12.1 Are Climates Changing?

Understanding and making predictions about climate change is a challenging process because climate is influenced by so many different factors. In addition, most observed climate records go back less than 150 years. Therefore, scientists must rely on indirect evidence of climate change such as gases trapped in ice cores, size of tree rings, composition of corals, and lake sediments. The evidence makes it clear that climates have changed in the past. The causes of past climate changes, whatever they are, will most likely continue to change climates in the future. The reason for the current concern is the *rate* at which global temperatures have increased in the last 50 years, as well as the rate at which greenhouse gases have increased in the last 100 years. When you consider all of the factors that influence climate, how can scientists determine whether there is a connection between increasing greenhouse gases and what appears to be global warming? What, if anything, should society do about global warming?

Rate of Global Warming

The graph in Figure 12.1 shows average annual global temperatures between 1856 and 2002. Air temperatures near the surface of land and sea were averaged and recorded for each year. The centre line labelled 0.0 represents the 30-year average for the years 1961 to 1990. All of the vertical lines are compared to this value. For example, a value of +0.25 would mean that for that year the average temperature was 0.25°C higher than the 30-year average. The smooth line represents five-year average temperatures.

Earth's average surface temperature has risen by 0.6°C during the last century. Although 0.6°C may not seem like a large increase, this *rate* of increase has not occurred in over 10 000 years. Scientists predict the increase in average global temperature in this century could be between 1.4°C and 5.8°C. It is important to understand that this increase is an average. In some areas there may be cooling, and in others, the warming could be much greater. For example, the Northern Hemisphere, with its larger land mass, is projected to warm more

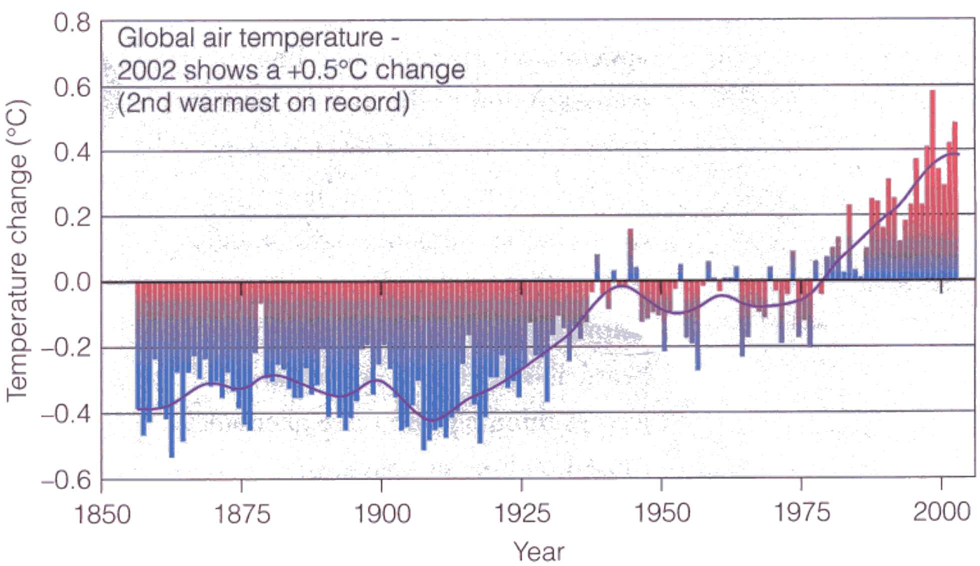


Figure 12.1 The warmest global air temperature (+0.58°C) occurred in 1998.

than the Southern Hemisphere. Land has a lower specific heat capacity and lower albedo than the oceans. Therefore, land absorbs more solar energy and heats more readily.

When does the warming occur? Is it a uniform warming from day to day over the years? For example, are the summers warmer or are they just longer? Are the winters less severe and shorter? Are the daytime temperatures higher or is there less cooling in the evenings? Check the data in Table 12.1 and see which of these questions you can answer.

