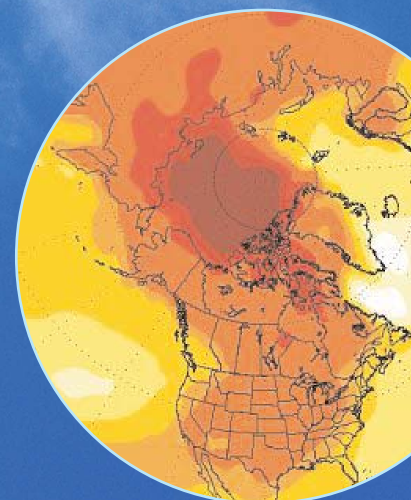
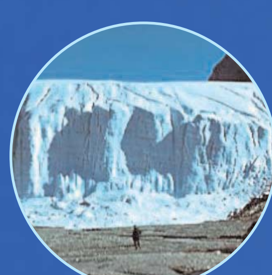
Frequently Asked Questions



about the Science of Climate Change



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FREQUENTLY ASKED QUESTIONS ABOUT CLIMATE CHANGE SCIENCE

by

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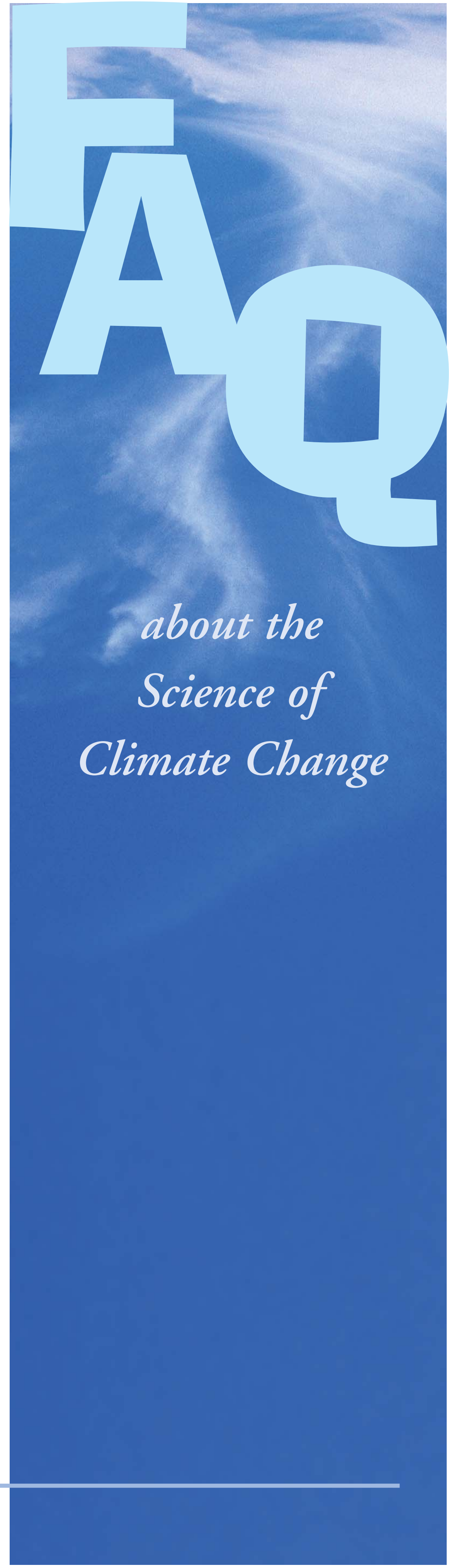
Meteorological Service of Canada
Environment Canada

This document contributes to state of the environment reporting



Canadians frequently ask questions that indicate considerable public confusion about many aspects of climate change science and related research. This confusion is compounded by contrarian arguments raised by skeptics that, for the most part, have not stood the tests of peer review and time but are still often put forward by media and others as 'sound science'. This document addresses some of these questions and arguments by providing both a simple response and a more detailed background explanation for each. Responses are based on fundamental, well-accepted principles of physics, on related information contained in the various IPCC reports published between 1990 and 2001, and in recent peer-reviewed scientific papers. References are provided for diagrams and for responses where specific values are introduced.

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A General Overview: What is Climate Change?

A.1 What is climate and how does it differ from weather?

Response: Climate describes average day-to-day weather, including seasonal extremes and variations, for a specific location or region. In many respects, climate is what we can expect, and weather is what we get.

Explanation: Weather in any particular location or region can change quickly from hour to hour, day to day, season to season and year to year, even within an unchanging climate. Such changes include shifts in temperature, snow and rainfall, winds, and clouds. They are caused by an interplay of a number of factors, including rapid shifts in air circulation, slower variations in ocean conditions, or seasonal changes in the amount of sunshine. The climate of a locality or region is calculated by averaging these weather conditions over an extended period of time, usually at least 30 years. The climate also describes how weather conditions can vary from these average values. Such variations are described in statistical terms such as standard deviations or frequency of occurrence.

A.2 What is climate change?

Response: Climate change is a long-term shift or alteration in the climate of a specific location, a region or the entire planet. The shift is measured by changes in some or all the features associated with average weather, such as temperature, wind patterns and precipitation. A change in the variability of climate is also considered climate change, even if average weather conditions remain unchanged.

Explanation: Climate change occurs when the climate of a specific location, region or the entire planet is altered between two different periods of time. This usually occurs when something alters the total amount of the sun's energy absorbed by the Earth's atmosphere and surface, or changes the amount of heat energy from the Earth's surface and atmosphere that escapes to space over an extended period of time. Such changes can involve both changes in average weather conditions and changes in how much the weather varies about these averages. They can be caused by natural processes like volcanic eruptions, changes in the sun's intensity, or very slow changes in ocean circulation or land surfaces which occur on time scales of decades, centuries or longer. Alternatively, humans can also cause climates to change by releasing greenhouse gases and aerosols into the atmosphere, by changing land surfaces, and by depleting the stratospheric ozone layer. Both natural and human factors that can cause climate change are called 'climate forcings', since they push, or 'force' the climate to shift to new values.

A.3 What is the difference between climate change and global warming?

Response: Climate change refers to general shifts in climate, including temperature, precipitation, winds, and other factors. This may vary from region to region. On the other hand, global warming (as well as global cooling) refers specifically to any change in the global average surface temperature. In other words, global warming or cooling is one type of planetary scale climate change. Global warming is often misunderstood to imply that the world will warm uniformly. In fact, an increase in average global temperature will also cause the circulation of the atmosphere to change, resulting in some areas of the world warming more, while other areas warming less than the average. Some areas can even cool.

Explanation: The initial response of the Earth's atmosphere to a 'climate forcing' is a change in flow of sun and heat energy through the atmosphere that causes temperatures at the surface, in the atmosphere and within the oceans to change. However, these changes in temperature are more rapid over land than water, and can cause changes in many other aspects of the climate. For example, warmer temperatures would cause more evaporation, higher humidity in the atmosphere, changes in cloud cover and in rain or snowfall, more snow and ice melt, and changes in winds and ocean currents, and so forth. Many of these secondary changes also affect temperature, resulting in a complex interplay of different processes that can amplify the increase in temperature in some regions and moderate changes, or even cause cooling, in others. In other words, a climate forcing that causes global warming also causes many other aspects of the climate to change in complex ways. Therefore, the term 'climate change' is the more accurate description of how climate system responds to a forcing. Unfortunately, although it can significantly misrepresent what really happens, the term 'global warming' is still often used by media and others to describe climate change.

A.4 What is the "greenhouse effect" and how does it affect climate?

Response: The greenhouse effect describes the role of the atmosphere in insulating the planet from heat loss, much like a blanket on our bed insulates our bodies from heat loss. The small concentrations of greenhouse gases within the atmosphere that cause this effect allow most of the sunlight to pass through the atmosphere to heat the planet. However, these gases absorb much of the outgoing heat energy radiated by the Earth itself, and return much of this energy back towards the surface. This keeps the surface much warmer than if they were absent. This process is referred to as the 'greenhouse effect' because, in some respects, it resembles the role of glass in a greenhouse.

Explanation: Earth is heated by sunlight. Although ozone in the stratosphere absorbs much of the harmful ultraviolet part of sunlight, most of the sun's energy passes through the atmosphere relatively unaffected by other gases in the atmosphere. About 31% of the sunlight is reflected back to space by clouds and the Earth's surface, but the remainder warms the Earth's surface, oceans and atmosphere. However, in order to keep the atmosphere's energy budget in balance, the warmed Earth also emits heat energy back to space as infrared radiation. As this energy radiates upward, most of it is absorbed by clouds and molecules of greenhouse gases (including water vapour) in the lower atmosphere. These re-radiate the energy in all directions, some back towards the surface and some upward, where other

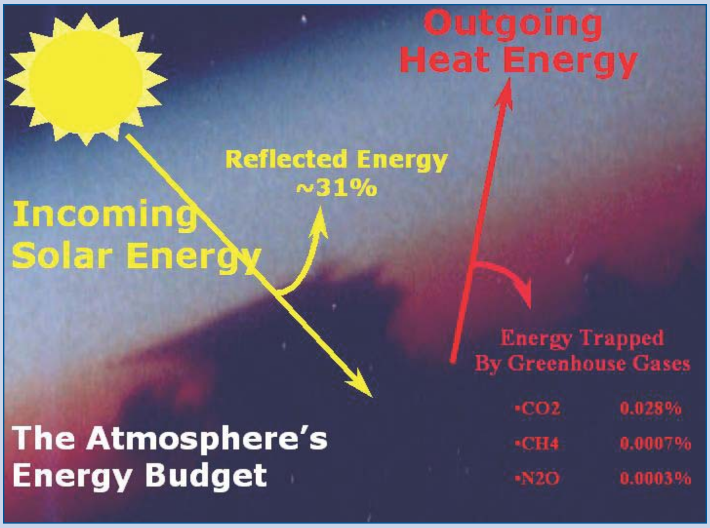

FIGURE A.4
A simple diagram of the natural greenhouse effect. In a stable climate, the net solar energy absorbed by the Earth's atmosphere, surface and oceans is equal to the net heat energy returned back to space by the Earth's surface and atmosphere.

molecules higher up can absorb the energy again. This process of absorption and re-emission is repeated until, finally, the energy does escape from the atmosphere to space. However, because much of the energy has been recycled downward, surface temperatures become much warmer then if the greenhouse gases were absent from the atmosphere. This natural process is known as the greenhouse effect. Without greenhouse gases, such as water vapour, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), the Earth's average temperature would be -19°C instead of +14°C, or 33°C colder. Over the past 10,000 years, the amount of these greenhouse gases in our atmosphere has been relatively stable. Then a few centuries ago, their concentrations began to increase due to the increasing demand for energy caused by industrialization and rising populations, and due to changing land use and human settlement patterns.

Reference: IPCC, 2001 WGI, pp 89-90.

A.5 What causes climate change?

Response: Changes in climate can be caused both by natural events and processes and by human influences. Key natural factors include changes in the intensity of sunlight reaching the Earth and in the concentration of volcanic dust, which reflects sunlight back to space. Both of these factors alter the amount of sunlight that is absorbed by the Earth's climate system. Key human influences include changes in greenhouse gas concentrations, stratospheric ozone depletion, local air pollution and alterations in land use. Most of these affect the amount of heat energy escaping to space, although some also change the amount of sunlight reflected to space.

Explanation: Changes in the intensity of sunlight reaching the Earth can cause cycles of warming and cooling that have been a regular feature of the Earth's climatic history. Some of these solar cycles, like the four large glacial-interglacial swings during the past 400,000 years, extend over very long time scales and can have large amplitudes of 5 to 6°C. For the past 10,000 years, the Earth has been in the warm interglacial phase of such a cycle. Other solar cycles are much shorter, with the shortest being the 11 year sunspot cycle. However, the magnitudes of changes in climate for these shorter cycles are much smaller than those for the long cycles. Within the past 1000 years, for example, such changes have been within a range of about 1°C. Other natural causes of climate change include variations in ocean currents (which can alter the distribution of heat and precipitation) and large eruptions of volcanoes (which can sporadically increase the concentration of atmospheric particles, blocking out more sunlight).

