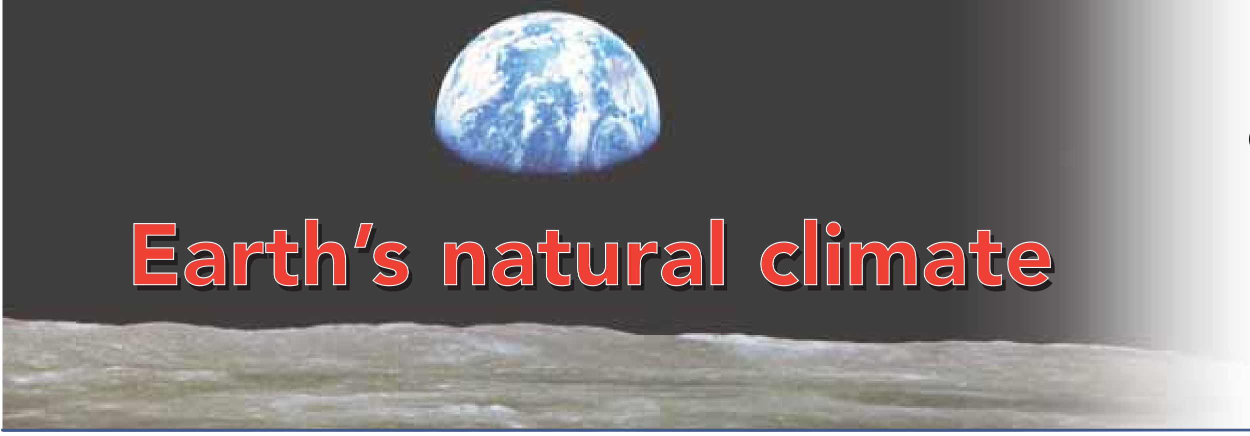
This experiment is a by-product of two factors – rapid technological development and an unprecedented expansion of human population – both of which began in the eighteenth century. Technological development, by utilizing new forms of energy and multiplying productive capacity, has greatly increased the human impact on the environment, not only through greater consumption of resources but also through the creation of vast quantities of environmentally harmful products and by-products. The growth of the global population – from approximately 600 million at the beginning of the eighteenth century to about 6.5 billion today – has compounded these effects, with the result that human activities are now on such a scale as to rival the forces of nature in their influence on the environment.

Associated with these phenomena are rapid changes in land use, increased industrialization, and a voracious appetite for energy. Some of the consequences of these developments – smog, water pollution, and impoverished and contaminated soils – are already painfully obvious on a local and regional scale and have been the object of strong anti-pollution legislation within many countries. On a global scale, however, the effects have been much more subtle, because the damage is being caused by the unnatural release into the atmosphere of gases that are mostly odourless and invisible – seemingly innocent substances, whose effects are not immediately apparent. Only recently have we recognized that the release of these gases is capable of changing the composition of the atmosphere. Because the atmosphere is the Earth's most vital life support system, such changes will inevitably have a major impact on the biosphere.

The changes in the atmospheric composition that are now taking place raise two fundamental global concerns. One is the gradual depletion of the protective ozone layer in the upper atmosphere. The other is the warming of the Earth's surface and lower atmosphere. The latter concern is the subject of this report, which is intended to summarize our current scientific understanding of the processes involved in a changing climate and of the related implications for the global ecosystem, the world community, and Canada.

Chapters 1 to 4 of the report summarize our current scientific understanding of climate change and its global impact. The data in these chapters have been derived primarily from the reports of the Intergovernmental Panel on Climate Change (particularly the third assessment report released in 2001) and key scientific papers published in the international peer reviewed literature in recent years. The Panel's reports represent the most recent and comprehensive assessments of the issue by the international scientific community.

Chapter 5 examines the many possible impacts of a warmer climate on Canada. Much of the information in this chapter is derived from related national assessments. In conclusion, Chapter 6 examines what must be and is being done to respond to this important issue.



CHAPTER 1

Earth's natural climate

Through its constituent gases the atmosphere provides the basic conditions for life on Earth. But it is through climate that it shapes the patterns and helps to set the limits of terrestrial existence. Climate regulates the life cycle of plants and animals, affects their growth and vitality, and is a principal factor in determining how they distribute themselves around the globe. Almost all complex life forms are adapted to live within a specific and often relatively narrow climatic niche.

Thanks in part to technology, human beings have managed to expand their niche to include nearly every part of the globe. Yet even human life remains closely constrained by climatic factors. Settlement patterns, shelters, clothing, agriculture, transportation, and even culture all reflect the deeply pervasive influence of climate.

Climate is commonly defined as average weather. Thus, the climate of a place is the average over a number of years of the day-to-day variations in temperature, precipitation, cloud cover, wind and other atmospheric conditions that normally occur there. But climate is more than just the sum of these average values. It is also defined by the variability of individual climate elements such as temperature or precipitation and by the frequency with which various kinds of weather conditions occur. Indeed, any factor which is characteristic of a particular location's weather pattern is part of its climate.

Although the very notion of climate assumes a long-term consistency and stability in these patterns, climate is nevertheless a changeable phenomenon. The order of change may be small and relatively short – an abnormally cold winter here, a dry summer there. Or – like the great ice ages that have come and gone over thousands of years – it may be on a scale of geological immensity.

Our focus here will be on changes that can be expected to occur over the next few decades and centuries, since it is within this relatively short time span that the first major effects of human induced global warming are likely to be felt. But to understand how these changes are coming about, we must also extend our timeframe and look at the long record of climate change in the past. From this we can obtain a better understanding of the natural variability of Earth's climate and the processes involved in its often spectacular oscillations. Before doing so, however, we need to examine the physical forces that govern the flow of energy through the atmosphere, for it is these that ultimately determine the principal characteristics of our planet's climate.

THE NATURAL GLOBAL CLIMATE SYSTEM

The global heat engine

In a very simple way, the Earth's climate system can be thought of as a giant heat engine, driven by incoming short wave energy from the sun. As the solar energy enters the engine, it warms the Earth and surrounding air, setting the atmospheric winds and the ocean currents into motion and driving the evaporation-precipitation processes of the water cycle. The result of these motions and processes is weather and, hence, climate.

All of the energy entering the climate system eventually leaves it, returning to space as long wave infrared radiation. As long as this energy leaves at the same rate as it enters, our atmospheric heat engine will be in balance and the Earth's average temperature will remain relatively constant. However, if the rate at which energy enters or leaves the climate system changes, the balance will be upset and global temperatures will change until the system adjusts itself and reaches a new equilibrium.

The flow of energy through the system is regulated by certain gases and particles within the atmosphere. Surprisingly, however, the largest constituents of the atmosphere play little or no part in this process. Although 99% of the dry atmosphere is made up of molecules of nitrogen and oxygen (Table 1), these gases are comparatively transparent to radiation and have little effect on the energy passing through them. It is the remaining 1% of the atmosphere, together with water vapour and clouds, that play the major part in regulating the crucial energy flows that drive climate processes. This 1% is made up of a variety of particles and gases that reflect, absorb, and re-emit significant amounts of both incoming solar radiation and outgoing heat energy.

TABLE 1

Concentration of various gases in dry air (% by volume)

Nitrogen	78.08	Helium	0.0005
Oxygen	20.95	Methane	0.00017
Argon	0.93	Hydrogen	0.00005
Carbon Dioxide	0.03	Nitrous Oxide	0.00003
Neon	0.0018	Ozone	Variable

Source: CRC Handbook of Chemistry and Physics. *82nd Edition.

Incoming solar radiation

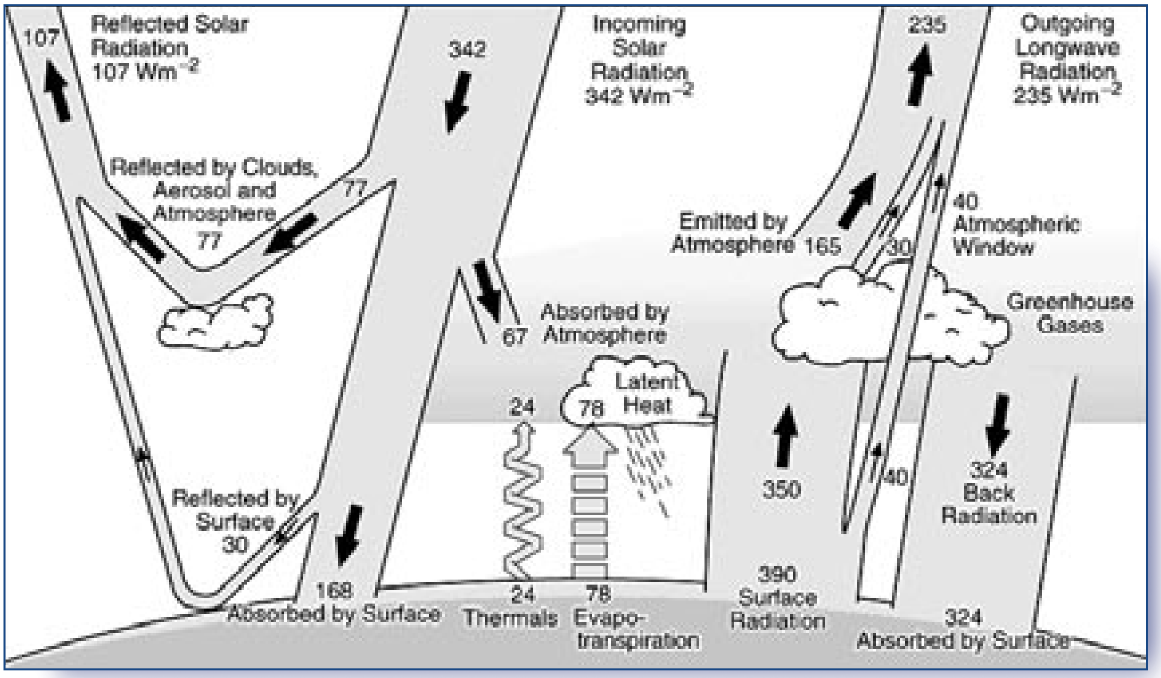
Averaged around the world, the amount of sunlight entering the atmosphere is about 342 watts per square metre (W/m^2). However, about 107 W/m^2 (31%) of this incoming short wave energy is reflected back to space by the atmosphere and the Earth's surface. The remaining 235 W/m^2 (about 69%) is absorbed within the atmosphere and by the Earth's surface as the fuel that drives the global climate system.

The left side of Figure 1.1 shows how this incoming energy is reflected and absorbed by the atmosphere and surface. The processes are as follows:

- ***Reflection by the atmosphere and Earth's surface –*** Clouds and aerosols within the atmosphere reflect and scatter a significant amount of incoming solar radiation back to space. Aerosols are fine particles and droplets suspended for an extended period of time within the atmosphere. Highly reflective aerosols include tiny droplets of sulphuric acid from volcanic eruptions, sulphates from surface fires and industrial processes, salt from sea spray and dust. The amount of shortwave radiation returned to

FIGURE 1.1

Energy flow in the global climate system



Source: Kiehl and Trenberth 1997.

space by clouds and aerosols varies considerably with time and from one location to another. For example, major volcanic eruptions can abruptly produce large amounts of highly-reflecting sulphate aerosols in the stratosphere that can remain there for several years before they settle out due to the forces of gravity. Alternatively, human emissions of sulphate aerosols into the lower atmosphere can significantly increase the reflection of incoming sunshine in industrialized regions compared to less polluted areas of the world. However, observational data indicate that, on average, clouds and aerosols currently reflect about 77 W/m^2 (22.5%) of incoming radiation back to space.

The Earth's surface also reflects a significant amount of incoming sunshine back to space. Like the atmosphere, the amount of reflection depends on the time of year and the location. That is because snow and ice, which cover much of the Earth's surface in mid to high latitudes in winter, are highly reflective. On the other hand, ice-free oceans surfaces and bare soils are low reflectors. However, when averaged over time and space, the Earth's surface reflects 30 W/m^2 (almost 9%) of the solar radiation entering the atmosphere back to space. Hence, in total, the atmosphere and Earth's surface return about 31% of the incoming solar radiation back to space, unused by the climate system.

■ ***Absorption in the atmosphere –*** In addition to reflecting and scattering solar radiation, the atmosphere also absorbs 67 W/m^2 (almost 20%) of this energy. About two thirds of this absorption is caused by water vapour. A second significant absorber is the ozone layer in the stratosphere, which absorbs much of the ultraviolet part of incoming solar energy. Thus, this layer not only protects the Earth's ecosystem from the harmful effects of this radiation but also retains a portion of the sun's energy in the upper atmosphere. About one-tenth of the absorption can be attributed to clouds. Finally, a small fraction of the absorption can be attributed to other gases and to aerosols (particularly dark aerosols such as soot).

Outgoing heat radiation

The Earth's atmosphere and surface, heated by the sun's rays, eventually release all of this energy back to space by giving off long-wave infrared radiation. When the climate system is in equilibrium, the total amount of energy released back to space by the climate system must, on average, be the same as that which it absorbs from the incoming sunlight – that is, 235 W/m^2. However, as this infrared radiation travels towards space, it encounters several major obstacles – primarily clouds and absorbing gases. The right side of Figure 1.1 illustrates the processes involved. These can be described as follows:

■ ***Clouds –*** Besides reflecting incoming solar radiation, clouds also absorb large quantities of outgoing heat radiation. The energy absorbed by the clouds is reradiated, much of it back to the surface. That is why air near the Earth's surface is usually much warmer on a cloudy night than on a clear one. The amount of radiation absorbed and returned depends on the amount, thickness and type of cloud involved.

■ ***Absorbing gases –*** A number of naturally occurring minor gases within the atmosphere, most of which are relatively transparent to incoming sunlight, absorb most of the infrared heat energy being transmitted by the Earth towards space. This absorbed energy is then radiated in all directions, some back to the surface and some upwards where other absorbing molecules at higher levels in the atmosphere are ready to absorb the energy again. Eventually the absorbing molecules in the upper part of the atmosphere emit the energy directly to space. Hence, these gases make the atmosphere opaque to outgoing heat radiation, much as opaque glass will affect the transmission of visible light. Together with clouds, they provide an insulating blanket around the Earth, keeping it warm. Because greenhouses retain heat in somewhat the same way, this phenomenon has been called the *greenhouse effect*, and the absorbing gases that cause it, *greenhouse gases*. Important naturally occurring greenhouse gases include water vapour, carbon dioxide, methane, ozone and nitrous oxide.

The magnitude of the natural greenhouse effect can be estimated fairly easily. Theoretically, the average surface temperature required to release 235 W/m^2 to space is -19°C, but no more. Yet we know from actual measurements that the Earth's average surface temperature is more like +14°C, some 33°C higher. This additional warming is a result of the greenhouse effect. It is enough to make the difference between a planet that can support life and one like the moon that cannot.

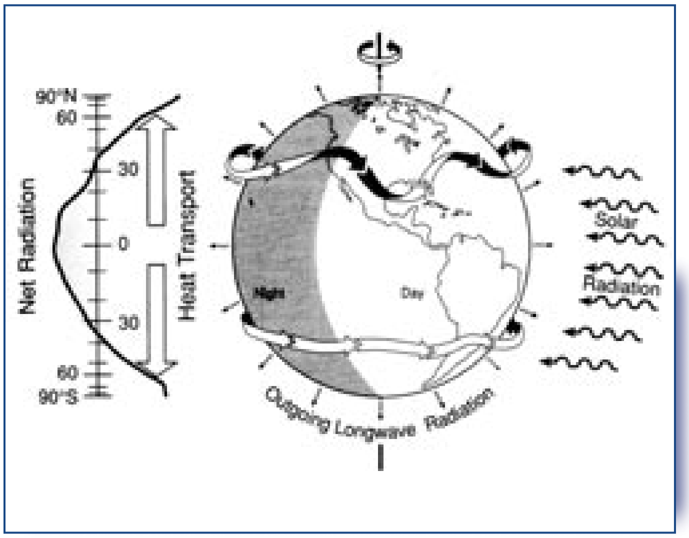
CLIMATIC BALANCE

Climate is ultimately a consequence of the way the atmosphere and the oceans redistribute heat energy that the Earth has absorbed from the sun. Because the intensity of the solar radiation changes with latitude, time of day and seasons, all parts of the planet are not heated equally. The heating effect is greatest in the tropics, where more energy is received from the sun then is re-radiated back to space (Figure 1.2). Temperatures there are subsequently much warmer than the global average and remain consistently within a few degrees of 30°C. At the opposite extreme, the Earth's polar regions experience a net loss of energy to space and temperatures can vary from highs of nearly 20°C in northern polar summers to a low of -60°C in southern polar winters.

This large temperature difference between the tropics and the poles is the primary driving force for Earth's atmospheric winds and ocean currents. Essentially, these carry warm air and ocean waters from the equator to the poles while cold air and ocean waters move in the opposite direction. This flow is modified, however, by the Earth's spin about its axis and the effects of land masses and topography to produce a complex pattern of vertical and horizontal circulation of air masses and ocean waters.

FIGURE 1.2

Net annual heating imbalance by latitude



Source:IPCC SAR WGI 1995.

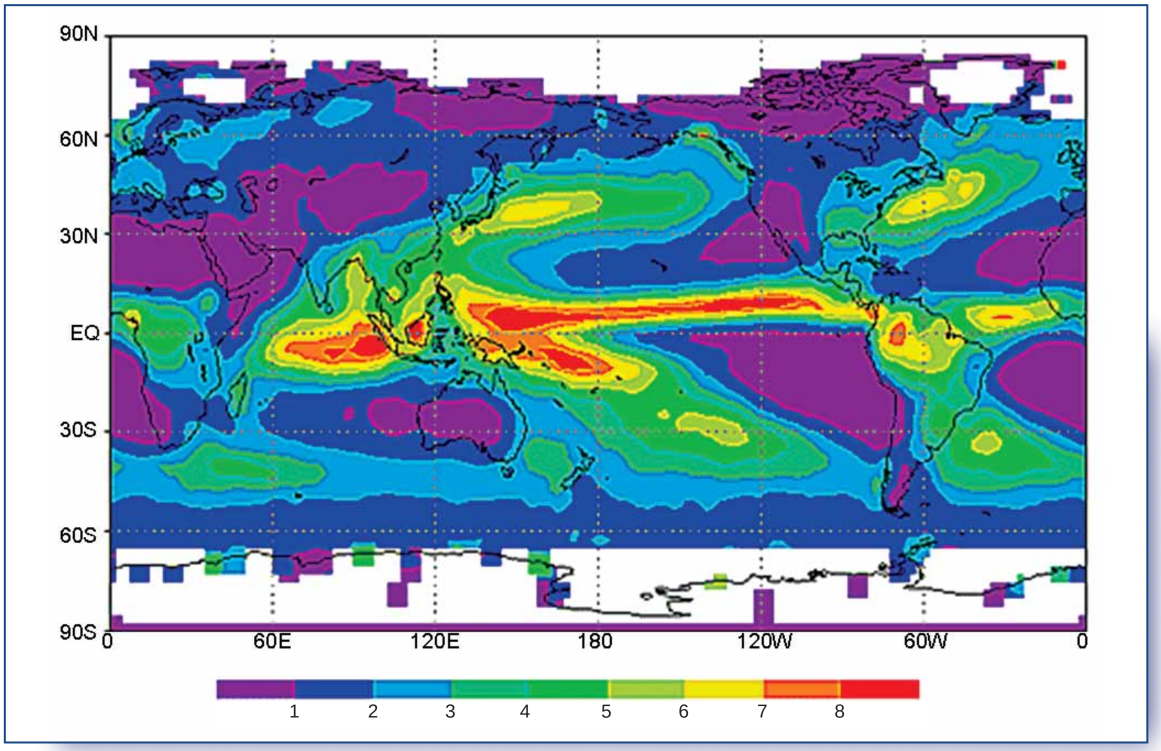
Much of the sun's energy absorbed at the Earth's surface is used to evaporate water from ocean and land surfaces and from vegetation. The more heat at the surface and the warmer the air temperature, the greater the amount of water vapour that can evaporate into and be retained in the atmosphere. However, once air becomes saturated with water vapour, it condenses again into tiny water droplets or ice crystals that form clouds. When the conditions are right, these droplets or crystals fall to the ground as precipitation. Where, when, how much and what type of precipitation falls will depend on the characteristics of a range of local atmospheric and surface factors. Furthermore, since atmospheric moisture is also transported horizontally by air currents, the precipitation patterns that emerge around the Earth are also influenced by the global atmospheric circulation patterns. As a result, the distribution of precipitation around the globe presents an even more complex pattern than that for atmospheric temperature (Figure 1.3). Some areas receive large surpluses of rainfall which support very lush, rich ecosystems, while others do not receive enough to nourish vegetation and so become deserts.

Numerous other factors also affect the Earth's climate. In addition to the circulation of the air, the currents of the ocean and the surface properties that influence evaporation processes, we must also consider the effects of clouds and large masses of snow and ice, the influence of topography and the impact of processes and activities within the biosphere. To these we must add the differences in solar heating, not only between regions, but between seasons and even between night and day.

All of these elements are interconnected, interacting parts of the climate system (Figure 1.4). If a change in one of these parts upsets the balance of that system, it is likely to initiate complex reactions in some or all of the other parts as the system adjusts to establish a new equilibrium. Some

FIGURE 1.3

Estimated distribution of average rainfall over the Earth's surface, in mm/day



Source: NOAA Global Precipitation Climatology Project

reactions occur very rapidly, while others occur very, very slowly. Furthermore, some may increase the initial change (a process known as a *positive feedback*), while others may oppose and partially offset it (a *negative feedback*). For example, anything that changes the amount of solar energy entering the atmosphere or the amount of this energy absorbed by the atmosphere will alter the amount of input energy that drives the climate system. Likewise, a change in the net amount of energy released by the climate system back to space will cause a change in the Earth's cooling mechanism. These initial changes will cause reactions and feedbacks in the rest of the system until it adjusts to a new balance between the incoming and outgoing energy at the top of the atmosphere.

Possible causes for such primary changes in absorbed incoming sunlight or emitted heat energy (called climate forcings) include variations in the concentrations of aerosols and greenhouse gases in the atmosphere, changes in the reflective properties of the Earth's surface, and alterations in the intensity of sunlight reaching the Earth's atmosphere. It is clear from studies of past climates that such changes are constantly taking place – on time scales varying from months to millions of years, and at spatial scales from local and regional to global. Yet, remarkably, reconstructions of past temperature patterns suggest that these natural fluctuations, though sufficient to cause tremendous shifts in global ecosystems, have for many millions of years remained within a relatively narrow margin needed to support terrestrial life.