Table 12.1 The Mean Temperature Changes for the Provinces (i.e., southern Canada) from 1901–2000

Seasons and months	Change in mean daily maximum (°C)	Change in mean daily minimum (°C)	Difference between daily max. and min. (°C)
Spring (March–May)	+0.9	+1.7	0.8
Summer (June–August)	+0.4	+1.2	0.8
Fall (September–November)	−0.2	+0.6	0.8
Winter (December–February)	+0.9	+1.7	0.8
Mean change	+0.5	+1.3	0.8

Data from Environment Canada, 2002

If the projected increase occurs during the 21st century, it could have both positive and negative effects for Canadians. What are some of the positive effects of a warmer climate? Warmer winters will reduce heating costs. However, the reduced heating costs could be offset by increased cooling costs if the summers are also warmer. Climates would shift northward. Thus, land in the northern half of the province would be suitable for growing crops and raising livestock as the taiga is reduced and replaced by grassland and temperate deciduous forest.

Enhanced Greenhouse Effect

If global climates have changed so much in the past, why is there so much concern that significant climate change is occurring now? To answer this question, take a closer look at greenhouse gases and how their concentrations are changing, possibly due to human activities. Recall that the greenhouse gases are water vapour, carbon dioxide, methane, dinitrogen monoxide, halocarbons, and tropospheric (ground-level) ozone (see Figure 12.2). With the exception of water vapour, these gases make up less than one percent of the atmosphere.

The next section will discuss the role of the various greenhouse gases in what is known as the "enhanced greenhouse effect."

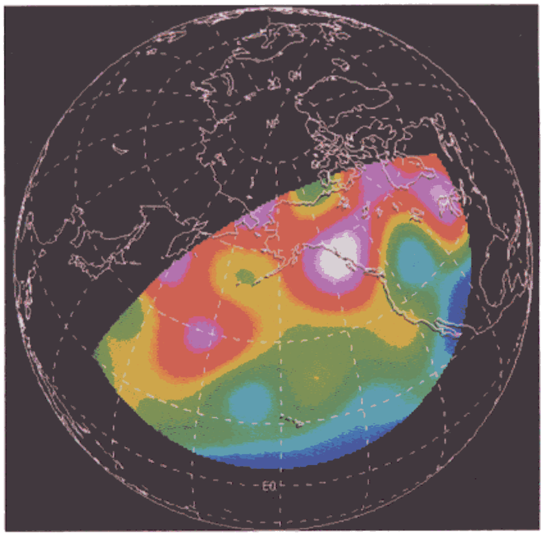
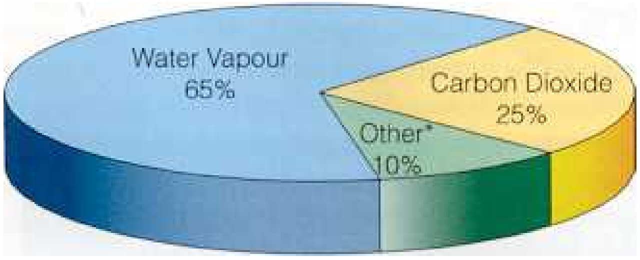


Figure 12.2 Sensors in satellites can detect specific greenhouse gases. Computers convert the information about gas concentrations into colours.

Water Vapour

Water vapour is part of the *natural* greenhouse effect. Water vapour has an average lifetime of 10 days in the atmosphere before falling as precipitation. Water vapour does not accumulate in the atmosphere. Nevertheless, it is the most abundant greenhouse gas and is responsible for about 65 percent of all the infrared radiation absorbed by and radiated to Earth's surface (see Figure 12.3).



*Includes: methane, nitrous oxide, CFCs, and tropospheric ozone

Figure 12.3 The percentage contribution of greenhouse gases to the greenhouse effect.

The *enhanced* greenhouse effect results from greenhouse gases that are added to the atmosphere mostly by human activities. Although water vapour is not increasing, it can produce a feedback that is both positive and negative. If the greenhouse effect is being enhanced, will a warmer surface increase the evaporation of water from oceans, lakes, rivers, soil, and vegetation? And if the atmosphere is warmer, will it contain more water vapour and thus increase the greenhouse effect and the warming?

The answer to the first question is *yes*, and to the second question, *maybe*. This is an example of positive feedback whereby an increase in one factor (increased warming) causes an increase in another factor (increased water vapour), which in turn causes an increase in the first factor (increased warming). This is known as **positive water vapour feedback**.

What if the increased water vapour results in the formation of more clouds that reflect sunlight before it reaches Earth's surface and therefore has a cooling effect? This is known as **negative water vapour feedback**. The net water vapour feedback depends on many variables. Therefore, predicting the effect of water vapour on surface warming is uncertain.

