How Might Climates and Biomes Change in the Future?

The Canadian Centre for Climate Modelling and Analysis of Environment Canada prepares and analyzes models of future climate. General circulation models (GCMs) are complex mathematical models. These models use supercomputers to analyze and make quantitative projections of future climate change. GCMs create detailed three-dimensional models of the land, oceans, and atmosphere. These models use the laws of conservation of momentum, mass, moisture, and energy. GCMs simulate how various factors such as temperature, humidity, wind speed and direction, ocean currents and salinity, soil moisture, and many other factors may affect climate.

In Figure 12.13, data from one of the Canadian General Circulation Models were used to prepare the predicted temperature change for the twenty-first century. The models divide Earth's land surface and oceans into a grid. The grid is extended vertically to provide a three-dimensional representation of Earth's surface and atmosphere.

Predicting Climate Change

There are two major uncertainties in predicting future climate change. One is predicting the amounts of greenhouse gases that will be emitted in the future. This factor will largely determine future greenhouse gas concentrations of the atmosphere. The amount of emissions depends on future human population growth, energy use per person, the types of energy that are used, and the amount of greenhouse gas that the energy use produces. The second uncertainty is how climates will respond to an increase in greenhouse gas concentration. This factor involves a whole series of climate feedbacks, including:

- the melting of snow and ice and the degree to which the resulting change in albedo will increase surface warming, and
- the increase in the amount of water vapour in the atmosphere as the climate warms and the resulting cloud feedbacks.

Figure 12.12 GCM managers create scenarios from the past and compare them to current scenarios. They use information from such studies as the Geological Survey of Canada. They also apply information from groups including Ocean Project, SHEBA (Surface Heat Budget Arctic), NASA, and the International Research Institute for Climate Change.

Figure 12.13 The observed temperature change from 1900 to 1997 and the projected temperature change from 1990 to 2100 of the Canadian General Circulation Model 1 for changes in global average surface temperature. Predictions that include changes in greenhouse gases and aerosols suggest an increase of more than 4°C over the 21st century.
The general circulation models enable scientists to make projections of the temperature changes that might occur over North America, Europe, and Eurasia during different time intervals. These projections are shown in Figures 12.14A, B, and C, for the combined effects of projected greenhouse gas and sulfate aerosol increases.

How would the forests of the Canadian taiga adapt to the predicted climate changes? In order to answer that question, scientists investigate how species have adapted in the past. You can analyze some of the evidence in Inquiry Investigation 12–C: Grains of Truth.


The Canadian GCM projects greater warming over land than oceans, and over high latitudes than low latitudes. Land surfaces have a lower specific heat capacity than oceans. Reduced snow and ice cover in the north reduces the albedo. Therefore, more solar energy is absorbed, contributing to greater warming. Warming by about 2020 would average 1–2°C over most of the northern hemisphere land areas and 2–4°C over Arctic ice-covered waters. European temperatures are moderated by movement into the region of warm tropical ocean currents. Snow and ice feedbacks are the primary reasons for enhanced polar warming.


By about 2050, projected warming by the Canadian GCM exceeds 3°C, with ice-covered waters in the Arctic Ocean warming by more than 5°C. A slower ocean circulation and reduced flow of warm water from the tropics northward would cause an area of cooling near Labrador.


By about 2090, most continental regions of the northern hemisphere are projected to warm by more than 5°C, and Arctic waters by 10–20°C. The area of cooling near Labrador is still evident. European warming would continue to be moderated by a weaker Gulf Stream. The Arctic Ocean would be entirely ice-free in summer.

Source: Diagrams from Environment Canada
Grains of Truth

Scientists study pollen left in layers of lake sediment. These pollen grains from plants that grew centuries ago tell us what plants lived in the area and the climate that existed at the time. If plants grew in an area that used to be warmer than it is now, scientists can more accurately predict the types of plants that will thrive if human-caused climate change is a reality.

Question
What can you tell about the climate that existed at the time specific samples of pollen were shed from surrounding plant life?

Safety Precautions
- Wash your hands thoroughly after completing this investigation.