Most scientists are now convinced that human activities are also changing the climate. The main cause of such change is the increasing atmospheric concentration of greenhouse gases. Particularly important is the increase in carbon dioxide, which is released through the burning of fossil fuels (coal, oil and natural gas) and through deforestation and land degradation. An increase in greenhouse gases enhances the natural greenhouse effect and leads to an increase in the Earth's average surface temperature. At the regional scale, emissions of other polluting gases and particles into the atmosphere can also have large effects, although some of these can have opposing impacts. Sooty aerosols, for example, tend to warm regional climates, while sulphate aerosols will cool it by reflecting more sunlight. While their direct effects will be felt primarily within the industrialized regions, these aerosols can also indirectly alter average global temperatures and wind currents. Finally, human induced depletion of ozone in the stratosphere also tends to cool the Earth's surface, while land use change can change the amount of sunlight reflected to space by the Earth's surface and hence contribute to climate change.

A.6 Since greenhouse gases (e.g. carbon dioxide, methane, nitrous oxide, etc.) represent such a small fraction of the atmosphere, how can changes in their concentrations have a significant effect on the global climate?

Response: Most greenhouse gases are very effective in absorbing heat escaping from the Earth and keeping it trapped, much like a blanket on a bed. It takes only small amounts of these gases to significantly change the properties of the atmosphere. This allows human emissions to have a significant effect on their influence on climate.

Explanation: 99% of the dry atmosphere consists of nitrogen and oxygen, which are relatively transparent to sunlight and infrared energy. Hence, they have little effect on the flow of sunlight and heat energy through the air. By comparison, the atmospheric gases that cause the Earth's natural greenhouse effect total less than 1% of the atmosphere. However, these gases (including water vapour) collectively increase the Earth's average surface temperature from -19°C to +14°C — a difference of about 33°C. Furthermore, because the concentrations of these gases in the atmosphere are so low, it is possible for human emissions to have a significant effect on them. For example, human emissions of carbon dioxide (CO_2) currently amount to roughly 28 billion tonnes per year and, over the next century, are expected to increase the concentration of carbon dioxide in the atmosphere from about 0.03% today to almost certainly 0.06% (a doubling), and possibly to 0.09% (a tripling). Since the production of each molecule of carbon dioxide removes one molecule of oxygen from the atmosphere, a doubling of CO_2 concentrations would only reduce the volume of oxygen in the atmosphere from 20.95% to about 20.92%. That is, because the volume of oxygen is much larger, the same human activities have very little effect on its concentrations.

Reference: IPCC 2001 WGI, Chapter 1.

B Human Influences on the Atmosphere

B.1 How much have atmospheric greenhouse gas concentrations increased in recent years?

Response: Since the Industrial Revolution began, concentrations of CO_2 have increased by about 31 percent, methane has more than doubled, and nitrous oxide has risen by 17 percent. There is clear evidence that these increases are mostly due to the burning of fossil fuels for transportation, heating and electricity and other human activities. Carbon dioxide accounts for about two thirds of the predicted increases in the greenhouse effect that these changes have caused to date.

Explanation: Data from cores extracted from polar ice sheets, which contain fossilized air bubbles that provide samples of the chemical composition of the atmosphere in the distant past, show that the atmospheric concentration of carbon dioxide was very stable between 10,000 and 250 years ago, remaining between 260 and 280 parts per million by volume (ppmv). During the past 250 years, this has increased to about 370 ppmv, with most of the increase occurring in recent decades. Meanwhile, the concentrations of methane and nitrous oxide, which were also both quite stable throughout the past 10,000 years, have increased by 151% and 17%, respectively. Concentrations of ozone in the troposphere have also increased. Finally, there is also evidence of significant concentrations of a number of other trace gases, particularly halocarbons, that were largely absent in the pre-industrial atmosphere.

Reference: IPCC, 2001 WGI, pp 39-42.

B.2 How do scientists know that the atmospheric buildup of greenhouse gases is due to human activity?

Response: A number of factors clearly point to the role of human activities as the primary source of these increases in greenhouse gas concentrations. For example, the current rate of rise in concentrations agrees well with changes in rate of human emissions, and is unprecedented in many millennia of atmospheric history. Furthermore, trends in ratios of carbon isotopes in atmospheric carbon dioxide and in the distribution of CO_2 in the atmosphere are consistent with emissions from human sources. Similar evidence demonstrates the role of humans in increases in the other greenhouse gases.

Explanation: The rapid rise in greenhouse gas concentrations during the past century is consistent with trends in human emissions, and unprecedented in at least the last 420,000 years and likely in the past 20 million years. Furthermore, the concentration of CO_2 molecules in the atmosphere containing the radioactive carbon 14 atom (after adjustment for atomic explosion testing activities in the 1950s) is declining. This is consistent with increased concentrations of burning of coal, oil and natural gas, all of which contain 'old' carbon that has no carbon 14. Changes with time in ratios of carbon 13 and carbon 12 in oceans are also consistent with human emissions, as is the north-south gradient in atmospheric concentrations of CO_2. Finally, carbon budget models, which can now reproduce the global carbon cycle quite accurately, point to human emissions. Similar studies have been undertaken for methane and nitrous oxide, which also indicate a major human contribution. However, the exact magnitude of the human role for these gases is less well understood because of the uncertainty surrounding the many biological processes involved in both their natural and human emissions. Finally, trace gases such as the halocarbons and sulphur hexafluoride have no significant natural sources. There is strong evidence that changes in their concentrations are entirely caused by human emissions.

B.3 The amount of carbon dioxide (CO_2) added to the atmosphere by human activities each year is only a small fraction of that released from natural sources. How can our actions significantly change the concentration of atmospheric CO_2?

Response: Over thousands of years, the large natural emissions of CO_2 into the atmosphere by oceans and land ecosystems have been almost perfectly offset by the large amounts of CO_2 removed from the atmosphere through natural processes such as photosynthesis and ocean absorption. Human emissions have upset this balance. Just as an accumulating deficit in a financial budget can cause a large debt, this imbalance has, over time, caused a large accumulation of additional carbon dioxide in the atmosphere.

Explanation: Human emissions of carbon dioxide into the atmosphere, currently estimated at about 28 billion tonnes annually, represent approximately 5% of the average natural flow of carbon dioxide into the atmosphere through plant and soil respiration and venting from the surface waters of the oceans (a total of about 550 billion tonnes each year). However, natural emissions are offset by the natural absorption processes such as the uptake of CO_2 by plant photosynthesis, as well as absorption by the oceans. Like a bank account, changes in the amount of carbon dioxide in the atmosphere (the 'balance' of the global carbon budget) are determined by the net average *difference* between inflow (emissions, or 'sources') and outflow (uptake, or 'sinks'), not by the magnitude of the flows themselves. Air samples from the distant past, trapped as bubbles within ice buried deep within the Greenland and Antarctic polar ice sheets, can provide good indicators of how this 'balance' has changed over the past 420,000 years. These provide clear evidence that, during the pre-industrial period of the current interglacial (the past 10,000 years), the atmospheric concentration of carbon dioxide varied by only a few percent from an average value of 280 parts per million by volume (ppmv). This implies that the natural carbon budget was, on average, well balanced (i.e. on average, inflow equaled outflow) during this time period. This, together with other sources of evidence, indicates that the cumulative effect of a small but increasing imbalance introduced into the carbon budget by humans is the principle cause for the 31% increase in CO_2 concentrations noted over the past several centuries. It is, in effect, the accumulated human 'debt' within the global carbon budget.

Reference: IPCC, 2001 WGI, Chapter 3.

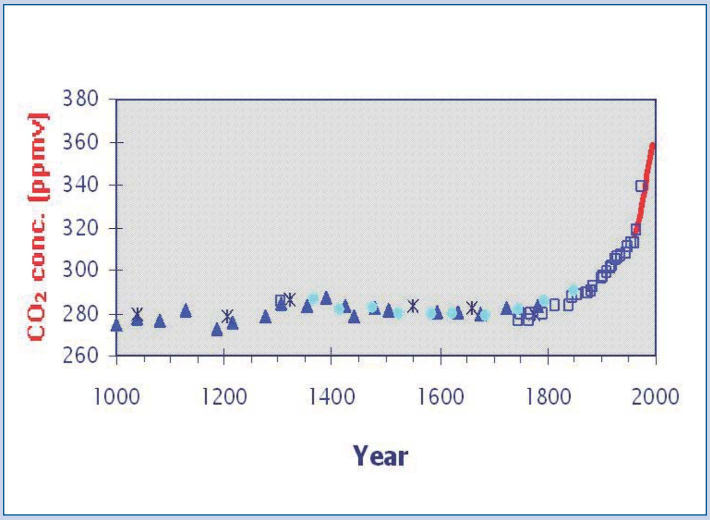

FIGURE B.3

Until recently, atmospheric concentrations of carbon dioxide have remained close to a mean concentration of 280 parts per million by volume. This figure shows concentrations obtained from ice cores representative of the past 1000 years as data points, while the solid line represents concentrations based on direct measurements of the atmosphere during the past 40 years. These results indicate that the pre-industrial natural carbon cycle was almost perfectly balanced (IPCC, 2001 WGI, pg 201).

B.4 Don't volcanoes naturally release far more CO_2 into the atmosphere each year than humans?

Response: No. On a global scale, volcanoes release less than 1% of human emissions of carbon dioxide and hence are a minor contributor to changes in its atmospheric concentrations. Furthermore, emissions from volcanoes have always been part of the natural cycle, which has been in approximate balance for many millennia, until the industrial revolution.

Explanation: Most recent estimates by volcanic experts with the U.S. Geological Survey suggest that, globally, volcanoes release about 150 million tonnes (Mt) of CO_2 into the atmosphere each year. By comparison, humans annually emit more than 22 billion tonnes (Gt) of CO_2 from fossil fuel combustion alone, and another 6 Gt or so of CO_2 from deforestation activities. That is more than 100 times as great as volcanic emissions.

Mount Etna, in Sicily, is the largest single volcanic emitter of CO_2, estimated at 25 Mt of CO_2 per year. By comparison, emissions from Mount St. Helens following its eruption several decades ago were less than 2 Mt of CO_2/year.

Reference: Gerlach 1991.

B.5 Which human activities contribute the most greenhouse gases to the atmosphere?

Response: The use of fossil fuel currently accounts for between 70 and 90% of all human emissions of carbon dioxide. Fossil fuels are used for transportation, manufacturing, heating, cooling, electricity generation, and other applications. The remainder of the carbon dioxide emissions comes from human land use activities — ranching, agriculture and the clearing and degradation of forests. For other greenhouse gases, primary sources include the production and transport of fossil fuels, agricultural activities, waste management and industrial processes.

Explanation: Each year, humans release more than 22 billion tonnes of carbon dioxide into the atmosphere through the burning of fossil fuels for energy. However, deforestation activities, forest degradation and agricultural land mismanagement also add large amounts of carbon dioxide emissions — between 2 and 9 billion tonnes — each year. Some, but not all of these land use emissions are being offset by growth of new forests and improved soil management in some regions of the world.

Methane emissions occur both naturally and as a result of human activities. It is the second most significant greenhouse gas, next to carbon dioxide. Rice cultivation, cattle and sheep ranching, and decaying material in landfills all release methane, as do coal mining, oil drilling operations, and leaky gas pipes. Nitrous oxide come from both natural sources and human activities. Fossil fuel combustion, industrial practices, and agricultural practices including the use of chemical fertilizers, all increase atmospheric nitrous oxide. The industrial production of chlorofluorocarbons (CFCs) and other halocarbons — used in refrigeration, air conditioning, and as solvents — have added other greenhouse gas, but many of these sources are gradually being eliminated under existing international agreements because they deplete the stratospheric ozone layer. Ozone in the troposphere (the lower part of the atmosphere) is another important greenhouse gas resulting from industrial activities. It is created naturally, but is also produced by atmospheric reactions caused by smog precursors such as nitrogen oxide from motor vehicles and power plants.