CLIMATE OF THE PAST

Reconstructing climate

Earth's natural climate system is in fact in a constant state of change. It is a dynamic system. Forces, both internal and external, are continually altering the delicate balances that exist within and between each of its components. Evidence from the Earth's soils, its ocean and lake bottom sediments, its coral reefs, its ice caps, and even its vegetation provides a clear indication that major changes

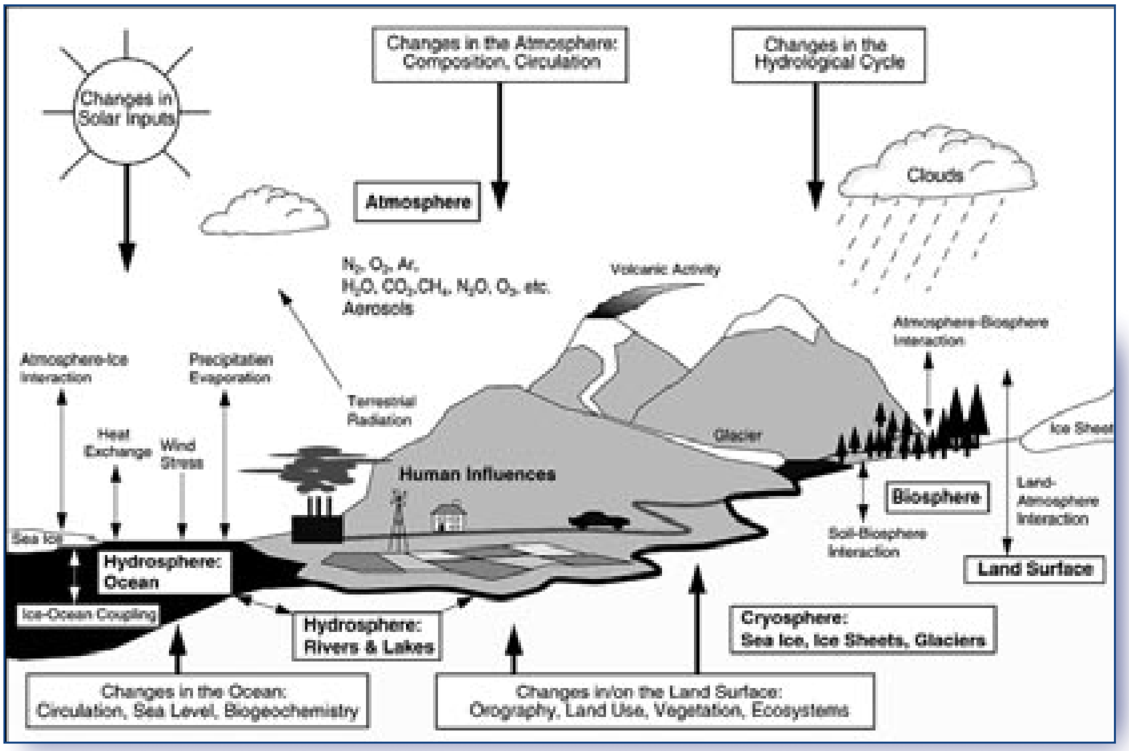


FIGURE 1.4

Complex array of components and feedbacks within the global climate system

Source: IPCC TAR WGI 2001.

in climate have occurred naturally in the past. This evidence also suggests that such changes are likely to occur again in the future.

Our most accurate information about past climates comes from the data collected over the past 100 to 150 years at climate and other observing stations. Recorded by trained observers using precision instruments, this information is not only reasonably reliable but also very comprehensive, covering daily and even hourly variations in conditions over almost all inhabited regions of the globe. Over the past few decades, these data have been complemented by measurements of surface and atmospheric conditions taken by advanced instruments on satellite platforms. Both types of records have become extremely useful databases for identifying and analyzing climate patterns of the past century or so, and even relatively small fluctuations in them.

To study larger climate fluctuations over longer periods of time, science must turn to 'proxy' data sources – that is, indirect evidence from which the nature of previous climate conditions can be inferred or derived. For example, written accounts of weather conditions, especially in regions like Europe and Asia where extensive documentation exists, can provide a useful basis for the analysis of some aspects of climates over the past 1000 years. Though they lack the reliable quantitative data of recent records, these documents can nevertheless yield considerable qualitative information about former climates.

For areas lacking anecdotal records, and for times beyond the last millennium, however, the reconstruction of climate history must rely primarily on the rich supply of paleoclimatic indicators that the Earth itself provides. Plant pollens deposited deep within old bogs, lake and ocean bottom sediments, and even ice caps can bear witness to the nature of growing seasons at the time of their deposition. Residues of aquatic life forms in lake sediments attest to past fresh water temperatures, quality and abundance, while ocean sediments and corals reveal information about ocean temperature and salinity. Old beaches indicate former shorelines and hence sea levels. Even the air pockets fossilized within the frozen ice sheets of polar and alpine regions tell of the composition of ancient air masses, while the ice that surrounds them provides information about their temperatures and about the atmospheric transport mechanisms that influenced them. Tree rings, soil composition and structure and the vertical thermal profile of the Earth's crust also tell their stories. From this varied and spotty assortment of clues, paleoscientists have given us enough information to construct a relatively continuous, though admittedly fragmented picture of the world's surface temperature patterns and trends over the past one million years and beyond.

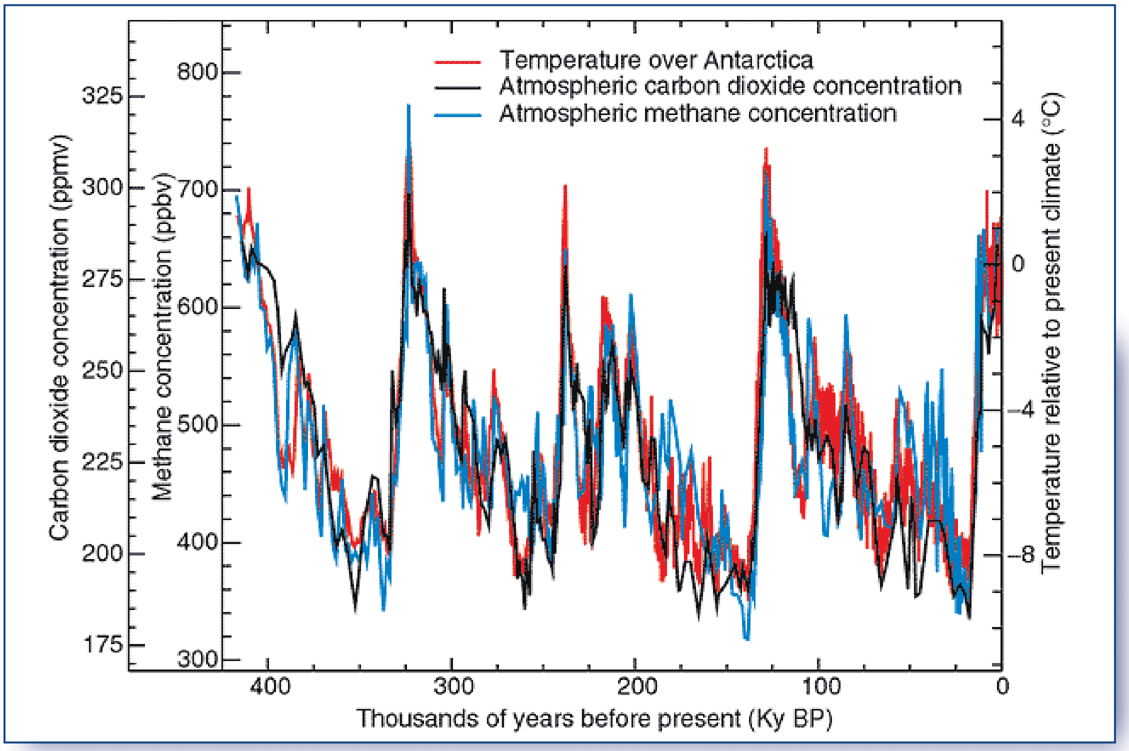
The past million years

Some idea of the history of Earth's climate behaviour during the past one-half million years can be gleaned from temperature records for Antarctica reconstructed from ice core data (Figure 1.5). Temperatures during much of this period seem to have followed a cycle of long-term, quasi-periodic variations. Extreme minimum temperatures, corresponding to major global glaciations, appear to have occurred at roughly 100 000-year intervals. Each of the glacial periods has then been followed by a dramatic 4-6°C warming to an interglacial state. Within this 100 000-year cycle, smaller anomalies have occurred at approximately 20 000 and 40 000-year intervals.

Many theories have been advanced to explain these temperature variations. The most widely accepted hypothesis for explaining the variations that occur on time scales of about 20 000, 40 000 and 100 000 years is changes in the wobble (called precession) and tilt (obliquity) of the Earth's rotation axis relative to Earth's orbit around the sun, and the ovalness (eccentricity) of that orbit, respectively. These changes affect the seasonality and latitudinal distribution of incoming sunlight around the Earth. However, while the large glacial-interglacial cycles that occur at the 100 000 year time scale correlate well with changes in orbit eccentricity, the forcing caused by those changes is far too weak to fully explain these cycles. Hence, various feedback processes appear to significantly amplify this forcing.

FIGURE 1.5

Trends in Antarctic temperature and greenhouse gas concentration over the past 420 000 years



Source: IPCC TAR WGI 2001

Recent analyses of Antarctic and Greenland ice cores also indicate a strong correlation between past long-term changes in climate and the natural atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), all important greenhouse gases. As Figure 1.5 indicates, the correspondence between atmospheric carbon dioxide and methane concentrations and local Antarctic temperatures during the past 420 000 years has been remarkable. This relationship would suggest that one of the primary feedback mechanisms that amplify long-term external changes to the atmosphere's energy balance, like those caused by orbital cycles, may involve the greenhouse effect.

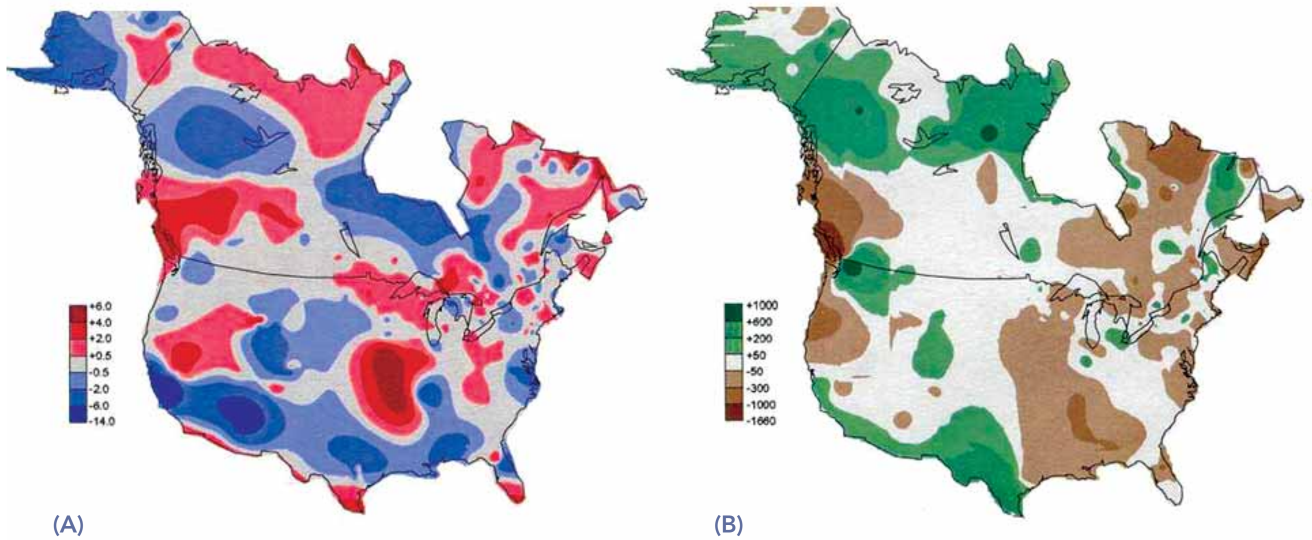
The current interglacial period, often referred to as the Holocene, has now existed for more than 10 000 years. During this period, temperatures in at least some parts of the world, particularly during summers in mid to high latitudes of the Northern Hemisphere, peaked at about 5000 to 6000 years before present (YBP) and have cooled slightly since then. This interglacial warm peak is commonly referred to as the Holocene maximum.

However, it remains uncertain as to whether this warm peak also occurred in low latitudes. In fact, recent model studies suggest that changes in solar insolation during the mid-Holocene would have favored warmer summers but cooler winters, and that global annual mean temperatures at the time may have actually been slightly cooler than today.

These slow millennial scale changes in global climate have also imposed a number of vastly differing climates on what is now Canada. By examining these variations, we can also better put Canada's present climate in context and find clues pointing to the kinds of changes it might undergo in the future. These suggest that the pattern of change can be complex, with some parts of Canada's summer climate being significantly warmer, drier and windier 6000 years ago than that of today, and other parts being cooler and wetter (Figure 1.6).

FIGURE 1.6

Estimates of changes in North American July climate between 6000 years ago and today, based on pollen data analyses



(A)
Temperature (°C)

(B)
Precipitation (%)

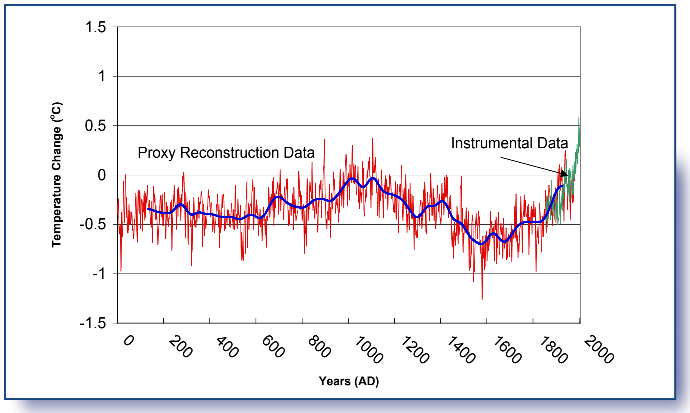
Source: Gajewski et al. 2000.

The last 2000 years

Figure 1.7 illustrates how average temperatures of the Northern Hemisphere have likely varied during the past 2000 years. Based on several studies using multiple proxy data sources at many different locations around the world, it suggests that average temperatures today are now warmer than at any previous time during the past two millennia. However, current temperatures are still perhaps 1-2°C cooler than the peak of the last interglacial of 135 000 YBP.

FIGURE 1.7

Reconstruction of Northern Hemispheric mean annual temperatures for the past 2000 years based on multi-proxy data analyses



Source: Moberg et al. 2005

For fluctuations on shorter century time scales, there have been encouraging results from efforts at correlating changes in solar irradiance cycles with temperature patterns. Such comparisons, for example, indicate that solar forcing may have been a key factor in triggering the 'little ice ages' that have occurred during the current Holocene. Likewise, much of the variations in climate over the past three hundred years appear to be closely linked to solar variability. However, the mechanisms by which relatively small change in solar irradiance can significantly affect climate are as yet not well understood.

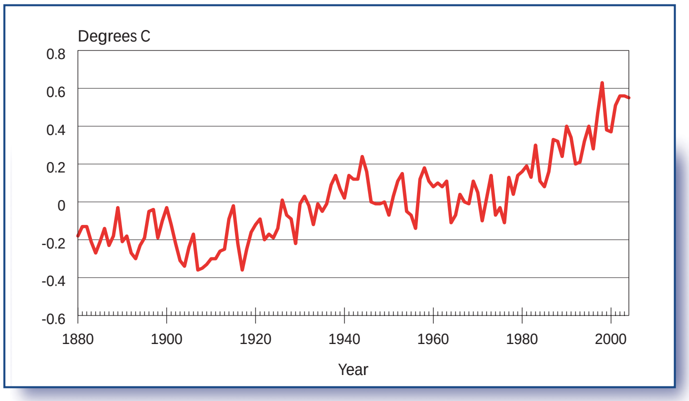
While Figure 1.7 indicates that Northern Hemispheric temperatures during the Medieval period of about 1000 years ago were, on average, likely still cooler than today, some regions may have been somewhat warmer than today. Studies suggest these regions include western Europe, Greenland and eastern Canada. Since this 'Medieval Warm Period' lasted several hundred years, treelines and other natural vegetation boundaries gradually moved northwards. Milder Arctic climates brought substantial decreases in sea ice cover. These conditions may have encouraged not only the migration of Inuit within the Arctic but also the survival and settlement of the European Vikings in Iceland and Greenland. Vikings appear to have navigated freely throughout much of the Canadian archipelago, and in Greenland they were able to carry on a viable agriculture. Ironically, European attempts from the seventeenth to the nineteenth centuries to find a northwest passage to India failed. This was primarily because they began after the Medieval Warm Period gave way to the Little Ice Age, which lasted from 1400 to about 1850 AD. If only Franklin had tried his passage six centuries earlier! Since regional temperatures have now returned to something similar to the Medieval Warm Period, it is likely that the vegetation and ice regimes that prevailed years ago will return, even if climates do not become any warmer than they are now.

The last hundred years

Climatic change during the past century can be studied with much greater precision than earlier periods, thanks to the existence of a large body of scientifically collected climate records. These records make it possible to analyze both the spatial and temporal patterns of change in significantly finer detail and with a smaller margin of error. Studies of these records show that, even within the relatively short span of a century, global climate has experienced noticeable variations (Figure 1.8). Average temperatures over southern Canada for these years show much the same broad pattern as global temperatures — a warming until the early 1940s, then a moderate cooling until the mid-1970s, followed by a renewed and pronounced warming continuing through the 2000s (Figure 1.9). Temperatures in the 1990s were among the warmest on record, with 1998 being the warmest individual year on record for both Canada and the world. The variability in the warming also holds true for the temperature records that cover all of Canada since 1950.

FIGURE 1.8

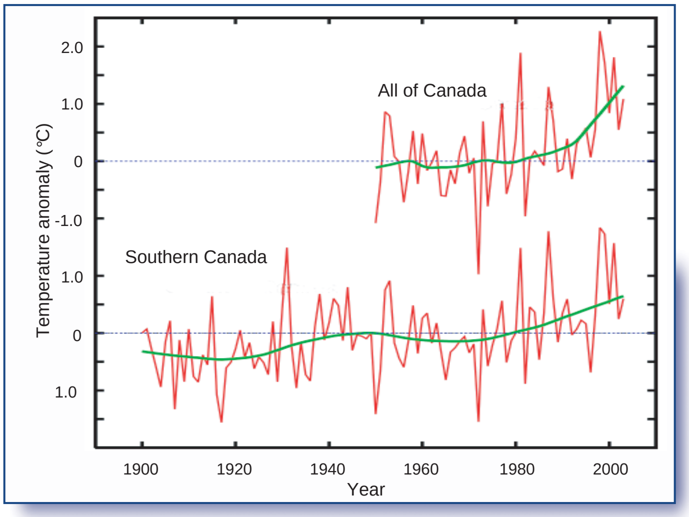
Observed changes of average global surface temperatures since 1880.



Data source: NOAA

FIGURE 1.9

Observed trends in temperatures across southern Canada since 1900 and all of Canada since 1948

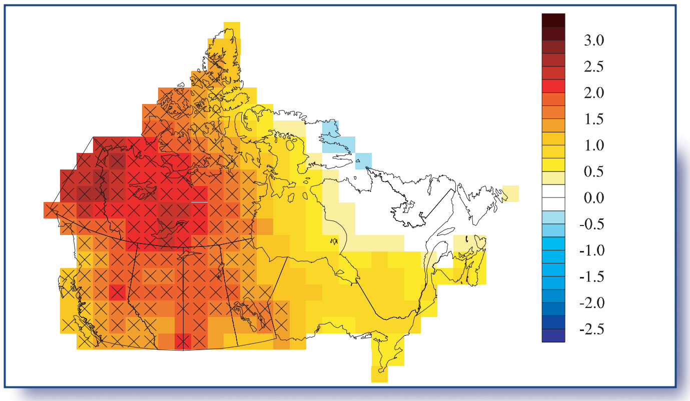


Source: Zhang et at. 2000 (updated 2005)

While Canada as a whole has experienced an increase in temperature of slightly more than 1°C over the last 54 years, this temperature increase has not been evenly distributed across the country. Some regions, like the Yukon and Northwest Territories, are experiencing greater warming, whereas over Baffin Island in the eastern Arctic there has actually been some moderate cooling (Figure 1.10).

FIGURE 1.10

Regional distribution of linear temperature trends (°C) observed across Canada between 1948 and 2003



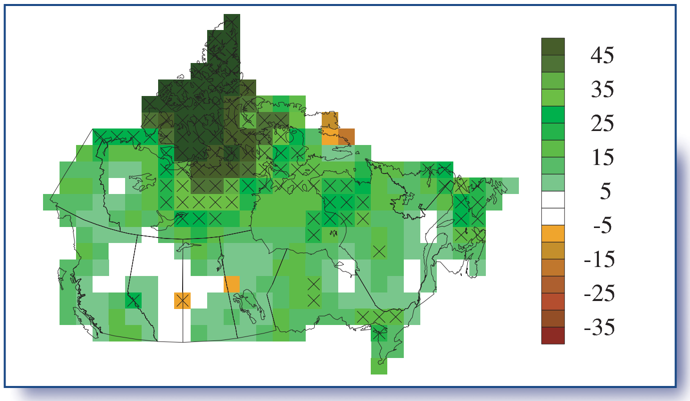
The symbol X indicates areas where the trends are statistically significant.

Source: Zhang et at. 2000 (updated 2005)

Precipitation patterns have also changed. For the most part precipitation amounts have increased significantly over the Northwest Territories and Nunavut, with increases over much of the rest of the country. The only exceptions are little to slight decreases in precipitation over the Prairies and over the eastern edge of Baffin Island. (Figure 1.11).

FIGURE 1.11

Regional distribution of linear precipitation trends (%) observed across Canada between 1948 and 2003



The symbol X indicates areas where the trends are statistically significant.