Warming Potential of Greenhouse Gases

Greenhouse gases other than water vapour differ in several important ways. These include the following:

- their global warming potential (a measure of how well a gas absorbs and emits infrared radiation compared to carbon dioxide)
- the length of time that each gas remains in the atmosphere before undergoing a chemical change
- the rate of increase since 1850

The global warming potential of a greenhouse gas depends on the following factors:

- the amount of the gas entering the atmosphere each year
- the lifetime of each gas in the atmosphere
- the effects of each gas on the atmospheric chemistry
- the effect of each gas on other gases

STRETCH Your Mind

Droughts caused by climate change could set off a biochemical process in northern soils that would release large amounts of carbon dioxide into the air. More droughts could activate a dormant enzyme in moist, peaty northern soils, triggering decomposition of their organic matter. This decay might release large amounts of carbon dioxide. The soils are believed to contain 460 Gt (gigatonnes) of carbon, or about 60 percent of the amount in the atmosphere, as carbon dioxide. What could this mean for climate change?

Carbon and Carbon Dioxide

Carbon occurs in various forms. Some examples are carbon dioxide in the atmosphere, carbonates in limestone and Earth's crust, carbon in fossil fuels such as coal, and various hydrocarbons in oil and natural gas. Carbon also occurs in compounds such as carbohydrates, lipids, and proteins in all organisms, and in decaying organic matter in soils. The oceans, lakes, and rivers contain dissolved carbon dioxide in the form of hydrogen carbonates.

Carbon dioxide is the most abundant greenhouse gas that contributes to the enhanced greenhouse effect. It is released when fossil fuels such as coal, oil, and natural gas are burned, when forests are removed and burned, and when soil is cultivated.

Carbon cycles through the biosphere as shown in Figure 12.4. Next to the hydrologic cycle, the **carbon cycle** has the largest annual exchange of matter. Each year about 158 Gt of carbon are exchanged among the atmosphere, oceans, and land. (A gigatonne, Gt, is 10^9 tonnes.) Of those 158 Gt, about 6 Gt are released annually from burning fossil fuels. Deforestation accounts for 2 Gt because of the carbon dioxide that would otherwise be absorbed by trees during photosynthesis. Of the approximately 8 Gt that humans release annually, about half remains in the atmosphere. The other half is absorbed by vegetation, soils, and the oceans.

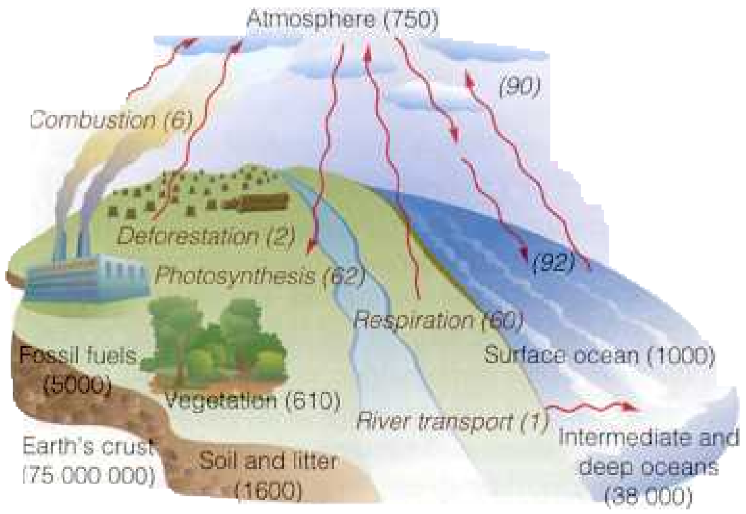
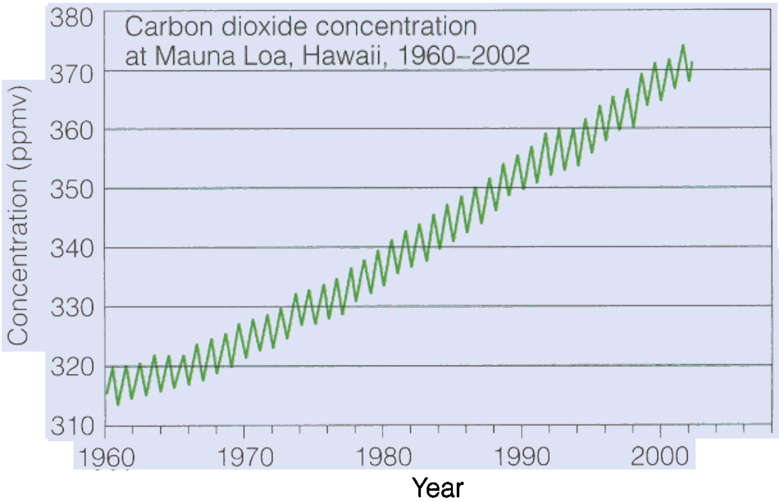