In Canada, about one-third of all greenhouse emissions are caused by the production of energy for Canadians and for exports, almost equally divided between the production of electricity from the combustion of fossil fuels and the exploration and production of coal, oil and natural gas for the energy market. Another 27% is produced by the transportation of goods and people across Canada — whether by truck, car, airplane, train, boats or other means. Manufacturing and construction add another 17%, while non-electrical use of energy in the residential, commercial and institutional sector emit about 13% and the agricultural sector almost 9%.

Similar sources of emissions occur in other countries, although the ratios differ with the type of economy, culture and climate.

Reference: Environment Canada Report on Greenhouse Gas Inventory (2002).

B.6 Humans also release a lot of carbon dioxide into the atmosphere by breathing. Are we supposed to stop breathing to stop climate change?

Response: Just as for trees, the carbon dioxide that humans exhale is part of an active natural carbon cycle involving intake of carbon from food we eat and the release of carbon through breathing and human wastes. The growth of the food we eat in turn involves the removal of carbon dioxide from the atmosphere through photosynthesis and other processes. The net balance for each human being is a small sink for atmospheric carbon dioxide, achieved indirectly through the accumulation of body mass. If, upon death, a human body is buried below-ground, the carbon component of the body mass becomes a long term carbon sink.

Explanation: Each human being takes in large volumes of carbon each year through the plant food, meat and fish he or she eats. That food carbon was amassed through photosynthetic and other processes that removed carbon dioxide from the atmosphere, either directly (for plants) or through the food chain (for animals, birds and fish). Most of the carbon taken in by a human is removed again through respiration (as carbon dioxide) and body wastes. During the years of growth, a small amount is retained each year to accumulate human body mass. This represents a small net sink for carbon, and stops accumulating for a mature human of stable mass. Upon death, many human bodies are buried underground, providing a small long-term sink for carbon.

Unlike ruminant animals, which have different digestive systems, gases erupting from humans through flatulence or belching contain very little methane and hence do not contribute significantly to increased methane concentrations.

B.7 I understand water vapour dominates the natural greenhouse effect. Doesn't this make changes in the concentrations of other greenhouse gases insignificant?

Response: No! While water vapour represents about two-thirds of the natural greenhouse gases, changes in its concentrations are determined primarily by changes in atmospheric temperature and related effects on the hydrological cycle. As increases in other greenhouse gases warm the atmosphere and surface, the amount of water vapour also increases, amplifying the initial warming effect of the other greenhouse gases.

Explanation: Water vapour is indeed one of the most potent and abundant greenhouse gases in the atmosphere. If the effects of all greenhouse gases other than water vapour were ignored, the natural greenhouse effect would be about 60-70% of observed values, compared to about

25% if only CO_2 were present. However, humans have little direct effect on water vapour concentrations. Rather, its concentrations respond to changes in temperature and other natural atmospheric processes. Warmer atmospheric temperatures, whether caused by increased greenhouse gas concentrations or other causes, increase the amount of water vapour that the atmosphere can hold. Likewise, warmer surface temperatures increase the rate of global evaporation of water from land ecosystems and ocean surfaces. Much of the increased evaporation comes down again as increased precipitation, but some remains in the atmosphere as water vapour. During recent decades, for example, a rise in global temperatures has been accompanied by an increase in global precipitation and observations of rising moisture content of the atmosphere over many parts of the world. The increase in water vapour also affects other aspects of the climate system, particularly clouds. Most scientists agree that the overall effect of the direct and indirect feedbacks caused by increased water vapour content of the atmosphere significantly enhances the initial warming that caused the increase — that is, it is a strong positive feedback. However, the magnitude of this effect depends on where the increases take place within the atmosphere. If these occur in atmospheric regions where air is already near saturation levels, the additional effect is small. If, on the other hand, it occurs in dry air like that over deserts or in the upper troposphere, the effect can be very large. Most models suggest that the enhancement effect will be quite large (on the order of 60%). However, this feedback is very complex, and its magnitude remains one of the key uncertainties in climate models.

Reference: IPPC, 1990 WGI, pp 47-48.

B.8 Don't human emissions of aerosols cool the climate and therefore offset emissions of greenhouse gases?

Response: Many human activities also result in the emission of sulphate and sooty aerosols, biomass burning particles and soil dust. These aerosols, in addition to directly reflecting or absorbing sunlight, can alter cloud processes and have significant impacts on regional climates. However, some aerosols cause warming while others cause cooling. While their effects are not well understood, most studies indicate that their complex role during the past century has been significant but are secondary to that of the greenhouse gases. Because emissions of these aerosols are now being controlled in many countries to reduce local air pollution, the relative effect of greenhouse gases on the climate is expected to be much more important than that of aerosols in the future.

Explanation: Many of the same human activities that release greenhouse gases also release aerosols (small solid particles and liquid droplets) into the atmosphere. These include sulphate aerosols and soot from the burning of fossil fuels, biomass aerosols from the burning of vegetation, and mineral dust from agricultural activities. Some, like soot, are dark and thus absorb sunlight and warm the atmosphere. Others, like sulphate aerosols, reflect sunlight and cause cooling. These aerosols can also make clouds brighter and last longer. Since, unlike long-lived greenhouse gases, aerosols only remain in the lower atmosphere for days to weeks, they do not spread around the world but remain concentrated in and downwind of industrial or agricultural regions. Because they are not evenly distributed, their effect is much greater in some parts of the world than others, and hence they have a complex effect on climate that includes changes in circulation and in cloud characteristics as well as local areas of warming and cooling.

Globally, some of their effects cancel out. However, while very uncertain, it is likely that these aerosols have 'masked' some of the impacts of the greenhouse gases. If their emissions were to stop overnight, they would quickly disappear, unmasking that part of the effect of greenhouse gases they were offsetting on a regional scale.

Many countries have already undertaken programs to reduce the emissions of these gases to improve local air quality, and hence their emissions are decreasing in most industrialized regions. However, they continue to increase in other industrializing regions. It is likely that these regions will also need to curtail emissions in the future to protect local air quality. Experts estimate that the role of aerosols will be far less than that for greenhouse gases in the decades to come.

B.9 What other human activities affect the climate?

Response: Humans also affect the climate through ozone depletion in the stratosphere, which slightly cools the surface, and by changing the reflectivity of the Earth's surface through land use change (primarily a warming effect). These effects are believed to be relatively small compared to those for greenhouse gases.

Explanation: Ozone depletion allows more ultraviolet radiation to reach the lower atmosphere but also reduces the greenhouse effect of the ozone involved. Since the latter dominates, this has resulted in a slight surface cooling in recent decades. This depletion is expected to stabilize and subsequently be reversed in the future as the effect of measures under the Montreal Protocol reduce the concentrations of ozone depleting substances in the stratosphere.

Deforestation, reforestation, desertification, soil cultivation and urbanization are all processes that can affect the surface albedo (the amount of sunlight reflected by the Earth's surface back to space). These effects are complex, and depend on the time of year. For example, replacing forests in mid-latitudes with agricultural fields can decrease albedo in the spring and fall (when the bare soils are exposed to the sun) but increase albedo in winter (when the fields are covered with snow rather than a tree canopy). Some studies suggest these impacts can be significant. However, other studies indicate that, while these effects can have important local impacts on climate, the net global effect is secondary to that of past changes in greenhouse gas concentrations, particularly since the land area involved is a relatively small area of the total Earth's surface.

C Detecting and Attributing Climate Change

C.1 Has the world warmed?

Response: Yes. The average global temperature at the Earth's surface has warmed by about 0.6°C since the late 19th century.

Explanation: Best estimate for the magnitude of average global surface warming over the past century is 0.6°C, with an error range of ±0.2°C . It is important to note that these refer to average global surface warming. In some areas, particularly over continents, the warming has been several times greater than the global average. In a few areas, temperatures have actually cooled. In Canada, for example, there has been an increase in average annual temperature of about 1°C over the period 1895-1992. According to recent research results for the Northern Hemisphere, the 20th century is now likely the warmest century, the 1990s the warmest decade, and 1998 and 2001 the hottest years of the past millennium.

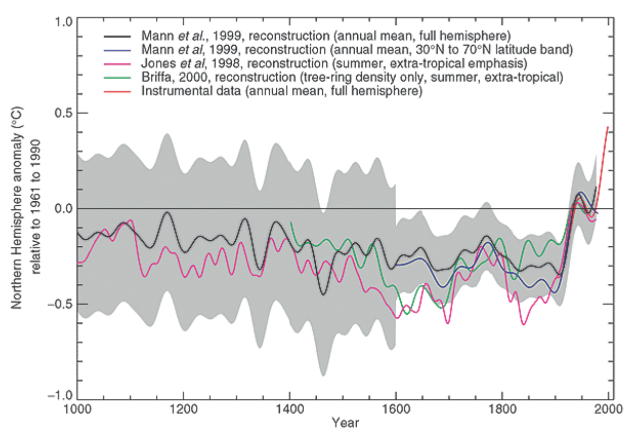

FIGURE C.1
Data from various proxy indicators of past temperatures, including tree rings, ice cores and corals, have been used to reconstruct Northern Hemisphere temperatures over the past 1000 years. The solid blue line is a smoothed average for hemispheric temperature from the proxy data, while the red line represents the hemispheric average surface air temperatures as measured at climate stations over the past 140 years. Gray shading represents estimate error margin for the proxy record. The records indicate that the 20th century was likely the warmest of the millennium, the 1990s the warmest decade, and 1998 the warmest year (IPCC, 2001 WGI pg 134).

C.2 How do scientists know that the Earth has warmed?

Response: In addition to the consistency of evidence for warming obtained from both the instrumental air temperature records and other proxy temperature data, there are many other indicators of a warming world. These include warming of the upper layers of the world's oceans, melting mountain glaciers, retreating sea ice and snow cover, rising sea levels, and shifts in distribution of many species of plants and animals.

Explanation: The instrumental records of surface atmospheric temperatures collected over the past 120 years agrees well with proxy indicators of climate, such as data from tree ring, ice cores, corals and ground temperatures. All show substantial warming over the past century. Furthermore, as shown in Figure C.1, when these proxy records are extended back, they show that the 20th century warming in the Northern Hemisphere is unprecedented in at least the past 1000 years, and that the 1990s was the warmest decade and 1998 and 2001 the two single warmest years for that time period. Furthermore, a variety of other climate variables provide supporting evidence of a warming climate. These include: a 10% reduction in the extent of snow cover in the Northern Hemisphere since the late 1960s; a coincident reduction in Northern Hemisphere lake ice cover seasons; a reduction in Arctic sea ice cover since the 1950s of 10 to 15% and a considerable decline in sea ice thickness; a 10 to 20 cm global sea level rise during the 20th century; an increase in global ocean heat content since adequate measurements began in the 1950s; and an decrease in the frequency of extreme low temperatures since the 1950s.

C.3 Despite the overall global warming during the 20th century, some argue that current average temperatures are still lower than during warm periods experienced in the past, such as the Medieval Warm Period. Doesn't this suggest that current increases are likely due to natural causes, and therefore of no real concern?

Response: Natural causes, such as increased sunlight intensity and reduced volcanic dust in the atmosphere, may have contributed to the warming in the first past of the 20th century, but cannot explain the rapid warming during the most recent half-century. However, Figure C.1 shows that the warming in recent decades is consistent with that expected due to human interference with the atmosphere. Furthermore, as illustrated in Figure C.3, careful analysis of both measured and indirect indicators of global temperatures indicate that the 20th century was very likely the warmest century of at least the past millennium, and the 1990s were likely the warmest decade of this period. The IPCC concludes that most of the warming during the past 50 years was likely due to human influences.

