

Science

SNC2D-B

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Course Description

Welcome to Grade 10 Academic Science, SNC2D-B.

This course focuses on the science skills that will help you understand concepts in biology, chemistry, earth and space science, and physics. You will develop your scientific research skills by planning and conducting investigations into scientific theories related to factors affecting climate change, chemical reactions, human cells and body systems, and the interaction of light and matter.

Materials

SNC2D-B is divided into four units of five lessons each. Each unit is contained in a separate book.

In your first course package, you will receive

- one lesson book
- a Course Journal, in which you submit your work and reflection writing, and receive a teacher's evaluation of your work, by mail. You may choose to submit your work and receive your evaluation by e-Journal.

When you have successfully completed Unit 1, you will be sent a second course package containing three lesson books, one for each of Units 2, 3, and 4.

There are some optional activities in this course that use common materials found at home. It will also be useful, but not necessary, to have a basic calculator.

Computer Access

Be sure to register on the ILC website so that you can access the online components during your course. You will need your student number and your PIN to register. Create your own unique username and password and write them in the front of your lesson book as a reminder. To reach your course page, log in and click on "My ILC" at the top of the home page. Then choose "My Courses" and your course page will appear.

On your course page, you will find online components that you need to use to complete the work in your course. They are noted in the lessons and you are told to visit the website where necessary. After completing Lesson 20, you will need to go to your course page on the ILC website to do the Practice Test, which you will mark yourself using the Practice Test Suggested Answers, also found on your course page. In addition, from time to time, new resources and components may be added, so remember to check your course page regularly while working through the lessons.

If you do not have a computer with Internet access at home, you may be able to use one at a public library. Ask at the library to learn how to sign up for time on the Internet.

Online Components of SNC2D-B

In this course, you will need to access material on the ILC website in all units:

- In Lesson 2, you will explore Canada's different habitats using the ecozones interactive map.
- In Lesson 6, you will explore the periodic table using an online interactive version.
- In Lesson 7, you will explore physical and chemical changes in a variety of substances using the virtual chemistry lab.
- In Lesson 9, you will explore acid-base reactions using the virtual chemistry lab.
- In Lesson 10, you will conduct a water-quality test using the virtual chemistry lab, as well as explore the Workplace Hazardous Material Information System through an interactive tutorial.
- In Lesson 11, you will view plant and animal cells with a virtual microscope.
- In Lesson 12, you will view and classify cells in various stages of mitosis.
- In Lesson 13, you will view specialized cells with a virtual microscope.

- In Lesson 15, you will do a virtual dissection.
- In Lesson 16, you will view examples of various luminous objects. You will also see a video of a rainbow.
- In Lesson 17, you will experiment with reflections in mirrors using a simulated optics workbench.
- In Lesson 18, you will experiment with light refraction using a simulated optics workbench.
- In Lesson 19, you will experiment with images in lenses using a simulated optics workbench.

Expectations

The expectations listed in this course describe the knowledge and skills that you are expected to develop and demonstrate throughout the course. The overall expectations you will cover in each unit are listed on the first page of the unit. Specific expectations are listed at the beginning of each lesson under the heading “What You Will Learn.”

Evaluation

In each lesson, there are Support Questions and Key Questions.

Support Questions

Support Questions will provide you with an opportunity to assess your own understanding and mastery of the ideas and skills you are learning in the course. They will also help you to improve the way in which you communicate your ideas. Many of the Support Questions will prepare you to answer the Key Questions. Write your answers to the Support Questions in your lesson book or on a separate piece of paper. **Do not send your answers to ILC to be marked.** Suggested Answers to Support Questions are provided at the end of each unit so that you can check your work.

Key Questions

The Key Questions are used to evaluate your achievement of each unit's expectations. Your answers will show how well you have understood the ideas and mastered the skills in the unit, and how well you can communicate your ideas. You must complete most of the Key Questions successfully in order to pass each unit. Save your answers to the Key Questions in your Course Journal or e-Journal until you have completed all the lessons in a unit. Remember to label your answers clearly with the correct unit, lesson, and question numbers. For each Key Question, the way marks are allocated is explained in detail.

Submitting Your Course Journal or e-Journal

After you have completed the work for a unit, you will send your Course Journal or e-Journal to ILC for evaluation. Make sure that you include answers to all Key Questions in the unit. You must also complete the Reflection and Student's Evaluation pages. For each unit, there is an Achievement Chart and a Teacher's Evaluation page, which an ILC teacher will use to record an evaluation of your work. There is also a Student's Response page, so that you can comment on the teacher's evaluation of your work when it is returned to you.

Reflection

As you work through each unit, think carefully about what you are doing. Use the Reflection page in your journal to make comments, express feelings, and give opinions about your learning and about the course. The more you think about and reflect on what you are doing, the better you will learn. This also provides important feedback for the teacher. You must complete it before proceeding.

Student's Evaluation

For each unit, you are required to look back over the lessons and evaluate your learning experience in the unit. Use the Student's Evaluation page in your journal to describe the skills you have developed or improved on, and the things that gave you problems.

Achievement Chart

An ILC teacher will mark your work for each unit. The teacher will use a Marking Guide to evaluate your work and assign a mark. The teacher will highlight a level on the Achievement Chart for the work done in that unit, indicating whether your work is below, within, or above the standard for the course. The teacher will write your mark out of 100 in the journal.

Teacher's Evaluation

The teacher will write comments on the Teacher's Evaluation page, giving you feedback to help you improve your work.

Student's Response

Use the Student's Response page to respond to the comments in the Teacher's Evaluation. Go over each point the teacher has made, and make sure that you understand it. Ask about anything you don't understand.

What You Must Do to Earn a Credit

In order to receive a credit for this course, you must

- successfully complete all Key Questions for each unit
- complete the Reflection and Student's Evaluation pages for each unit in your Course Journal or e-Journal
- pass the Final Test (50% or over)

You will receive a mark out of 100 for each unit and for the Final Test. Your course mark will also be out of 100.

Weighting

Coursework	Weight (%)
Unit 1	17.5%
Unit 2	17.5%
Unit 3	17.5%
Unit 4	17.5%
Final Test	30.0%
Total	100%

You must receive a passing mark for Unit 1 before ILC will send you the remaining units. If you do not receive a passing mark on any unit, the teacher will ask you to redo and resubmit the unit. The teacher will give you suggestions to help you pass the next time.

If your resubmitted unit does not reach the passing standard, you will receive a Course Recommendation form, asking you to withdraw from the course and enrol in a different course. You may re-enrol in the original course later.

Final Test

Every ILC credit course has a Final Test. After you have successfully completed the last unit of this course, you will receive information about writing the test. You can have two opportunities to pass the Final Test. No matter how well you do on the unit work, if you do not pass the Final Test, you will not get a credit for the course.