Figure 12.4 Amounts of carbon that move through the carbon cycle in one year are shown in italics. The amounts of carbon (as described on the next page) are shown in regular type. All values are in gigatonnes (Gt). When 1 t of carbon is in the form of CO_2, the mass of the CO_2 is 3.7 t. Therefore, the 8 Gt of carbon produced by human activities, such as combustion and deforestation, are equivalent to 30 Gt of CO_2.

Increasing CO_2 in the Atmosphere

Atmospheric carbon dioxide has risen by 31 percent from 1750 to 2002. The concentration of carbon dioxide has not been as high as it is now in at least 420 000 years and probably not in the last 20 million years. An important concern is the rate of the increase. About three-quarters of this increase has occurred in the last 75 years. Figure 12.5 shows the increase in atmospheric carbon dioxide from 1960 to 2002 as measured at the observatory at Mauna Loa, Hawaii.

The reason for the increase is the unprecedented rate at which humans are burning coal, oil, and natural gas. Humans are using the energy for transportation, electrical energy generation, heating and cooling buildings, and industrial processes such as the manufacture of steel and cement.



Data from Keeling, C.D. and T.P. Whorf. 2002. Atmospheric CO_2 records from sites in the Scripps Institute of Oceanography air sampling network. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge. Tenn., U.S.A.

Figure 12.5 Increase in atmospheric carbon dioxide in parts per million by volume (ppmv) from 1960 to 2002

Carbon Sinks

A **carbon sink** is a major source or a reservoir of carbon compounds. The carbon compounds include carbon dioxide in the atmosphere and carbon dioxide dissolved in water. Carbonates are found in oceans and in limestone deposits in Earth's crust. Fossil fuels, such as coal, oil, and natural gas, are composed of carbon and hydrocarbons. Most of the carbon in living organisms is found in plants in the form of the carbohydrate, cellulose. Other biological forms of carbon include a variety of carbohydrates, proteins, and lipids.

Some carbon sinks are both a source and a reservoir for carbon. For example, plants, both on land and in water, take up carbon as carbon dioxide from the air or as carbonates from water during photosynthesis. When it is dark, plants use cellular respiration to obtain energy and therefore release carbon dioxide. Carbon dioxide is also released when plant matter decays. Oceans absorb carbon dioxide from, and release it to, the atmosphere. Other carbon sinks are large reservoirs such as Earth's crust and the deep oceans. In these places, most of the carbonates are not part of the annual carbon cycle.

Forests and CO_2 Buildup

How can the environment be in a state of CO_2 equilibrium, or balance? For this to happen, the amount of carbon dioxide released into the atmosphere must be about the same as the amount absorbed by CO_2 sinks. Forests primarily absorb CO_2. However, large amounts of leaves, twigs, and dead tree trunks build up on forest floors. These materials release CO_2 when they decompose. As global temperatures rise, the decomposers produce greater amounts of CO_2. Some scientists predict that by the middle of the 21st century, the world's forests will actually produce more CO_2 than they absorb.

The natural balance of carbon cycling between oceans, land, and the atmosphere may be changing due to human activities. Human activities account for about five percent of the total annual carbon cycled between the oceans, land, and atmosphere. You will learn more about the carbon cycle in the next investigation.

DidYouKnow?

Shortly after the formation of Earth, the early atmosphere was composed of ammonia, carbon dioxide, hydrogen, methane, and water vapour. Since then the atmosphere has changed to what we have today — 78 percent nitrogen and 21 percent oxygen, and about 1 percent water vapour, and traces of the other gases. This change occurred over millions of years largely as a result of chemosynthetic and photosynthetic bacteria. As green plants evolved, photosynthesis became the primary influence on the composition of the present atmosphere. Today, photosynthesis by plants and respiration by animals are nearly in balance at 62 and 60 Gt (gigatonnes) of carbon per year.

Tools of Science

Worldwide, the activities of humans release about 8 Gt (gigatonnes) of carbon per year. Of that amount, 4 Gt remain in the atmosphere and 2 Gt are absorbed into the oceans. What about the other 2 Gt? Scientists thought it was absorbed by land vegetation, but they were not sure. Finding an answer took the co-operation of many researchers.