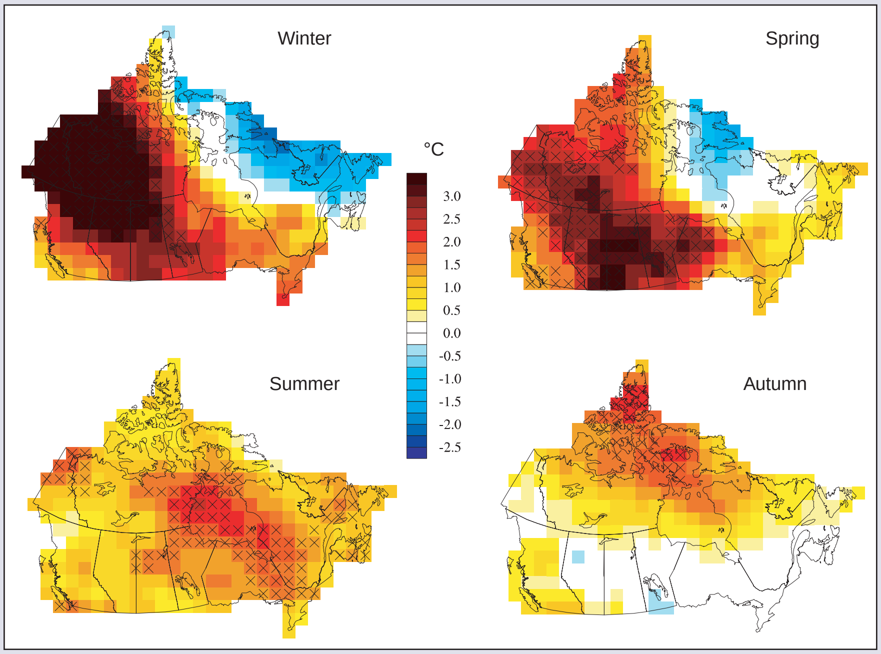
Source: Zhang et at. 2000 (updated 2005)

SEASONAL AND DAILY CHANGES IN CANADA'S CLIMATE

Changes in seasonal temperatures show another aspect of the complex pattern of Canada's temperature trends. When comparing the four seasons, winter and spring show the greatest changes in temperatures, whereas summer and autumn show much smaller changes (Figure 1.12). Regionally, the Prairies show the greatest warming in the spring and show some cooling in autumn. The eastern Arctic experiences the greater cooling in the winter, but conversely shows a warming trend in the summer.

FIGURE 1.12

Trends (in °C) in Canadian climates since 1950, shown by season

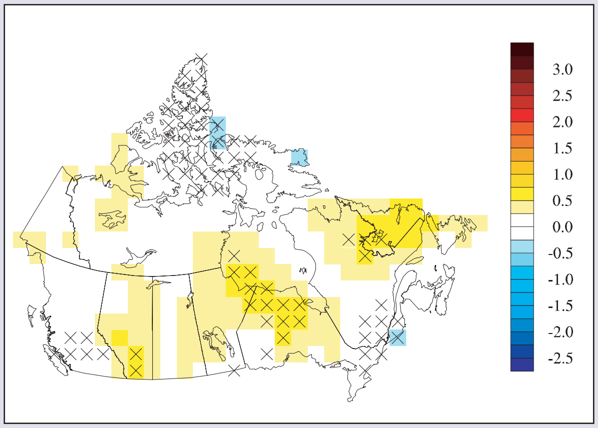


These maps illustrate that, at a regional scale, the national trends to warmer climates have been modified by shifts in seasonal wind patterns. By altering the net flow of cold and warm air masses in different patterns of the country, these shifts have amplified warming in some areas and seasons and offset it in others. This provides an important reminder that future climate change will not be uniform in space or time.

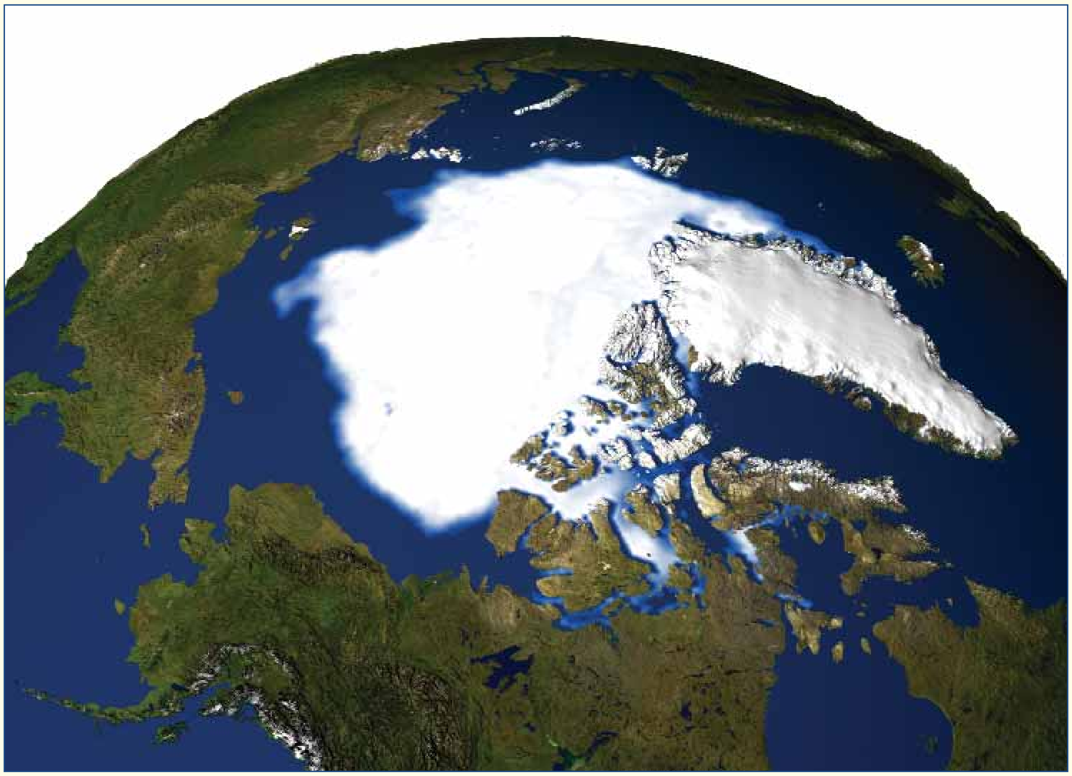
Another way to analyze the changes in temperature is to examine the changes in the maximum daytime temperatures and the nighttime minimum temperatures. When the changes in maximum temperatures are subtracted from the changes in minimum temperatures, the diurnal temperature range (DTR) is calculated (Figure 1.13) The DTR shows that for most of the areas over Canada since 1950, the maximum temperatures have been increasing slightly faster than the minimum temperatures. Only areas in the Arctic islands and southern Quebec have had minimum temperatures increasing faster.

FIGURE 1.13

Change (in °C) in the average annual DTR across Canada since 1950



▲ Observed sea ice in September 1979



▲ Observed sea ice in September 2005

Source: NASA/Goddard Space Flight Center Scientific Visualization Studio

CHAPTER 2

Enhancing the greenhouse effect

Analyses of ice cores extracted from the polar ice caps provide some important clues about the past relationship between the natural greenhouse effect and the Earth's climate. The Antarctic and Greenland cores – the deepest which penetrated more than 2 km beneath the south polar ice – have been especially informative. From them, scientists have reconstructed local temperatures as well as records of carbon dioxide, methane and nitrous oxide concentrations in the polar regions for the past 420 000 years.

When compared, these reconstructed temperature and greenhouse gas records show a remarkable correlation, particularly during the transition from cold glacial periods to warm interglacials (see Figure 1.5 in Chapter 1). The processes that cause this relationship are as yet not well understood. However, most experts agree that changes in solar radiation due to variations in the Earth's orbit around the Sun likely triggered the initial changes in climates. These changes in climate seem to have induced major changes in atmospheric and ocean circulations and in the flux of greenhouse gases into and out of the atmosphere. Because of the role of greenhouse gases in insulating heat loss from the planet, the resultant changes in their atmospheric concentrations played an important part in enhancing the initial changing in climate and thus contributing substantially to the very large magnitude of differences in average global temperatures between glacial and interglacial conditions.

While the ice cores confirm that the concentrations of greenhouse gases vary naturally with time, they also indicate that there are natural limits to these variations. During the past 420 000 years, carbon dioxide concentrations have never gone lower than approximately 180 parts per million by volume (ppmv). Nor, until recently, had they ever gone higher than about 300 ppmv. Likewise, concentrations of methane have remained within a relatively narrow range of 0.3 to 0.7 ppmv.

However, recent measurements of greenhouse gas concentrations over the past several centuries, again obtained from ice cores, reveal that a major departure from past patterns is emerging. This is supported by direct measurements of atmospheric composition trends of the past few decades, which show average carbon dioxide concentrations around the world in 2003 greater than 375 ppmv. As figure 1.5 shows, such levels exceed the highest values of the past 420 000 years by more than 20%. In fact, long term paleo records from ocean sediments suggest these levels may be without precedence in at least the past 20 million years. Meanwhile, methane concentrations appear to have more than doubled over pre-industrial values, while nitrous oxide levels have undergone a more modest increase of 17%. If, indeed, these gases are primary players in the natural greenhouse effect, their increasing concentrations portend a possible enhancement of that effect well beyond the level suggested by the ice core record.

During recent years, intensive research has been devoted to measuring the concentrations of these gases more accurately. At the same time, scientists have been working hard to better understand the processes involved in their release and removal from the atmosphere and to estimate likely concentrations in the future.

CARBON DIOXIDE

Understanding how the amount of carbon dioxide in the atmosphere changes is not a simple task. Carbon dioxide is constantly being removed from the air by its direct absorption into water and by the transfer of the carbon atom to biotic substances through photosynthesis. In turn it is released into the air by plant and animal respiration, decay of dead biomass and soil organic matter, outgassing from water surfaces, and combustion. Small amounts of carbon dioxide are also injected directly into the atmosphere by volcanic emissions, and through slow geological processes such as the weathering of rock.

The more active carbon storage areas within the Earth's ecosystem are the living terrestrial biosphere, the atmosphere and the oceans. These contain about 600, 750 and 39 000 billion tonnes of carbon, respectively. The atmosphere exchanges about 90 billion tonnes of carbon with the oceans each year and approximately 60 billion tonnes per year with the terrestrial biosphere.

The Earth's soils, rocks and carbon based fuels are also large reservoirs of carbon. Estimates suggest that soils may contain up to 1600 billion tonnes of carbon. Fossil carbon fuels contain about 5000 billion tonnes, while rocks store much more (an estimated 75 million billion tonnes). However, these reservoirs, unless unnaturally disturbed, only exchange carbon with the atmosphere very slowly and over thousands to millions of years.

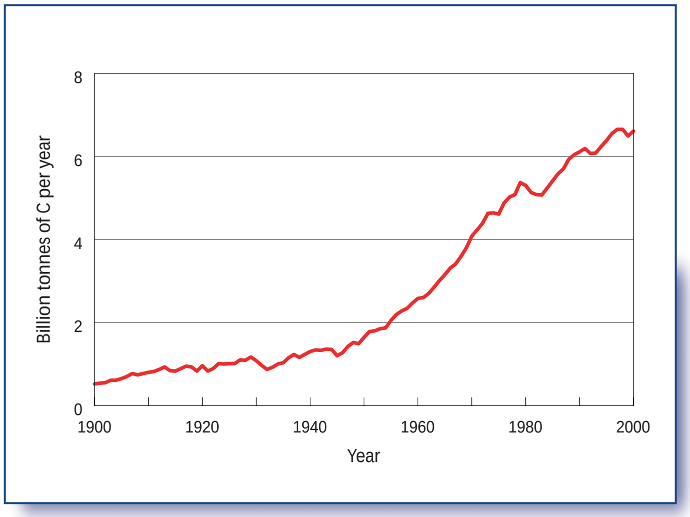
If, over time, more of the carbon in the terrestrial and ocean reservoirs is released into the atmosphere than is removed, a net increase of carbon in the atmosphere (as carbon dioxide) results. Conversely, if more carbon is removed from the atmosphere than released into it, its concentration in the atmosphere decreases. However, the evidence from ice cores indicates that the atmospheric concentration of carbon dioxide has remained relatively constant at 260 to 280 ppmv throughout the past 10 000 years of the current interglacial - until several centuries ago. This means that the natural active flow of carbon between the atmosphere, the oceans and the atmosphere (often referred to as the global carbon budget) has been in remarkable balance. That is, on average, the amount released into the atmosphere each year has been approximately equal to the amount removed again.

Human activities now appear to be significantly affecting this natural balance within the global carbon cycle. This anthropogenic contribution already began more than 8000 years ago, when humans first began to clear lands and cultivate soils to support emerging civilizations. However, rapid human population growth during the past few centuries has resulted in large-scale conversions of forested landscapes to agricultural, urban or other uses. These conversions have released more than 100 billion tonnes of additional carbon into the air over the past century, and have been accelerating in recent decades, primarily due to extensive slash-and-burn activities in the tropical forests of South America, Africa and Southeast Asia. Although new growth from replanted forests in the mid-latitudes of the Northern Hemisphere may be partially offsetting this release, the net biospheric contribution of carbon into the atmosphere directly due to human land use and land use change is estimated at between 0.6 and 2.5 billion tonnes per year.

However, of much greater significance is the ever increasing extraction of fossil fuels (coal, oil and natural gas) from the Earth's crust to meet the energy demands of an increasingly industrialized global society. During combustion, the carbon content of fossil fuels is oxidized and released as carbon dioxide. For every tonne of carbon burned, 3.7 tonnes of carbon dioxide are produced. Production of cement also adds a modest amount

FIGURE 2.1

Carbon content of annual carbon dioxide emissions from fossil fuel combustion and cement production, 1900-2000



(approximately 2%) to these releases. During the 1990s, these sources on average added an estimated 6.4 billion metric tonnes of carbon, or about 23 billion tonnes of carbon dioxide, to the atmosphere each year. This is more than ten times the estimated rate of emissions one century ago (Figure 2.1).

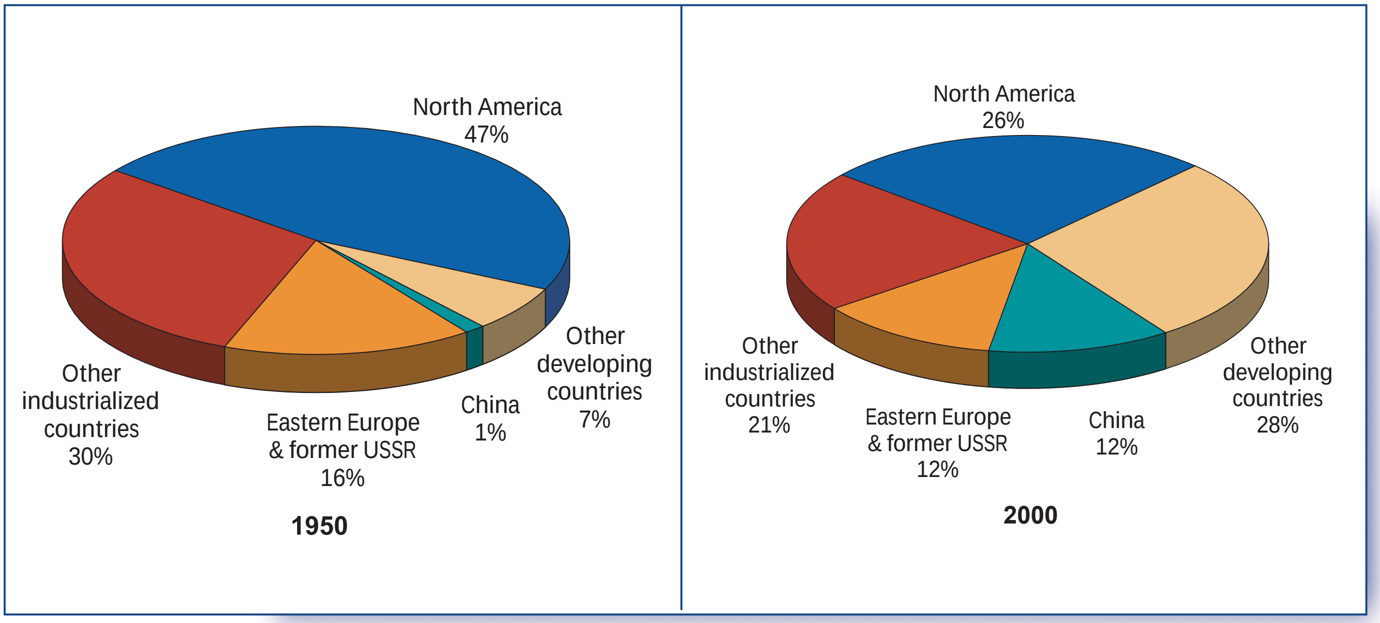
Not surprisingly, the release of carbon dioxide from fossil fuel burning is very unevenly distributed around the world, with the largest share being released by developed countries in the Northern Hemisphere. However, emissions are increasing more rapidly in many of the nations of the developing world (Figure 2.2), particularly in Southeast Asia.

Anthropogenic releases of carbon dioxide are actually relatively small compared to the truly enormous amounts that enter and leave the air each year through natural processes. In fact, human activities annually release about 1/20 of the amount of carbon dioxide produced by nature. However, the human emissions provide a net addition to one side of a global carbon cycle that is already in approximate balance. Over time, this net addition can cause a significant accumulation of excess carbon dioxide in the atmosphere, much like a deficit in a financial budget, repeated year after year, can lead to the accumulation of a large debt.

Over the past four decades, atmospheric carbon dioxide concentrations have been carefully measured at many locations around the world, and the consequences of human emissions are clearly evident in the results. The trends (Figure 2.3) show current rates of increase of about 1.6 ppmv, or 0.4%, per year and a net rise over the past 45 years of 19%. Current concentrations are now about 375 ppmv, more than 30% higher than the pre-industrial concentrations of 280 ppmv observed in ice cores. The observed increase in recent decades is, in fact, significantly less that should have occurred if all carbon dioxide released due to human activities were to remain in the atmosphere. However, approximately 50-60% of more recent anthropogenic emissions appear to be finding their

FIGURE 2.2

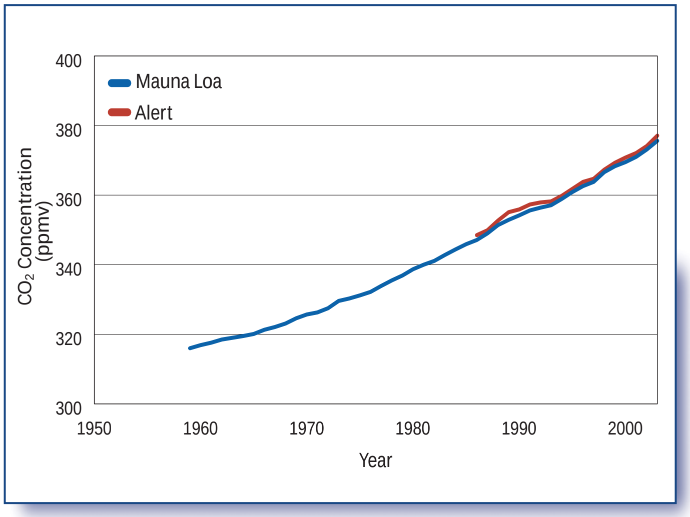
Regional distribution of CO_2 emissions from fossil fuel combustion, 1950 and 2000



Data source: CDIAC online.

FIGURE 2.3

Atmospheric carbon dioxide concentrations since 1959



way back into the natural cycle. Although the net sink for this carbon is not well understood, both the oceans and the terrestrial ecosystems are believed to be important recipients. In other words, the natural uptake of carbon by these systems compensates for a part of the human interference, but only part.

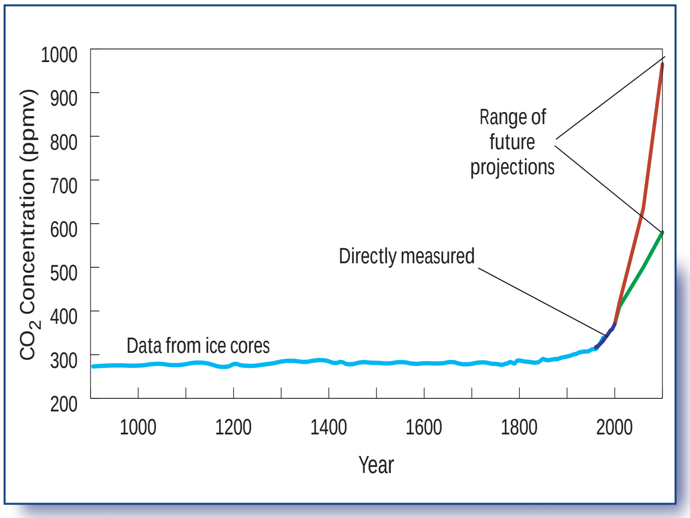
Predicting future concentrations of atmospheric carbon dioxide is very difficult. The largest uncertainty pertains to future rates of emissions from human activities. These will depend on a number of variables. How fast, for example, will the world population grow? Will we use the same types of energy in the future that we do now? Will our energy use be more efficient? How far will developing countries improve their standard of living and hence increase their consumption of energy? Will land use change through deforestation and forest degradation continue to exceed efforts to increase forest productivity? The answers to such questions, in turn, will depend on human decisions, political action, and technological and socio-economic developments that themselves are largely unpredictable. Experts suggest that, when all these questions are considered, annual carbon dioxide emissions from human sources in 2100 could range from a low of 70% (assuming significant improvements in energy efficiency and the extensive use of non- fossil fuel energy sources) to a high of 500% (assuming low improvements in energy efficiency and much expanded use of coal) of that in 1990.

Lesser but still important uncertainties relate to how much of these carbon dioxide releases will be retained in the atmosphere. Will the natural system continue to absorb more than 50% of the human release of carbon dioxide into the terrestrial biosphere and oceans? Or will the fraction remaining in the atmosphere increase with time? The answer is as yet unclear and must await the results of further intensive research and observation of the natural carbon cycle.

Taking these uncertainties into account, our best estimates of future atmospheric concentrations of carbon dioxide yield a range of scenarios. The most pessimistic suggests a possible doubling of concentrations over pre-industrial levels by mid-21st century and a tripling by 2100. An optimistic scenario envisions concentrations slightly below a doubling of pre-industrial levels by 2100 (Figure 2.4).

FIGURE 2.4

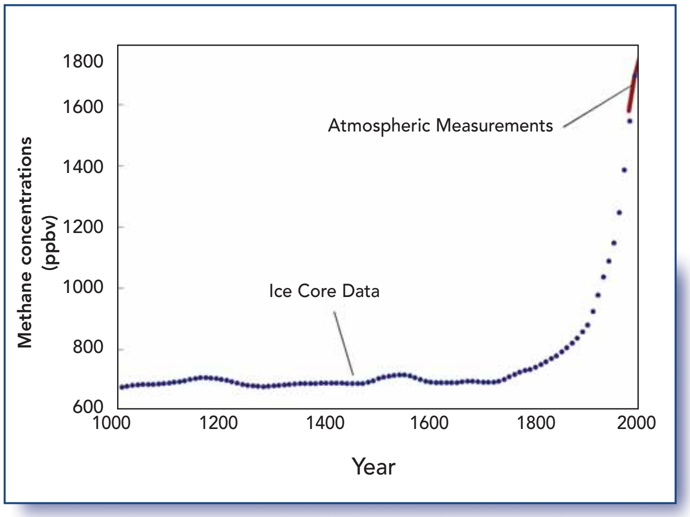
Projections for future atmospheric CO_2 concentrations, relative to concentrations of the past millennium



Data sources: CDIAC on line; IPCC WGI 2001.