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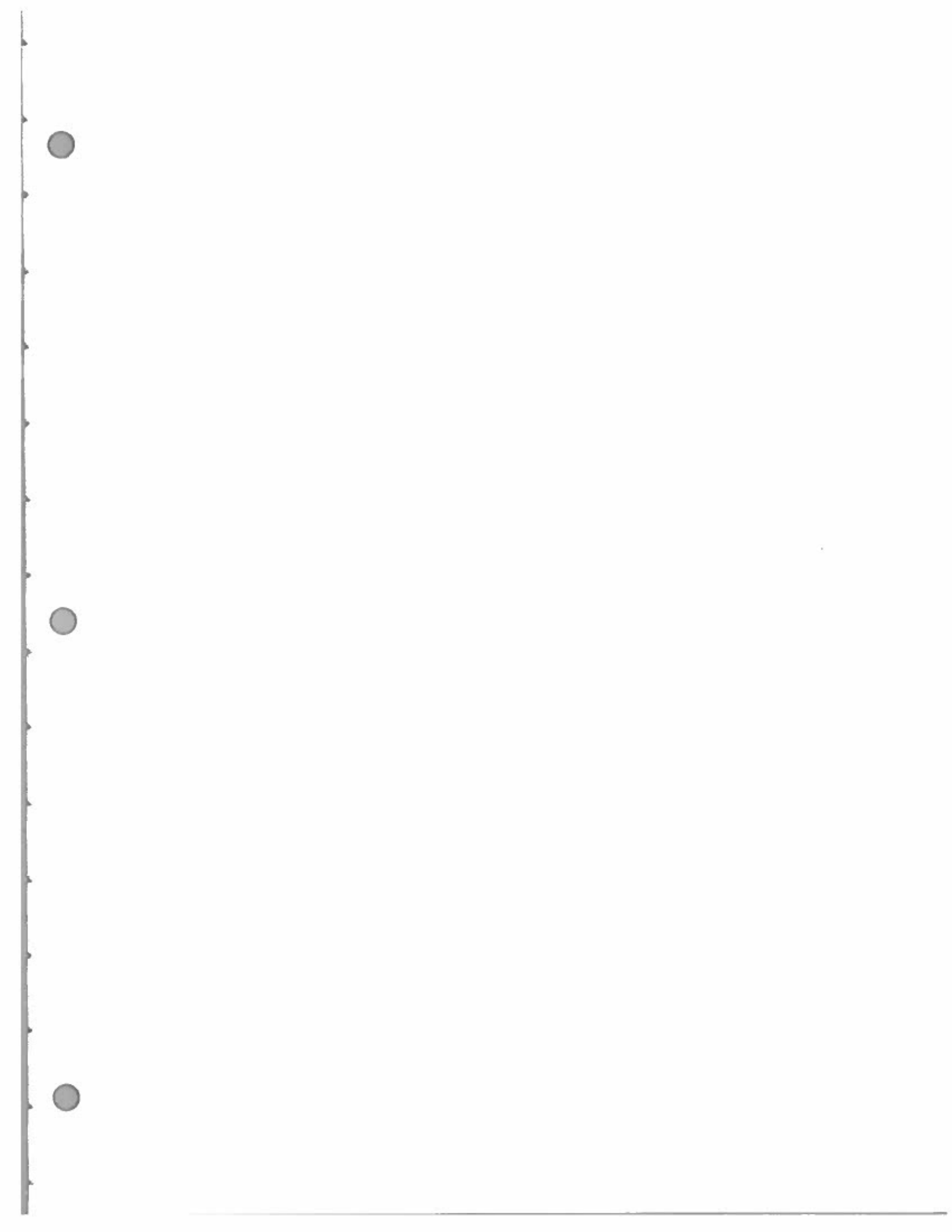
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Earth's Dynamic Climate

SNC2D-B

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Lesson 19: Let's Get Focused: Forming Images with Lenses

Lesson 20: Optical Devices

Suggested Answers to Support Questions

Introduction

In this unit, you will examine climate and the problem of human-caused climate change. You hear warnings about climate change nearly every day. Governments, businesses, community groups, and scientists all propose solutions. Chances are that your own community has even started programs to save energy and so reduce its output of greenhouse gases. But what is climate and how can we tell it's changing? Don't things change naturally anyway? How can we tell normal change from human-caused climate change?

The unit will start by investigating the components of the earth's climate. Next you will learn how the greenhouse effect works and how humans are altering it. Finally you will examine how climatologists assess climate change, past and future, and evaluate proposed solutions.

Besides being an important problem on its own, climate change is also a very complex scientific issue that brings together ideas from chemistry, physics, and biology.

Overall Expectations

After completing this unit, you will be able to

- demonstrate an understanding of natural and human factors that influence climate and cause climate change
- describe the greenhouse effect and how human activities are increasing climate change
- describe the effects of climate change around the world and analyze the effectiveness of some proposed solutions

If you have not yet registered on the ILC website, please do so now. Follow the instructions in the Course Introduction, in the "Materials" section, under "Computer Access."

SNC2D-B



Climate and Heat Energy Transfer

Introduction

There is a lot of confusing talk about climate change in the media. You hear many opinions expressed, some contradictory. If this were only a minor issue, you probably wouldn't care. But this is potentially one of the biggest problems society will have to face. It could dramatically alter the world you and your children live in, so it is important to know something about it.

In this first lesson, you will learn about the basic components of the earth's climate system and the complex ways they are interconnected. As you will see, what happens in one place has consequences for the entire globe. But why is it so connected? It's because of the transfer of heat. Heat transfer causes ocean currents to flow, storms to move across the country, and flowers to start growing in Vancouver in February while Winnipeg is still freezing under feet of snow—even though both cities are at similar latitudes.

Planning Your Study

You may find this time grid helpful in planning when and how you will work through this lesson.

Suggested Timing for This Lesson (hours)	
Climate Components	½
Radiation	½
Activity: Albedo and Radiant Energy	1
Conduction	¾
Convection	¾
Key Questions	1

What You Will Learn

After completing this lesson, you will be able to

- use the terminology associated with climate and climate change
- describe the three ways that heat energy is transferred (radiation, conduction, and convection)

Climate System and Climate Change

To understand climate change, you first need to know what climate is and how it works. Then you can begin to tackle the important questions like how much it could change and how to distinguish normal variation from human-caused climate change.

The study of the climate system is really the study of heat transfer. In this first lesson you will learn how heat is moved around the planet from the hot tropics to the cold polar regions.

Climate is the pattern of temperature and precipitation for a region averaged over many years. The localized day-to-day variations in climate are called **weather**. As you know, predicting weather can be very difficult, but predicting climate is easier because it is controlled by big forces over large areas, and so is more consistent. The weather office can't predict what the weather will be like on a specific day next July, but it can predict it will *be* summer.

When you look at the other planets in our solar system, you see worlds that are bitterly cold or hotter than a pizza oven, swirling with poisonous gases. None can sustain life. So what's so special about earth? What regulates our climate so that it stays moderate and consistent?

Climate Components

The three main components interacting to regulate our climate are solar energy, the atmosphere (air), and the hydrosphere (water). Solar energy is ultimately responsible for life on earth. The energy coming from the sun is absorbed by the air, water, and land. It is then converted into heat energy. This keeps the earth warm enough for life to survive. But the earth does not overheat like some planets because of the way that the atmosphere and hydrosphere move that heat energy around the globe and eventually radiate it back out into space.

As long as the main components of the climate system remain intact, the climate is fairly predictable. This allows us to plan where to plant crops, build cities, create industries, manage water flows, and preserve wild ecosystems. But recent human activities have begun to change the components of this system, with dramatic and unforeseen consequences.

Solar Energy

The climate of the earth is ultimately determined by **solar energy**: the amount of energy coming from the sun. The amount of solar energy hitting the earth depends on how strongly the sun is burning and how close the earth is to the sun. Small changes in earth's orbit and periodic changes in the sun's energy output have caused ice ages and warm periods in the past. But the amount of solar energy hitting the earth does not change very quickly, so variation in solar radiation can't account for the rapid changes we are now seeing in our climate.

Atmosphere

The **atmosphere** is the blanket of gas (air) surrounding the earth. It starts at ground level and reaches up about 100 km to the edge of space. The atmosphere is composed of many layers. The layer closest to the earth's surface is called the **troposphere**. It extends upwards to approximately 15 kilometres above the ground and has the greatest effect on our climate system. This lesson will focus on what happens in the troposphere.

The air in our atmosphere is made up mainly of nitrogen (78%), oxygen (21%), and small amounts of other gases (1%) such as argon, carbon dioxide, water vapour, and methane. You can see in Figure 1.1 that the "other gases" make up only a tiny part of the air. Although small in percentage, they play a big role in regulating our climate.