The Boreal Ecosystem-Atmosphere Study (BOREAS) was a project that involved 85 science teams from five nations. The science teams selected two large regions of boreal (northern) forest in Manitoba and Saskatchewan to study. Using sophisticated sensing equipment, they collected data from the forest floor and from towers standing high above the forest canopy. They also collected data from remote sensors aboard aircraft and satellites. They measured such variables as soil temperature and moisture, the amount of CO_2 released from the forest floor, and the amount of cloud cover.

The scientists estimated that trees living in the taiga contain about 13 percent of the world's carbon. As well, the soil in the taiga, which contains a large amount of fallen leaves and spruce needles, holds about 43 percent of the world's carbon that is stored in soil. Further calculations show that the taiga has been building up an average of 0.6 Gt of carbon per year for the last 7000 years!

THINK & LINK

INVESTIGATION 12-A

SKILL CHECK

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Carbon Dioxide and Global Temperature

Think About It

Globally, the combustion of carbon in fossil fuels (coal, oil, and natural gas) and the burning of forests produce about 30 Gt of carbon dioxide per year. About half of this carbon dioxide is absorbed by carbon sinks. The other half accumulates in the atmosphere. Although this amount of carbon dioxide seems large, it is about one-twentieth of the total carbon dioxide produced by nature as part of the global annual carbon cycle. Still, the rate at which carbon dioxide is increasing due to human activities is a cause for concern.

In this investigation, you will compare changes in the global emissions of carbon dioxide with the changes in the concentration of carbon dioxide in the atmosphere, and changes in the global temperature from 1860 to 2000.

What to Do

1. Write a hypothesis about the effect of fossil fuel combustion on levels of CO_2 in the atmosphere.

2. Based on what you already know about the greenhouse effect, write a second hypothesis about the effect of increased CO_2 levels on average global temperatures.

Skill FOCUS

For tips on how to make a line graph, turn to Skill Focus 7.

3. Use the data in the table below to make three separate line graphs, showing the relationship between
   (a) year and CO_2 production
   (b) year and CO_2 concentration in the atmosphere
   (c) year and average global temperature change

   Note: CO_2 concentration in the atmosphere is given in parts per million by volume (ppmv).

4. Describe the pattern of changes over time in
   (a) the quantity of CO_2 emissions from burning fossil fuels
   (b) the concentration of atmospheric CO_2
   (c) average global temperature change

   Use terms such as "trend," "increase," "decrease," "constant," "random," and "cyclic." (*Trend* means moving in one direction. *Random* means no pattern or trends. *Cyclic* means the data repeats again and again, and again, such as up and down, and up and down.)

CO_2 Levels and Average Global Temperature Change

Year	CO_2 emissions* (Gt)	CO_2 concentration in the atmosphere (ppmv)	Temperature change compared to 1861 (°C)
1860	0.67	285	0.00
1880	1.15	292	0.00
1900	2.63	298	0.05
1920	3.42	303	0.29
1940	4.95	307	0.46
1960	9.98	318	0.35
1980	20.72	340	0.41
2000	23.42	365	0.63

*Global CO_2 emissions from fossil fuel burning, cement production, and natural gas flaring (does not include CO_2 from burning of forests)

Source: Carbon Dioxide Information Analysis Center (CDIAC)

Analyze

1. Do the patterns of changes support each of your two hypotheses? Explain.

2. To see the relationships among variables more easily, all the data can be plotted on a single graph. Decide how you would do this, and then make your graph. How does your graph help you interpret the data?

Extend Your Knowledge and Skills

3. Climate is the result of complex interactions among Earth's atmosphere, lithosphere, hydrosphere, and living organisms in the biosphere. Most scientists agree that CO_2 and other greenhouse gases are affecting the climate. However, some critics argue that the enhanced greenhouse effect is oversimplified. They claim that the data may be explained in other ways. Some of the ideas and arguments are listed below.

   - Similar trends in two measurements, such as CO_2 concentration and temperature, do not mean that one causes the other.
   - There is evidence that the quantity of atmospheric CO_2 has varied over geological time. How was this evidence obtained?
   - Historical temperature data are distorted by the locations of the measuring instruments.
   - Gases other than CO_2 also contribute to the greenhouse effect.
   - Can increased growth of vegetation (forests) or increased absorption of CO_2 in ocean water compensate for increased CO_2 levels in the atmosphere?
   - Are the effects of human activities on the atmosphere and climate significant compared with long-term natural trends, such as those that have produced past ice ages?
   - CO_2 forms nearly 0.04 percent of the atmosphere. Is there anything to worry about, even if this small amount increases by one-third?
   - An increase of only one or two degrees in average temperature does not seem to be very significant.