Explanation: Researchers have indirectly collected information about past climates from various indicators such as tree rings, ice cores and ocean corals. These indicate that, for at least the Northern Hemisphere, the 20th century was the warmest in at least the past 1000 years. Furthermore, the 1990s was the warmest single decade. By comparison, the Medieval Warm Period of about 1000 years ago appears to have been warm in regions surrounding the North Atlantic but not in other parts of the Northern Hemisphere. Hence, average temperatures for the entire hemisphere during that period were cooler than that for the past century (see Figure C.1). Proxy data for the Southern Hemisphere are as yet too sparse to

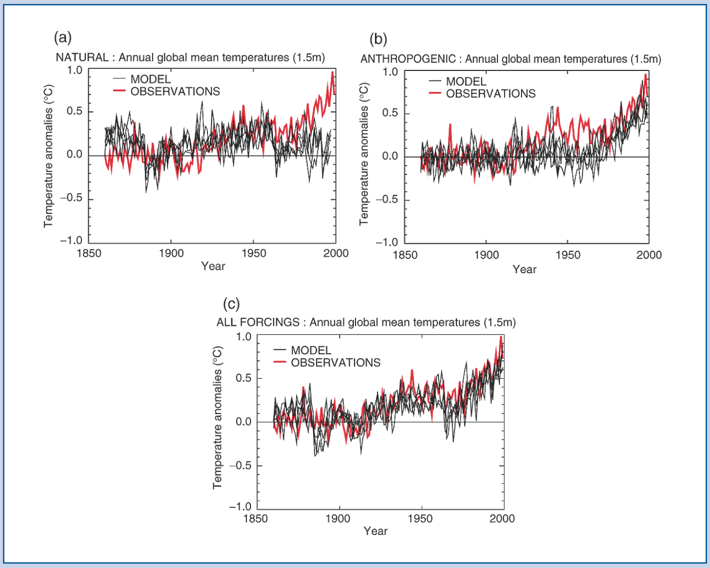

FIGURE C.3

Comparison of observed changes in globally average surface temperatures (red line) with model simulations of different combinations of radiative forcing (grey lines): a) natural forcing due to solar and volcanic activity; b) forcing due to human activities only (greenhouse gases, aerosols, stratospheric ozone depletion; c) forcing due to both natural and human causes. IPCC 2001 Synthesis Report, Figure 2.4.

make similar conclusive comparisons in that region. However, paleo-climate scientists have also made some approximations of global temperatures further back in time. These suggest that temperatures experienced during the peak of the current interglacial period some 68,000 years ago were about 1°C warmer than today, and that temperature variations within this range have occurred on thousand year time scales since then. This suggests that some of the recent warming could be due to natural causes. As shown in Figure C.3, climate model studies indicate that, during the first half of the 20th century, a significant part of the warming is, in fact, likely due to a combination of increased solar radiation, decreased volcanic dust in the atmosphere, and rising greenhouse gas concentrations. However, during the past 50 years, solar intensity has not shown a significant long-term trend and more frequent major volcanic eruptions have, on average, increased the level of volcanic dust in the atmosphere with time. Thus, the combined effects of the natural causes for change, by themselves, would have caused cooling during that period. In contrast, the observed climate record shows a rapid warming in recent decades consistent with that expected due to human influences. Hence, the IPCC concludes that, while the changes during the past century is due to a combination of natural and human factors, that for the past 50 years is likely due to the dominance of human influences.

References: IPCC, 2001 WGI, Chapter 2 and 12.

C.4 Since temperature records of the past century may be distorted by observational errors, relocation of observing sites, and other human influences such as the urban heat island effect, can we rely on them to determine how the climate is changing?

Response: Yes, collectively they provide a good indication of how our climate is changing. As required for proper use of data from all monitoring programs, the climate data used to study the climate is first evaluated for quality and systematic sources of error. In addition to deleting records with major errors or non-climatic influences and correcting others where the error is readily identifiable, climate scientists also compare the climate records used with other types of information. To allow for any remaining non-climate factors affecting these records, experts provide a margin of error in their estimates. They state with confidence that the warming over the past century has been at least 0.4°C, and not more than 0.8°C.

Explanation: One method of dealing with random errors that occur at single stations is to average the temperature values over many stations. Global temperature analyses use many thousands of stations, and hence such random errors are largely removed through averaging. Systematic changes that are unrelated to climate but that can affect many or all of the records at the same time or in the same way are more difficult to remove. These include changes in observed values due to urban heat island effects, large-scale changes in instrumentation, changes in the density of recording stations, or a systematic shift in the location of instruments at weather stations. These can be at least partially addressed through careful analysis and adjustments. In undertaking the global trend analyses, climate experts have made careful allowance for a number of such systematic influences, including the heat island effect, the change in observing processes on ships, and other non-climatic influences on observations. There remains solid evidence that the warming of the recent decades is real and global. Furthermore, surface temperature records are in good agreement with the long term trend apparent in upper air radiosonde measurements over the past half-century, with evidence from tree rings, and with information obtained from bore holes drilled into the Earth's surface in different parts of the world. They are also consistent with concurrent trends towards reduced global snow cover, glacier retreats and other indicators of a warming world.

However, because of the uneven global distribution of observation sites, climate records are still dominated by land data obtained in the Northern Hemisphere. Considering these uncertainties, the science community estimates that the Earth's surface has, on average, warmed by at least 0.4°C and possibly by as much as 0.8°C.

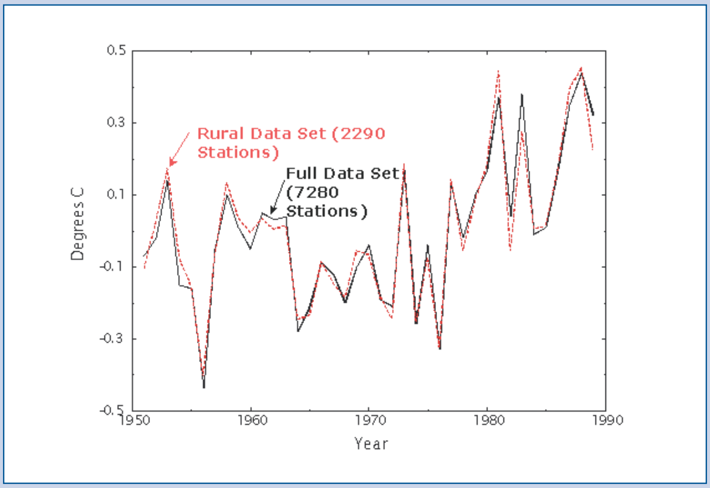

FIGURE C.4
Comparison between temperature trends of the full corrected land data set used in global temperature trend analysis and a subset of rural stations suggest there is very little residual effect of urbanization remaining in the data (Peterson et al. 2001. Geophys. Res. Lett. 26: 329-332.)

C.5 A large increase in temperature occurred in the early part of this century when CO_2 emissions were still relatively low. However, temperatures actually cooled in the 1950s and 1960s, when emissions began to increase rapidly. Doesn't this contradict the idea that increased CO_2 emissions will cause warmer climates?

Response: In addition to the effects of CO_2, the temperatures of the past century have been influenced by changes in the climate system due to natural factors (such as internal variability within the climate system, solar variability and/or emissions of aerosols due to volcanic eruptions), by increased concentrations of other pollutants released into the atmosphere by human activities (such as sulphate aerosols and dust), and most recently by ozone depletion in the stratosphere. The response to these various causes of change is further modified by the slow response of oceans. When all these factors are included in model simulations of temperature change, the results agree quite closely with those observed.

Explanation: The behaviour of the climate system is complex, involving many different components, variables and feedbacks. The system has significant natural internal variability that causes fluctuations in climate conditions from one region to the next and one decade to the next. For example, fluctuations associated with the El Niño-Southern Oscillation and the North Atlantic Oscillation can alter global temperature patterns for years and even decades. In addition, the climate system responds to a variety of different causes of change (called climate forcings). Of these, an increase in greenhouse gas concentrations, although probably dominant during the past century, is only one. These include the effects of natural changes in solar intensity (higher intensity means warmer surface temperatures) or the amount of volcanic dust in the atmosphere (which tends to cool the surface), as well as other human influences such as emissions into the atmosphere of various types of aerosols or their precursors (primarily a surface cooling effect), and stratospheric ozone depletion (a surface cooling effect). These effects vary in time. The cooling offset from human emissions of sulphate aerosols, for example, increased rapidly in the Northern Hemisphere between the 1950s and the 1980s, thus masking some of the influence of greenhouse gas increases in recent decades, but has stabilized in recent decades because of measures to improve air quality. In contrast, the surface cooling influence of ozone depletion began in the late 1970s, and is now peaking as the measures of the Montreal protocol to reduce emissions of ozone depleting substances take effect.

Furthermore, the long-term response of climate to the effects of increases in CO_2 concentrations or climate forcing is delayed by a significant lag effect due to ocean inertia. This is similar to how large inland lakes can influence and delay the seasonal changes in adjacent land temperatures. The more rapid the increase in the cause for climate change, the greater the gap between the instantaneous response of the climate and the full potential of its response to the forcing. Thus, because the rate of increase in CO_2 up to 1940 was quite slow (over 150 years), most of the related effects on climate would already have been fully evident within the climate system by 1940. However, since the increase in CO_2 since 1940 has been much more rapid, ocean inertia will have delayed a much larger fraction of its full potential climatic effect.

The upward trend in temperature observed over the past century is dominated by a fairly abrupt warming of about 0.3°C between 1920 and 1940, a slight cooling trend between 1940s and 1970s, and another period of rapid warming (about 0.3°C) between 1975 and today. When the various forcing factors mentioned above are all included in model simulations, the projections agree quite well with the observed pattern of change. They also suggest that the human factors have dominated the trends during the past 50 years.

Reference: IPCC 2001, WGI, Chapter 12.

C.6 Doesn't the substantial cooling in places like the eastern Canadian Arctic, Greenland and in eastern Antarctica over the past few decades contradict model predictions of global warming?

Response: No. A regional cooling can be fully consistent with a warmer world. Although increasing greenhouse gas concentrations apply a rather uniform global forcing, other factors such as natural variability, local feedbacks and regional changes in atmospheric and oceanic circulation can enhance their effects in region while reducing them in another. For example, in the Arctic, some regions, such as the western Canadian Arctic and Siberia, have warmed dramatically. Although the eastern Arctic also warmed slightly during the past 50 years, some regions within it have cooled somewhat. Despite these regional variations, the average temperatures across the Arctic are becoming considerably warmer in a manner largely consistent with recent model projections. Likewise, while some regions of east Antarctica have cooled over the past few decades, the Antarctic Peninsula has warmed dramatically. Advanced climate models are now able to capture this variability quite well, and can simulate regional changes that are broadly similar to that observed.

Explanation: The climate system is highly variable, both from region to region and in time. This is because local feedbacks, changes in atmospheric circulation and other factors can affect one part of a region much differently than another. For example, there is evidence that, over the past 50 years, changes in the Arctic/North Atlantic Oscillations have been important factors in causing the western Canadian Arctic and parts of Siberia to warm dramatically (by more than 2°C) while parts of the eastern have cooled. Despite the areas of cooling, the eastern Arctic has still warmed slightly (about 0.2°C). Likewise, in Antarctica, parts of the eastern region of the continent have cooled in recent decades, while the Antarctic Peninsula has warmed significantly. In this region, there is evidence that regional atmospheric circulation changes that contributed to these regional differences may be linked to stratospheric ozone depletion. Some of these differences also disappear when the length of the record is increased. For example, while the entire Atlantic Canada region has cooled slightly during the past 50 years, the Maritime Provinces show a significant warming of 0.6°C when the full 100 year record available for the region is considered. Meanwhile, supporting evidence for large scale warming trends in Arctic regions include a decrease of some 400,000 square kilometers in the extent of sea ice and a concurrent decrease in snow cover in the Northern Hemisphere over the past decade.

Climate simulations with coupled climate models are as yet not able to predict the precise decade-to-decade shifts in these regional changes in atmospheric circulation and other factors affecting regional temperatures. However, they do show regional patterns of change that show differences broadly similar to that observed.