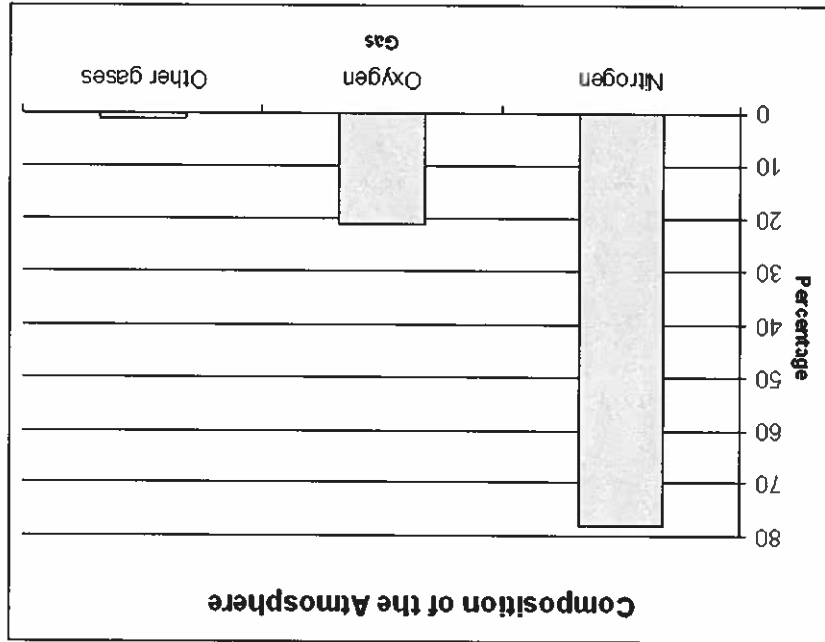


Figure 1.1 Composition of the atmosphere

Hydrosphere

There are fewer particles of air as you go higher up in altitude, though the composition stays relatively the same. The thinness of the air explains why it is so hard to breathe at the top of a mountain and why jet planes can't fly into space. Some of the "other gases" in the atmosphere act as an insulating blanket around the earth, preventing heat energy from radiating out into space. These are called **greenhouse gases** because they act like the glass panels in a greenhouse: they allow sunlight in but block the heat from getting out. You will learn about the greenhouse effect later in this unit.

The main greenhouse gases—such as carbon dioxide, methane, and water vapour—naturally occur in the atmosphere at very low levels. But as you will see in later lessons, small increases in these seemingly insignificant gases can have a large impact on the climate system.

About 70% of the earth's surface is covered by water. The term **hydrosphere** refers to all the water in the earth system, including the water in oceans, lakes, rivers, and groundwater. The hydrosphere also includes water in the form of ice at the poles and in high mountains. Most of earth's water is salty (97.5%). Only 2.5% of the hydrosphere is fresh water. Most of this fresh water is in the form of glaciers and polar ice, leaving only a very small percentage of water available for human use.

Water has a tremendous capacity to absorb heat. You've probably noticed this if you live near a large body of water, like one of the Great Lakes. During summer the water heats up, absorbing heat from the surrounding air and land, so that it feels cooler down by the lake on a hot day. By the time winter comes around, the lake has stored up enough heat to act like a giant hot water bottle, giving off heat to the surrounding air so that it's less cold near the lake.

The oceans are a huge basin of water that can absorb a tremendous amount of heat. The way they absorb heat and move it around the globe in currents plays a big role in determining the earth's climate. You will learn more about this in Lesson 2.

Support Question

Do not send your answers in for evaluation.

- 1. What are the main components that interact to form our climate?**

There are Suggested Answers to Support Questions at the end of this unit.

Transfers of Heat Energy

The earth is warmed up by solar energy. Because the tropical zones are closer to the sun than the poles are, they get more solar energy and so are warmed up more. But just like in a pot of boiling soup, the heat energy entering the earth doesn't just stay in one place. It gets moved around because heat always flows from the warmer areas to cooler areas.

There are three ways to transfer heat: radiation, conduction, and convection. In this lesson, you will examine each of these three methods and its relative importance in regulating our climate.

1. Radiation

Light from the sun takes the form of an **electromagnetic wave**. There are many examples of electromagnetic waves, such as visible light, ultraviolet light, microwaves, radio waves, and X-rays (see Figure 1.2). Not all electromagnetic waves have the same amount of energy, as you can see below. The sun sends us all kinds of electromagnetic waves, but the ones you are most familiar with fall into the range of visible light. You will learn more about the properties of electromagnetic waves in Unit 4.

AM radio waves	TV/FM waves	microwaves	infrared light	visible light	ultraviolet light	X-rays	gamma rays	cosmic rays
		← decreasing		Energy level	increasing →			

Figure 1.2 Electromagnetic waves

Electromagnetic waves bring the energy from the sun to the earth. The process by which electromagnetic waves transfer energy is called **radiation**. Energy that travels by radiation, such as light, is often called **radiant energy**. Radiation does not need to be in any material (or medium, as scientists call it) in order to get from one place to another. As a result, radiation is able to travel through outer space, which is pretty much empty of material. These electromagnetic waves from the sun deposit their radiant energy when they interact with some form of matter, such as the air in the atmosphere, the surface of the earth, or your skin.

Example

If you place your hand near a flame, hot iron, or stove, the radiant energy travels from the hot object to your hand, as shown in the diagram below. The radiant energy then interacts with your hand and is changed into heat (thermal) energy, which your skin can detect.

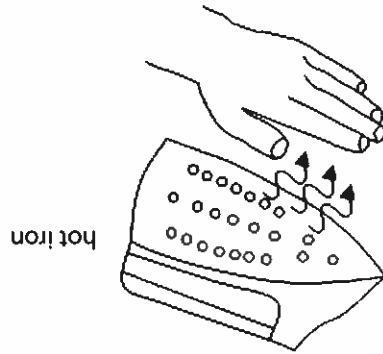


Figure 1.3 Radiant energy flowing from hot iron to a hand

When the radiant energy from the sun reaches the earth, two things happen. Approximately 30% of this energy is reflected back into outer space. The remaining 70% is absorbed by the earth's surface (land and water) and air. Since most of the earth's surface is water, the interaction between radiant energy and water has a major influence on climate.

Support Question

2. Radiant energy does not require a medium. Explain why this is important to life on earth.

Albedo

Not all material reflects the same amount of solar energy. The percentage of energy that is reflected is called the **albedo**. Because white snow and ice reflect almost all of the light, they have a very high albedo. A black asphalt road has a very low albedo because it absorbs almost all of the light energy that hits it. A forest also has a relatively low albedo, as does a farmer's field.

Any material that absorbs radiant energy is called a **heat sink**. Dark surfaces absorb more energy than light-coloured surfaces. That's why a black asphalt road gets so much hotter in the sunshine than the concrete sidewalk right beside it. This even works in winter. You may have noticed that dark trees surrounded by snow gradually develop rings of melting around them when the sun shines. This is because the dark surface of their bark absorbs the sun's energy, converting it to thermal energy. The warmed-up tree trunks radiate this energy as heat and melt the snow around them, forming rings of bare ground.

Different types of surfaces absorb heat differently. For example, sand, soil, and rock are poor heat sinks since they cannot absorb large quantities. This is true even though, having low albedo, they get hot quickly. That's why deserts can get so cold at night, even as low as freezing, despite the fact that they can be blistering hot during the day. As soon as the sun goes down, the desert starts to cool down rapidly, and within a few hours the rocks have lost all their heat. Even though water has a higher albedo than land (since water reflects more than soil), the oceans are good heat sinks. This is because water is able to absorb much more radiant energy than land. In fact, water absorbs five times more energy than soil. As well, radiant energy is able to penetrate much deeper into water than it can on land, which increases the amount of water available to absorb the energy. As a result, large bodies of water can absorb a great deal of energy with little change in temperature.



Activity: Albedo and Radiant Energy

You can experiment with the albedo effect at home using soup cans and sunlight.

Purpose

To determine which colour or material is best at turning radiant energy into heat.