   Form small groups and discuss these points. Determine whether the majority of your group agrees or disagrees with the following statement: "There is very strong evidence that combustion of fossil fuels is causing a significant increase the global average temperatures. Human activities are causing global warming." Prepare a summary statement of your group's position on the cause of global warming.

Computer CONNECT

Enter the data in the table into a spreadsheet, and generate your graphs using a software program.

INTERNET CONNECT

www.mcgrawhill.ca/links/sciencefocus10

Data about climate change may be presented in many different ways, which can lead to very different conclusions. In order to assess the relationship among variables correctly, you need to be able to interpret the data properly. To examine data on climate change, go to the web site above to find out where to go next. Study the data you find and draw your own conclusions. Consider how the data are presented and why. Do the conclusions given agree with your conclusions?

Figure 12.6 Cattle feedlot

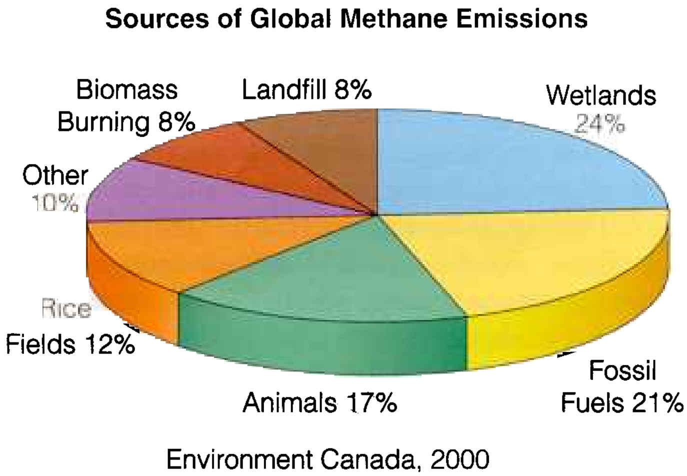


Figure 12.7 Sources of methane emissions

Methane

Methane is often called "natural gas" because it is produced by the bacterial decay of organic matter. It is used extensively to heat homes and buildings, and to generate electricity. Methane is an important part of the enhanced greenhouse effect because it has a global warming potential 21 times that of carbon dioxide. It contributes about 20 percent to the enhanced greenhouse effect. The concentration of methane in the atmosphere has increased by 146 percent since 1800 (see Table 12.2, page 439). Methane is released from a number of sources (see Figures 12.6 and 12.7). It comes from coal, oil, and natural gas deposits during mining and drilling. Some methane escapes during transmission in natural gas pipelines, although efforts are being made to prevent these emissions. Methane is also released from rice paddies, wetlands, and landfill sites during bacterial decay of organic matter. It is similarly produced in the digestive tracts of cattle, sheep, and termites as intestinal gas. About 75 percent of methane emissions come from human activities. The remainder is released naturally from wetlands.

Methane Hydrate

Methane hydrate is a unique structure of methane combined with water. It forms under specific temperatures and pressures. Methane hydrate was discovered only a few decades ago. Until recently, little research has been done on methane hydrate. The methane is very concentrated in these deposits, primarily in deep oceans. Therefore, scientists think that the energy the deposits contain is more than twice the amount of all conventional natural gas, oil, and coal deposits combined. Research may determine if methane can be obtained from methane hydrate deposits without risking an unwanted release of this potent greenhouse gas. Some methane may escape into the atmosphere naturally from these deposits.

Other Greenhouse Gases

Nitrous oxide has a global warming potential that is nearly 300 times that of carbon dioxide. This gas contributes about 6 percent to the enhanced greenhouse effect (see Table 12.2) and has increased by 15 percent since 1800. Nitrous oxide is released when fossil fuels and wood are burned at very high temperatures. It is also released when soil bacteria chemically alter nitrogen-containing fertilizers. (Although dinitrogen monoxide is the correct IUPAC name for this gas, nitrous oxide is the name most widely used in publications and on the Internet.)