FIGURE 2.5

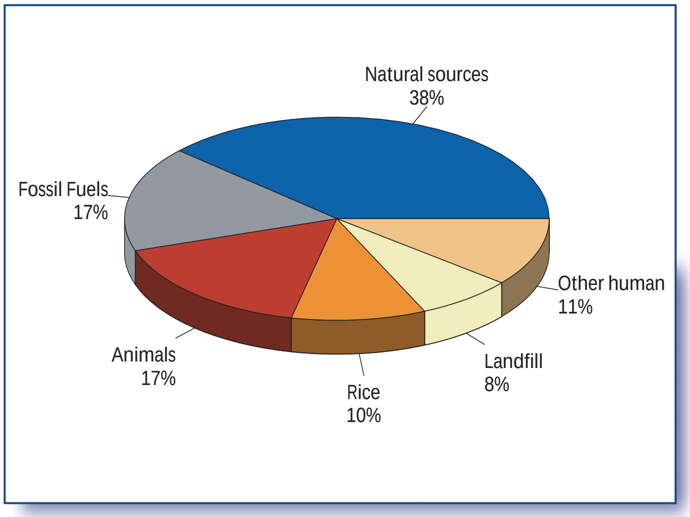
Trends in methane concentrations over the past millennium



Data sources: CDIAC on line

FIGURE 2.6

Estimated contribution of various sources to total global emissions of methane



Data sources: CDIAC on line.

METHANE

Methane (CH_4) is produced naturally by the decay of organic matter in the absence of oxygen. Methane concentrations in the atmosphere have been measured continuously since 1978. These measurements indicate that current concentrations are about 1750 parts per billion by volume (ppbv), which is an increase of about 150% over the pre-industrial concentrations of 700 ppbv noted in ice core records (Figure 2.5). Between 1978 and the early 1990s, concentrations continued to increase at about 10 to 15 ppbv/year. However, they have increased very little in recent years. The reason for this variation is not yet clear. One possible factor may be changes in the rate of human emissions, but there are also indications that changes in natural emissions in high latitudes may be another important factor.

Like carbon dioxide, methane is exchanged naturally between the Earth's surface and atmosphere. Wetlands are a primary source – hence its popular name, "swamp gas." It is also released through the digestive processes of certain insects and ruminant animals, such as termites, sheep and cattle. Although the global area of natural wetlands may actually be decreasing due to human interference, the total acreage of rice paddies appears to be increasing rapidly, while the global population of domestic cattle has quadrupled during the past century. Other sources include industrial processes, fossil fuel extraction, and garbage decomposition in landfill sites (Figure 2.6).

Unlike carbon dioxide, however, methane is removed from the atmosphere primarily through chemical processes involving the chemical hydroxyl radical, OH. These chemical interactions finally produce water and carbon dioxide. A small amount of methane is also absorbed directly by soils.

The increase in methane emissions has been primarily caused by the global growth in agricultural activities and fossil fuel use for energy, which are both linked to the rapid rise in global human population. Since the world's population is unlikely to stabilize for at least the next century, a continuation of these changes and further increases in methane releases can be expected. At the same time, the rate of removal of methane from the atmosphere by natural processes could change, since the abundance of OH is sensitive to changes in air pollution around the world, particularly tropospheric ozone. Despite uncertainties about such changes, experts expect atmospheric methane concentrations to continue to rise for at least the next 50 years. They project that, by 2100, concentrations are likely to be somewhere between about 1500 ppbv (about 15% less than today) and 3700 ppbv (110% higher than today).

OTHER GREENHOUSE GASES

Nitrous oxide (N_2O) concentrations in the atmosphere are now increasing by 0.2 to 0.3% per year. Present levels are about 319 ppbv, or about 17% above pre-industrial values. Although both the natural cycle and the magnitude of human sources of nitrous oxide are poorly understood, emissions from agricultural soils and animal wastes are believed to be the largest contributors to increases in the atmospheric concentrations of N_2O. Other important contributors include the industrial production of nylon and nitric acids, biomass burning, and the combustion of fossil fuels in cars equipped with catalytic converters.

Ozone (O_3) is found naturally in the lower 10-15 km of the atmosphere (known as the troposphere) in minute concentrations. Much of this background ozone is transported down from the upper atmosphere (the stratosphere), where it is produced directly from a reaction between oxygen and solar radiation. However, during the past century or so it has also been produced in increasing quantities near the Earth's surface through chemical processes involving nitrogen oxides, carbon monoxide, other air pollutants, and sunlight. These pollutants are largely produced by transportation and stationary combustion processes. Hence, since ozone decays very quickly, its concentrations in the troposphere are highest downwind of industrialized regions and lowest over areas far removed from such regions, particularly over Southern Hemisphere oceans. Average global concentrations within the troposphere are now believed to be about 35% higher than in pre-industrial times. The rates of growth in low-level ozone concentrations in the highly industrial regions of the Northern Hemisphere appear to have decreased significantly since the 1980s, while those in south and south-east Asia have increased.

Trends in ozone concentrations in the upper part of the troposphere, where it is most effective as a greenhouse gas, are as yet poorly observed or understood. Thinning of the ozone layer in the lower stratosphere by chlorofluorocarbons (CFCs) and other ozone depleting substances (see below) may also significantly offset the warming effects of ozone increases in the troposphere. Consequently, the net impact of changing ozone concentrations on the greenhouse effect is still not clear.

Halocarbons containing chlorine, fluorine, and bromine are, molecule for molecule, among the most potent greenhouse gases in the atmosphere (see "Greenhouse gases: a comparison"). In general, they do not occur naturally but are produced industrially in significant quantities. The best known of this group of chemicals are the CFCs, which have been widely used as solvents, refrigerants, spray can propellants, and foaming agents. Also significant are the halons, bromine-based compounds that are used as fire-extinguishing agents.

Because these and many other halocarbons are very stable and do not readily react chemically with other gases, each molecule released into the atmosphere can remain there for decades and even many centuries, until it is finally broken down in the upper atmosphere by intense ultraviolet radiation or escapes into space. Many of these, when they break down, release chlorine, bromine and/or fluorine atoms that then become responsible for depleting the stratospheric ozone layer. Although atmospheric concentrations of the principal CFCs are very low, until recently some of these have been increasing at the rate of more than 4% per year and had come to be considered significant factors in the enhancement of the greenhouse effect. However, CFC concentrations have recently begun to stabilize and, for some gases, even decline as a result of international action under the Montreal Protocol. Furthermore, the direct greenhouse effects of these substances, like those of tropospheric ozone, may be offset indirectly by the depletion of the ozone layer and a consequent cooling of the lower stratosphere. Hence, as with ozone, the net effect of ozone-depleting halocarbons on the climate system remains uncertain.

Water vapour is actually the largest contributor to the natural greenhouse effect. In fact, studies suggest that, if water vapour was the only greenhouse gas in the atmosphere, the natural greenhouse effect would still be about 65% as strong as that with all greenhouse gases present. However, water vapour is not itself a *primary* cause of changes in the greenhouse effect. Rather, it is an important factor because it is involved in a number of important climate system feedbacks – both positive and negative - triggered by rising temperatures caused by other primary causes of change. The net effect of these feedbacks in response to an initial enhancement of the greenhouse effect is expected to be an increase in the water vapour content of the atmosphere, since warmer air can hold more moisture, and higher temperatures are likely to cause more water to evaporate from the Earth's surface. Thus, water vapour feedbacks are believed to significantly add to any enhanced greenhouse effect caused by increased concentrations of other greenhouse gases. However, additional moisture in the atmosphere can also increase cloud formation which may significantly reduce the amount of solar energy warming the Earth's climate system, thus at least partly offsetting the increased greenhouse warming caused by water vapour. Although these feedbacks are as yet not well understood and hence difficult to quantify with confidence, there is a general consensus amongst experts that they are significant and positive.

OTHER HUMAN INFLUENCES

The enhancement of the natural greenhouse effect will undoubtedly be humanity's primary impact on global climate. However, human activities can also affect climate significantly in other ways on local and regional scales. The effects of some of these activities could ultimately become globally significant.

- ***Land use change –*** As humans replace forests and other natural vegetation with agricultural fields, asphalt or concrete, they substantially alter the way the Earth's surface reflects sunlight and releases heat. In general, flooded lands and wet soils absorb more sunlight than a forest canopy, and paved parking lots more than grasslands. On the other hand, deserts created by deforestation and overgrazing reflect more sunlight than natural vegetation, and snow covered fields more than the forests that they replace. All these changes also affect regional evaporation, runoff and rainfall patterns. Although these land use changes can have a substantial local influence, in most cases the net impact on climate globally is likely to be small.

- ***Atmospheric aerosols –*** Humans are adding large quantities of fine particles (aerosols) to the atmosphere, both from agricultural and industrial activities. Although most of these aerosols are soon removed by gravity and rainfall, they still affect the radiation balance in the atmosphere. Whether this effect adds to or offsets any warming trend depends on the quantity and nature of the particles as well as the nature of the land or ocean surface below. The regional effects, however, can be significant. Scientists have suggested that high regional concentrations of sulphate and some of the other aerosols from fossil fuel and biomass burning may be significantly reducing solar heating in some parts of the world, particularly in the Northern Hemisphere. That is because these aerosols not only reflect more sunlight back to space directly but also increase condensation rates in low clouds, thus making them more reflective. These processes may have temporarily reduced the magnitude of any hemispheric warming that may be occurring due to enhanced greenhouse effect. However, other aerosols, particularly soot, may be having the opposite effect. Hence, although the net effect of sulphates and other cooling aerosols is likely significantly greater than that of soot, these effects are as yet not properly understood and hence difficult to estimate with confidence.

- ***Arctic haze –*** Since the 1940s, observers in the Arctic have reported the increasing presence of layers of reddish-brown haze. The haze, which is observed primarily during winter and spring when the Arctic air is very cold and calm, consists of industrial aerosols, mostly from Europe and northern Asia, that have been transported long distances into the Arctic by prevailing winds. These aerosols include sooty and acidic particles which increase the net absorption and diffusion of spring sunlight in the lower atmosphere. They also increase the surface absorption of sunlight as they settle out on snow and ice. Both roles can cause spring temperatures in the Arctic to become slightly warmer and hemispheric wind patterns to change.

- ***Urban heat islands –*** City environments are substantially different from the rural landscapes they replace. Buildings and vehicles release heat directly to the atmosphere, while air pollution and the dark surfaces of pavements and roof tops add to the absorption of sunlight. Buildings also alter wind flow: wind speed increases between large buildings but may drop to zero in their lee. The net result is that large cities are, in general, significantly warmer than the surrounding countryside, particularly in the winter. Central Toronto, for example, is on average about 3°C warmer that surrounding regions. The effect is primarily local, however. All the urban heat islands around the world added together do not significantly affect global climate conditions.

- ***Water diversions and storage –*** Water, whether flowing in streams and rivers or stored in lakes, is a source of moisture for the air above it, and an important means of storing heat. Bodies of water help to cool local climates in summer and warm them in winter. Large-scale projects to dam or divert water flows can therefore have a significant influence on regional climates.

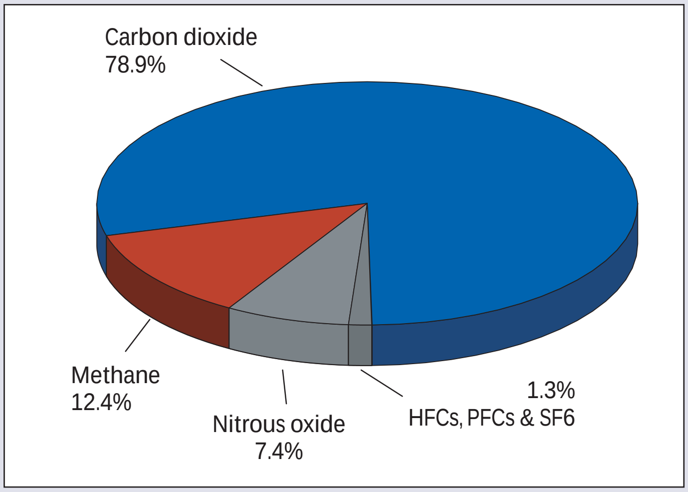
GREENHOUSE GASES: A COMPARISON

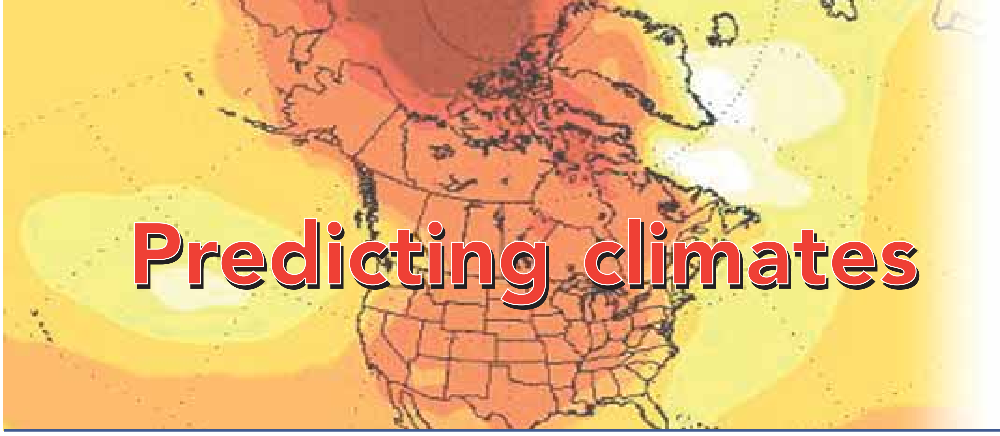
Accurate comparisons of the net potency of different greenhouse gases as forces of climate change are difficult and dependent on how these comparisons are made. However, best estimates suggest that the net accumulated climatic effect over the next century of the release of a gram of nitrous oxide is almost 300 times that of a gram of carbon dioxide. That for a gram of methane is about 23 times as great. Some gases, while still very low in concentration, are much, much more potent. One gram of sulphur hexafluoride released into the atmosphere, for example, has about 22 000 times the effect of a gram of carbon dioxide.

However, although the potency of carbon dioxide released into the atmosphere through human activities may be significantly lower than many other greenhouse gases, the much greater volume of emissions still make it the most important influence in human enhancement of the natural greenhouse effect. For example, as shown in Figure 2.7, the projected climate forcing commitment for the next century due to Canadian emissions of carbon dioxide from human activities during 2001 was about six times that for methane and about ten times that for nitrous oxide.

FIGURE 2.7

Relative contribution of Canadian greenhouse gas emissions in 2001 to future global warming





CHAPTER 3

Predicting climates

Major changes in climate inevitably create the likelihood of a radical and relatively rapid transformation of global ecosystems. Should that happen, human society would be faced with physical, social and economic disruptions and dislocations that could equal or even surpass any that humanity has yet experienced. Preparing and responding to such challenges would be a priority for all societies, and it is thus vitally important to know what changes could occur and what their consequences would be. But, given the complexity of the Earth's climate system, can we in fact predict with any degree of certainty what changes are likely to take place?

Unfortunately, the complex processes and interactions that make up the global climate system are far too large and intricate to reproduce in a laboratory experiment. Studying the climate systems of other planets, such as Mars and Venus, does not help significantly either, since these systems do not include oceans or terrestrial biospheres.

Studies into the past behaviour of Earth's climate can provide much information on how previous climates have evolved and can point to possible causes of change. However, while such observational studies can shed light on some aspects of the physical processes in climate change, they can only give us a very limited picture of how the climate system works. Nor can we simply extrapolate the trends and variations of past and recent climates to predict the future, particularly when the forces involved in future changes may be uniquely different from those of the past.

Fortunately, most of the detailed processes, interactions and changes that occur within the climate system can be described in terms of well-defined physical laws such as the laws of conservation of mass and energy or Newton's laws of motion. These physical laws can be developed into mathematical expressions and, with the help of advanced computer facilities, can be used to calculate how the system will respond to forces of change.

Such mathematical models are now being used extensively to study the climatic effects of current phenomena such as volcanic eruptions or ocean temperature anomalies. They are also being used to help explain past climate events and to simulate how the climate system might respond to human interferences, including land use change and the emission of aerosols and greenhouse gases.

MATHEMATICAL CLIMATE MODELS

Because of the limitations in mathematical techniques and computer capabilities, we cannot replicate every process of the climate system in full detail. Furthermore, many of these processes are as yet inadequately measured or understood. Modellers must therefore simplify and approximate these processes, making assumptions about which ones are most important and which are least affected by such adjustments. Many different kinds of models can be developed. The nature of each depends on the application for which it is intended, the simplifications required and the amount of spatial and chronological detail needed.

An extremely simple climate model is a zero dimensional energy budget model that simplifies the temperature of the Earth to a global average at a single point. Such a model can, for example, be used to calculate the Earth's average surface temperature as an energy balance arising from the reflective, absorptive and radiative properties of the Earth's atmosphere and surface.

At the opposite extreme are the very sophisticated climate system models (CSMs) that consider the dynamic and complex interactions within and between the atmosphere, the oceans, the cryosphere, land surfaces and the biosphere in three dimensional space and over time. At the heart of these models are coupled Atmosphere-Ocean General Circulation Models (AOGCMs), in which mathematical equations representing the physical laws of conservation of momentum, mass, moisture and energy are used to simulate the evolution of the dynamics and energy flows of the entire coupled ocean-atmosphere system. However, a few advanced versions of these climate system models now also include an interactive, dynamic vegetation system as well as responsive atmospheric chemistry. These models can explore in greater detail how different climate parameters – temperature, humidity, wind speed and direction, soil moisture, and a large range of others – may evolve over time as various conditions are altered and feedbacks come into play.

In between are a large variety of one and two dimensional models and more detailed regional climate models that are used to study various climate processes and interactions in varying degrees of complexity. These can be very effectively used to study many smaller-scale climatic relationships, and the results of these investigations can help to improve the equations used within coupled climate models or add further detail to CSM outputs at a regional scale.

But even the most complex climate system model is, in fact, only a crude description of the real climate system. Despite the tens of thousands of spatial points within the atmosphere and oceans for which such a model makes calculations and the hundreds of thousands of lines of computer code used for these calculations, such simulations cannot fully describe the climate characteristics and processes of continuous space and time.

A typical CSM divides the Earth's surface into a grid or series of boxes. Early low resolution General Circulation Models used boxes that were relatively large – with each one covering an area about the size of Manitoba. Today, some high resolution models use atmospheric boxes of less than 60 000 square kilometres in area – roughly 20% smaller than New Brunswick – and ocean boxes that are even smaller. Vertically, the atmosphere is represented by anywhere from nine to 30 layers, and the oceans by up to 40 layers.

Many important climate processes, however, take place on scales much smaller than even the smallest of these grid boxes and must be dealt with collectively rather than individually. Values for these processes are established through a procedure known as parameterization. This involves the development of physical and statistical relationships between these processes and large-scale variables that can be calculated by the model. Cloud characteristics, evaporation, precipitation, and land surface characteristics are examples of processes that must be parameterized. Models must also include the complex feedback mechanisms that exist between the various processes.

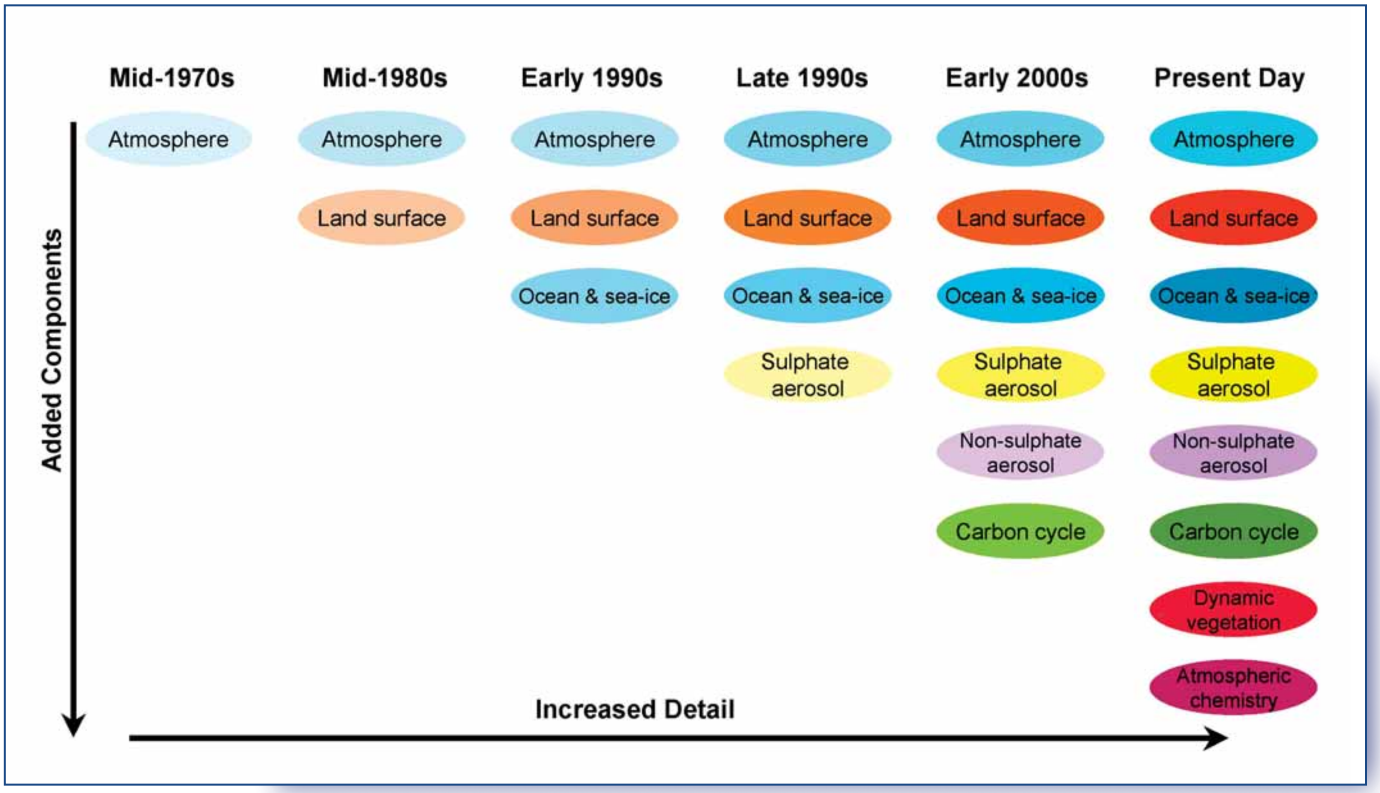
A simple time line for the development history of climate system models is illustrated in Figure 3.1. Uncertainty about how processes within and between the various components are best described is a primary reason why different models can disagree significantly on the consequences of a change imposed upon the system and why the results of experiments with these models cannot as yet be used as reliable predictors of future climates.