C.7 Satellite measurements show temperatures in the lower atmosphere above the Earth's surface are warming much more slowly than the surface. Doesn't this imply that the Earth isn't warming as expected?

Response: No. When the surface data is compared with lower atmospheric temperatures obtained from weather balloon data for an extended period of more than four decades, the two trends are almost identical. Unfortunately, the satellite data is only available for the past two decades. On such short time scales, unusual climate events such as volcanic eruptions and El Niños can significantly bias trends, and affect the surface differently than the atmosphere above it. Hence, the satellite data record by itself is still too short to be useful for long-term climate tends analysis.

Explanation: Microwave satellite data have been used since 1979 to estimate temperatures of the lower troposphere between about 8 km altitude and the surface. Over this short period of time, the trends observed at the surface and in the lower atmosphere are both significantly influenced by the warming influence of a strong El Niño event in 1982-83 and the cooling influence of increased volcanic dust in the atmosphere for several years following the eruption of Mt. Pinatubo in 1991. However, these influences affect the surface differently than the lower atmosphere. Much of these differences should average out over time. In fact, comparison of mean surface temperature trends with those for the lower atmosphere compiled from radiosonde data suggest the two trends are almost identical when averaged over the past four decades.

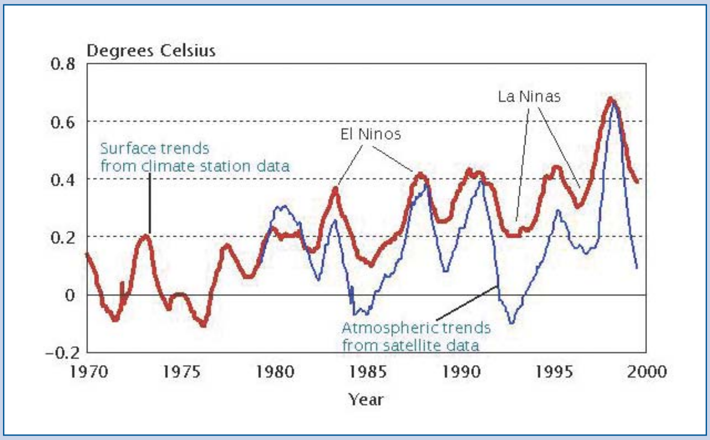

FIGURE C.7
Comparison of trends in annual anomalies in surface temperatures since 1970 (heavy line) with satellite based observations of temperatures in the lower atmosphere since 1979 (light line). (NOAA).

Like surface data records, the satellite data must also be corrected for changes unrelated to the climate. For example, while earlier estimates of trends in the satellite data suggested a cooling trend of about -0.06°C per decade since 1979, recent corrections for the influence of satellite orbital decay and the addition of several more years of data have resulted in a slight warming trend of 0.04°C per decade. There are also concerns about other possible inaccuracies in the data, since the record consists of measurements taken by instruments on eight different satellites and pieced together into a single series. Furthermore, the effects of water vapour and droplets in the atmosphere on the microwave data may not have been adequately corrected when calculating the related temperatures.

Reference: IPCC 2001, WGI, Chapter 2.

D Predicting Climate

D.1 How much is the Earth expected to warm in the future?

Response: Without coordinated global action to reduce greenhouse gas emissions, the global average surface temperature relative to 1990 is expected to rise by between 1.4 and 5.8°C (about 2 to 10˚F) by the year 2100. Even if greenhouse gas concentrations are stabilized, temperatures will continue to rise for centuries after stabilization because of the delay in ocean response.

Explanation: This is the current best estimate based on the probable range of projected future concentrations of atmospheric greenhouse gases and sulphates (which have a cooling effect) if no specific action is taken to reduce greenhouse gas emissions. The projections also include uncertainties related to climate model performance. Since most greenhouse gases remain in the atmosphere for a long time, the effects of past emissions will persist for centuries even if greenhouse gas emissions from human activities were to stop immediately. It is important to note that temperature changes will occur unevenly around the world. Land will warm more than oceans and greater year round warming is predicted for high latitudes, with more warming in winter than summer at middle to high latitudes. In Canada, the annual mean temperature could increase between 5 and 10°C over the next century.

Reference: IPCC 2001, WGI, Chapter 9.

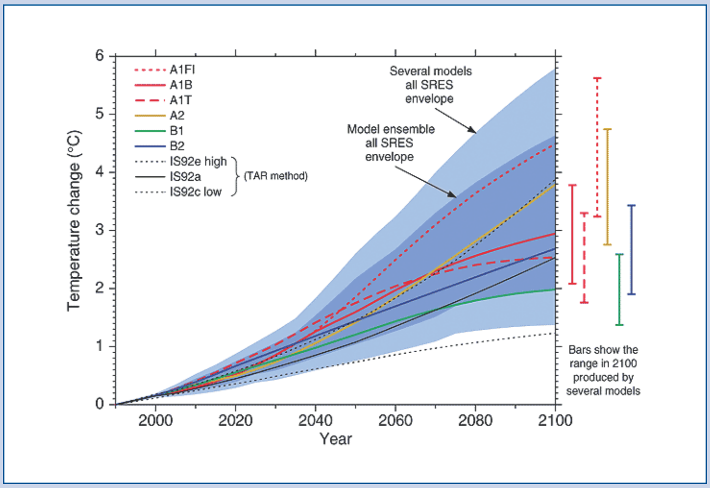

FIGURE D.1
Projected range of increase in average global surface temperatures over the next century compared to changes during the past millennium. The dark area of shading represents uncertainty due to future human emissions of greenhouse gases, while the lightly shaded area indicates the added uncertainty related to the sensitivity of the climate system to such emissions (IPCC 2001 Synthesis Report, pg 34).

D.2 Why is there more than a 4°C range in the amount of global warming projected?

Response: There are two key factors that contribute to the range of estimates. The first is uncertainty about future human behaviour and how these may affect concentrations of greenhouse gases and aerosols in the atmosphere. The second is scientific uncertainty about how fast and how much the climate system will be affected by changes in these concentrations. When combined, these show a range of more than 4°C, extending from the most optimistic outcome of a 1.4°C warming by 2100 to the most pessimistic outcome of 5.8°C warming.

Explanation: Future emissions of greenhouse gases and aerosols will depend on how rapidly human populations and economies will grow in future decades, how efficiently societies will use energy, the type of energy they use and how human use of land is likely to change. These are uncertainties about future social behaviour, rather than about the climate system. However, there also remains considerable uncertainty about how the climate system will respond to changes in concentrations of greenhouse gases and aerosols. During the next few decades, the latter is the more important, while the former is the primary source of uncertainty in the second half of the century. The 4°C range in projected warming for 2100 arises when these uncertainties are combined in model simulations.

D.3 How are we to believe the results of climate models when their various forecasts for future climate differ so much?

Response: While the models disagree on the details of future climate change, there is actually good general agreement on the continental scale pattern and significance of expected future changes in temperature, particularly over the next few decades.

Explanation: Various models use alternative techniques for describing how different components of the climate system function. Furthermore, there is significant natural variability within the climate system, so that identical experiments with the same model can be expected to show different details in their results. Hence, there are some significant differences between model experiments on the details and rate of future climate change. However, all models agree that the warming will be significant and likely unprecedented in human history, that continents will warm more than oceans, that high latitudes will warm more than low latitudes, that sea levels will rise, snow and sea ice extent and thickness will decrease, and that there will be an increase in average global precipitation, accompanied by major changes in the distribution of precipitation.

D.4 How reliable are the models used to predict future climate change?

Response: Climate modellers use the most advanced physics and mathematics available today to develop complex climate models. Models are first tested against observed climates and climates of the past to ensure they can adequately simulate real climates. Once they have past these and other tests, they are used to project future climates for various scenarios of future greenhouse gas and aerosol emissions. While these tests show significant disagreements with observed and past climate data at regional scales, the advanced models of today can replicate the global pattern and trends quite well. Hence, modelers are confident that they can provide useful indicators of how the climate will respond to continued human interference with the climate system.

Explanation: The computer climate models used to predict future climates are based on well-accepted physical principles of science and a wealth of scientific observations of the climate system. Complex mathematical equations are used within the models to describe how these principles affect the interactions of land, sea, ice and air, which together determine the Earth's climate. These models are then operated on very large computers to simulate how the climate behaves, starting from a stand still. Models are first tested to see how well they can describe today's climate, and most are now able to describe the main features of the climate system quite accurately. There are, however, significant regional differences apparent in most models, both because the resolution of the models is too coarse to capture all the important regional interactions of the climate system and because some of these interactions are as yet inadequately understood. The models are then also run for climates of the past, including the last 100 years, the peak Holocene climate of 6000 years ago, and the last glacial maximum of 18,000 years ago. Most advanced models now also simulate these quite well, particularly for the past 100 years. Finally, there are also model inter-comparison studies that seek to understand where and why the model results differ. Over the past four decades of climate model evolution, the confidence in their performance has improved immensely. Hence, while there are still significant uncertainties in model performance, there is considerable confidence that they can help provide useful advice on future climate change.

D.5 Models used for weather forecasting often can't even properly predict the weather for the next few days. How can we expect credible predictions from climate models for decades and even a century into the future?

Response: Climate is *average* weather, which is more predictable than day-to-day and hour-to-hour weather changes. Weather behaviour is chaotic and often difficult to predict beyond a week or so into the future. By comparison, climate is largely determined by global and regional geophysical processes that change slowly. Hence, if these factors are properly understood and predictable, then the climate can be forecasted far into the future with some confidence.

Explanation: Day-to-day local weather is largely determined by atmospheric circulation and the formation of large scale weather systems. Because of the chaotic nature of the atmosphere, predictability decreases with time, and is quite poor beyond a few weeks into the future. Climate, on the other hand, represents average weather and its expected variability. These are determined by factors such as incoming solar radiation (which varies with latitude and time of year), the influence of prevailing characteristics of cloud cover, aerosols and other components of the atmosphere on the flow of the sun's energy into the atmosphere and of heat energy out again, prevailing winds and other atmospheric conditions, and local geophysical conditions that, in general, change slowly and in a more predictable manner. Thus, while forecasters would be unable to predict day-to-day weather six months into the future, they can provide good approximations of the changes in seasonal climates because of known physical processes that cause conditions to change from winter to summer and back again. They can also provide estimates of the changes in probability of different kinds of weather events, such as sub-zero minimum temperatures, maximum temperatures in excess of 30°C, snow blizzards or thunderstorms. Likewise, climate models, when looking much farther into the future, project how the climate characteristics, averaged over several decades, might change in response to projected changes in the factors that determine the climate.

D.6 Don't the comparisons between climate observations and predictions by computer models suggest that models exaggerate global warming?

Response: No. As Shown in Figure C.3, model simulations conducted in recent years that include all of the key factors affecting climate over the past century show very good agreement with observations. Hence there is no evidence that the model projections for global warming are biased one way or the other.

Explanation: A decade ago, when most model experiments only included the climatic effects of rising greenhouse gas concentrations, the warming rates simulated for the past century often exceeded those observed. However, recent experiments that also include the more complex effects of other human activities (such as emission of aerosols and the depletion of the stratospheric ozone layer) and of natural factors (solar changes and volcanic aerosols) produce simulations of long-term temperature trends that agree well with those derived from observations. This suggests that the models do not exaggerate the sensitivity of climate to human influences.

D.7 Earlier IPCC estimates of global warming for the 21st century ranged from 1.0°C-3.5°C. In the IPCC Third Assessment Report, the range of projected warming actually increased to 1.4°C-5.8°C. If global climate models are becoming more sophisticated, why is the scientific uncertainty increasing?

Response: The primary reason for the increase in the range of estimates for future climate change presented during the last IPCC assessment was the use of new emission scenarios for greenhouse gases and aerosols. These scenarios suggest a larger range in possible human induced emissions than projected in earlier emission scenarios. The increase in projected temperature range is therefore primarily due to demographic factors, not increased scientific uncertainty.