Materials
- samples of sediment containing “pollen”
- pie tin
- key to the different pollen colours showing which colours represent which plants, and information about the climatic requirements for each
- worksheet (provided by your teacher)

Procedure
1. Examine the illustrations of the different pollen types, noting the structural differences in each. Discuss how scientists could use these differences to identify plants from which they came.
2. Your teacher will show you a model sediment core containing five separate layers, each laid down at a different time in the past. Pay attention to the colour and texture of each layer to help you identify the samples from each layer with which you will be working.
3. Each pair of students will be given a sediment sample, a pie tin, and a worksheet. Each sample contains “pollen” from plants that grew in the area at the time the sediment was deposited.
4. Empty the sediment into the pie tin. Sift and dig until you have found all of the pollen grains. Keep the pollen grains separated by colour.
5. Use the pollen key to determine what species of plants are represented in your sample and what percentage of the total pollen comes from each species. Fill in the worksheet for the sediment layer on which you are working.
6. Use the pollen key to figure out what the climate was when your layer was deposited. Be sure to compare your sediment sample to those in the entire sediment core. By doing so, you will know what level your sample is from and how old it is.
7. Compare your conclusions with others in your class who were assigned the same sediment layer.

CONTINUED...
## Pollen Key and Climatic Characteristics of the Vegetation

<table>
<thead>
<tr>
<th>Dot colour</th>
<th>Species</th>
<th>Climatic characteristics</th>
</tr>
</thead>
</table>
| white      | western hemlock          | • principal dominant tree of many lowland, temperate sites  
|            |                          | • requires very moist, temperate conditions for growth                                    |
| brown      | Douglas fir              | • broadly distributed throughout Pacific Northwest from moderately cool to warm sites  
|            |                          | • grows best under temperate, somewhat moist conditions                                   |
| dark green | grasses and sedges       | • typically found in very cool alpine/subalpine meadow sites characterized by very    
|            |                          | cool summers, harsh winters, and short growing seasons                                    |
| red        | alder                    | • widespread throughout the Northwest, often colonizing gravel bars or other poor     
|            |                          | soils, prefers abundant water, and can grow in cool climates                              |
| pink       | grand fir                | • found at mid-elevations in Cascade Mountains  
|            |                          | • grows in cool climates, but not as cold-tolerant as trees found at higher altitudes   |
| light green| Englemann spruce         | • found in cold, usually subalpine sites                                                 |
| light blue | lodgepole pine           | • an important timberline species in the Rocky Mountains                                  |
| yellow     | alpine sagebrush         | • found in areas of very cool climates typically growing on poor soils, often at high 
|            |                          | altitudes (above 1065 m) under the present climate                                       |
|            |                          | • woody, low-growing shrub                                                               |
|            |                          | • found only at high-altitude, cold sites                                               |

### Pause & Reflect

Changes in temperature and precipitation come with climate change, but more than these two factors determine the types of plants and animals that can inhabit an area. Imagine the Northwest Territories as warm as Alberta by the year 2100. Could the crops that now grow in Alberta be raised in the Northwest Territories in 2100? In your notebook, write down at least two reasons why this might not be possible.

### Analyze

1. Did all students who were assigned the same sediment layer find the same plant types? If not, why not? Do all students agree on the climate that probably existed at the time? If not, why not?

2. Fill in the rest of your worksheet with the information provided by other students who studied different sediment layers. Determine what the overall pattern of climate change was during these last 20 000 years. Speculate what might have caused the changes.
Changes to Canadian Biomes

How is global warming expected to affect Canadian biomes? Climate determines where certain plant species are likely to grow and flourish. Hence, as the climate changes, biomes, with time, will change. For example, projected doubling of carbon dioxide is expected to reduce the taiga and increase the grassland and temperate deciduous forest biomes. The taiga could be lost to insects, diseases, and fire in regions where climate change imposes greatest stress. These regions are expected to be at the southern boundaries where higher temperatures and reduced precipitation could be more common than elsewhere (see Figure 12.15). Changes in biomes and their ecosystems are likely to be much more complex than those shown here. Direct effects of increased carbon dioxide and other factors such as changes in precipitation also influence ecosystems. Changes in ecosystems can also, in turn, significantly affect regional climates.

Some Specific Effects of Global Warming

Changes to the global climate are predicted to be greater in the Northern Hemisphere than in the Southern Hemisphere, and greater in the continental regions than in the coastal areas. What changes might occur? Read the examples that follow, then predict other changes that might occur over many decades.