The ultimate test of a model's ability to simulate the real world, of course, is its ability to replicate changes that have already happened. This can be done by using the model to simulate current and past climate conditions. If the simulation results agree well with observed data, the confidence in the model's usefulness for simulating future climates is enhanced. Most of the climate system models in the use of climate change studies today are able to simulate current and past climates reasonably well. However, although some perform better than others, none can be considered highly accurate, particularly with respect to regional climates.

Climate system model experiments have added significantly to our understanding of how climates are likely to change. Even so, our knowledge remains far from complete, and many questions about the details of future climate change continue to go unanswered. Scientists believe that getting these answers will require the use of

FIGURE 3.1

Evolution of climate model development over the past three decades



Source: IPCC TAR WG1 2001

much larger, yet to be developed computers and a much better understanding of some of the physical processes of the climate system. Such developments will take many more years of research.

MODEL PROJECTIONS FOR THE FUTURE

What do climate model experiments tell us about the kind of climate we can expect from an enhanced greenhouse effect?

One common type of climate model experiment conducted during the past decade involves simulating how the global climate system responds with time to a gradual change in the composition of the atmosphere. Beginning with a pre-industrial climate that is in a near-equilibrium, stable state, modellers undertaking these simulations first apply historical changes in greenhouse gas and aerosol concentrations to simulate how climates have changed over the past century or so. They then use one or more projections of how the composition of the atmosphere is likely to change due to future human emissions of greenhouse gases and aerosols to develop projections of future climates. This type of experiment has now been performed many times with a number of different coupled climate models. Since the results depend both on the type of model used and on the assumptions about future changes in natural and human factors affecting climate, projections about how Earth's future climate is likely to change are not always consistent from one experiment to the next. Nevertheless, these projections do agree on a number of points. Among the more reliable conclusions, the following stand out as the most important.

- Within the next century, average global surface temperatures are likely to rise by at least 1°C, relative to current values. They could increase by more than 5°C. Even at the lower end of this range, the expected rate of warming is likely to be without precedence in human history (Figure 3.2).

- Surface warming over land areas will, in general, be faster and greater than over oceans. In winter, polar regions will also warm much more significantly than low latitude regions.
- Night-time low temperatures are expected to increase more rapidly than day-time high temperatures, thus decreasing the diurnal range in temperature.
- An increase in mean temperatures leads to more frequent high temperatures and less frequent extreme low temperatures.

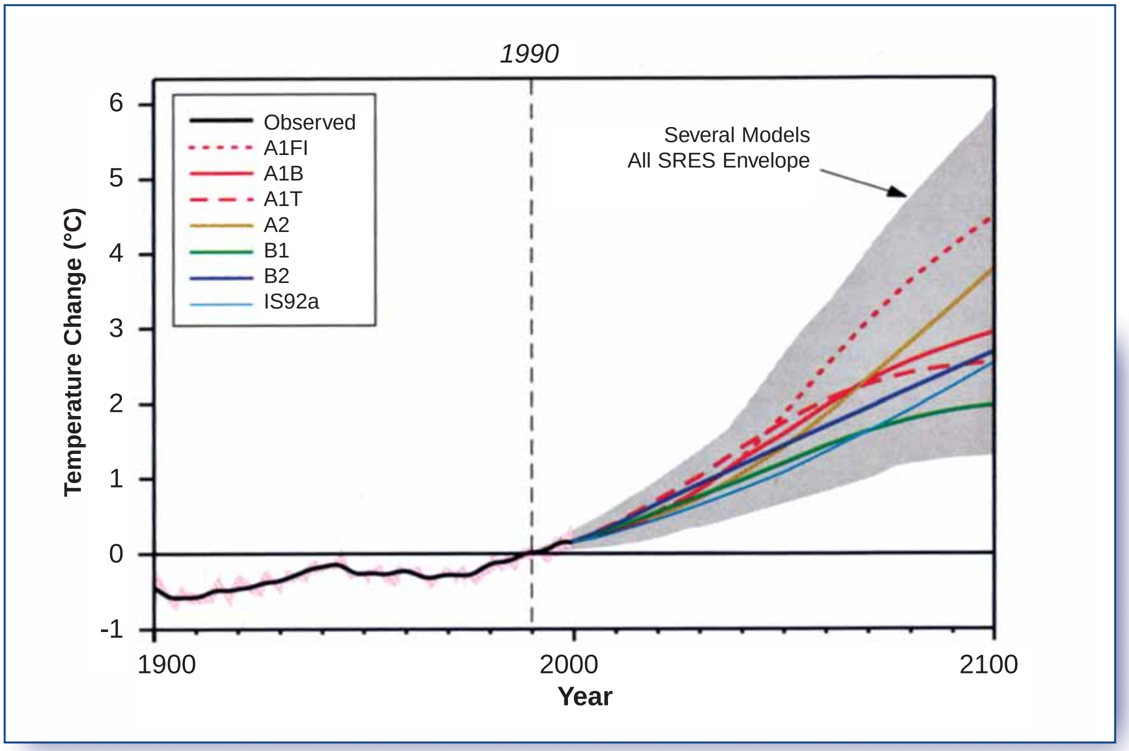
Changes in these temperature patterns will also cause alterations in atmospheric wind patterns and in ocean currents. A likely slow-down of the cycling of surface and deep ocean waters is expected to reduce ocean advection of heat from equator to poles. This could cause a smaller warming in some ocean regions, such as the North Atlantic and the circumpolar Southern Ocean, and may even cause some parts of these regions to actually cool relative to current temperatures.

- Average global evaporation and precipitation will rise.
- As temperatures rise, the extent of snow and sea ice cover in the Northern Hemisphere will decrease.

Certain other aspects of future climate, however, have been harder to predict. One of these is the distribution of precipitation where rain and snow fall is largely determined by the tracks taken by storms. However, the location of these depends on the complex pattern of atmospheric circulation, which climate models cannot yet simulate with sufficient accuracy. Consequently, model predictions about changes in storm tracks and hence in local precipitation patterns are not very reliable. Nevertheless, it is clear that there will be important changes in the distribution of rain and snow fall from place to place. And, as temperatures warm and some regions become drier and others wetter, the climate conditions that determine the natural growth of vegetation around the world may shift significantly.

FIGURE 3.2

Model projections of future temperature changes



Source: IPCC TAR Synthesis Report 2001

Another area of significant uncertainty relates to weather variability and many types of extreme weather events (see Table 3.1). Most studies indicate that, on average, extreme precipitation events will become more frequent. While some models show that there may be an increase in intense mid-latitude storms, there is no general agreement on these storm characteristics among various studies. Likewise, while there is some evidence to suggest that the upper limit of tropical storm intensity could rise, there is little agreement on how the average intensity and frequency of these events might change. Finally, while climate studies suggest that the frequency of lightning and hail could rise as temperatures increase, these events are too small in scale to be as yet resolved within coupled climate models.

TABLE 3.1

Confidence levels in projected changes in extreme climate events

Changes in Climate Event	Confidence in Projections
Higher maximum temperatures and more hot days over nearly all land areas	Very likely
Higher minimum temperatures, fewer cold days and frost days for nearly all land areas	Very likely
Reduced diurnal temperature range over most land areas	Very likely
Increase of discomfort due to combined effects of heat and humidity	Very likely, for most areas
More intense precipitation events	Very likely, for many areas
Increased summer continental drought	Likely, over most mid-latitude continental interiors
Increased peak wind intensity of tropical cyclones	Likely, over some areas
Increased mean and peak precipitation intensity in tropical cyclones	Likely, over some areas

Source: IPCC TAR WG1 2001

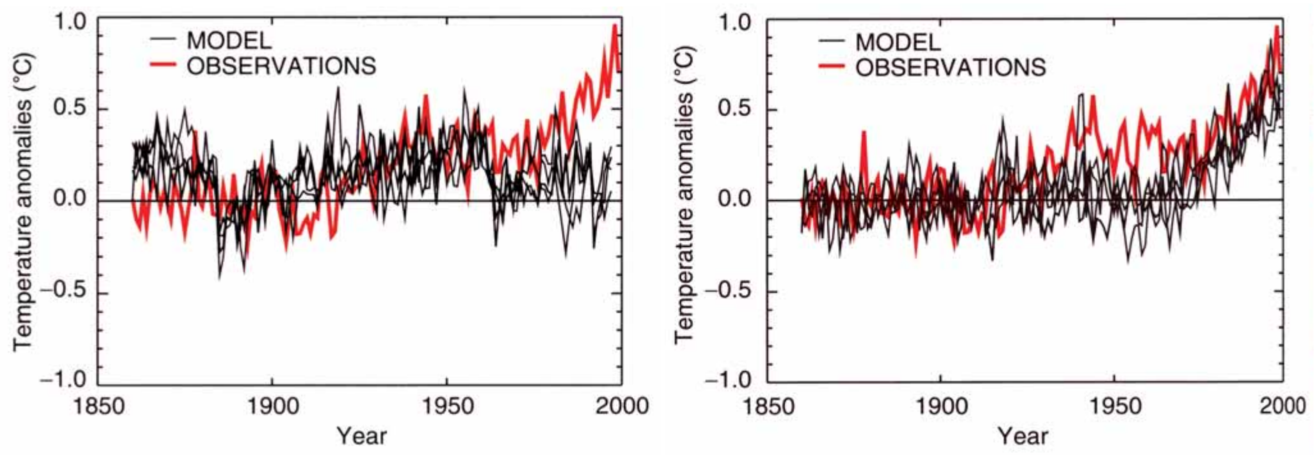
Although climate system models gives us significant insight into the effects of changing atmospheric concentrations of some of the key greenhouse gases and aerosols, there are a number of other factors that most do not as yet adequately take into account.

For example, most model projections of future climate change do not consider the natural climatic effects of changes in solar radiation or in the volcanic eruption aerosols released into the atmosphere from time to time. These factors have influenced climate throughout the history of the Earth, and will continue to do so in the decades and centuries to come. During some periods these forces will add to the warming effects of rising greenhouse gas concentrations. In others, they could slow down or even temporarily reverse the expected greenhouse warming. However, these natural changes are difficult to predict. Furthermore, based on evidence of climate variability during the past two millennia, it appears likely that these natural forces will not significantly alter the long term trends towards warmer climates expected from rising greenhouse gas concentrations.

There are also other human induced climate change factors that climate model studies have not yet adequately evaluated. Changes in land use, in addition to affecting carbon dioxide levels in the atmosphere, can change how much sunlight is reflected from the Earth's surface. Some argue that may have been an important factor in the warming of the Earth's climate to date. Likewise, very few model studies have considered the role of dark aerosols (like soot), which can add to the heating of the planet. The presence of air pollutants in the Arctic, and large scale water diversions may also have local climate effects that, in some cases can influence global climates. However, our best scientific estimates indicate that, over the next century, changes in the Earth's climate will be dominated by the enhancement of the greenhouse effect.

FIGURE 3.3

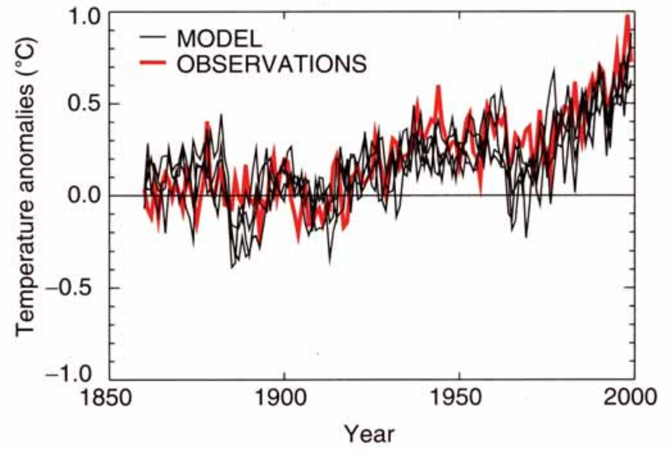
Comparison of modelled global temperature trends since 1860 with that observed



(a) Natural

(b) Anthropogenic

(c) All forcings



Source: IPCC TAR WG1 2001

ARE HUMANS ALREADY CAUSING THE EARTH TO WARM?

As illustrated in Chapter 1 (Figure 1.8), the Earth's average surface temperature has increased by about 0.6°C over the past century. How unusual is this warming, and can we attribute the observed changes to specific causes?

Paleoclimate records (Figure 1.5) suggest that average global surface temperatures during the past few decades are unprecedented in at least the past 2000 years. Furthermore, climate model experiments also suggest that a warming of 0.6°C in one century is not likely to be due to internally generated variability of the climate system. These research results indicate that the warming over the past century is very unusual and unlikely to be due to natural causes only. Nevertheless, these data by themselves do not help us understand what may have caused recent trends in climate.

To do so, experts turn to climate models and complex statistical studies. While such studies cannot hope to address the role of all possible factors, they can, one by one and in combination, consider how past changes in the key factors should have affected the climate and compare the results with the observed changes. Related experiments use various combinations of forcings due to volcanic eruptions, changes in solar irradiance, increases in greenhouse gases, recent changes in stratospheric ozone and/or variations in concentrations of sulphate aerosols to test which combinations best match the observed changes.

Results from these studies indicate that the dominant factors in the warming that took place in the early part of the 20th century was likely due to the combination of increased intensity of incoming solar energy, a gradual decline in the amount of volcanic material floating in the atmosphere, and a slow increase in atmospheric greenhouse gas concentrations. However, since 1950, the average load of volcanic material in the atmosphere has once again increased, while the solar intensity has modulated around a relatively constant mean value. These natural factors should have caused a cooling, and hence cannot explain the recent warming trend (Figure 3.3a). In contrast, rapidly increasing human influences on the climate system, particularly that of rising atmospheric concentrations of greenhouse gases, caused a very strong warming influence (Figure 3.3b). Thus, experts conclude the most of the warming observed over the past 50 years is likely attributable to human activities.

▲ Arctic flowers

Source: Brent Colpitts

CHAPTER 4

A warmer world

Each biological species has a unique set of climatic and other limits within which it flourishes and beyond which it stagnates or dies. Air and soil temperature, the type and amount of precipitation and its variability, the strength of the wind, the amount of sunshine, and other climatic factors play a role in determining which species will occupy a given region. The influence of climate on biological survival is clearly seen in the distinctiveness and variety of the world's many vegetation regions – from tundra and boreal forests to grasslands and tropical rain forests. Each of these regions can be seen as a distinct ecological entity – an ecozone – whose characteristics have been largely shaped by a corresponding ecoclimate which is unique to the region and essential to the life within it.

When local and regional climates change, as has often happened in the past, the boundaries of the ecozones change, forcing the ecosystems to adjust. Species whose climatic requirements no longer match those of the region migrate or die out, while other species, once foreign to the region, begin to enter it. Climatic change is a stimulus to the migration of both plants and animals. If the changes are gradual, the process usually occurs with minimal disruption. If rapid, the transformation can be dramatic and result in the extinction of species.

Human societies, like natural ecosystems, are attuned to the characteristics of regional climates. Our behaviour and tolerances, our cultures and economies, and, in particular, our sources of food are climatically influenced. In the past, as climates fluctuated over extended periods of time, people learned to respond and adapt. In some cases, such adaptation was a spur to social and technological development. In others, failure to cope brought adversity and even catastrophe.

While we can learn much from studying how ecosystems and human societies have responded to climate variations in the past, history may not be a reliable guide to the effects of future climate change. That is because both the magnitudes and rates of changes in average global temperatures may, within the next few decades, exceed any that we have experienced during the last 10 000 years. What indications do we have, then, of how such rapid and large changes may affect natural ecosystems and human societies?

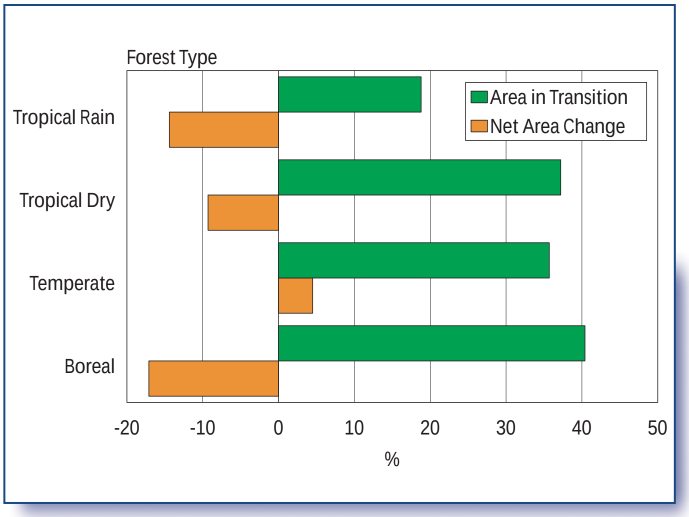
Climate model projections are as yet too uncertain to help us accurately predict regional effects on vegetation or threats to human health and well-being. However, the models do provide a basis for constructing plausible scenarios that can be used to assess the sensitivities of nature and societies to the range of changes that can be anticipated. Furthermore, the development of improved dynamic vegetation models that can be coupled to these climate models allow researchers to explore the complex manner in which ecosystems may respond to climatic changes. Complemented by research into the effects of past climate changes, scientists can now offer some important clues as to which ecosystems and which sectors of society are more resilient or less sensitive to these changes. Although the results must as yet be used with caution, they nevertheless provide us with a number of tentative but important general conclusions about both the human and ecological implications of climatic change.

NATURAL TERRESTRIAL ECOSYSTEMS

On land, warmer climates will likely have the greatest impact on unmanaged ecosystems, particularly forests. By the time that ecosystems have fully adapted to the changes in climate projected for the next century, about one-third of the global forests will undergo major changes in

FIGURE 4.1

Projected percent changes in global extent of various forest ecosystem types under an equilibrium response to a typical $2xCO_2$ climate scenario



vegetation types. The greatest ecosystem changes are likely to occur in high latitudes, and the least in the tropics (Figure 4.1). Many of the species involved would adapt through migration, but some could become extinct. In some regions these changes are likely to cause a decrease in ecosystem biomass. However, on a global average, biological productivity is likely to increase.

However, full ecosystem adjustment to changed temperatures could be delayed by many centuries, and be very disruptive. That is because the migration rate of many plant species is an order of magnitude slower than that expected for future climate change. For example, in mid-latitudes, a projected increase in temperatures on the order of 1-3.5°C over the 50 years or so would effectively shift climate regimes poleward by some 150-550 km (or, in alpine regions, upward by 150-550 m). By comparison, most trees migrate at a rate of 4 to 200 km/century, depending on the species. Hence, until ecosystems reach a new equilibrium with the changed climate, many parts of ecosystems (particularly along their warm margins) will become mismatched with the prevailing climate, thus stressed and more vulnerable to the ravages of diseases, insects and fire. Some species will stagnate and die, while others will benefit from the changes. Hence species composition within ecosystems will also change. In general, warmer temperatures will be most stressful to those species close to their warm tolerance limits and most beneficial to those near their cold limits. However, warmer climates will allow more frequent breakouts of damaging pestilence currently constrained by climate conditions and could dramatically affect soil moisture conditions. Hence the response of natural ecosystems will be complex and varied in both time and space.

Increased warming and changing precipitation behaviour will also have major impacts on aquatic ecosystems. In northern latitudes, shorter ice cover seasons will lengthen the season for active biological production, but deep lake waters will have increased problems with anoxic conditions in summer. Fish distribution will change, with a significant loss in habitat for cold water species and a gain for warm water species. In many regions, reduced water supply and warmer temperatures will help exacerbate existing environmental concerns such as eutrophication, acidification and enhanced UV-B radiation. The distribution and characteristics of inland wetlands will also change in response to changes in local water tables and melting permafrost.

Greater mobility allows most wildlife species to be physically better able to migrate in response to changing climates than plant species. Recent observations indicate, for example, that many wildlife species have already migrated due to the changes in climate that have occurred in recent decades. However, many of these species are also very dependent on habitat and food supply, which are likely to migrate at different rates. Such varied rates of migrations can effectively tear apart ecosystems, and be particularly harmful to species already under stress from climate and other factors. Hence, the number of species threatened by extinction may rise significantly.

AGRICULTURAL ECOSYSTEMS

The combined effects of enhanced atmospheric carbon dioxide concentrations and climate change on regional food production will be variable. That is because agricultural crop yields depend on the complex interactions of different plant species with soil properties and available plant nutrients, pests and diseases, air quality and temperature and moisture conditions.

Carbon dioxide is an important factor because it functions as an essential plant food source. Experimental studies in greenhouses indicate that, for many plants, the current atmospheric concentration of carbon dioxide is a limiting factor for growth. Hence, for these, rising CO_2 concentrations can stimulate crop growth and yield. This effect would have minimal influence on the growth rate and yield of crops such as maize and sugar cane, but could significantly benefit important cereal crops such as wheat and rice. However, insufficient soil nutrients, air pollution and increased UV-B exposure may limit or at least partially offset these benefits. Furthermore, many weeds may also grow faster under higher CO_2 concentrations.

On the other hand, the impacts of changes in climate on agricultural productivity depends both on the changes in temperatures and water availability, including their extremes.

In higher latitude and altitude regions, where temperatures are relatively cold, crop yields can benefit significantly from milder winters and warmer, longer growing seasons. However, even in these regions, such benefits can be more than offset by other stresses, such as more frequent and sustained periods of extreme heat and drought or the effects of intense rainfall events and related floods. Likewise, livestock and poultry production can be susceptible to changing access to water resources and/or increased exposure to heat stress. Of all the world's regions, however, it is the tropics that are likely to be most vulnerable to the disruptions of climate change. In the tropics, the distribution of rainfall is highly variable, both seasonally and spatially. Some areas are already marginal for agricultural production and highly sensitive even to minor changes in the occurrence of precipitation. Climate studies suggest that, even for regions that receive more rainfall, much of this increase will occur as more intense rainfall, increasing the risk of erosion and floods. This will add to other factors that are slowly degrading agricultural soils and water quality. Furthermore, warmer temperatures are likely to increase both surface evaporation and heat stress on many plant species, lowering crop yields.