Explanation: For the first IPCC assessment, experts focused on the use of equilibrium climate models to predict that, once the climate system has fully responded to a world with twice as much CO_2 as today, the average surface temperature would be about 1.5 to 4.5°C warmer than today. Although they also presented some preliminary results from coupled climate models forced by hypothesized business-as-usual emission scenarios, these results did not reflect the full range of uncertainties about future emission rates. During the Second Assessment, a series of six business-as-usual scenarios (known as IS92 scenarios) were used to approximate the range of emissions due to human activities to 2100, and the cooling effects of increasing concentrations of sulphate aerosols were added into model simulations. The results suggested a possible range of warming by 2100 of 1.0 to 3.5°C. In the Third Assessment Report (TAR), completed in 2001, a new set of emission scenarios, believed to be more representative of the range of future human activities without policies specifically aimed at reducing risks of climate change, was used for future projections. These new scenarios had a slightly larger range in emissions between 1990 and 2100 than the older IS92 scenarios. They also reduced the magnitude of the offsetting effects of aerosols used in the IS92 scenarios, noting that local air pollution concerns would force nations to take action to curtail aerosol emissions. These changes in emission scenarios were the primary reason for the enhanced range for the TAR climate change projections. Hence, they reflect increased uncertainties about future human behaviour, not increased uncertainties in climate models. In fact, the range of scientific uncertainty in climate model projections of how the climate will respond to a specific emission scenario has not changed significantly. While advanced models do reflect a significant improvement in understanding of the climate system, there continue to be major challenges in accurately describing some aspects of the climate system in models, which are still limited by available computing power.

D.8 Why are estimates for future sea level rise under various global warming scenarios becoming progressively lower as new research results emerge?

Response: The slightly lower estimates for sea level rise by 2100 provided in the more recent IPCC assessments occur for two reasons. First, the offsetting effects of aerosols on rates of climate warming and hence rates of sea level rise were not included in the First Assessment Report, but were in the second and third assessments. Second, improvements in the understanding of how oceans and ice sheets will respond to warmer climates suggest that the rate of heat uptake by these systems from the atmosphere may be slower than previously thought. However, while these improvements have lowered projections for sea level rise within the next century, they do not significantly alter the projections for full long-term response of sea level rise to human interference with the climate over subsequent centuries.

Explanation: Estimates for sea level change as a result of global warming continue to cover a broad range of values. In the first IPCC assessment (1990), sea level rise by 2100 was estimated at a possible range of between 30 and 100 cm. In its Second Assessment, IPCC lowered this estimate to a range between 15 cm and 95 cm, primarily because of the inclusion of the masking effect of aerosols in estimated rates of surface climate change. The Third Assessment in 2001 revised this slightly to a range of 9 to 88 cm, reflecting improved estimates of ocean and ice sheet inertia. The largest uncertainties in these estimates relate to the role of the Greenland and Antarctic ice sheets. The Greenland ice sheet currently appears to be decreasing in volume, and is therefore an apparent source of water for sea level rise. It is expected to continue to do so, but the contribution to sea level rise is very sensitive to changes in precipitation, melting and ice sheet dynamics. In contrast, while ice shelves along the Antarctic Peninsula show signs of disintegration, the Antarctic ice sheet itself may be slowly building due to a moister climate. The combined changes in ice sheets appear to be secondary to the contributions to rates of sea level rise from direct thermal expansion of oceans and melting of temperate glaciers as they warm. Because oceans and ice sheets respond very slowly to changes in climate, sea levels will continue to rise for centuries after surface climates have already stabilized. Hence sea level rise continues to present a serious future threat of catastrophic inundation of coastal and island states.

Reference: IPCC 2001, WGI, Chapter 11.

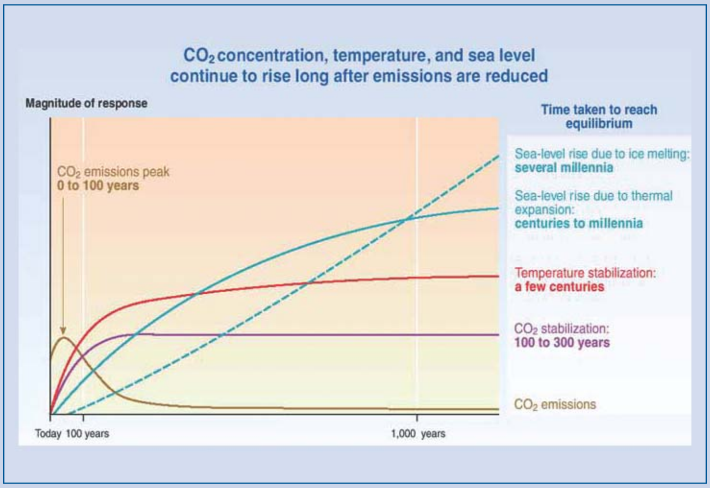

FIGURE D.8

Even if atmospheric concentrations of greenhouse gases are stabilized by the end of the 21st century, sea levels will continue to rise for centuries thereafter. This is because both oceans and ice sheets respond slowly to changes in atmospheric temperatures (IPCC 2001 Synthesis Report, pg 89)

E Global Impacts of Climate Change

E.1 The global temperature has warmed by only 0.6°C in the last 100 years. Such a change is much less than we get from one year to the next. What's the big deal?

Response: Natural variability in climate can cause large differences in conditions from one year to the next and one region to the next. However, the 0.6°C warming is a long term trend in the *global average* of all these variations in space and time. This average warming appears to exceed any changes detectable during at least the past 1000 years. By comparison, it took only about 5°C of warming to cause the Earth to slowly change from the last glacial period some 15,000 years ago, when large volumes of ice covered what is now Canada, to today's conditions.

Explanation: Natural variability in climate can cause one region of the world to warm several degrees relative to the preceding year, while another cools a similar amount. However, when such variability is averaged globally, the spatial variability is much less. Likewise, averaging weather conditions over many years also reduces the year-to-year variability of climate. The trends in global temperature represent a long-term change is such average global conditions. The 0.6°C warming over the past century makes the 20th century the warmest of the past 1000 years, at least in the Northern Hemisphere (data is still inadequate for such comparisons in the Southern Hemisphere). By comparison, the change in temperature between the last glacial maximum, which ended about 15,000 years ago, and today was about 4-6°C. That change was associated with the transformation of the Canadian landscape from a large ice sheet several kilometres thick to today's mosaic of productive ecosystems (IPCC 2001 WGI, Chapter 2).

E.2 What are the potential consequences of a few degrees of warming?

Response: A change in climate of that magnitude would significantly alter weather behaviour around the world from that which we are used to. Some of these changes are effectively irreversible. Since both ecosystems and human societies have adapted to the climates of today and the recent past, they will be ill-prepared to deal with the changes if these are too rapid to allow ecosystems and societies to adapt. For many developing countries, this may have very harmful effects on basic human values of where to live, what to eat and drink and how to live healthy lives. For all countries, increased frequency of severe weather events will enhance the risk of weather-related disasters.

Explanation: Ecosystems evolve slowly in response to changes in the average conditions and variability of past weather. Many species, like most trees, can respond only very slowly. Others have unique climate niches that may disappear, leaving them vulnerable to extinction. Likewise, the socio-economic infrastructure and culture of human societies are closely adapted to the climate within which these evolved, and a rapid climate change would make it difficult to adapt quickly, causing an increased risk of weather-related economic disasters. Experts also predict longer and more frequent extreme weather events such as heavy rains, droughts, floods, and severe storms whose impacts on humans and natural ecosystems could be significant (for example, longer and more frequent heat waves could increase heat stress related deaths). Regional changes in crop yields and productivity due to climate change are likely to increase the risk of famine, particularly in semiarid and arid regions of the tropics and subtropics. Global warming is also expected to increase the potential transmission of infectious diseases such as malaria, dengue, and yellow fever through the expansion of the range in which disease carrying organisms can survive.

Reference: IPCC 2001, Synthesis Report, pg 91-92; IPCC 2001, WGII Chapters 4, 5, and 18.

E.3 What could be the consequences for global sea levels?

Response: Experts project that the average global sea level will rise 9 to 88 cm by 2100. This rise is primarily due to the combined effects of melting glaciers and the expansion of sea water as it warms.

Explanation: As the oceans warm, the seawater expands. This alone could cause sea levels to rise between 10 and 40 cm by 2100, depending on how fast the heat penetrates into the ocean. Furthermore, mountain glaciers around the world are expected to continue to melt, adding another 5 to 15 cm of water to the ocean level as the water runs off to sea. Finally, slow changes in polar ice sheet thickness and extent could modify sea levels. Experts estimate that the combination of these factors could cause a rise by 2100 of between 9 and 88 cm, with levels continuing to rise centuries thereafter as all three factors continue to catch up with warmer global air temperatures and changing precipitation patterns.

Today, about 46 million people are at risk from flooding in low lying coastal areas, where 50 to 70% of the world's population live. A 40 cm rise in the sea level would increase those whose land will be at risk from serious flooding or permanent inundation by up to 200 million, even after expected population growth is incorporated into the projection. Adaptation measures, such as the installation or enhancement of protective sea walls and dikes, can help reduce the impacts on people. However, such measures will be costly. Estimates for protection of U.S. coastlines, for example, range from US$20 billion to US$150 billion. Furthermore, such protection will still leave an estimated 80 million additional people vulnerable to flooding during storm surges.

While Canadian coastlines are relatively rugged and hence less vulnerable to the impacts of sea level rise than those for many other countries, some coastlines are also low lying and or soft and hence vulnerable to erosion. Studies for PEI, for example, suggest that flooding levels in the Charlottetown area that now occur once every century could occur once every decade before end of century, and that up to 50% of current coastal property could be lost by 2100.

Reference: IPCC 2001, WGI, Chapter 11; IPCC 2001, WGII, page 363; McCulloch et al. 2002.

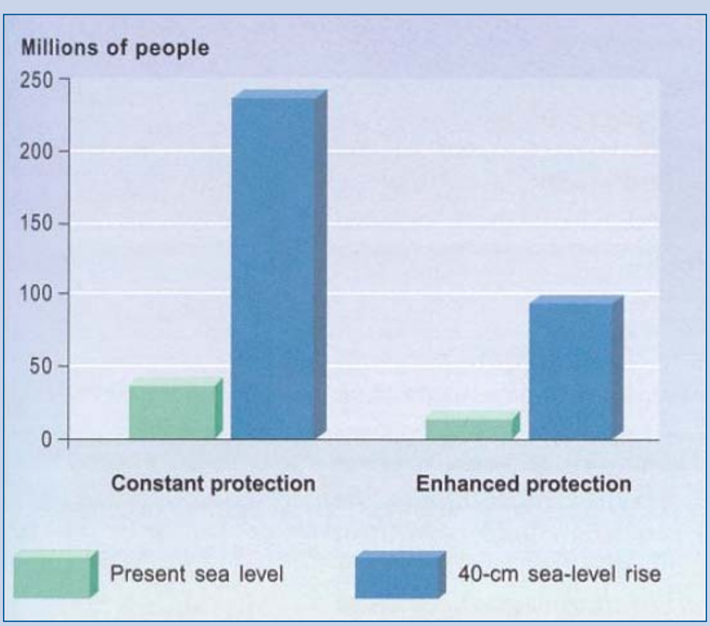

FIGURE E.3
While adaptation to the risks of sea level rise can reduce the risks of a 40 cm sea level rise by about 50%, many people will still be affected. The bars show the number of additional people flooded by storm surges by 2080, with and without the projected rise in sea level. (IPCC 2001, Synthesis Report pg 77).

E.4 There appears to be a recent trend towards increased frequency and intensity of disasters related to extreme weather events. Is this linked to climate change?

Response: It is very difficult to establish trends in weather-related disasters or to attribute recent disasters to specific causes. Hence, the perceived increase in disasters in some parts of the world in recent years may not be real or may be entirely natural. However, studies suggest that the frequency and severity of many types of extreme weather events that can cause disasters will change as the climate warms. Hence, many of the current weather-related disasters may be viewed as examples of what can be expected more often in the future as the global climate continues to warm.