- Changes to the amounts and patterns of precipitation would affect the snowpack, stream flow, and the replenishment of ground water. These changes could affect agricultural regions that rely on irrigation. Crops vary greatly in their response to climate change. An increase in atmospheric carbon dioxide can stimulate crop growth and yield. However, this may be offset by increased heat, drought, insect pests, and reduced mineral nutrients.

- Coastal zones and marine ecosystems would be affected if the increase in sea surface temperature and average sea level continues. Changes in salinity and ocean circulation would likely cause shoreline erosion, loss of wetlands, and the mixing of seawater with freshwater sources.

- Human settlements and industries could be at risk from rising sea levels and coastal storms. Primary resource industries such as agriculture, forestry, and fisheries, would be more vulnerable to climate change than diversified economies.

- Human health could be affected. Heat stress and urban air pollution would put the elderly and those with respiratory conditions at risk. Infectious diseases, such as malaria and dengue fever, and waterborne diseases, could affect those who do not have clean drinking water and access to health care.

- Abrupt shifts in terrestrial and freshwater ecosystems and biomes are unlikely. Instead, changes in composition and dominance of species at the edges of biomes would occur. Freshwater fish populations are likely to migrate to the higher latitudes following the changes to water temperatures.

Figure 12.15 Changes expected in present-day biome boundaries if the preindustrial levels of carbon dioxide double from 280 ppmv to 560 ppmv.
Addressing the Risk
Addressing the risk of climate change requires a global solution. Several recent global assessments are described below.

The Intergovernmental Panel on Climate Change (IPCC) was formed in 1988 by the United Nations Environment Program and the World Meteorological Organization to assess the existing knowledge about climate and climate change. The panel consists of 2500 scientists from 70 countries. It is the largest gathering of scientists to work on one issue. The IPCC nominates lead authors who develop regular assessment reports. The process of developing these reports involves review by a panel of science experts.

The Third Assessment Report prepared in 2001 projects a global temperature rise of between 1.4°C and 5.8°C by 2100. The Report summarizes recent climate changes as follows:

- an increasing set of observations gives a collective picture of a warming world and other changes to the climate,
- the global average surface temperature has increased by about 0.6°C over the twentieth century,
- temperatures have risen during the past four decades (1960–2000) in the lowest 8 km of the atmosphere,
- snow and ice cover have decreased, and
- the global average sea level has risen 0.1–0.2 m and the ocean heat content has increased.

In light of the second assessment report, the United Nations Framework Convention on Climate Change was improved by another agreement at a meeting that took place in Kyoto, Japan in 1997. This agreement is known as the Kyoto Protocol. It is a set of new terms for the reduction of greenhouse gas emissions. Some specifics of the Kyoto Protocol include:

- over 160 countries signed the Protocol,
- the goal is to reduce greenhouse gas emissions of the industrialized countries by an average 5.2 percent below 1990 levels to be achieved over the period from 2008 to 2012,
- the agreement will take effect if it is ratified by at least 55 countries whose emissions make up 55 percent of the 1990 emissions from the industrialized countries,
- some reduction targets are: Canada (6 percent), European Union (8 percent); United States was 7 percent, but opted out in 2001,
- no binding emission-reduction targets were made for developing countries such as India and China to allow for fossil fuel-based economic growth,
- If by 2012 a country has not met its reduction target, it must make up the difference in the second commitment period, plus a 30 percent penalty,
- The developing nations, such as China, India, and the Latin American countries, who were not required to make reductions during the first commitment period, 1997–2012, will be required to do so in the second commitment period after 2012. Countries that signed the Kyoto Protocol may start negotiating the specifics of the second commitment period in 2004,
- reduction mechanisms will take into account those factors that have an impact on atmospheric carbon dioxide, such as agriculture, deforestation, reforestation, and afforestation.

![Figure 12.16](image)

Canada's greenhouse gas emissions as carbon dioxide equivalents in megatonnes (Mt) with respect to the Kyoto Protocol. The dotted line shows the rate of change required to achieve Canada's reduction in greenhouse gas emissions for the Kyoto target. The shaded area (2008–2012) indicates when the greenhouse gas reductions are to be achieved.