Changing farm management practices – such as adjustments in planting dates, fertilization rates, irrigation and selection of plant and animal species – can help capitalize on some of the benefits and reduce the harmful effects that changes in climate may bring. Experts suggest that, as long as warming over the next century is less than a few degrees C, such adaptive measures are likely to help increase net food production in mid-latitudes. However, this region is also where most of the world's wealthier countries happen to be. In contrast, even moderate rates of warming would likely cause significant reductions in food production in many tropical and dry regions. While the net global change in food production may be small, the inequities of global food distribution would likely be exacerbated. Should the average global rise in temperatures over the next century exceed 2-3°C, adaptation measures are unlikely to be adequate to deal with the consequences, and most regions of the world are likely to experience a decline in food production. The related increase in cost of food would likely significantly increase the number of people around the world at risk of hunger.

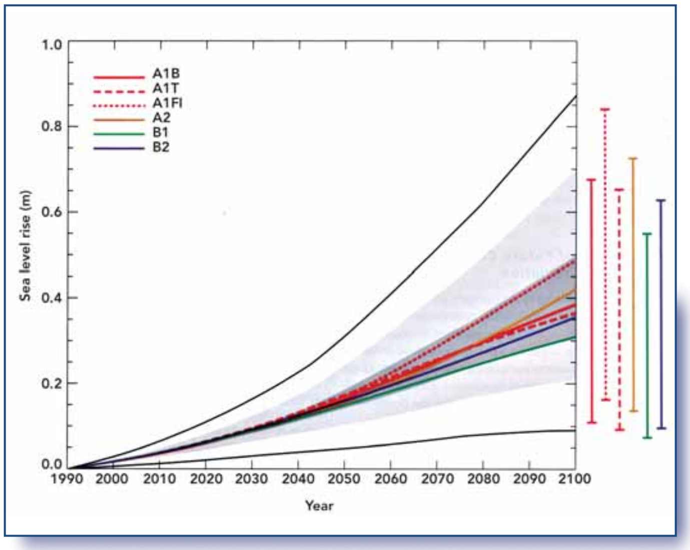
COASTAL REGIONS

The mean levels of the world's seas have been rising slowly over the past 100 years at a rate of 1.5 cm each decade. Although there is no evidence that this rate has accelerated since 1900, that could soon change. During the next century, the rate of sea level rise is likely to be between 1 to 9 cm/decade, depending on the future rate of global temperature rise and how quickly oceans and ice sheets respond to warmer climates (Figure 4.2). The primary reasons for the expected rise over the next 100 years are the expansion of sea water as it warms and the melting of glaciers around the world. However, because oceans warm very slowly, sea levels will continue to rise for centuries thereafter, even if temperatures at the Earth's surface stop rising.

Furthermore, the large ice sheets that store vast quantities of water as ice covering Greenland and Antarctica are

FIGURE 4.2

Projected sea level rise for various greenhouse gas emission and model scenarios



Source: IPCC TAR 2001.

expected to slowly release this water into the oceans if global temperatures rise significantly. While experts suggest that these ice sheets will not contribute significantly to sea level rise over the next century, the Greenland ice sheet alone could add as much as 3 m to sea levels within the next 1000 years. A complete disintegration of the unstable West Antarctic Ice Sheet, although not likely within the next millennium, would add another 5 to 6 metres to sea levels.

Warmer ocean temperatures, changes in storm frequency and intensity and shifts in ocean circulation would also seriously affect coastal ecosystems, including the health of coral reefs and the distribution of fish populations. Many coral reefs exist at or near temperature tolerance thresholds. Large rises in temperature along with decreased calcium carbonate formation rates due to higher atmospheric CO_2 could create a progressively more hostile environment for these reefs and the invaluable marine habitats they support.

Human societies are highly vulnerable to such coastal changes. Approximately one quarter of humanity inhabits the Earth's coastal regions. These regions are already under great pressure from accelerating population growth, pollution, upland water diversions, flooding and coastal erosion. Approximately 70% of the world's beaches are currently receding. Many of the world's coral reefs have undergone extensive bleaching in recent years, likely as a result of intense warm events linked to El Ninos coupled with other local environmental stresses caused by humans. In many coastal areas, mangrove forests and tidal marshes may respond too slowly to the effects of a rapid rise in sea level to survive. Since these ecosystems protect coastlines from storm damage, their collapse would further aggravate the vulnerability of coastal infrastructure and ecosystems to such damage. Deltaic regions, often heavily populated with humans, would be particularly vulnerable to flooding and erosion, resulting in significant loss of agricultural land.

Many countries will be able to alleviate some of these impacts by building defence structures such as dykes and sea walls. But such actions would be costly. In Japan, for example, countermeasures to defend the country against the impacts of a 50 cm sea levels rise would be almost US$2 billion per year. Similar protection for American shorelines could have an accumulated cost over the next century of US$20 to 150 billion. The Dutch and British, already defending themselves against the sea with finely tuned coastal defence infrastructures, would also need to invest additional billions of dollars to cope with the effects of similar increases in sea levels.

However, the most significant effects of rising seas will be on those countries whose low-lying coasts are largely indefensible, or who lack the resources to defend themselves. As the seas advance and storm surges reach new heights, these countries are likely to experience great loss of land, property and life. Nations such as the Maldives, an island chain in the Indian Ocean whose highest point is about six meters above the current sea level, could virtually disappear, while countries such as Egypt, Bangladesh and Vietnam, with much of their population settled on low-lying deltas, could lose a major portion of their habitable lands.

The cost of sea level rise in human terms would be immense. Even if defensive measures are taken to address some of these coastal threats, it is estimated that a sea level rise of 40 cm would increase the number of people around the world annually flooded out by coastal storms by 2080 by about 80 million.

OTHER IMPACTS

While the impacts of climate change on natural and agricultural ecosystems and on coastal regions will undoubtedly have some of the largest direct effect on the biosphere and humanity, there will be other important consequences. These include:

- Changes in the quantity and quality of fresh water. Under most future climate change projections, streamflow and water supply are likely to decrease in many tropical to mid-latitude regions, and generally increase in most high latitude regions. By 2080, up to 3 billion of the people already living in water stressed regions could experience a further significant reduction in water supply. Higher temperatures will, in general, also reduce the quality of water unless offset by increased flows.
- Less hostile and more accessible high-latitude regions, as winters become warmer and sea ice recedes poleward
- Increased problems with tropical diseases and insects in mid-latitudes as these migrate with changing climates. These will affect the health of both humans and plant species.
- Intensification or, in some cases, moderation of ecological and human stress from other sources of pollution
- Increased heat stress on humans
- Increased land instability and infrastructure damage in high latitude regions as permafrost decays

IMPLICATIONS FOR GLOBAL SECURITY

Shifts in agricultural productivity, increased fresh water scarcity, impacts of sea level rise and other direct consequences of climate change may also trigger a number of disturbing secondary impacts. Perhaps most unsettling are the implications for the world's economic and political security.

Access to shelter, food and water is the most fundamental of all human concerns. We do not as yet know for sure what the net effect of future climate change on global food and water supplies will be. It could be negligible. It could even be positive. But it is almost certain that the regional distribution of these essentials will change dramatically, aggravating existing uncertainties in food and health security. Furthermore, the ravages of increased coastal inundation due to sea level rise, floods from more intense precipitation events and droughts from longer periods of inadequate rainfall could displace many people from their homes. These effects will be most acute for the world's poorer regions, which are least able to cope with the costs of supplementing deficiencies in food and water supplies or accommodating displaced peoples.

Furthermore, significant changes in the environment, particularly if they bring major human disasters in their wake, will present grave obstacles to sustained economic and social development in the affected regions.

In the past, such scarcities and effects have led to armed conflicts and massive human migration. They could do so again. Furthermore, recent experience has shown that, at the very least, famine, floods and other environmentally related crises necessitate large transfers of relief funds to the countries that have been affected.

In an increasingly interconnected global society, one nation's problem inevitably becomes every nation's concern.

GLOBAL REASONS FOR CONCERN

Many argue that we should not allow future climate change to exceed levels or rates that are ‘dangerous’ to humans or ecosystems. However, danger is a function of both how harmful the impacts of climate change may be and of the acceptability of such harm. Thus the decision as to what is or is not dangerous is a value judgement that cannot be determined by science alone. Rather, scientists have focused on identifying a number of ‘reasons for concern’ and determining how these might escalate as the magnitude and/or rate of climate change increases. In global terms, there are five common reasons for concern that have been noted, as follows:

- The irreparable loss of unique and threatened ecosystems. Such ecosystems include tropical glaciers, coral reefs, mangroves and biodiversity hotspots. These ecosystems are generally confined to narrow geographical ranges and are very sensitive to climate change. Many of these will be adversely affected by even a small temperature increase. Furthermore, their degradation or loss could have far reaching effects well beyond the regions where they exist. The larger or more rapid the change in climate, the greater the number of such systems at risk and the damage that is likely to occur.
- Inequitable distribution of impacts. Developing countries tend to be more vulnerable to climate change than developed countries, and poor people more than wealthy people. Thus, while a small rise in temperature appears likely to have a net benefit for many developed countries, it would cause net harm to many developing countries. In general, climate change is likely to also exacerbate income inequalities between and within countries. Large or rapid increases in temperature would likely cause net harm to most countries, but more so to poor ones.
- Net global impacts will become increasingly negative as global temperature changes become large. Some experts argue that, for small changes in temperature, net economic benefits around the world may be greater than the net damages. However, since most people live in developing countries, the majority of humans would already be adversely affected. At medium to high increases in temperature, the net economic impacts are likely to become overwhelmingly negative.
- Rising temperatures are expected to increase the risks associated with extreme weather events. Examples of such events include floods, droughts, tropical and other storms, extremely high temperatures, and wild fires. If the global change in temperature becomes large, there is an increasing risk of exceeding critical design or natural thresholds for infrastructure collapse and hence catastrophes.
- Large scale climate surprises. There is a very low risk that climates may undergo an abrupt, quantum change as long as global temperature changes are small. Examples of such changes include the abrupt cessation of the Gulf Stream in the North Atlantic, or the collapse of the West Antarctic Ice Sheet. However, large changes in climate could cause critical thresholds that limit these risks to be exceeded. Such large-scale climate surprises would be calamitous.

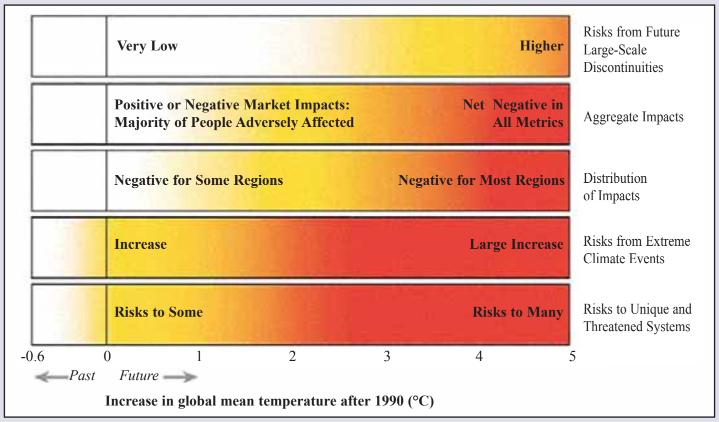


FIGURE 4.3

Global reasons for concern increase with rising temperatures

Source: IPCC TAR WGII 2001

CHAPTER 5

A warmer Canada

A large number of Canadian researchers from a broad range of scientific disciplines are now actively investigating the possible environmental, social, and economic effects of climate change in Canada. Many of these scientists share their research results with each other under programs such as the Canadian Climate Impacts and Adaptation Network (C-CIARN) to help provide more comprehensive pictures of how future changes in our climate and weather may affect our ecosystems, our economy and our society – region by region and sector by sector. These results also become important Canadian input for international assessments into how climate change may affect the world as a whole. The information included in this chapter is largely based on recent results emerging from these studies.

CANADA'S FORESTS

About 45% of Canada's landmass is covered by trees, from the black spruce and birches of the cold boreal forests to the pine and hardwoods of the warmer and more humid southern latitudes. The two regions that remain treeless do so partly for climatic reasons – the Prairie grasslands because of low soil humidity, and the northern tundra because of low temperatures.

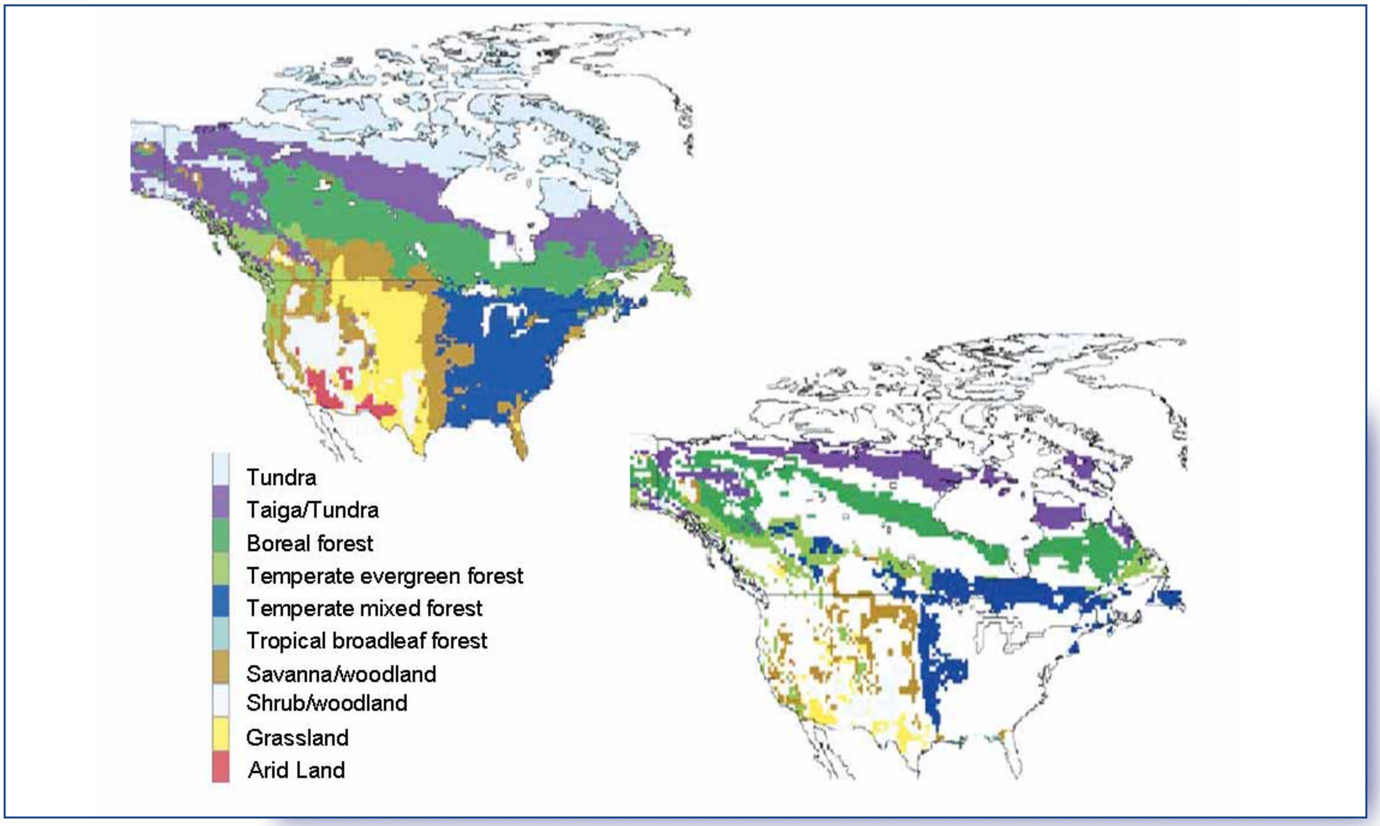
Given the extent of this resource, it is not surprising that forestry is Canada's largest industry. Companies involved in the harvesting and processing of wood products in this country generate revenues in excess of $45 billion and directly employ more than 360 000 people. The forest-related tourism industry adds several billion dollars of additional benefits. Furthermore, forests are important from an ecological perspective. They provide vital habitats for wildlife, significantly affect the hydrological and radiative processes of the climate system, reduce soil erosion and form a major part of the global reservoir of living carbon. Hence their future health is important not only to Canada's economic well-being but also to the elemental processes of the biosphere.

Even small changes in temperature and precipitation can significantly affect the growth behaviour of trees. For example, a modest 1°C warming over the past century has already caused a significant increase in the length of the growing seasons and enhanced plant growth in mid to high latitudes of Canada. Trembling aspens in central Alberta now bloom more than three weeks earlier than they did 100 years ago. With model projections of increases in temperatures of some 2 to 6°C and changes in precipitation patterns across much of Canada during the next 50 years, much larger impacts on its forests can be expected in the decades to come. The net impact on the biosphere and on Canadians will depend on a wide range of other biophysical and socio-economic factors, and hence will vary considerably from region to region. It could be positive in one region and negative in another, and will slowly shift the boundaries of the different forest types over time. Once forests have fully responded to these changes — a process that could take centuries — the distribution of ecozones across Canada will likely have been altered radically (Fig. 5.1). This shift is expected to substantially reduce the total area of Canada covered by trees, with most of the losses occurring due to the expansion of grasslands northward and eastward, in step with warmer temperatures and reductions in available soil moisture levels in the interior of the North American continent.

The largest changes would occur in areas now covered by boreal forests. At the southern edges of these forests, the dominant black spruce would gradually yield to the encroachment of grasslands and the evergreens and hardwoods of the cool temperate forests. Meanwhile, at the northern margins, some northward expansion of the boreal

FIGURE 5.1

Potential changes in North American forest and grassland boundaries resulting from a typical doubled CO_2 climate. The graphic on the upper left shows typical vegetation for current climate conditions while the lower right graphic shows new vegetation areas based on a simulated double CO_2 climate. Areas where there is no change in vegetation type remain white.



Source: Bachelet and Neilson 2000.

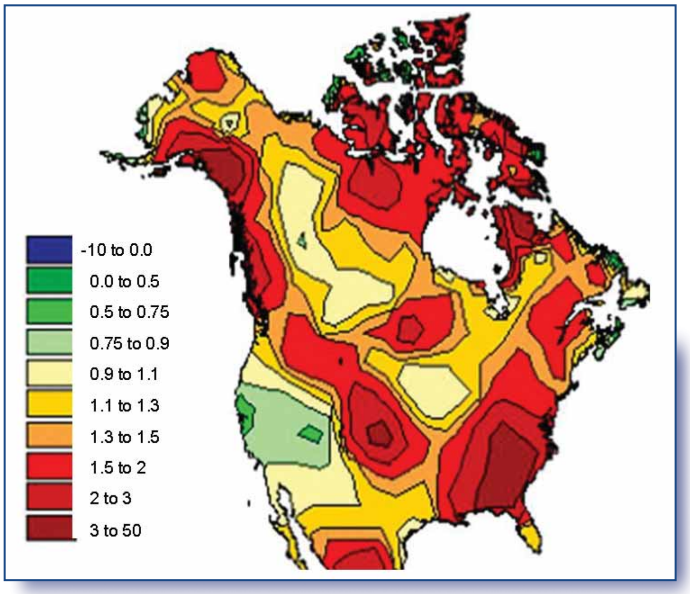
forests into tundra regions would occur, although greatly delayed by the comparatively slow decay of the underlying permafrost and the poor quality of the soils in many parts in the tundra landscape.

The net effect of the projected changes in climate could eventually result in a Canadian forest ecosystem that is more productive than today. In Quebec's forests, for example, the combined effects of higher carbon dioxide concentrations, warmer temperatures and more humid conditions could help increase average forest growth by 2050 by some 50 to 100%. However, in many regions the process for change is likely to be very disruptive. That is because most Canadian tree species can migrate at the rate of 700 m or less per year, while the temperatures that help determine the range within which each species grows well can shift by about 100 km for every 1°C of warming. Hence, along the warm margins of ecosystems, many of the plants end up in climate conditions ill-suited for their healthy growth. This is especially the case at ecosystem margins and threshold areas. Since these vulnerable areas are more prone to the sporadic stresses caused by diseases, insect infestations and wild fire, their transition from one forest type to another will also be sporadic, and often abrupt. The related consequences for the services that forest ecosystems provide to the biosphere and to Canadians may be severely negative.

Canada’s forests are also vulnerable to other stresses that, when added to that of climate change, can substantially add to these negative impacts. Particularly in eastern Canada, increased ultraviolet radiation, ground-level ozone pollution, acid rain, and leaching of chemicals from the soil are all factors that can harm trees. Past diebacks of birch and maple stands in Ontario and Quebec may be symptomatic of such stresses. Furthermore, warmer climates will also quickly bring with them the danger of increased insect and disease infestation, as insect species and viruses once alien to Canadian forests migrate northward and existing ones become more virulent. In addition, the more rapid accumulation of dead biomass caused by these stresses will exacerbate the effects of drier summer conditions and increased lightning activity in increasing the frequency and severity of forest fires. Such changes are already evident in some parts of Canada. During the warm, dry years since the early 1980s, infestations of mountain pine beetles in western Canada have increased dramatically. In 2001 alone, some 18.6 million ha of these forests were affected by insect defoliation. These direct and indirect effects of climatic change have helped to cause a dramatic rise in the annual loss of our Canadian forests to wildfire. In 2002, for example, some 2.8 million ha of Canadian forests were swept by fire. Experts agree that, in most regions of Canada, these losses will likely increase as temperatures rise (Figure 5.2).

FIGURE 5.2

Projected changes in forest fire risks in 2100 relative to today, calculated as a ratio of seasonal severity ratings (based on CGCM climate simulations)



Source: Canadian Forestry Service.

While such destruction of forest cover can initially add large volumes of excess carbon dioxide into the atmosphere and eventually amplify the warming that has already occurred, re-growth in affected areas will over many decades slowly remove much of this carbon from the atmosphere again.

AGRICULTURE

In 1998, the Canadian agriculture and agri-food industry generated approximately $95 billion in domestic revenue and was the country’s third largest employer. However, despite the importance of agriculture to its citizens, Canada’s agricultural potential is limited by, among other things, its cold climate. With the length of frost-free growing seasons restricted to between 200 days in the extreme south and merely a matter of weeks in the far north, Canadian soils remain inactive for a major part of the year. Furthermore, severe winters can cause frost damage even to dormant vegetation, thus restricting the cultivation of over-wintering crops, such as winter wheat, on the Prairies and in other similarly affected areas. When growing seasons do arrive, growth rates of plants in Canadian climates are further restricted by the amount of heat energy available to them during the season. These factors impose major limitations on the types of crops that can be grown in Canada, as well as on the yields and the number of crops that can be harvested in one year.