Halocarbons are carbon compounds that contain halogens, such as chlorine, fluorine, or bromine. The most common halocarbons are chlorofluorocarbons (CFCs) and their replacements, the hydrochlorofluorocarbons (HCFCs) and the hydrofluorocarbons (HFCs). Halocarbons have a global warming potential thousands of times that of carbon dioxide (see Table 12.2). CFCs were developed in the early 1930s and were widely used as coolants in fridges, freezers, and air conditioners and as propellants in aerosols. Because CFCs cause thinning of the stratospheric ozone layer, their use has been banned in most countries.

Ground-level (tropospheric) ozone is a powerful greenhouse gas unlike the stratospheric ozone that blocks harmful ultraviolet light. Ozone is formed when oxides of nitrogen and vapours of gasoline, solvents, and oil-based paints react in heat and sunlight. This combination of compounds is known as photochemical smog. Ground-level ozone does not mix well in the atmosphere. Its effect on global warming has been difficult to quantify.

Table 12.2 Comparison of the Greenhouse Gases Emitted Through Human Activities

Greenhouse gas	Heat-trapping ability related to CO_2 (GWP)	Atmospheric lifespan (years)	Concentration (ppmv)* 1850	2002	Contribution to global warming	Origin
Carbon dioxide (CO_2)	1	Variable	280	370	60%	mostly human
Methane (CH_4)	23	8	0.700	1.760	20%	natural & human
Dinitrogen monoxide (N_2O)	296	120	0.275	0.316	6%	natural & human
CFCs R-11	12 400	50	0.000	0.000272	4%	human
CFCs R-12	15 800	102	0.000	0.000532	10%	human

Note: GWP is global warming potential as related to carbon dioxide. *ppmv is parts per million by volume.
Source: Adapted from L.D. Danny Harvey, *Climate and Global Environmental Change*, (Harlow: Prentice Hall, UK), page 32.

Career CONNECT

What do meteorologists do? Physical meteorologists study aspects of the atmosphere, such as clouds, rain, and lightning. Synoptic meteorologists investigate weather systems. Dynamic meteorologists study winds and atmospheric motion. Agricultural meteorologists explore the relationships among weather, crops, and vegetation. Some meteorologists forecast the weather or study severe weather or storms. Others use their training to suggest causes and effects of weather and climate. What training do meteorologists need? What skills and abilities do they use in their occupation? Research to find the answers, then make a list of qualities you have that would be useful in the field of meteorology.

DidYouKnow?

Chlorinated rubber (CR) is an important component of industrial coatings. It is also used in road paints, on ship hulls, and in factory paints. It is resistant to solvents and water, and is insensitive to temperature changes. However, production of CR most often uses carbon tetrachloride, CCl_4 (CTC), as a solvent in the manufacturing process. Unfortunately, CTC is an ozone-depleting substance. A new technology has been developed by Rishiroop Rubber International Limited, in Gujarat, India. This technology uses an aqueous solvent process to manufacture CR, which eliminates the need to use CTC at all. This process has recently been implemented by Rishiroop Organic Limited, also in Gujarat, India, in its chlorinated rubber plant.

Pause& Reflect

Systematic global temperature records have been available only since about 1860. These include land-based air and sea-surface temperature measurements. Such data need to be checked carefully for any inaccuracies that may be introduced by changes in observation methods or sites. What kinds of changes might affect the records?

Section 12.1 Summary

Atmospheric greenhouse gases have increased significantly in the last 150 years, largely due to human activities. Many scientists link this increase in greenhouse gases to recent global warming. The average global temperature increase in the past century was 0.6°C. The temperature increase has been greater in the Northern Hemisphere than in the Southern Hemisphere. This difference is due to the larger landmass in the Northern Hemisphere. The greenhouse gases such as carbon dioxide, methane, and dinitrogen monoxide have increased in the last 100 years due to fossil fuel combustion, use of agricultural fertilizers, cement making, and deforestation. Carbon sinks, particularly the ocean, absorb about half of the atmospheric carbon dioxide released as a result of human activities.

Check Your Understanding

1. Distinguish between the natural and enhanced greenhouse effect.
2. Describe how water vapour can produce both a positive and a negative water vapour feedback.
3. What carbon sinks play a major role in absorbing atmospheric carbon dioxide released by human activities?
4. Name the greenhouse gases. Describe the role each plays in the enhanced greenhouse effect.
5. **Thinking Critically** On a summer day, why might a beach be cooler than a meadow a few kilometres away?