How Do You Compare?

Canadians produce about 2.5 percent of global greenhouse gas emissions. We are among the largest users of energy use and highest per capita emitters of greenhouse gases. How does your family's carbon dioxide output compare with that of other Canadians? What steps could you take to reduce these emissions?

Question

How much carbon dioxide do you produce annually? How does this amount compare with the amount produced by other Canadians?

Materials

at least two electricity bills (one summer, one winter)
at least two heating bills (one summer, one winter)
atlas
calculator

Procedure

1. Copy and complete the table below as accurately as possible.

<table>
<thead>
<tr>
<th>Carbon dioxide source</th>
<th>Annual consumption (per year)</th>
<th>Amount of carbon dioxide (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home heating (see chart at right)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity (kW*h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garbage bags</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycling bags</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local travel (km car)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local travel (km bus or public transit)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holiday travel (km car)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holiday travel (km rail)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holiday travel (km bus)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. To determine your consumption of natural gas or heating oil per year, find the heading that states the energy amount used. Find the average consumption per month (add the amounts used and divide by the number of bills). Multiply by 12 to get the consumption per year. Record this value in the annual consumption per year column. If your bill does not measure consumption per year in GJ, convert to this unit.

3. Divide the annual consumption by the number of people in your household with whom you share the amount of heat (and carbon dioxide produced).

4. Copy the table below. Record the conversion factor for this heating source (see below) in the conversion factor column. This is how much carbon dioxide is produced for every GJ of heat produced.

<table>
<thead>
<tr>
<th>Type of heating</th>
<th>Conversion factor</th>
<th>Amount of carbon dioxide (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>58.37 kg CO₂/GJ</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>1.03 kg/kW*h</td>
<td></td>
</tr>
<tr>
<td>Heating oil</td>
<td>3.0 kg/L</td>
<td></td>
</tr>
</tbody>
</table>

5. To determine the amount of carbon dioxide produced in providing heat for an entire year: \[
\frac{\text{annual consumption}}{\# \text{people that share this source}} \times \text{conversion factor}
\]

Record this value in the Amount of CO₂ column.

6. Repeat the steps for your electricity bills. Electricity is usually measured in kW\*h (kilowatt-hours). The conversion factors for electricity depend on how your province generates electricity. For Alberta, the conversion factor is 1.03 kg/kW\*h. Record this value in the Amount of CO₂ column.

CONTINUED
To calculate the carbon dioxide production due to garbage, multiply the number of bags of garbage your household creates each year by the conversion factor of 0.0085 kg. If you recycle, each bag of recycling produces as much carbon dioxide as half a bag of garbage, so multiply the number of bags of recycling your household creates each year by the conversion factor of 0.0042 kg.

To calculate your annual carbon dioxide production due to travel, follow these steps:
(a) To calculate your yearly consumption of gasoline, ask the drivers in your household how often they fill up the car, and determine how many tanks of gas they use in a year. Multiply the number of tanks of gas per year by the size of the gas tank to find the annual consumption of gasoline. (A good guess will be close to the actual value.) Include only your gasoline consumption; multiply the actual consumption of gasoline by the percentage of time you are in the car. (Don’t count the time when someone else is using the car.) If your family has two cars, include both in the calculation.
(b) If you take the bus, determine the length of your bus trips in kilometres over an entire year.
(c) Include any holidays you have taken in the last year. The amount of carbon dioxide depends on how far you travelled and your method of transportation. Estimate trip length using an atlas if necessary.

### Analyze

1. The results below are for the “average” Albertan and “average” Canadian. Construct a bar graph to compare your results with the averages (graph all of your holiday travel as one bar).

<table>
<thead>
<tr>
<th>CO₂ (g) source</th>
<th>Average annual emission per capita (Alberta) (kg)</th>
<th>Average annual emission per capita (Canada) (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>2 800</td>
<td>1 600</td>
</tr>
<tr>
<td>Electricity</td>
<td>2 600</td>
<td>768</td>
</tr>
<tr>
<td>Local travel</td>
<td>2 600</td>
<td>2 112</td>
</tr>
<tr>
<td>Holiday travel</td>
<td>1 700</td>
<td>1 280</td>
</tr>
<tr>
<td>Garbage</td>
<td>700</td>
<td>640</td>
</tr>
<tr>
<td>Total</td>
<td>10 400</td>
<td>6 400</td>
</tr>
</tbody>
</table>

2. Which of your annual emissions are higher than the average Albertan’s? Lower than the average Albertan’s? Higher than the average Canadian’s? Lower than the average Canadian’s?