It would seem, therefore, that warmer temperatures would be very good for Canada’s agriculture. For example, under typical climate scenarios for 2050 AD, growing seasons around Whitehorse and Yellowknife would be similar to those in Edmonton today, while conditions in New Brunswick would resemble those of the Niagara peninsula. Hence, across Canada, there would be considerable potential for cultivating higher yield crops requiring longer and warmer growing seasons, for increased multi-cropping in southerly latitudes, and for the expansion of frontier agriculture northward. Grain corn could become an important agricultural crop in areas such as Manitoba and northern Ontario, winter wheat could do well on the Prairies, and apples and grapes could become highly productive in Quebec. The direct effects of higher carbon dioxide as a fertilizer for plants could further add to these benefits.

However, agricultural crop production is also very sensitive to changes and extremes in weather and climate. Many crops, for example, are sensitive to heat stress, particularly during key stages of development, and may be adversely affected by the increased frequency and severity of summer heat waves. Furthermore, projected changes in summer precipitation patterns and characteristics suggest that the duration and severity of drought periods may increase significantly in many areas within the mid-latitudes of the Northern Hemisphere. Rising temperatures will also increase the rate at which vegetation and soils lose water to the atmosphere, thus further reducing available soil moisture. However, when rain does occur, it is expected to be more intense, thus increasing the risks of periods of excessive soil moisture and regional floods and related soil losses to water erosion. In fact, most major crop disasters that occur each year are caused by such extremes in temperature and soil moisture. Recent events in the Canadian Prairies, such as the sequence of drought years between 2000 and 2003, as well as the very wet year in many parts of that region in 2004, while not unprecedented in Canada's climate history, are in many respects useful examples of what may occur more frequently during the decades to come.

Other factors affecting crop production will not stay constant or unrestrictive. In the first place, the availability of soils suitable for agriculture in Canada is limited. At present, only about 10 million hectares of potential agricultural land in Canada are unutilized due to climate constraints, and much of this consists of marginal soils unsuitable for cereal grain production. Some of this potential farmland is also covered with valuable timber stands. Consequently, the potential for expanding agriculture into the northern frontier is not large. Secondly, because insects, pests and plant diseases respond quite quickly to climatic shifts, the probability of severe infestations in future decades is increased.

WATER RESOURCES

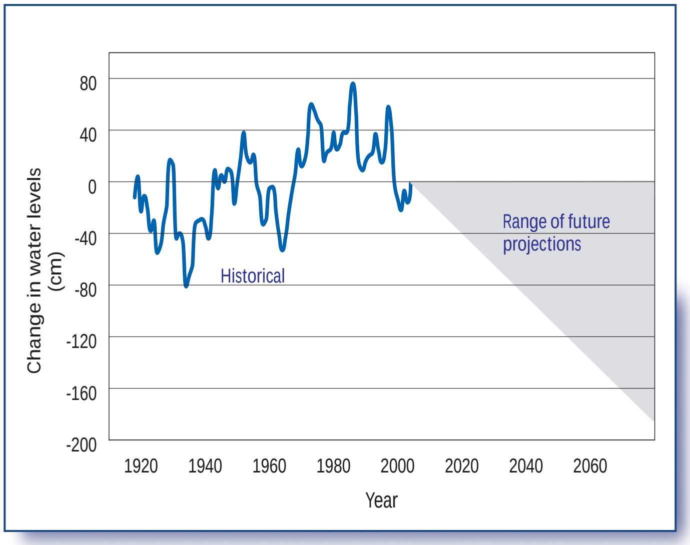
Canada's freshwater is an immensely valuable resource that is considered by many to be plentiful, renewable and relatively clean. It is stored in its liquid form in rivers, lakes, soils and aquifers and in vegetation. It is also present in its solid form in glacier ice, snowpacks, lake and river ice and permafrost. Its presence is essential to life and very important to a broad range of economic activities and sectors of society. Some estimates suggest that its measurable contribution to the Canadian economy may exceed $20 billion/year. However, its overabundance can also cause catastrophic floods and related damage to ecosystems and society. Despite Canada's abundance of water, this valuable resource is now under pressure from growing and often conflicting human requirements. Furthermore, it is particularly vulnerable to the impacts of climate variability and change.

Climate models project that, during the coming decades, water resources will become more abundant across much of northern Canada. Furthermore, its presence as snow and ice will decrease over time, being replaced by water in its liquid form. Consequently, winter stream flows are expected to increase across much of Canada, spring freshets will occur earlier, and peak melt water runoff will be lower in magnitude. However, slowly degrading permafrost will also change the ground water hydrology in the north, changing streamflows and breaking down natural barriers that currently control much of regional drainage patterns.

In contrast, summer water abundance in southern Canada will likely decrease – and become more variable. Various studies suggest that the combined effects of increased evaporation of surface water under warmer climates and altered precipitation patterns will likely cause summer meteorological droughts in the interior of southern Canada to become more frequent, more intense, and of longer duration. These will, in turn, result in intervals of very low

FIGURE 5.3

Various model projections of future changes in Lake Erie water levels, compared with historical changes since 1920



streamflows and lake levels and depleted ground water resources. For larger water reservoirs, this is expected to lead to persistent decreases in mean water levels. For example, some of the Great Lakes, which collectively provide freshwater to some 45 million people, could experience a drop in water levels of a metre or more within the next 50 to 75 years.

Such intense periods of water shortages will have major impacts on hydro electricity production, marine transportation, agricultural irrigation, on-water recreational activities, municipal water supply, and a range of other socio-economic uses. In western Canada, these shortages will be exacerbated by the gradual disappearance of alpine glaciers that currently provide much of the freshwater input in regional streams and rivers in summer. Competition for water use and political pressures for water transfers between hydrological basins will increase. Furthermore, severe droughts will also cause increased degradation of water quality, greater risk of eutrophication and extensive harm to aquatic ecosystems.

Ironically, while spring floods due to rapid snow melt may decrease in frequency, there may be an increase in the risk of more intense and frequent summer flooding and the related damages that such floods can cause. That is because hotter summers are likely to increase the intensity of rainfall events when they do occur. For example, Canadian studies suggest that, by 2080, an extreme summer rainfall event that now occurs about once every 40 years might occur as often as once per decade. When precipitation is intense, less of the water enters the soils to recharge groundwater and more runs off into streams, rivers, wetlands and lakes. Such run-off can help recharge surface reservoirs depleted by drought. However, it can also enhance soil erosion and can result in much more disastrous summer floods.

FISHERIES

With its long coastline and its many fresh water lakes, commercial and recreational fishing is an important part of Canada's economy, contributing more than $10 billion each year. More importantly, for many Canadians, particularly in aboriginal and small coastal communities, it is a way of life – and an inherent part of their culture. Hence the well-being of fish resources in waters within and adjacent to Canada is important.

However, most fish species have a distinct, although complex set of environmental and habitat conditions within which they thrive and beyond which they decline and possibly perish. These conditions include a number of climatic factors, such as air and water temperature, precipitation and wind patterns. Hence, fish health, productivity and distribution are also sensitive to changes in climate. For any given region, some species will become healthier and more abundant, others will become distressed and perhaps disappear completely, and new species may invade and even dominate. There is good evidence to suggest that such changes are already taking place. For example, climate change appears to be an important factor in declining salmon stocks off the coast of British Columbia, while sockeye and pink salmon are being reported in Arctic regions well beyond their known range. In the Atlantic Ocean, recent rises in water temperatures are believed to have contributed to a decline in flounder.

This relationship between climate and fish resources is complex, involving both the direct effects on each species as well as the indirect effects through changes in abundance of food supply and predators. Some species, like salmon, are also affected by changes in both freshwater and ocean habitats. In addition, there are other important non-climatic factors affecting fish resources, particularly those of man-made pollution and resource mismanagement. Although these interconnections are as yet poorly understood, there are some useful projections that can already be made. For example, projections for higher water temperatures and more frequent periods of low river flow suggest increased salmon mortality as they head up-stream to spawn. Furthermore, more frequent flash floods could also damage gravel beds used for spawning. However, this may be offset by reduced mortality of juvenile salmon as they head out to sea. Changes in ocean climate also affect the distribution and significance of certain marine diseases, such as the eastern oyster disease, and the risks of harmful toxic algae blooms. In the Arctic, more open water may increase the food supply and hence abundance of many fish species, but could threaten Arctic cod and alter traditional northern fishing practices because of changes in sea ice cover.

In fresh water lakes and rivers, warmer temperatures would generally benefit warm water fish such as bass and sturgeon, but reduce the abundance of cold water species like trout and lake salmon. New species that thrive in warmer waters can be expected to migrate into these lakes, competing with existing species, some of which may disappear completely. Lower water levels would threaten shoreline wetlands that provide important fish habit and result in degraded water quality. However, shorter ice cover seasons would reduce over winter fish mortality.

COASTAL ZONES

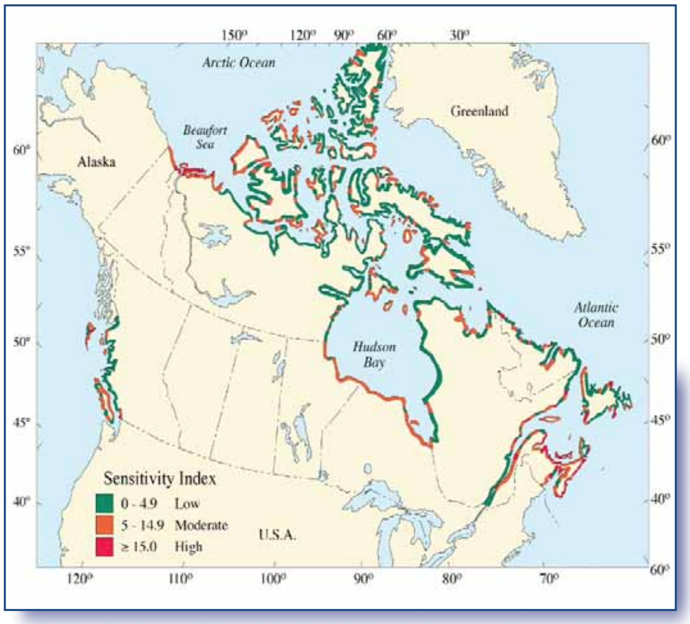
Canada has more than 240 000 kilometres of ocean shoreline. Along these shores are the coastal ecosystems, where the dynamic interaction of land and sea help provide high ecological diversity. Roughly seven million Canadians live in these coastal areas, many in smaller communities that depend on the ocean's resources and tourism to make a living. Hence, healthy coastal ecosystems are of critical importance to their culture and economic well-being.

The sensitivity of these coastlines to the impacts of climate change, particularly those due to sea level rise, is influenced by a variety of factors, particularly the regional characteristics of ocean processes, the nature of the shoreline, and whether vertical movements of the Earth's crust are causing the regional land masses to rise or sink. Much of Canada's coastline is rugged and unpopulated. In areas such as the Hudson Bay region, the land mass is also still rebounding due to the delayed effects of deglaciation many thousands of years ago. This can offset at least some of the effects of global sea level rise. Thus, Canada is much less vulnerable to the impacts of global sea level rise than many other nations. However, it will not remain unaffected (Figure 5.4).

In the Maritime Provinces, for example, the combination of sinking land masses and abundance of sandy shores make more than 80% of the region's coastline moderately to highly sensitive to sea level rise. Accelerated sea level

FIGURE 5.4

Sensitivity of Canada's coastlines to sea level rise



rise would inundate much of the region's lowlands, causing some of the highly productive tidal salt marshes to disappear. Many of the freshwater coastal marshes would become salt marshes, and soft coastlines would erode more rapidly. Both stronger waves in winter due to reduced sea ice cover and a likely increase in intense storm surges would increase the risks of local flooding and erosion. In populated areas, this will have large impacts on built infrastructure. Along the north shore of Prince Edward Island alone, about 10% of current assessed coastal property values could be lost within 20 years, and almost 50% within the next century.

Along the Arctic coast, the largest impacts of climate change will likely be caused by changes in reduced ice cover and the decay of permafrost. Reduced sea ice cover will benefit some ocean species, such as whales, that need access to open water, but will threaten species such as seals and polar bears that rely on the presence of ice. It would open up Arctic waters to increased marine shipping and create new opportunities for economic regional development. However, this also adds to concerns about pollution and sovereignty, and adversely impacts northerners who rely on extended, stable ice cover for safe travel, access to communities and hunting grounds, and other traditional activities. Decaying permafrost would also destabilize coastal land areas, increasing the risks of land slides and compounding the coastal erosion caused by rising sea levels and reduced ice cover. Some communities in low lying regions of the western Arctic are already undergoing such changes. Parts of Tuktoyaktuk, for example, have experienced extensive coastal retreat since 1935, resulting in the destruction or relocation of a number of community buildings. While protective measures have helped to stabilize this retreat, further sea level rise and permafrost decay would cause further inundation and erosion.

Another highly sensitive coastal region is the Fraser delta region of British Columbia. This region is highly populated, and significant parts of the region are less than one metre above sea level and already protected by an extensive dyke system. Here the main concerns include the breaching of these dykes, erosion of soft shoreline areas and the consequent risks to coastal ecosystems, infrastructure and archaeological sites. A one metre rise in sea level would put more than 15 000 hectares of residential and industrial properties and 4 600 hectares of highly productive farmland at risk, and would contaminate much of the regions ground water with salt intrusion.

TRANSPORTATION

Canadians spend more than $150 billion each year to travel and transport goods across Canada and to and from other nations. The infrastructure involved employs more than 800 000 people, uses more than 1.4 million km of roads, 50 000 km of rail lines and 1700 airports and involves more than 17 million motor vehicles, 28 000 airplanes, and 2000 commercial marine vessels. It is a system that is essential to Canada's economy and its culture. It is also a system whose various components are sensitive to climate and weather throughout their service lifetimes – in planning, design, construction, maintenance and performance.

Although the transportation infrastructure in Canada is quite robust, future changes in climate will have significant impacts – some positive and other adverse. For example, warmer winters will likely reduce frost damage to pavements and rails in many southern parts of Canada, and would shorten the season for snow removal and related transportation hazards. However, milder winters may increase surface transportation infrastructure damage in areas where warmer temperatures are likely to increase freeze-thaw cycles. More frequent hot days in summer may also increase road and rail damage. In northern regions, milder winters would reduce the bearing capacity and length of time winter roads can used to transport goods and resources to and from isolated communities. Degradation of permafrost would further affect all-season roads and transport of resources by rail and pipelines.

Changes in the frequency and severity of other types of extreme weather can also be important to transportation. Large floods, which are expected to become more frequent, can wash out large sections of roadways and rail beds, while more frequent intense winter storms may trigger additional economic losses due to major disruptions of air and surface transportation.

For marine transportation, shorter and milder winter ice seasons will allow longer shipping seasons and may reduce the risk of ice damage to ships and coastal infrastructure. The Northwest Passage could eventually become a major international shipping route. On the other hand, increased surging of Greenland glaciers may increase iceberg hazards. Further, in the Great Lakes and St. Lawrence Seaway system, lower lake levels would reduce the carrying capacity of marine transports through the system.

HUMAN HEALTH AND WELL BEING

Good health is one of the most important aspects of well-being. In fact, Canadians spend more than $100 billion each year to maintain and improve their health.

Weather is an important factor in how healthy we are. In Canada, for example, deaths due to heat stroke or heart attacks are most prevalent in summer, when heat stress is more likely to affect people. On the other hand, illnesses and deaths due to respiratory infections such as pneumonia or flu viruses occur much more frequently during the winter season. Extreme weather events, including floods, droughts, wind storms, bad air days and lightning, can also cause serious and sometimes deadly damage to our well-being.

Climate change will alter this relationship between health and weather in complex ways. For example, a modest increase in average temperatures can cause a disproportionate increase in the number of very hot days, and hence the occurrence of heat stress related deaths and illnesses. Intense smog episodes are also projected to become more frequent during such hot summer days, causing further stress for young children, the elderly and those with respiratory problems. During periods of intense drought, dust storms and smoke from forest fires can add to this stress.

Warmer climates and altered weather behaviour will also affect the spread of various harmful substances and diseases. During floods, bacteria and chemicals from sewage spills and run-off from farmlands can inject these into drinking water and necessitate the closing of beaches to swimming. Warmer climates also increase the risk of food poisoning due to enhanced microbial activity or the occurrence of toxic algae blooms in marine environments. Recently the warming of climates in southern Canada has also contributed to the spread of insect and rodent borne diseases, such as the West Nile Virus and Lyme disease. Another potential health risk is the re-emergence of malaria in southern Canada.

In northern Canada, changes in the physical environment will make winters less stressful, but will increase the health risks associated with travel over weaker ice surfaces and will make the harvesting of traditional food sources more difficult. Furthermore, changes in atmospheric circulation and warmer temperatures may increase the transport of harmful pollutants from industrial regions to the north.

ENERGY PRODUCTION AND USE

Each year, Canadians consume about 11 petajoules of energy and export more than 5 petajoules of energy to other countries, primarily the United States. Hence, the exploration, production, transportation and use of energy is an important aspect of Canada's economy, directly employing some 225 000 people and contributing about $65 billion to Canada's Gross Domestic Product.

The energy sector is also very sensitive to weather and its variations, and hence will be significantly impacted by climate change.

For example, energy consumption for space heating and cooling in our homes, offices and factories changes with outside temperatures. Within the next 50 years or so, the projected warming of our climate could reduce winter heating costs in Canada by some 20-30%. These savings will be partially offset by increased summer cooling costs

in southern Canada. Warm climates would also generally improve the efficiency of surface and marine transportation of oil and gas.

However, climate change may also have significant effects on the production and transportation of energy. For instance, in southern Canada, an expected decrease in mean lake levels and river flows and increased frequency of severe droughts will likely decrease the potential for hydro electricity generation. The reverse is likely in northern Canada, where water abundance is likely to increase. There is also a risk that more intense winter storms could increase damage and disruption of electricity transmission grids. Milder winters would also benefit this sector through shorter ice seasons but also challenge it with the risk of more frequent mid-winter river ice jams.

In northern and coastal regions, fossil fuel energy production and transportation activities will also need to deal with the effects of decaying permafrost on pipelines and roads, and of increased iceberg hazards along Canada's east coast.

GLOBAL SECURITY

Experts predict that the greatest economic and social costs of climate change will likely occur in poor regions of the world, many of which are already challenged with inadequate food and water resources and with other challenges such as rising sea levels. However, climate related disasters abroad will also have wide ranging indirect implications for the economic, social and political security of Canadians. Changes in the global distribution of food production, for instance, will alter traditional food trade patterns. Canada, as a major exporter and importer of food, will need to adapt to the new conditions, finding new supplies in some cases and new markets in others.

Meanwhile, the potential social upheaval from chronic food shortages and other disasters from climate change in the developing world will place further pressure on Canada to provide emergency relief assistance, accept environmental refugees and help resolve armed conflicts that may arise from increased resource scarcities. Furthermore, while pursuing aggressive and perhaps costly domestic action to reduce their own emissions of greenhouse gases, Canada and other industrialized nations will be expected to transfer financial and technical resources to help developing nations undertake similar action.

CLIMATE CHANGE AND EXTREME WEATHER

In spite of the uncertainties associated with them, climate models now provide a reasonably clear indication of the probable direction of the large scale change of average surface climates during the decades to come. However, both humans and ecosystems are much more vulnerable to the frequency, intensity and duration of extreme weather events such as droughts, floods, wind storms, heat waves and cold spells than to gradual shifts in climate. Because such events often exceed the tolerance of our social and ecological systems and are difficult to predict in advance, they can bring with them hardship, economic loss, severe social and ecological disruption, and even loss of life.

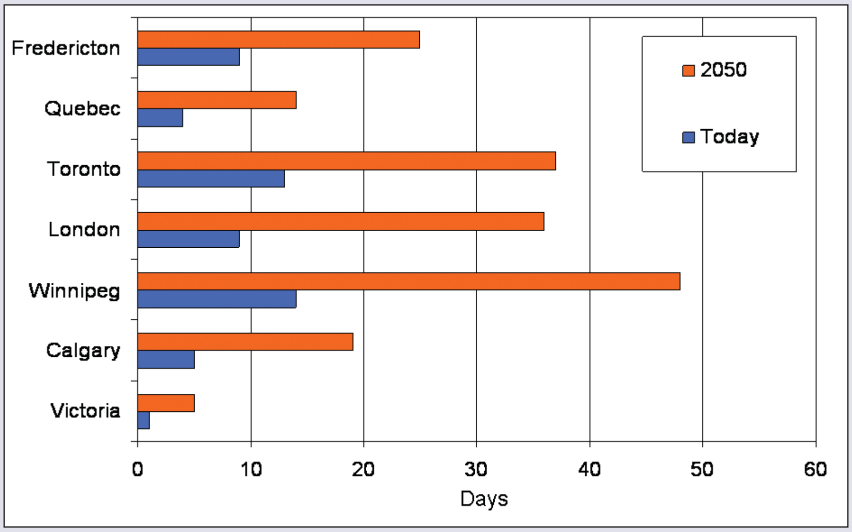
Determining the influence of warmer climate on the risks associated with extreme weather events is therefore critical to our understanding of the impact of an enhanced greenhouse effect. However, climate models have so far provided only preliminary indications of how these risks may change. Studies into past relationships between climate and extreme weather, and the use of extreme event models linked to climate models have helped to provide additional insights. Experts have considerable confidence in some of the results, like those related to temperature extremes, but much less so for other types of extremes.

Not surprisingly, these studies suggest with considerable confidence that hot spells in summer will become more frequent and more severe, while very cold periods in winter will become less frequent – although they will still occur. By 2050, for example, hot summer days in southern Canada exceeding 30°C are likely to become four times more frequent than today. Both extreme low and high precipitation events are also expected to become more frequent. For instance, by mid-21st century, extreme periods of low precipitation across central North America which presently occur about once every 50 years could happen as often as once every 15 to 20. At the other extreme, intense rainfall events could also occur twice as frequently. These changes have major implications for the frequency of intense droughts and floods.

Much less certain are the impacts of climate change on the frequency and severity of storms such as hurricanes, tornadoes and winter blizzards. There are indications, however, that the maximum potential intensity of such storms are likely to increase as the surface temperatures of the Earth increase.

FIGURE 5.5

Number of days with temperatures exceeding 30°C, 2050 vs today



CHAPTER 6

How do we respond?