Materials

- 3 large empty cans, rinsed out and with labels attached (e.g., from soup or canned vegetables)
- 1 thermometer, or 3 small clear plastic bags with 2 ice cubes in each
- 1 piece of white paper
- 1 piece of dark-coloured paper. If you don't have dark-coloured paper, use a dark-coloured page from an old magazine, or darken the label on the can with a black marker.
- 3 pieces of foil wrap, enough to cover the tops of each can
- adhesive tape
- scissors
- sunny location where you can leave the cans exposed to direct sunlight for about 30 minutes (e.g., a window ledge inside or a table outside)

Procedure

1. Take one of the cans and wrap the label with a piece of white paper cut to fit the can. Tape the paper in place so that the sides of the can are now white.
2. Take the second can and wrap the label with a piece of dark paper cut to fit the can.
3. Take the third can and tear the label off so that the sides are bare, shiny metal.
4. Add water to each can to a depth of about 2 cm. Make sure each can has the same amount of water.
5. If you do not have a thermometer, place a sealed plastic bag containing two ice cubes in each can.
6. Cover the top of each can with a piece of foil wrap. Your experimental set-up should look like this:

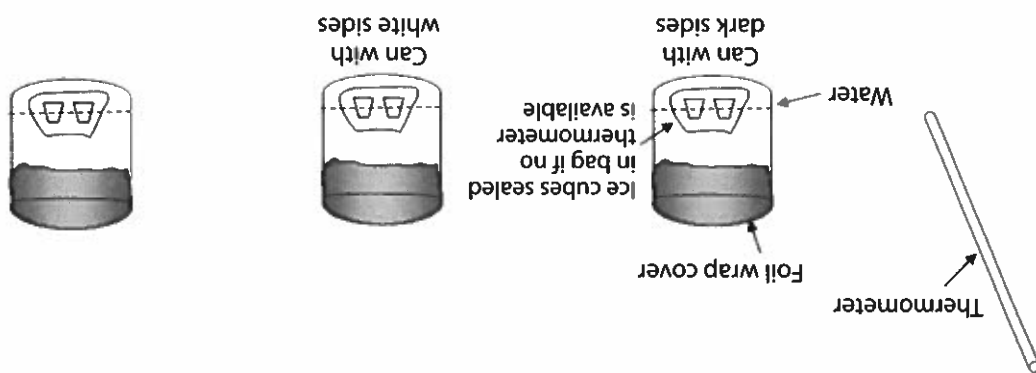
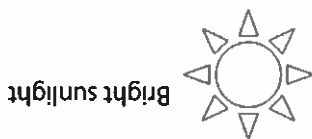


Figure 1.4 Experimental set-up for three cans

7. Place all three cans in the sunny location so that their sides are exposed to the light. Leave them for 30 minutes.
8. While you are waiting, think about what might happen. Which can do you think will get the hottest?
9. After 30 minutes, use the thermometer to record the water temperature inside each can. If you are using the ice-cube method, remove the bags from each can and record which cans produced the most melting.

Observations

Record your observations in a table like this:

Can	Temperature or relative amount of ice melt
White	
Dark	
Bare metal	

Analysis

Complete Support Question 3.

Conclusion

Complete Support Question 4.

Support Questions

- 3. Which can become the warmest? Explain why.
- 4. Was there a difference in temperature between the white can and the bare metal can? Explain your answer.
- 5. If a leaf from a tree landed on fresh snow, over time what would happen to the snow under the leaf?

2. Conduction

Another method of transferring heat is **conduction**: the transfer of heat energy through the collisions of atoms in the substance. For example, a metal rod is made up of billions of vibrating atoms. If one end of a rod is held over a flame, the atoms in the flame become more energetic and vibrate more quickly. They collide with other nearby atoms, causing them to vibrate more quickly. This process continues along the rod from the hotter end towards the colder end. The atoms themselves vibrate in place and do not move along the rod—only the energy travels from one end of the rod to the other.

Example

Consider a metal rod with beads of wax evenly placed along the rod (as shown in the following diagram). When heat is applied to one end of the rod, the beads of wax closest to the flame will melt first as the heat is conducted along the rod.

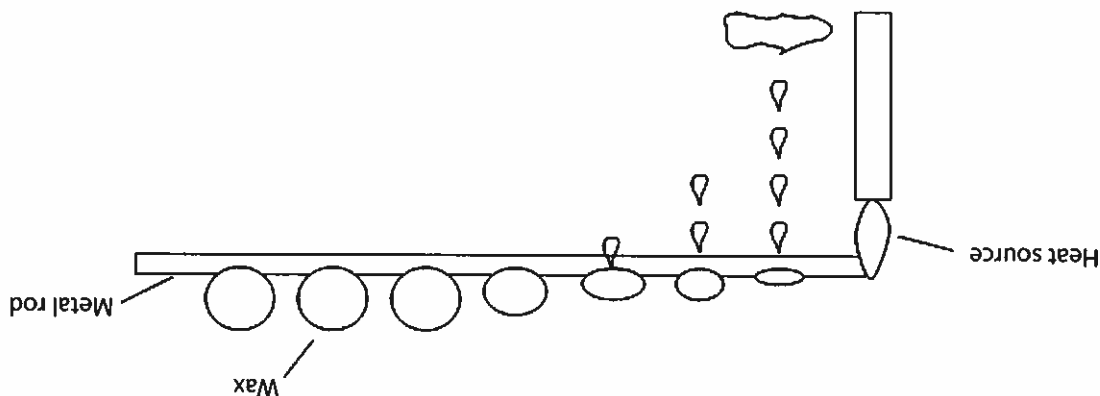
6.

Materials in which heat can travel by conduction are referred to as good conductors. Solids are better conductors than liquids or gases. Why do you think that window manufacturers leave a space between the sheets of glass when constructing double-paned windows?

Support Question

The material in which the energy is transferred is called the **medium**. In this case, the metal rod is the medium. Though radiation does not require a medium, conduction cannot take place without one. You have probably experienced heat from the heated pot to your hand. Pot designers try to reduce this conduction by making the handles out of non-conductive material or by making sure the handle gets a lot of air around it to help it cool faster. When you are walking barefoot on a sandy beach on a warm day, the heat is transferred from the sand to your feet by conduction. As well, the air touching the warm sand is heated by conduction. This also happens to the air in contact with warm water in the oceans and lakes. For conduction to occur, the particles must be in contact with each other. Because of this, conduction is a slow process and is not responsible for most of the heat transfer around the globe.

Figure 1.5 Heat conduction along a metal rod melting beads of wax



3. Convection

A third method of transferring heat is **convection**: the transfer of heat energy in a fluid by the actual movement of the fluid's particles from one place to another. The term "fluid" can refer to either a liquid or a gas. In conduction, the particles vibrate but do not move to another location; in convection, the particles *do* change location.

This movement is brought about by different densities within the fluid. For example, if a pot of water is heated, the water molecules at the bottom of the pot receive heat (thermal) energy by conduction because they are in contact with the hot bottom of the pot. As this water heats up, the distance between the molecules expands and the water at the bottom of the pot becomes less dense. Since the colder water at the top of the pot is now denser than the warm water at the bottom, the colder water sinks and pushes the warm water upwards. This circulating path of moving water is called a convection current.

Example

If you heat up chicken noodle soup in a pot, you can see the pattern of the convection currents as the noodles move up the centre of the pot and go down the sides. The soup is moving away from the hottest region at the bottom of the pot and moving towards the cooler regions near the top and the sides, where it loses a bit of its heat to the surrounding air. Because this portion of the soup is now cooler than the recently heated soup at the bottom of the pot, it sinks and the cycle repeats itself.

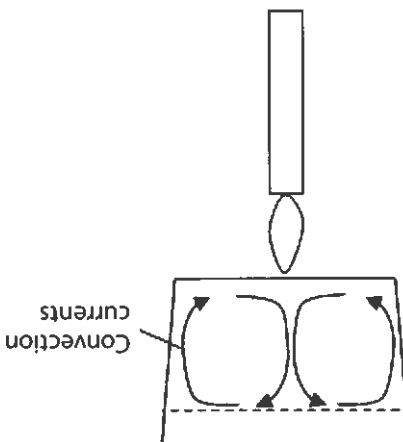


Figure 1.6 Convection currents forming in a pot of soup with heat source in the middle

If the heat is applied to just one side of the pot, the soup moves towards the cool side, resulting in a single convection current as seen in the following diagram.