### Conclude and Apply

3. Compare each of your results with other Albertans’ and other Canadians’. Are your results more similar to other Albertans’ or to other Canadians? Discuss reasons for why your values are higher or lower.

4. If you could choose one carbon dioxide source to reduce over the course of next year, which would you choose? List three initiatives you could take to reduce the amount of carbon dioxide you produce from this source.
An Environment-Energy-Economy Issue

The Kyoto Protocol has received criticism for reasons such as the following:

- a greenhouse gas reduction of 5.2 percent below 1990 levels by 2008 to 2012 will not reduce future emissions of carbon dioxide,
- under a “business-as-usual scenario,” carbon dioxide emissions are projected to rise throughout the twenty-first century,
- to avoid a doubling of atmospheric carbon dioxide from pre-Industrial Revolution levels of 280 ppmv to 560 ppmv, emission reductions from both industrialized countries and developing countries will be needed, and
- greenhouse gas emissions will have to be reduced by more than 50 percent over this century if climate change is to be averted.

![Pie chart showing Canada's greenhouse gas emissions by sector](image)

Figure 12.17 Canada's greenhouse gas emissions by sector. Industry includes fossil fuel production, mining and smelting, pulp and paper, industrial chemicals, and cement making. About 55 percent of emissions from transportation come from personal vehicle use of cars, SUVs, and light trucks.

Reducing global greenhouse gas emissions will be a long process. The Kyoto Protocol's reduction of global emissions by 5.2 percent of 1990 levels is a start. Future international agreements that involve the industrialized nations and the developing nations are expected to continue the reductions.

Reducing Emissions

How will nations reduce their emissions of greenhouse gases? Most reductions focus on energy, since a large percentage of greenhouse gases come from the production and use of energy. These reductions include conserving and using energy wisely, improving energy efficiency, reducing fossil fuel use, and using alternative fuels. Other measures include expanding renewable energy sources such as wind, solar, and geothermal energy. Other greenhouse gas emission reductions focus on agricultural and industrial practices. Some of these changes can occur by looking at low cost practices that can be implemented easily. Others that require significant financial investments will occur over a longer period of time. A number of industries and federal, provincial, and municipal governments in Canada are developing action plans to reduce their emissions. They are also investing in renewable energies.
Section 12.3 Summary
Climate scientists use general circulation models (GMCs) that make projections about future temperature and precipitation. There are two significant uncertainties in predicting future climate:

1. The first is the difficulty in predicting the change in concentration of greenhouse gases in the future.

2. Even if it were possible to predict the concentrations of greenhouse gases, it would still be difficult to predict how these gases would influence the climate. Current projections show a greater warming in the higher latitudes in the Northern Hemisphere than in the Southern Hemisphere. This projection is based largely on the greater land mass and greater absorption of solar energy in the Northern Hemisphere due to the reduction of snow and ice.

In 1997, over 160 countries entered into an agreement (the Kyoto Protocol) to reduce the concentration of greenhouse gases to a level 5.2 percent below that of 1990. Further reductions are expected when developing nations are scheduled to make reductions in their greenhouse emissions. Most greenhouse gas reductions will come from energy conservation and more efficient use of energy. Scientists and engineers will continue to develop renewable energies and new technologies to reduce the concentration of greenhouse gases in the atmosphere.

Check Your Understanding

1. Describe how a general circulation model projects future climate changes.

2. What are the two uncertainties in predicting future climate change?

3. Describe the factors involved in determining future greenhouse gas emissions.

4. Summarize the projected temperature changes for the northern hemisphere for the 20-year periods ending in 2030, 2060, and 2100.

5. How are Canadian biomes predicted to change if a doubling of carbon dioxide over the pre-industrial level of 280 ppmv occurs?

6. Thinking Critically Describe how marine ecosystems may be affected if climate changes projected for 2100 occur.