As the preceding chapters indicate, climate change is a complex issue that is only partially understood. Yet it is also an issue of critical importance to human societies, particularly those in developing regions of the world and of future generations. In general, experts agree that policy makers cannot wait until all the scientific questions are answered before they act, since by then it may be far too late to do so. Hence, we must approach this as a risk management problem. To do so requires three distinctly different but complementary types of responses.

First, scientists need to continue to work diligently to better understand how the climate system works, how it is likely to change in the future, how such changes may affect natural ecosystems and human society and how we might adapt to these changes. Such enhancement of understanding will be important to policy makers in the future as they deal with increasingly tough decisions on how to respond to the risks that a changing climate will pose.

Secondly, policy makers already need to consider what measures can be taken now to reduce the emissions of greenhouse gases, which are projected to be the primary drivers for future climate change. Emissions need to be reduced to a level that would ensure that the rate and magnitude of future climate change remain within acceptable limits. Such measures would not be able to stop future climate change from happening – we are too late for that – but would hopefully buy both ecosystems and societies time to adapt to the changes that do occur. While initial measures can be modest, they will likely need to be strengthened as the scientific understanding improves, and as the evidence for potentially dangerous changes in climate becomes more convincing.

The third response strategy is to anticipate the changes in climate that we expect to be unavoidable, and to prepare for these through adaptation measures. Such measures can improve our tolerance for change and raise the thresholds of acceptability.

ENHANCING OUR UNDERSTANDING OF CLIMATE CHANGE

The global research effort

In 1957, American researchers Roger Revelle and Hans Seuss issued a clear warning to the international science community that human interference with the climate system was a serious concern that needed to be investigated. They noted that the rapid increase in carbon dioxide emissions from the exponential rise in use of fossil fuels for energy was initiating a global scale geophysical experiment with the planet that was poorly understood and potentially dangerous. Revelle and Seuss called for a major global research effort to understand the implications. They themselves started a program for rigorous monitoring of atmospheric composition.

It took another two decades after this warning before the international science community began to respond in an organized and coordinated manner. A major milestone in this development was the first World Climate Conference, held in Geneva in 1979. Conference participants considered the unusual global weather behaviour of the previous decades, discussed how to move forward to better understand how the climate system works, and agreed on the need to coordinate and accelerate related national research efforts. In response, the World Meteorological Organization (WMO) collaborated with the United Nations Environment Programme (UNEP) and the International Council of Scientific Unions (ICSU) to launch the World Climate Programme (WCP). In 1986, the ICSU established a complementary and ambitious initiative called the International Geosphere-Biosphere Programme (IGBP). The IGBP sought to expand the WCP research efforts to include the Earth's entire living ecosystem.

These and other related programs have already contributed substantially to our understanding of the global climate system and the sensitivity of ecosystems and human society to changes within it. Continued research is expanding our knowledge of how elements such as clouds, sea ice, and the hydrological cycle affect climatic processes. It is also unraveling such major uncertainties as the complex role of the oceans as a reservoir for greenhouse gases and as a sink, source and transporter of heat. Because the effects of climate shifts will vary from one area to another, efforts are being made as well to develop useful scenarios of regional climate change. As these research efforts continue, impact and adaptation studies are beginning to identify those natural and human systems that are most sensitive to climate change and to investigate how such sensitivities might be ameliorated through actions to mitigate the impacts. As they progress, such studies also need to look carefully at the total impact of all assaults on natural ecosystems and human health, including acid precipitation, increased ultraviolet radiation and local air pollution as well as climate change.

Assessing and communicating climate change science

Traditionally, scientists seek new knowledge by observing the behaviour of physical and chemical systems, proposing hypotheses to describe the processes that contribute to such behaviour, then testing these hypotheses through experimentation. Results are shared with peers, who engage in adversarial debate in an effort to disprove the hypothesis and/or seek to reproduce results. This scientific process helps to slowly build up the incremental knowledge that helps humanity to understand the behaviour of natural systems and to advise non-scientists accordingly. In many respects, confidence in the science being communicated is thus based largely on the unsuccessful attempts to disprove hypotheses and theories, rather than the ability to provide absolute proof.

However, scientific issues such as climate change are very complex. They involve a very broad range of scientific disciplines, and must therefore consider the intricate interactions and feedbacks between the various components of the issue. Furthermore, at least for the climate system, human society is an inextricable part of the challenge in understanding its behaviour – both in terms of causes for change and feedbacks from human response to impacts. Finally, because the consequences of the 'geophysical' experiment that humans are now undertaking with the planet are already occurring today and are potentially dangerous, there is urgency in taking action to reduce the risks. In other words, politicians and the public may need to respond to the threat well before all the scientific answers to their concerns and questions are fully addressed. This presents a major communication challenge for the scientific community - one that seeks to effectively provide decision makers with the available information they need without compromising its scientific integrity.

To ensure such evolving scientific knowledge is made available to the policy community in a timely and effective manner, regular multi-disciplinary science assessments are needed. Furthermore, to help ensure the accuracy, relevance and completeness of such assessments, they need to be reviewed by both the scientific peer community and stakeholders outside of the science community. The WMO and UNEP, at the request of the United Nations General Assembly, established the Intergovernmental Panel on Climate Change (IPCC) in 1988 to coordinate and facilitate such assessment processes for climate change science.

To date, the IPCC has prepared three major comprehensive assessments of climate change science, the first completed in 1990, the second in 1995 and the third in 2001. A fourth assessment, to be completed in 2007, is now underway. The assessments have focused on the three themes: climate science, impacts and adaptation, and mitigation options. Each assessment takes more than two years to complete, and each has involved several thousand scientific experts from countries around the world to draft and review the contents of the reports. The full report is also summarized in a Summary for Policy Makers (SPM) report and a Synthesis Report (SR). The simplified contents of these two reports are jointly drafted by lead scientific authors of the main report and staff members of the IPCC Bureau, and then negotiated - line by line - by government representatives meeting in IPCC plenary session. Lead authors are present during this process to ensure the accuracy and integrity of the information provided, but the involvement of government representatives helps to enhance their comprehensibility and relevance to policy makers.

Some individuals have argued, primarily through media outlets and web sites, that the confidence in climate change science is inadequate to justify action at this time and that the integrity of the IPCC assessment process has been compromised by political interference. However, following the release of the third IPCC assessment, seventeen academies of sciences from various countries around the world released a strong endorsement of both the IPCC assessment process and the conclusions of its reports. Independently, a special committee of the American National Academies of Sciences advised their country's President that the full IPCC Third Assessment Report on climate change science was "an admirable summary of research activities in climate science". While the committee acknowledged that the SPM puts stronger emphasis on concerns about the risks posed by climate change and less emphasis on uncertainties than did the full report – to be expected from a summary document – it had the full consent of convening lead authors. Furthermore, they noted, such differences in emphasis did not affect the fundamental conclusions of the report.

Exploring linkages to other atmospheric issues

Climate change and other atmospheric issues, such as stratospheric ozone depletion, acid rain and local air quality, are not separate environmental concerns but related consequences of a more fundamental issue – the effect of human activities on the chemical composition of the atmosphere itself. In fact, the relationships between these concerns are multiple and complex.

One way in which these issues are related is through common human activities that release the gases and aerosols that cause them. These activities fall into three broad but related categories: land use change, industrial processes and the burning of fossil fuels. The release of chlorofluorocarbons, for example, both contributes to the destruction of the ozone layer in the stratosphere and enhances the greenhouse effect. The burning of gasoline in a car engine releases greenhouse gases such as carbon dioxide and nitrous oxide, but also emits volatile gases such as nitrogen oxides that contribute to urban smog issues. The chemical processes that contribute to smog also remove the hydroxyl radicals that cleanse the atmosphere of methane - another greenhouse gas.

Another linkage is the complex physical processes and chemical reactions within the atmosphere. An enhanced greenhouse effect, for example, is expected to warm the lower atmosphere but cause the upper atmosphere to cool. This changes the rate of production and hence distribution of ozone in the upper region. However, it could also enhance the risks of ozone holes in polar regions. Near the surface, warmer temperatures enhance the risk of bad air quality days. Moreover, changes in wind direction caused by uneven warming of the Earth's climate may also alter where acid rain is deposited.

Finally, damage to ecosystems and human health is sometimes the results of several of these stresses acting together. Ecosystems that have already been weakened by the effects of acidification, surface ozone exposure and/or increased bombardment by UV-B radiation can die when exposed to the added stress of warmer temperatures or drought. Alternatively, acidified lakes that have slowly recovered over time can become re-acidified if droughts expose shallow parts of the lake bottom and re-oxidize the sulphates that have been deposited in the sediments over time. Studies also suggest that human deaths can rise significantly if vulnerable people seriously affected by bad air quality must deal with the added impacts of heat stress.

Understanding these linkages is therefore fundamental to the formulation of an effective response to these issues. Since action with respect to one problem can affect some or all of the others, a holistic approach is required to address them efficiently and effectively.

MOVING TOWARDS CONSENSUS ON THE NEED FOR ACTION

Dialogue between scientists and policy makers about the risks of human-induced climate change had already begun well before the IPCC began its comprehensive science assessments. In 1985, for example, an international gathering of climate change experts met in Villach, Austria to review the current state of understanding surrounding the issue of climate change. At the conclusion of their historic meeting, they released a statement to governments around the world warning them that many of the important economic decisions being made today are based on the assumption that climate is a constant. That, they cautioned, is no longer a valid assumption.

During the next five or so years, there followed a flurry of other meetings and conferences organized by various governments to discuss how to respond to the warning issued at the Villach meeting. The 1988 World Conference on the Changing Atmosphere, sponsored by Canada and held in Toronto, one of the first of these, was a pivotal event, in this process. It brought together nearly 300 politicians, policy advisors, legal experts, environmental advocates and scientists to discuss the scientific basis for concern about atmospheric change and to recommend a course of action to the world community. Participants were deeply concerned that the human impact on the atmosphere had now become so powerful as to amount to ‘an unintended, uncontrolled, globally pervasive experiment whose ultimate consequences could only be second to a global nuclear war.” A significant outcome of the conference was its success in transferring concern about climate change from the scientific community to the world community. Equally important was its recommendation to reduce global carbon dioxide emissions by 20% of 1988 levels by 2005.

Other meetings quickly followed. Out of these meetings came the realization that, although unilateral actions are also valuable, it was crucially important that the nations of the world work together in order to ensure that action on climate change would be globally effective. Hence, the international community began the process of formulating a common understanding of the issues and of exploring the feasibility of international consensus and a global political response.

GLOBAL POLITICAL RESPONSE

While this process of consensus building on principles for action on climate change was underway, the United Nations General Assembly began its own deliberations on the threat of climate change. After having passed several resolutions expressing concern about the risks of climate change for humanity and the need for action, in 1988 it asked the WMO and UNEP to organize the IPCC for the purpose of coordinating relevant science assessments. In addition, it established an Intergovernmental Negotiating Committee to begin the task of developing a Framework Convention on Climate Change (FCCC). Following two years of intensive negotiations, the FCCC was approved at the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992. The ultimate objective of the FCCC is to stabilize greenhouse gas concentrations at levels that would avoid ‘dangerous’ human interference with the climate system. It has now been signed and ratified by more than 190 member countries, and annual meetings of the Conference of the Parties (CoP) to the Convention have been held since 1995.

At the third meeting of the CoP, held in Kyoto in 1997, member countries moved a significant step further. They agreed on a Protocol to the Convention that sought firm commitments from industrialized member countries to take the first concrete steps to curtail global greenhouse gas emissions. One of the key provisions of this Kyoto Protocol is that these industrialized nations, known as Annex I countries, would be required to reduce their collective emissions of six key greenhouse gases by about 5.2% below 1990 levels by the first reporting period of 2008-12. Targets for individual countries varied from a reduction of 8% for the countries of the European Union to an increase of up to 10% for countries with special circumstances that were causing rapid growth in emissions (e.g., Iceland).

Further regional renegotiation of the European Union target saw some EU countries accept targets as high as a 27% increase (Portugal) and as low as a 28% reduction (Luxembourg). Canada agreed to a target of 6% reduction. While other non-Annex I countries were not held to a commitment for specific reduction targets in this first step, they would be required to report on emissions and seek voluntary action to curtail them.

To come into effect, the Kyoto Protocol had to be signed and ratified by at least 55 member countries. Furthermore, those who ratified had to represent at least 55% of the collective Annex I emissions in 1990. As of July 2005, 151 countries had ratified. More importantly, with Russia's ratification in November, 2004, the ratifying countries included representation of 61% the total Annex I emissions. With both criteria met, the Protocol became legally binding to its ratifying members on February 16, 2005.

THE CANADIAN RESPONSE

The Government of Canada maintains that climate change is one of the most significant environmental and sustainable development challenges facing the globe and that the Kyoto Protocol is the only global mechanism to start reducing greenhouse gas emissions. That is why Canada ratified the Kyoto Protocol in December 2002 and believes that it is an important step in the right direction.

The task of meeting Canada's Kyoto target is, however, a significant challenge. Both its population and its economy have been growing rapidly since 1990. This healthy development has also caused a significant increase in emissions. Between 1990 and 2003, Canadian greenhouse gas emissions increased by 24%. Canada's challenge is to reduce emissions to 6% below 1990 levels over the 2008-2012 period. This will require a reduction in emissions of some 270 megatonnes.

To tackle this challenge, on April 13, 2005 the Government introduced the 2005 Climate Change Plan: *Moving Forward on Climate Change: A Plan for Honouring our Kyoto Commitment.*

The Plan is a key component of Project Green, the government's broader environmental vision aimed at supporting a healthy environment and a competitive economy. It details the general approach and delivery mechanisms that will guide the actions needed across the economy to allow Canada to honour its commitment to the Kyoto Protocol in a way that encourages continued economic competitiveness in both the short and longer terms. These mechanisms include the Climate Fund, the Partnership Fund, the Large Final Emitter System, and federal programs.

A primary tool for Canada's approach to climate change, the Climate Fund is a market-based mechanism that will encourage emission reductions across the economy. The purpose of the Climate Fund is to create a permanent institution for the purchase of emission reduction credits on behalf of the Government of Canada.

Canada's Large Final Emitters include companies in the mining and manufacturing, oil and gas, and thermal electricity sectors. These sectors make an important contribution to Canada's economic base, but they are also large contributors (just under 50%) of Canada's total greenhouse gas emissions. The 2005 Climate Change

FIGURE 6.1

Country delegates discuss the Kyoto Protocol at one of the CoP meetings

Plan outlines a Large Final Emitter System that will reduce emissions from covered sectors while promoting their economic growth and competitiveness.

The Partnership Fund will provide the basis for synergy and collaboration with provinces and territories by cost sharing key initiatives. Clean energy and energy efficiency projects will be priorities, as will bringing programs and services closer to the individuals who need them.

Climate change programs play an important role in generating emission reductions and promoting early action. Budget 2005 and the Plan expanded a number of programs, including EnerGuide for Houses as well as the Wind Power Production Incentive. The Government also announced the Renewable Power Production Incentive to support emerging renewable energy sources. To further advance the deployment of renewable energy, the capital cost allowance rate for investments in highly efficient co-generation and renewable energy systems equipment was increased.

The Plan builds on the Governments previous investments in climate change. Between 1997 and 2003 the Government made incremental investments (to a total of $3.7 billion) in climate change though successive budgets. Action Plan 2000, for example, comprises 45 measures that target key sectors accounting for 90% of Canada's greenhouse gas emissions. Many of those measures broke new ground, while a number received additional support through subsequent allocations. These include, for example, programs to encourage energy efficiency retrofits of existing commercial buildings.

These early programs provided the foundation for the 2002 Climate Change Plan for Canada, which used a broader range of tools including information, incentives, regulations and tax measures, across a number of sectors including: transportation; housing and commercial / institutional buildings; large industrial emitters; renewable energy and cleaner fossil fuels; agriculture; forestry and landfills. While previous investments laid the groundwork for behavioral, technological and economic changes, investments made through Budget 2005 and outlined in the 2005 Climate Change Plan are critical in placing Canada on the lower emissions trajectory that will be needed to achieve the significant cuts required over time.

Canada has also moved forward to enhance its contribution to improve scientific understanding of climate change and to apply that understanding to help Canadians adapt to changes that will still unavoidably occur, regardless of efforts to curtail global greenhouse gas emissions. Infusion of new funding into government and academic research initiatives within Canada through programs such as the Climate Change Action Fund, Action Plan 2000 and resources provided directly to the Canadian Foundation for Climate and Atmospheric Sciences have complemented existing climate change research initiatives. While many of these programs have limited duration, their benefits include continued international leadership of Canadian scientists in reducing the scientific uncertainty surrounding the climate change issue. They also help to maintain and enhance Canadian capacity to investigate the impacts of climate change on Canadians and to explore options for adapting to projected changes in climate.

While the Kyoto Protocol was pivotal for mobilizing global action on climate change, a new international agreement must provide the framework to drive prosperous 21st century economies that are innovative and efficient as well as lead to deeper reductions in GHG emissions. Canada's Plan for Honouring our Kyoto Commitments: *Moving Forward on Climate Change* recognizes that a future international agreement must meet certain key objectives.

It must:
- Have broader participation with fair goals, including all industrialized and key emerging economies;
- Generate outcomes that will result in real progress over the longer term;
- Provide incentives to invest in developing and sharing transformative environmental technologies to reduce emissions at home and abroad;
- Maximize the deployment of existing clean technologies;
- Support a streamlined and efficient global carbon market; and
- Address adaptation as well as mitigation.

If we are going to build successfully on the Kyoto Protocol, we need a truly global and long-term approach, with efficiently operating market mechanisms in place. A truly global approach would have many points of participation and allow for truly global emissions trading, pay more attention to integrating climate change goals with development and trade policies, better address economic growth issues for all countries, and place greater emphasis on effective technology transfer by promoting and deploying innovative and existing technologies.

The objectives laid out in Canada's Plan for Honouring our Kyoto Commitment represent a solid foundation from which to launch a dialogue on the future.

THE ROLE OF THE CITIZEN

How can the individual Canadian citizen influence the outcome of a global environmental issue that is already challenging the wisdom and resources of the world's governments and international agencies? The answer, simply put, is that it is the individual citizens who must create the environment of opinion which will encourage governments to act. And it is the individual citizens who can take actions themselves to reduce their personal emissions and who can support the policies that an effective response to the risks of climate change will demand.

The estimated 23 billion tonnes of carbon dioxide that humans, globally, pour into the atmosphere each year through the combustion of fossil fuels are not produced by governments but by the more than 6 billion people who now occupy the Earth. Each time we turn up the thermostat, drive a car, turn on a hot water tap, or open a refrigerator door, we add to the problem. By changing our attitudes and lifestyles, by becoming more knowledgeable about the issue and rethinking our attitude to the environment, we can make a difference.

In addition to exerting our influence on policy matters, there are many other things that we can do in our personal lives to ease the burden that we place on the environment. Every year, each Canadian produces an average of over 5 tonnes of greenhouse gas emissions. The One-Tonne Challenge encourages all Canadians to reduce their personal greenhouse gas emissions by one tonne, or by 20%. They can achieve this goal by being more energy efficient, reducing waste and water use and wise consumers. There are many actions included in the One-Tonne Challenge and these are listed in the accompanying box on the next page. More information on the One-Tonne Challenge can be found on our website at: **www.climatechange.gc.ca/onetonne.**

PROTECTING THE ATMOSPHERE: A PERSONAL AGENDA

The One Tonne Challenge

The guide to the One-Tonne Challenge outlines the following actions Canadians can take on climate change. In general, it means using less energy, improving air quality and protecting our environment, while saving money. The One-Tonne Challenge is an educational program challenging Canadians to reduce their individual GHG emissions by one tonne, or about 20%.

On the Road

Cars and trucks on our road are responsible for about 18% of Canada's total GHGs. Every year, motor vehicles exhaust release more than 134 million tones of GHGs into the atmosphere. Here is what you can do.

- Drive 10% less.
- Use your vehicle's air conditioner sparingly.
- Give up your second vehicle.
- Don't idle.
- Drive at the posted speed limit.
- Use a block heater on a timer.
- Keep your vehicle well maintained.
- Use ethanol-blended gasoline.
- Measure your vehicle's tire pressure once a month.
- Remove roof racks when not in use.
- Don't buy more than you need.
- Buy the most fuel-efficient vehicle.

At Home

It takes a lot of energy to run a home for heating and cooling, major appliances, hot water and lighting. Maintaining a comfortable living space can be expensive, whether you rent or own your home. So it is important to "shop smart" for the most energy-efficient appliances and equipment and to keep them well maintained. Here are some tips of what you can do at home.

- Install one of today's energy-efficient furnaces
- Use caulking and weather stripping to seal air leaks.
- Look for the ENERGY STAR label on windows and sliding glass doors.
- Install storm windows.
- Replace exterior doors in poor repair with insulated core doors or add storm doors.

- Keep your furnace well maintained.
- Seal and insulate warm-air ducts.
- Upgrade your insulation in walls, basement and attic.
- Lower your thermostat in winter, at night and when you are away during the day
- Shut off the pilot light of your natural gas fireplace or wall heater in summer.

At Home (continued)

- Install a ceiling fan.
- Remove window air conditioners for the winter
- Keep window curtains open during the day in winter.
- Keep blinds, curtains and windows closed during the day in summer.
- Use fans as your first line of defense against summer heat.

- Set your air conditioner at 24°C
- Clean the air conditioner's filter every month.
- Turn off all sources of heat in summer.
- Maintain your refrigerator and freezer for better energy use.
- Look for an ENERGY STAR qualified refrigerator if you are in the market for a new one.

- Unplug that second refrigerator or freezer.
- Select the dishwasher's no-heat or air-drying cycle.
- Increase the efficiency of your refrigerator and freezer by keeping them away from heat sources.
- Rinse in cold water and wash in warm.
- Avoid over-drying clothes.

- Install outdoor automatic timers
- Use more-efficient light bulbs
- Ensure your computer system is set up to use its energy-saver option.
- Look on the box for ENERGY STAR- qualified equipment.
- Use as little paper as possible.

- Turn off lights and equipment when a work area isn't being used.
- If you are buying a laser printer, look for energy-saver features.
- Buy a monitor that is the right size for your needs.
- Capture rainwater for your garden.
- Practice "grass cycling"

- Water your garden or lawn early in the morning. Avoid using chemical pesticides or fertilizers.
- Limit your use of gas-powered lawn mowers.
- Maintain your pool efficiently
- Plant trees.
- Install a low-flow shower head with a shut-off lever.

- Go for a high-efficiency water heater unit.
- Take a quick shower instead of a bath.
- Avoid running the tap.
- Insulate water pipes. Turn-off your cottage's water heater.
- Recycle all recyclable materials.

- Compost your organic kitchen waste.
- Pay attention to goods and packaging.

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Notes