Explanation: A weather-related disaster can occur when society and/or ecosystems are unable to effectively cope with an extreme weather event. That is, both the extremeness of the weather event and the sensitivity of ecosystems or society are factors. The dramatic rise in damages in recent years due to such disasters may therefore be at least partly attributed to demographic factors, such as increased human population in vulnerable regions and increased wealth. On the other hand, there are indications that there have also been increases in various types of extreme weather events, at least in some regions of the world. Since these events, by definition, occur infrequently and irregularly, they are difficult to link to global causes. Furthermore, few events are without historical precedence, and, prior to the past few decades, most historical records of such events are not very accurate. However, in many respects, the trends towards more intense and unusual extremes for some types of weather and climate events in some regions in recent years are broadly similar to those projected by climate models and related studies. Hence, while there is no hard proof to link recent disaster trends to climate change, many of these events can be considered as examples of what could happen more frequently in the future.

E.5 Why would global warming lead to more frequent and extreme weather events?

Response: Higher temperatures lead to higher rates of evaporation and precipitation, more frequent heat waves, less frequent cold extremes, and generally more energy for storms and other extremes. However, while models can provide useful clues as to the direction and significance of such changes, the processes involved are complex and the changes in extremes are difficult to predict accurately with current models.

Explanation: Most extreme events are complex responses to a number of factors, and hence their responses to warmer climates are difficult to assess. However, as the Earth warms, experts expect more frequent high temperature extremes and less frequent cold extremes, and that more precipitation will fall over shorter periods of time. This will likely increase the frequency of very heavy and extreme precipitation events, and of local flooding. Tornados and the intensity of thunderstorms and related extreme wind and hail events will also increase in some areas. It is also expected that many regions of the world will experience more frequent, prolonged, or more severe droughts due to more rapid evaporation from plants, soils, lakes, and reservoirs. Increasing atmospheric moisture could also increase the intensity and frequency of blizzards and snow storms in some colder locations, while decreasing their frequency but increasing their intensity in more temperate latitudes. In effect, climate change will 'load the dice' with respect to the probability of occurrence of such events. There is as yet little consensus on how global warming will affect other extreme weather events such as tropical storms, cyclones and typhoons, although the potential maximum intensity of such storms is expected to increase.

E.6 Can scientists prove that recent extreme weather events are due to global warming?

Response: No. Although by definition extreme events occur very rarely, most of the recent events have likely happened before. Furthermore, because of their complexity, it is still difficult to assess the natural probability of occurrence for many of these events. However, in many respects, many of the recent events are also consistent with what is expected more frequently in the future, and could therefore already have been influenced by warmer climates. At minimum, many of these provide a good reminder of what may happen more frequently in the future.

Explanation: These extreme events may simply be the result of natural variations in climate. While floods, heat waves, a severe El Niño, and other extreme events are expected to increase as the world warms, it is difficult to attribute any particular climate or weather event definitively to global warming or any other natural or human cause. Nor is it possible to rule out the role of climate change. This is partly because data on climate extremes in many regions of the world are inadequate to draw robust conclusions about possible changes in their frequency of severity that may have occurred on a global scale. Furthermore, the link between the frequency of extreme events and global warming can only be determined through statistical analyses of long-term data because the natural climate system can produce weather and climate events that appear to be uncharacteristic of the recent climate.

E.7 Will global warming take place gradually or rapidly?

Response: Climate model studies suggest that the response of the climate to human influences will be gradual. However, there is evidence that the Earth's climate has occasionally made abrupt shifts in the distant past, primarily during periods of glacial climates or of climate change. Hence, similar abrupt changes, although unlikely, cannot be ruled out.

Explanation: There is clear evidence from paleoclimate data that the climate system underwent large-scale abrupt changes in climate during the past glacial maximum and the deglaciation process between 10,000 and 15,000 years ago. These appear to occur when the climate system is in an unstable mode, and to have caused regional changes in temperature over Greenland of up to 10°C within a few decades. Other regions around the world also seem to have experienced similar abrupt climate transitions. Such changes have not occurred during the past 10,000 years of stable Holocene climate. Some scientists, however, have expressed concern that a rapid, human induced climate change could return the climate to an unstable condition and once again trigger such events. Hence, while these are unlikely within at least the next century, they possibility cannot be ruled out. The risks appear to increase with increasing rates of change, and the consequences, should they occur, can be catastrophic, since they allow little chance of adaptation.

Reference: IPCC 2001, Synthesis Report, pp80-86; IPCC 2001, WGI, Chapters 4, 7, 9 and 11.

E.8 I hear that the 1997-98 El Niño may have been one of the most severe of this century, after another severe El Niño event only 15 years ago. Is climate change causing more extreme El Niños?

Response: Several recent studies have indicated that the behaviour of El Niños during the past two decades has been very unusual when compared with historical records, and that warmer climates might indeed cause more intense El Niño type behaviour. However, such linkages remain somewhat speculative, and more data and analysis will be required to prove they exist and to determine the mechanisms involved.

Expanation: Various studies suggest that El Niño Southern Oscillation (ENSO) behaviour since 1976 has been very unusual, and perhaps without precedence in at least the past several centuries. Some climate model studies of the effects of warmer climates on ENSO behaviour suggest that a warmer Pacific Ocean surface could induce stronger El Niño type behaviour until a new equilibrium in ocean climate occurs (centuries after changes in surface warming has stopped). However, other studies show little change. Furthermore, long-term model simulations of natural variability and paleo studies also indicate that the amplitude of El Niño events can vary substantially on century time scales. Hence, research results to date are as yet inadequate to establish convincing linkages between recent El Niño behaviour and climate change.

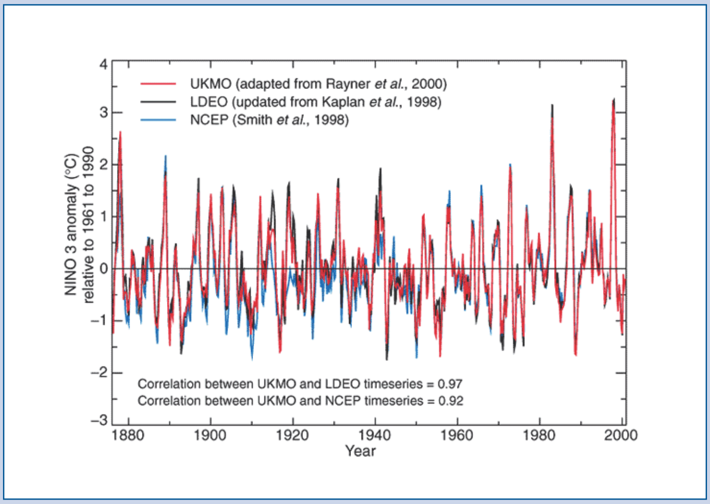

FIGURE E.8

Trends in sea surface temperatures in the eastern tropical Pacific since 1900. These temperature values are one indicator of El Niño and La Niña events, and suggest that El Niños have become more intense and frequent during the past two decades (IPCC 2001, WGI, pg 151).

F Canadian Impacts of Climate Change

F.1 Isn't there the possibility that we might be much better off with a warmer climate?

Response: For cold countries such as Canada, climate change can indeed provide some significant benefits, like reduced space heating costs and longer, warmer growing seasons. When averaged over the entire country of Canada, these benefits could help offset some or all of the harmful effects caused by climate change provided the rate and magnitude of climate change are modest. However, if climate change is rapid or large, the risks of danger increase significantly, and the overall effect on countries like Canada would be increasingly negative. That is because it is more difficult to adapt to large or rapid change. Moreover, major negative impacts are projected for many of the developing countries of the world, even for modest changes in climate. These off shore impacts can also have indirect yet significant negative consequences for Canadians.

Explanation: Warmer climates will provide benefits to some sectors of the economy or society, and to some regions of the world. For example, longer and warmer growing seasons will increase productivity of agricultural crops as well as many natural ecosystems in northern countries if there is adequate moisture. Likewise, warmer winters will reduce their space heating costs and make it easier to navigate through ice-covered waters. Climate change may also present major opportunities to expand into new areas of environmental technology and services, increase exports, and create jobs. Most of these benefits are due to changes in *average* temperatures.

However, other consequences of climate change are expected to be very harmful. These include: the combined effects of sea level rise and ocean storm surges, which can be economically and ecologically devastating and cause major loss of life in some parts of the world, particularly low-lying deltas and small island states; enhanced drought conditions that threaten large populations with starvation in some regions of the world, particularly in many developing countries; increased intensity of summer rainfall and related heavy flooding and erosion, sometimes in the same regions otherwise plagued by drought; and increased frequency of high temperature extremes are related stresses on ecosystems and human populations.

The more rapidly climates change, the more difficult it will be to take advantage of the potential benefits, and the more dangerous the consequences of the extreme events and other

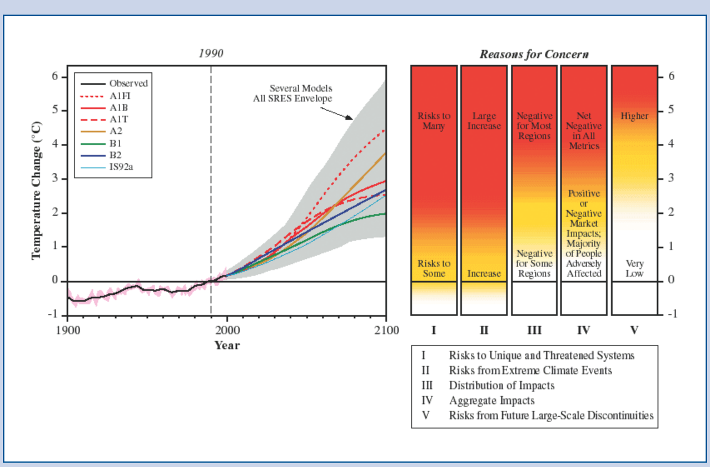

FIGURE F.1

Modest warming could provide some benefits in some regions, but if global temperature increases by more than 2-3°C, risks from extreme events are expected to increase, resulting in losses for all sectors and most regions. Recent warming has already affected ecosystems in some regions, including the Arctic (IPCC 2001, WGII Summary for Policymakers, pg 5).

harmful changes. Thus the concern is not about climate change of any particular kind, but about the possibility that rates and magnitudes of change will exceed human and ecological tolerance thresholds.

Even if the direct effects of climate change were, on average, beneficial to Canadians, disasters elsewhere may also be of major concern to Canadians (e.g. international security, environmental refugees, and aid to affected countries).

Reference: IPCC 2001, WGII, Chapter 19.

F.2 It has been suggested that, within 50 years, warmer climates will cause Halifax's climate to be similar to that of Boston today, Toronto's like that of Kentucky, and Vancouver's like that of San Francisco. What's so bad about that?

Response: Ecosystems, culture and socioeconomic infrastructures in Canada have been shaped by the local climate of today and the recent past. For example, storm sewer and drainage systems in Canadian cities are based on local rainfall characteristics, and residential and commercial buildings are designed for temperate to cold climates. Changing such infrastructure to suit warmer climates and associated changes in weather may be very costly. If climate change occurs rapidly, the process of adaptation becomes increasingly difficult and potentially unsuccessful, leading to risks of major disasters. The same is true for the natural environment.

Explanation: The past development of the infrastructure of Canadian cities, transportation systems and other social and economic well-being and activities has been significantly influenced by the past conditions of local climates. For example, most winter sport facilities and activities in most Canadian regions are dependent on the presence of snow and ice. Storm sewers and drainage systems in Canadian cities are based on, among other things, local rainfall characteristics, and residential and commercial buildings are designed for temperate to cold climates. Likewise, agriculture, water resource management and flood control infrastructures are based on current growing season and water resource characteristics. Many of these structures and activities require long lead times in order to prepare for future changes in climate. Hence, the more rapid the change in climate, the greater the potential mismatch of cultural, social and economic infrastructures with altered climate conditions, and the greater the risk of failure to adapt and of negative consequences of climate change.