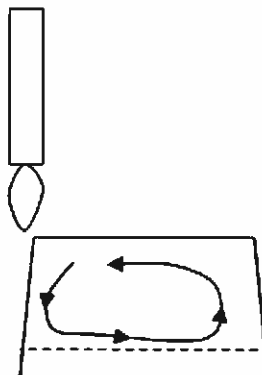


Figure 1.7 One convection current forming in a can of soup with heat source on one side

Global convection currents

Convection currents are also present in our oceans and atmosphere because both are fluids and the earth is not evenly heated by the sun. The area around the equator is warmer than the polar regions because the equator is closer to the sun. Just as in the heated pot of chicken noodle soup, convection currents form both in the oceans and atmosphere. These currents transfer heat away from the equator and move it towards the colder poles.

Ocean currents carry warm water from the equator to the north and south polar regions. One current, called the Gulf Stream, carries warm water from the Caribbean north along the east coast of North America and then curves northeast towards England. Because of the Gulf Stream current, palm trees can grow in southern England even though the latitude there is the same as in Winnipeg. You will look at the forces driving global and local convection currents in more detail in the next lesson.

Local convection currents

Wind is the movement of air in the atmosphere as a result of convection currents. Some winds are local, occurring only in a relatively small region. Land or water breezes are an example of a local wind that can form on a warm day near a body of water such as a lake.

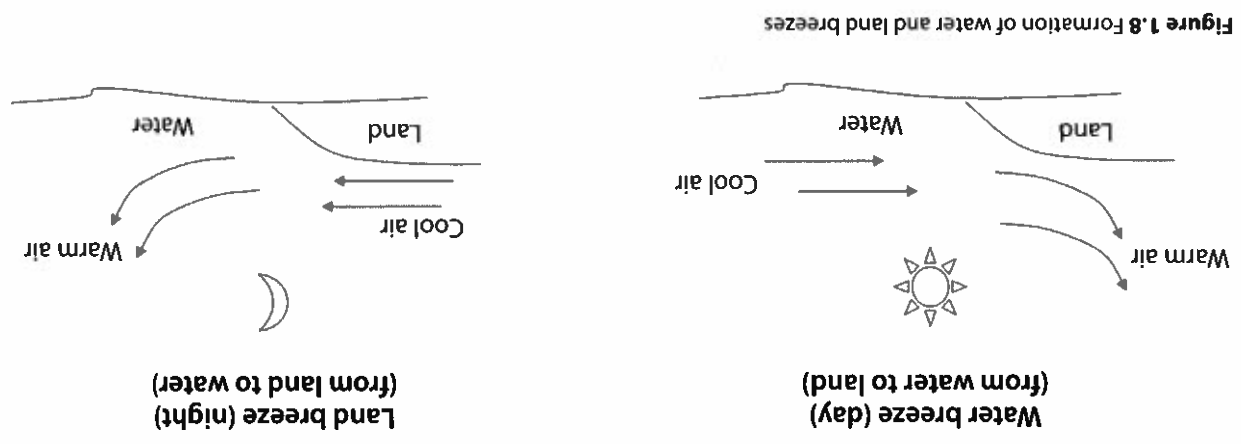


Figure 1.8 Formation of water and land breezes

A water breeze occurs during the day when the solar energy warms up the land and so can absorb a lot of energy without getting hot. As a result, the air above the land becomes warmer than the air above the water. This warm air rises faster over the land, which causes the colder, denser air off the lake to flow towards the land. The direction of the wind reverses in the evening when a land breeze forms. As the sun sets, the land cools faster than the water, again because water is a better heat sink. Now the air above the water is warmer than the air above the land, and a convection current forms going from the land towards the water.

There is usually a short period of calm between a water breeze and a land breeze while the wind switches direction. This usually happens just before sunset, and is a great time to go for a quiet walk on the beach.

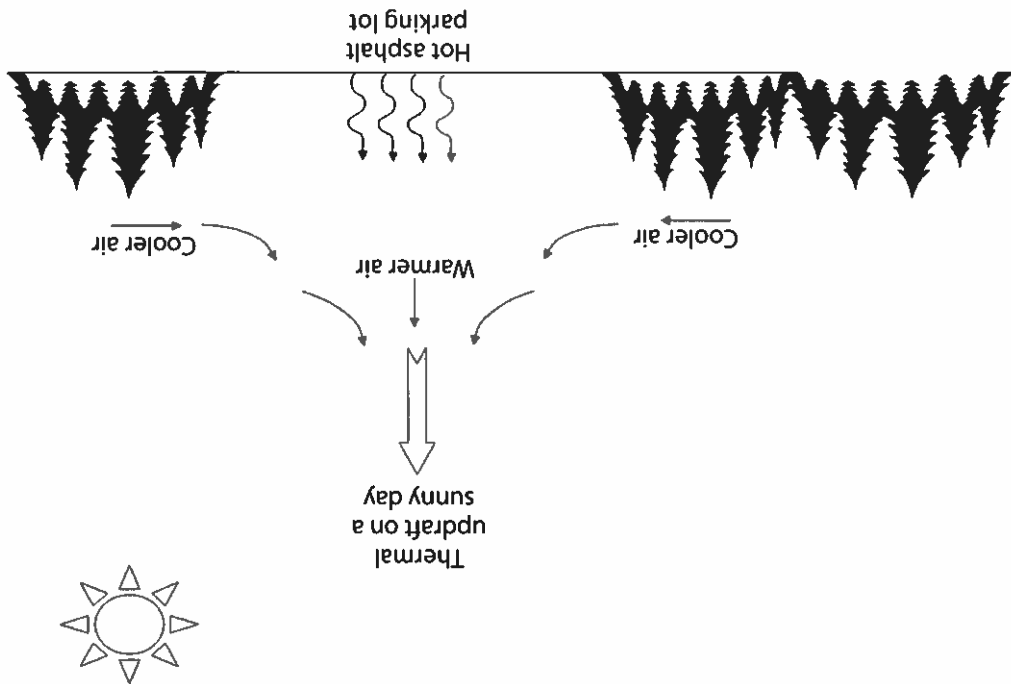
Another example of a local convection current that occurs during the day is called a **thermal or thermal updraft**. On a sunny day, over land areas, some parts get hotter than others because they have a lower albedo. For example, dark rocky areas, urban developments, and parking lots heat up more quickly than the surrounding forests and fields. The air over these patches gets hotter by conduction from the hot surface. This warm air rises rapidly, forming funnels of air shooting upwards called thermals (see Figure 1.9).

Support Question

7. Using an example, explain how convection currents are formed.

These updrafts are often strong enough to allow large birds like vultures and hawks to soar upwards in circles for hours. They use the thermals like elevators; they save energy by gaining altitude without having to flap their wings. Glider pilots also hunt for thermals to gain altitude.

Figure 1.9 Thermal updraft forming over a hot asphalt parking lot on a sunny day



Conclusion

In Lesson 1 of this unit on climate change, you have seen that life on earth exists because of a carefully regulated climate. You have been introduced to the three main components regulating climate: solar energy, the atmosphere, and the hydrosphere. You have also learned how heat can be transferred across the globe in three ways, with convection being the most important for climate regulation. In the next lesson you will study these processes in more depth. Once you understand what drives our climate system, you will see more clearly how human activities change the system.

Key Concepts

Climate: weather conditions in an area that are averaged over many years

Weather: the day-to-day pattern of temperature and precipitation in your local area

Solar energy: electromagnetic energy that comes from the sun

Atmosphere: a blanket of air (mainly nitrogen and oxygen) and moisture that surrounds the earth

Troposphere: the layer closest to the earth's surface, extending upwards to approximately 15 kilometres above the ground

Greenhouse gases: gases like carbon dioxide, methane, and water vapour that exist in low concentrations in the atmosphere; these gases allow sunlight in but block outgoing heat

Hydrosphere: all the water in the earth system, including the water in oceans, lakes, rivers, and groundwater

Electromagnetic waves: a group of waves that can travel through empty space and do not need a medium. Light is an example.

Radiation: the transfer of energy by electromagnetic waves (which do not need a medium)

Radiant energy: energy that travels by radiation, such as light

Albedo: the extent to which a given object reflects light from the sun

Heat sink: any material that absorbs radiant energy

Conduction: the transfer of heat energy, generally in solids, through the collision of atoms in the substance

Medium: the material through which energy flows

Now go on to Lesson 2. Remember, you do not send your journal to the Independent Learning Centre until you have completed Unit 1 (Lessons 1 to 5).