F.3 Reports indicate that warmer global temperatures will cause some of the largest changes in northern countries such as Canada. Does this mean we are much more at risk of danger than countries near the equator?

Response: No. Climate models indicate that future changes in temperature will likely be greatest at high latitudes and greatest in winter. Thus, the magnitude of climate change in Canada will probably be greater than in many other countries. However, because our current Canadian climate regularly undergoes large changes from week to week, season to season and year to year, Canadians may be better prepared to deal with climate variability and climate change. Furthermore, warmer temperatures will give us some benefits that will help offset some of the harmful effects. Hence, we may be less vulnerable to climate change than many poor tropical countries.

Explanation: Models suggest that changes in temperature in response to a global warming will be greatest at high continental latitudes and in winter. However, natural climate fluctuations are also greatest in these regions, and in winter. Hence, ecosystems and societies which have developed in these regions, in general, also have a greater tolerance for change and hence may be more adaptable to the large changes predicted for future decades. Furthermore, since cold temperatures are a limitation to many ecosystems and socio-economic activities in Canada, warmer climates will bring many benefits. Finally, Canada is a relatively wealthy nation with a social infrastructure that can help Canadians to adapt more readily. By contrast, societies of many developing countries in low latitudes already have a marginal existence and have less access to such resources. This can make them vulnerable to even very small changes in climate. Thus, while the large changes for Canada projected by models may result in significant impacts on Canada, many of which will be negative, Canadians may be less *vulnerable* to the consequences of climate change than residents of many developing countries.

G Scientific Credibility and Human Response — General

G.1 From one week to the next, media reports appear to tell vastly different stories about the importance of climate change. Do climate change scientists constantly change their minds?

Response: No. The vast majority of scientists studying climate change agree that the basis for concern is scientifically sound. Media reports often tend to focus on the more controversial elements of the science related to the details of climate change, and to talk to those scientists who represent polarized views of scientific understanding. They also frequently fail to place new science within the context of the large body of existing knowledge, hence ignoring the considerable agreement within the expert science community on the fundamental principles and processes involved. Hence, such reports are not a good representation of the understanding of the expert science community.

Explanation: Each year, there are several thousand new scientific papers published in peer-reviewed literature on topics related to climate change. Each paper adds a small increment to the large body of knowledge already available. Since the global climate system is very complex, these papers involve many different scientific disciplines, and are focused on a broad range of processes and various causes of possible climate change. Some processes involve negative feedbacks that reduce the initial climate response, others involve positive feedbacks that amplify it. Some causes for change, whether natural or human, tend to cool climate, while others induce warming. Media articles tend to focus on those few papers that present dramatic or controversial research results. Hence, statements by scientists with polarized viewpoints are more likely to get media exposure than the majority of scientists whose findings may be in general agreement with the background science — but also less entertaining to media audiences. Furthermore, much of the controversy reported by media focuses on details of the climate change science. Since most of the background science upon which concern about climate change is based is much less controversial, it is frequently not reported. A good summary of such background information was recently published in the Third Assessment synthesis report published by the IPCC in 2001, which can be accessed at www.ipcc.ch.

G.2 Who is recommending immediate international action to reduce the risks of climate change? Government or academic scientists?

Response: Both. The most detailed assessments of climate change science have been carried under the coordination of the Intergovernmental Panel on Climate Change (IPCC), which was jointly established by the United National Environment Programme (UNEP) and the World Meteorological Organization. The IPCC reports have become the primary scientific basis for policy debate on actions to reduce emissions. However, the IPCC reports are based on the collaborative work of a very large number of scientific experts from many countries and scientific disciplines. The experts come about equally from academic research institutions and government research organizations.

Explanation: The preparation and peer review of the full IPCC assessments are completed by leading international experts who work in academic as well as government research laboratories. These results are based on comprehensive synthesis of literature within peer reviewed scientific journals. For example, for the IPCC Working Group I report on science completed in 2001, more than 635 scientists from 40 countries were involved in preparing the contents of the report, which was then circulated to 420 reviewers for critique. Likewise, the Working Group II report involved 426 authors and 440 reviewers from 70 countries.

These experts come from a broad range of government, university and other institutions. The chapters within the full assessment reports are accepted by the IPCC without further changes, and remain the responsibility of the primary authors, not the IPCC.

The IPCC summary documents are prepared jointly by the lead experts involved in the assessment and the IPCC secretariat staff, then approved line-by-line by senior government representatives attending the IPCC plenary sessions. However, any changes made to the text during this approval process must also be acceptable to the expert authors.

In its related report to American President Bush, a US National Academy of Sciences panel of experts advised the President in 2000 that the full IPCC Working Group I report was an "admirable summary of research activities in climate science", and that any changes made to the summary texts did not significantly change the key conclusions of the full report.

G.3 I understand there are thousands of scientists who argue that we know too little about climate change, and that it is therefore premature to respond. Who are these dissenters and are they credible?

Response: The dissenting scientists are primarily located in the United States, although there are some in the UK, Germany, Australia and other countries. A few have sound academic credentials relevant to climate change, but most have backgrounds in nuclear physics, energy, oceanography, and earth sciences rather than atmospheric sciences. Their primary argument is that the human influence on climate is not yet apparent, and that the results of climate modeling are exaggerated. However, most generally agree with the fundamental science underlying the concern about climate change.

Explanation: There are several 'declarations' often cited by sceptics as evidence of a large body of scientists who disagree with the IPCC conclusions and the need for concern about climate change. For example, the Leipzig Declaration, which emerged out of two symposiums of sceptics held in Germany in 1995 and 1997, states that, based on the available science "we consider the drastic emission control policies deriving from the Kyoto conference — lacking credible support from the underlying science — to be ill-advised and premature". To date, 80 'scientists' and 25 television weather reporters have signed. Many of these are energy experts, and only a few are atmospheric scientists that have published research papers relevant to climate change. Other similar declarations and petitions have been organized in the past. These include internet-based campaigns in the USA to solicit signatures from academics and others to a petition urging the American governments not to undertake action on climate change because of scientific uncertainties. These petitions have garnered thousands of signatures, but there are no credentials associated with these signatures. Few, if any, are known to have expertise in science relevant to the climate change issue.

The primary focus of arguments by the few who do have at least some expertise is that the observed changes in climate do not agree perfectly with model projections. Therefore, they maintain, the evidence for discernible human influence on the climate system does not yet exist, and models exaggerate the effects of humans on climate. However, they are also unable to adequately explain the observed trends on the basis of natural influences. In general, most of their arguments are out of context with the larger body of related science and are based on misinterpretation of selective information.

One dissenting scientist, Richard Lindzen, has also argued that climate models significantly overestimate the water vapour feedback effect in their simulations. This argument has been more difficult for the science community to address, primarily because the water vapour-cloud feedback remains one of the more complex factors to simulate in models and is a key cause of uncertainty in climate models. The science community has included Lindzen as a participant in the assessment process, both as a lead author in the IPCC Third Assessment and as a member of the US National Academy of Sciences panel of experts advising the US president on climate change science. While relevant studies on water vapour feedbacks have to date not supported Lindzen's hypotheses, some of these have also as yet not been conclusively refuted.

G.4 With so much uncertainty about what we know about climate change, why don't we hold off any reductions in carbon dioxide emissions until we are better able to understand the global climate system?

Response: Much of the uncertainty is related to the details of the consequences of global climate change. Scientists are in general confident that the basis for concern about climate change is scientifically sound and that the risks of danger are real and significant. Such risks make it prudent that we begin precautionary action now.

Explanation: While there is uncertainty as to the magnitude and rate of climate change, particularly at the regional level, scientists generally agree that rates of change over the next decade will almost certainly be greater than anything experienced on Earth during the past 10,000 years. On the other hand, the change could be as large as that experienced during the deglaciation at the end of the last ice age, but more than 10 times as fast. Furthermore, because of the long delay in the response of the climate system to changes in radiative forcing, by the time all the evidence is in, it may be too late to avoid significant danger. In addition, there is considerable inertia in both society and the global climate system – the former to changes in cultural behaviour and in technological restructuring, the latter to changes in radiative forcing. Hence, early action is more prudent and likely less costly and disruptive than delayed action. The scientific community has recommended precautionary action that will at least reduce the risks by slowing down the potential rate of climate change.

G.5 I understand that Dr. James Hansen, who originally expressed considerable concern about the risks of climate change, has changed his views on the importance of curbing emissions of CO_2. Should mitigation strategies focus on reducing emissions of gases other than CO_2?

Response: The scientific views expressed by Hansen and his colleagues do not differ significantly from past advice released by the international science community, which has always indicated that there are many sources of human contributions to climate change in addition to that of CO_2. Both the UNFCCC and the Kyoto Protocol allow countries to develop a mitigation strategy that considers six well-mixed greenhouse gases and seeks the most effective method of reducing their collective effects on climate. However, reductions in emissions of CO_2 will still need to be a significant component of such strategies.

While Hansen and colleagues also argue that such strategies should include efforts to reduce atmospheric concentrations of tropospheric ozone and soot, the high uncertainty surrounding these make it as yet premature to include them in the Kyoto Protocol and hence in national inventories of emissions.

Explanation: Contrary to some media reports, Hansen and his colleagues at the NASA Goddard Institute for Space Studies continue to argue that human forcing has been a significant contributor to recent climate change, and that business as usual scenarios pose serious risk of dangerous climate change. Their discussion is focused on how humans might most effectively reduce these risks. They estimate that, of the total past climate forcing towards warming climates due to well mixed greenhouse gases, 54% (about 1.4 W/m^2) is due to increased carbon dioxide concentrations, 27% due to methane and the remaining 19% due to other gases. By comparison, the latest draft of the IPCC Third Assessment Report suggests that CO_2 causes 60% of forcing to date, methane 20%, and other gases the remaining 20%. Hence, while the numbers differ somewhat, both reports agree that carbon dioxide is the most significant contributor of well-mixed greenhouse gases.

Hansen and colleagues also note that increases in soot and tropospheric ozone add to this warming, the latter by an estimated 0.3 W/m^2. However, other aerosols cause cooling on the order of -1.4 W/m^2 (although highly uncertain). Since these aerosols are primarily a by product of fossil fuel combustion, they suggest that the net primary effect of fossil fuel combustion on global radiative forcing (i.e., carbon dioxide — fossil fuel derived aerosols) is much less than 1.4 W/m^2, and that the net historical human influence on climate can thus be largely linked to the forcing of non-fossil fuel combustion gases such as methane, CFCs, nitrous oxide and tropospheric ozone.

As an alternative to a mitigation strategy that focuses primarily on CO_2 reduction (and hence reduction in fossil fuel combustion), Hansen suggests a comprehensive strategy over the next 50 years that both significantly reduces contribution from non-CO_2 gases and seeks a more modest reduction in CO_2 emissions through energy efficiency measures and fuel switching. They acknowledge that aerosol emissions cannot be allowed to increase in step with CO_2 emissions for other environmental reasons, and hence that net fossil fuel forcing will become increasingly positive in the future. Hence, beyond the next 50 years, strategies must focus on technologies to replace fossil fuels.

G.6 Is it too late to stop climate change?

Response: Scientists agree that the current warming trend cannot be stopped or reversed, but that it can be slowed down to allow biological systems and human society more time to adapt.

Explanation: There are two reasons why further climate change is already unavoidable. First, there is a lot of inertia in the climate system (mainly because of the slow response of oceans), and hence the temperatures have only partially responded to the increased concentrations of greenhouse gases already in the atmosphere. Hence, even if all emissions stopped today, further residual warming would take place for a number of decades before the climate reaches new equilibrium conditions. Second, while global emissions of greenhouse gases can be slowed down, it will take time for transition from a fossil fuel based global economy to alternatives. Thus, further emissions and hence incremental warming are also unavoidable. However, mitigative actions can slow down and eventually stop this increase.

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