Column A	Column B
i) heat transfer through a vacuum	a) conduction
ii) heat transfer in a gas or liquid	b) brown
iii) heat transfer in a metal rod	c) yellow
iv) colour that absorbs a large amount of light	d) radiation
v) colour that reflects a large amount of light	e) convection

1. With reference to albedo, explain why wearing light-coloured clothing in summer can make you feel more comfortable when sitting outside in the sunshine. (2 marks)
2. Heat is transferred by convection in the air and in the water, and by conduction in the ground. Explain why conduction is not very effective for transferring heat in air. (2 marks)
3. Explain why putting heating vents near the floor in a room, rather than near the ceiling, helps convection currents distribute the heat. (3 marks)
4. Match each item in column A with the corresponding item in column B. (5 marks, 1 mark for each correct pairing)

Total: 12 marks

Save your answers to the Key Questions in your Course Journal or e-Journal.

Key Questions

Convection: the transfer of heat energy in a fluid (gas or liquid) by the actual movement of the particles in the fluid from one place to another

Thermal (or thermal updraft): a rising current of warm air created by solar energy heating the ground

- explain the influence of global prevailing winds and ocean currents
 - describe the main components of the earth's climate system
 - recognize and classify climates of ecozones in Canada
- After completing this lesson, you will be able to

What You Will Learn

Suggested Timing for This Lesson (hours)	
Prevailing Winds	1½
Ocean Currents and Nearby Water	¾
Elevation and Landscape Features	¾
Ecozones	¾
Key Questions	1

You may find this time grid helpful in planning when and how you will work through this lesson.

Planning Your Study

In this lesson, you will continue exploring the main mechanisms that create the earth's climate system. You will look more closely at the four main factors controlling heat transfer and climate regulation on earth: wind currents, ocean currents, landscape features, and terrestrial ecozones.

The earth's climate is a very complex system. These four factors interact with each other and with many local processes. You will learn how the main factors determine the kind of plant and animal communities that can exist in an area. You will also see how the kind of plants and animals in an area can in turn affect climate.

Introduction

Factors Controlling the Earth's Climate System

In the last lesson you saw that sunlight and latitude determine the amount of heat reaching the earth, and that large convection currents in the atmosphere move warm tropical air towards the poles. So why can wine grapes grow in Kelowna, British Columbia, but not in Kenora, Ontario, even though they share the same latitude? Each receives warm air coming up from the south through convection currents. Yet Kelowna has relatively warm winters with little snow, while Kenora gets too cold and snowy for grape plants.

The answer lies in the interaction of the four main factors affecting regional climate:

- prevailing winds
- ocean currents (and nearby water)
- elevation and landscape features
- the plant and animal life dominant in the area (called terrestrial "ecozones")

After exploring how each of these factors regulates regional climates, you will understand why Kelowna can grow wine grapes and why so many people want to retire there.

Prevailing Winds

Some winds are local and occur in a relatively small area, like the land and water breezes you learned about in the previous lesson. In contrast, **prevailing winds** blow predominantly from a single direction, affect large regions of the earth, and influence the global climate. The prevailing winds are responsible for the large-scale movement of atmospheric heat away from the equator. The pattern of prevailing winds is caused by two forces. The first is the convection currents created in the atmosphere by the heating force of the sun at the equator. This causes the air to move north or south over different parts of the globe. The second force, called the Coriolis Effect, is caused by the rotation of the earth and is responsible for moving the air east and west. Together these two forces act to create the prevailing wind where you live.

Atmospheric Convection Currents

Solar energy strikes most directly around the equator region, heating the air and the land. As with the convection currents you learned about in the last lesson, the warm air rises and moves away from the heat source towards the cooler zones. In the northern hemisphere, the convection current moves the warm air northward; in the southern hemisphere, it moves it south towards the South Pole.

The rising warm air does not make it to the poles in one step. Around 30° latitude, the air becomes colder and denser. It sinks back towards the earth and then flows back towards the equator. This creates a circular flow of air in the atmosphere called a **convection cell**. Figure 2.1 shows the six main convection cells that make up our atmosphere (three in the northern hemisphere and three in the southern). Ontario lies in the region between 30° N and 60° N.

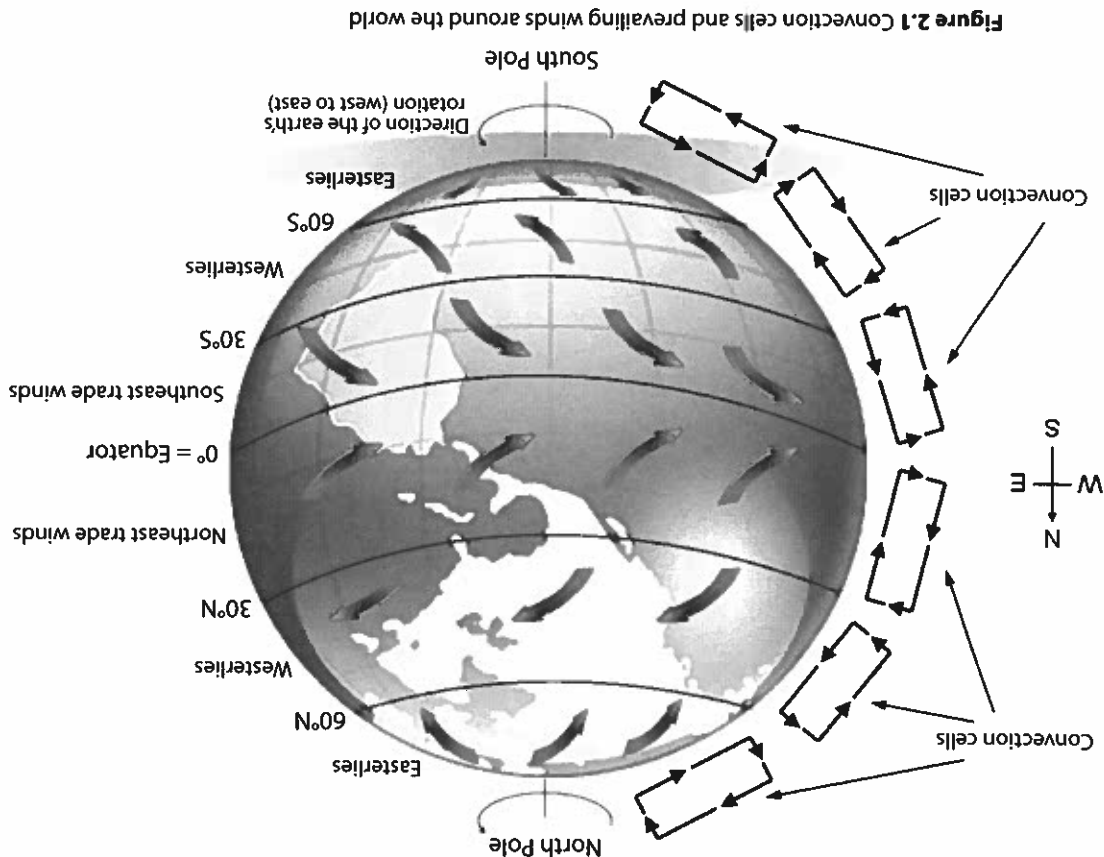


Figure 2.1 Convection cells and prevailing winds around the world

The pattern of movement in the convection cells is the same in the northern and southern hemispheres, so only the northern hemisphere cells will be described here. As the air at 30° N sinks and flows back towards the equator, it pulls down cooler air from the north. This cool northern air is heated up by contact with the warmer equatorial air, causing another convection cell to form between 30° N and 60° N latitude. This pattern is repeated with another cell that cycles air between 60° N and the North Pole.

Together, the three main convection cells in each hemisphere move heat away from the equator towards the poles.

Coriolis Effect

The earth's rotation from west to east affects the convection currents in both the atmosphere and hydrosphere. This influence of the earth's rotation on convection currents or any object moving in a rotating system is called the **Coriolis Effect**. In the northern hemisphere, the Coriolis Effect deflects objects to their right in relation to their forward motion. In the southern hemisphere, the Coriolis Effect deflects objects to their left in relation to their forward motion.

You can see the Coriolis Effect by rolling a ball on a rotating turntable or "Lazy Susan." When the turntable is not turning, the marble will travel straight across it (Figure 2.2A). However, when the turntable is rotating, the path of the marble appears to veer as it moves forward (Figure 2.2B).

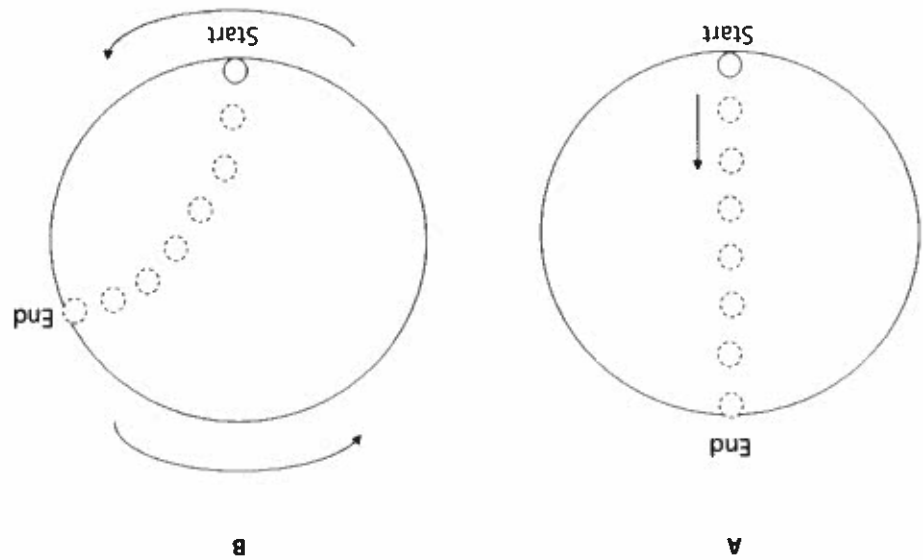


Figure 2.2 Trajectory of a marble rolled straight along a (A) stationary or (B) spinning turntable

Predicting Prevailing-Wind Patterns

Another way to think about how the Coriolis Effect creates prevailing-wind patterns is to look at the speed of the air relative to the land it passes over. Because the earth is round, a point at the equator is farther away from the axis of rotation than is a point near one of the poles. This means that a point at the equator moves faster than a point at higher latitude as the earth spins on its axis. Both points make one full rotation over 24 hours, but the point at the equator has to travel a longer distance, so it moves faster than the point at higher latitude.

Since the earth is always spinning towards the east, the air over the equator also moves east, and at the same rate as the land below it. But as the air moves away from the equator, the land beneath it is spinning east more slowly, while the air is still moving east at its original speed. North of the equator, any air flowing northwards is moving eastward faster than the land beneath it, so you feel a west wind.

The reverse is true if the wind is flowing towards the equator: the wind is moving eastward more slowly than the ground beneath it, so it is moving towards the west relative to the ground. This means you feel an east wind in those latitudes.

To predict what the prevailing winds will be at any point on earth, remember these two simple rules:

1. If the air is flowing away from the equator, it is moving eastward faster than the ground it passes over, so you feel a west wind.
2. If the air is flowing towards the equator, it is moving eastward slower than the ground it passes over, so you feel an east wind.

To find out whether the air is flowing towards the equator or not, look at the rotating cells in the global convection diagram on page 3. If the airflow in the bottom of the cell closest to the ground is flowing away from the equator, a west wind is produced.

For example, you can see from the airflow rotation in the cell between 30°S and 60°S that the air close to the ground is moving away from the equator. The resulting prevailing winds are from the west. But in the subtropical zone between 0° and 30°S, the air close to the ground is flowing towards the equator, so the prevailing winds are from the east.

Main Types of Prevailing Winds

Look again at the diagram of the global convection currents. It shows the main types of prevailing winds around the globe. The curved grey arrows indicate the direction of the prevailing winds on the ground created by the rotation of the convection cells. The winds are named for the direction the wind is coming from; for example, the westerlies blow from the west towards the east.

The winds around the equator blow in from the east. They are referred to as the **trade winds** because the early European sailing ships used them to get to their trading centres in the Caribbean. The **westerlies** exist in the mid-latitudes, between 30° and 60°. These are the prevailing winds that affect most Canadians. There is also a polar convection current (**easterlies**) above 60°N latitude that brings cold air towards the south. The meeting of two convection cells at about 60°N latitude is one reason why the Arctic boundary is usually considered to start there.

Example

Have you ever wondered why the weather fronts usually come in from the southwest in Ontario? It's due to a combination of the convection currents and the rotation of the earth. As you can see in Figure 2.1, the prevailing winds heading towards the Great Lakes tend to be from the southwest—the convection cell over Ontario draws warm air up from the south while the rotation of the earth under the flowing air creates the west wind.

In winter, you can deduce the prevailing wind pattern from the major highways that run north and south in Ontario, such as Highway 400. To prevent snow from drifting onto the highway, road crews put up snow fences on only the west side of the highway because generally that's where the wind comes from.

However, just because we call a wind “prevailing” doesn't mean that it never changes direction. It is not uncommon for the wind to come from another direction due to changes in the atmosphere. Also, the pattern of the prevailing winds in Figure 2.1 is simplified since other factors, such as the shape of the continents and changing seasons, can alter the pattern to some extent.

Jet Stream

Approximately 10 kilometres above the earth's surface are ribbons of extremely fast air moving from west to east known as the **jet streams**. They are caused by contact between cold and warm air at the convection current boundaries. The strongest jet streams occur where the cold polar air meets warmer air at about 60° latitude. There is one in the north and one in the south.

The polar jet stream that affects Canada's weather shifts further south in the winter and moves north in the summer. The wind speeds in the jet stream vary from 100 km/h to 300 km/h. Sometimes jet streams will even split into two separate streams. Their location changes with the seasons, and they continually curve and meander. Weather forecasters use the position of the jet stream to help them forecast local weather patterns.

Aircraft that fly high in the atmosphere may encounter the jet stream. In North America, planes flying west are going against the jet stream, which reduces their air speed. Planes flying east are going in the same direction as the jet stream, which increases their air speed. To some extent the prevailing westerly winds at lower altitudes can have a similar effect on the air speed of planes flying below the jet stream. Many airlines save fuel by planning their routes to take advantage of the jet stream.

Support Questions

8.

Do not send your answers in for evaluation.

The table on the next page lists the hourly wind direction over three days in the city of Barrie, Ontario, in January of 2005. Using the table, indicate the total number of times that the wind comes from the following directions: west (W), northwest (NW) and southwest (SW). Add these three totals together. Since there are 72 observations in the table, what percentage of the observations show the wind coming from a direction with the word "west" in it? Why do you think this is the case?

Wind direction for the City of Barrie, Ontario, recorded over 72 hours during January 2005

Date	Hour	Wind Direction	Date	Hour	Wind Direction	Date	Hour	Wind Direction
Jan 1	0:00	E	Jan 2	0:00	W	Jan 3	0:00	NW
Jan 1	1:00	E	Jan 2	1:00	SW	Jan 3	1:00	NW
Jan 1	2:00	SE	Jan 2	2:00	W	Jan 3	2:00	NW
Jan 1	3:00	E	Jan 2	3:00	NW	Jan 3	3:00	NW
Jan 1	4:00	E	Jan 2	4:00	NW	Jan 3	4:00	NW
Jan 1	5:00	E	Jan 2	5:00	NW	Jan 3	5:00	W
Jan 1	6:00	E	Jan 2	6:00	W	Jan 3	6:00	W
Jan 1	7:00	SE	Jan 2	7:00	NW	Jan 3	7:00	W
Jan 1	8:00	SE	Jan 2	8:00	W	Jan 3	8:00	W
Jan 1	9:00	SE	Jan 2	9:00	SW	Jan 3	9:00	SW
Jan 1	10:00	SE	Jan 2	10:00	W	Jan 3	10:00	W
Jan 1	11:00	S	Jan 2	11:00	NW	Jan 3	11:00	W
Jan 1	12:00	S	Jan 2	12:00	NW	Jan 3	12:00	NW
Jan 1	13:00	SW	Jan 2	13:00	NW	Jan 3	13:00	W
Jan 1	14:00	SW	Jan 2	14:00	W	Jan 3	14:00	W
Jan 1	15:00	SW	Jan 2	15:00	NW	Jan 3	15:00	SW
Jan 1	16:00	SW	Jan 2	16:00	NW	Jan 3	16:00	W
Jan 1	17:00	SW	Jan 2	17:00	NW	Jan 3	17:00	W
Jan 1	18:00	SE	Jan 2	18:00	NW	Jan 3	18:00	NW
Jan 1	19:00	W	Jan 2	19:00	N	Jan 3	19:00	NW
Jan 1	20:00	NW	Jan 2	20:00	NE	Jan 3	20:00	NW
Jan 1	21:00	W	Jan 2	21:00	SE	Jan 3	21:00	SW
Jan 1	22:00	W	Jan 2	22:00	N	Jan 3	22:00	W
Jan 1	23:00	W	Jan 2	23:00	NW	Jan 3	23:00	NW

9. What effect can the prevailing winds and the jet stream have on planes flying west? On planes flying east?

There are Suggested Answers to Support Questions at the end of this unit.

Ocean Currents and Nearby Water

Ocean currents also affect our climate. The prevailing winds create ocean currents, which are also influenced by such factors as the earth's rotation, the density of the water, and the shape of the continents.

Here is a map showing the main ocean currents on earth.

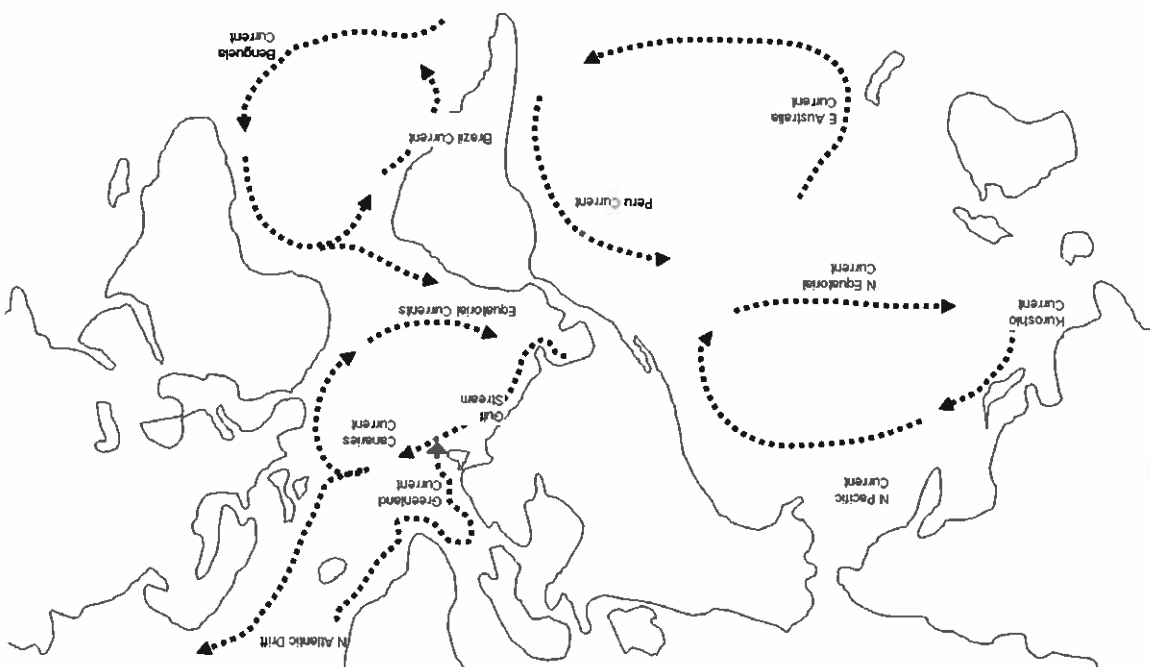


Figure 2.3 Main ocean currents in the world

Just like air currents, warm water tends to travel from the equator towards the poles, and cold water tends to travel in the opposite direction. For example, the Gulf Stream carries warm water from the Gulf of Mexico to the north Atlantic. This has a significant effect on temperatures and rainfall in England and northern Europe. The climate in this area of the world would be much colder without the Gulf Stream's warming effect.

Note that the Coriolis Effect influences the ocean currents in the same way that it influences the prevailing winds. Ocean currents turn to the right in the northern hemisphere and to the left in the southern hemisphere.

Oceans as Heat Sinks

The places where two main ocean currents meet often have an abundance of marine life. The meeting of two currents usually creates a convection current that brings water up from the bottom of the ocean to the surface. This bottom water is rich in nutrients. When this water reaches the sunny, warm surface, it creates ideal conditions for the growth of the tiny marine plants that are the basis for the marine food chain. Because food is abundant, many species gather to feed, producing very good fishing areas. The Grand Banks off Newfoundland are a prime example of this. Here the cold waters of the Greenland current meet the warm waters of the Gulf Stream, creating one of the richest fishing zones in the world.

As you can see, changes in the direction or intensity of the ocean currents can have important consequences for the climates of most coastal regions and have huge impacts on the world's fisheries.

The oceans and large lakes act as huge heat sinks. As the water absorbs solar energy, it takes a long time for the water to both heat up and cool down. This has a moderating effect on the climate near the coast of an ocean or large lake. Since the water is cooler than the land in the summer, the air above the water helps to cool the land. During the winter, the water is warmer than the land, and helps warm the land. Also, cities near oceans and lakes often experience more precipitation. Heat absorption by the ocean has helped to moderate the impacts of global climate change so far. However, it is hard to determine how much heat the oceans can continue to absorb. This makes predicting the speed of climate change difficult.

Support Question

10. The city of St. John's is on the east coast of Newfoundland. Its latitude is approximately 250 kilometres north of that of Ottawa, Ontario. However, St. John's is warmer in the winter than Ottawa. Explain why this is the case.

Elevation and Landscape Features

Though the prevailing winds and ocean currents play a big role in the global climate, other factors also affect climate. For example, a region's climate can be influenced by the solar radiation it receives, its elevation, and the presence of mountain ranges.

The amount of solar radiation reaching earth's surface varies from season to season and, of course, with latitude. In the northern hemisphere, the sunlight is less intense during winter, and temperatures become cooler as you travel further north. For example, the winter temperatures in Toronto (at approximately 43°N latitude) are generally much warmer than those in Whitehorse in the Yukon (at approximately 60°N latitude).

Air temperature also becomes colder as you climb to a higher elevation. As you learned in the last lesson, at higher elevations there are fewer air particles to absorb the radiant energy. As a result, the temperature drops approximately 6°C for every kilometre that you go up. This is why tall mountains have snow on their peaks. Cities at a high elevation tend to have cooler climates than the lower areas around them. For example, if the temperature near the ground is 20°C, then the temperature two kilometres up would be 8°C.

When air masses meet a mountain range, the air is forced up in order to get over it. As the air rises, it expands due to the lower air pressure and becomes colder. Cold air cannot hold as much moisture as warm air. The cooling air reaches a point where it can no longer hold the moisture, which is released as rain or snow.

As a result, the side of the mountain where the air rises (called the windward side) tends to be wet. Once the air mass passes over the mountain range and starts to fall back down, the air becomes warmer. It can now hold more moisture, which it gets from the surrounding area. As a result, the climate on this side of the mountain (called the leeward side) tends to be drier than the other side. The increased rain on the windward side of a mountain, along with the decreased rain on the leeward side, is called the "mountain effect."

Example

An example of the mountain effect occurs in Canada's western provinces, as shown in Figure 2.4 below.

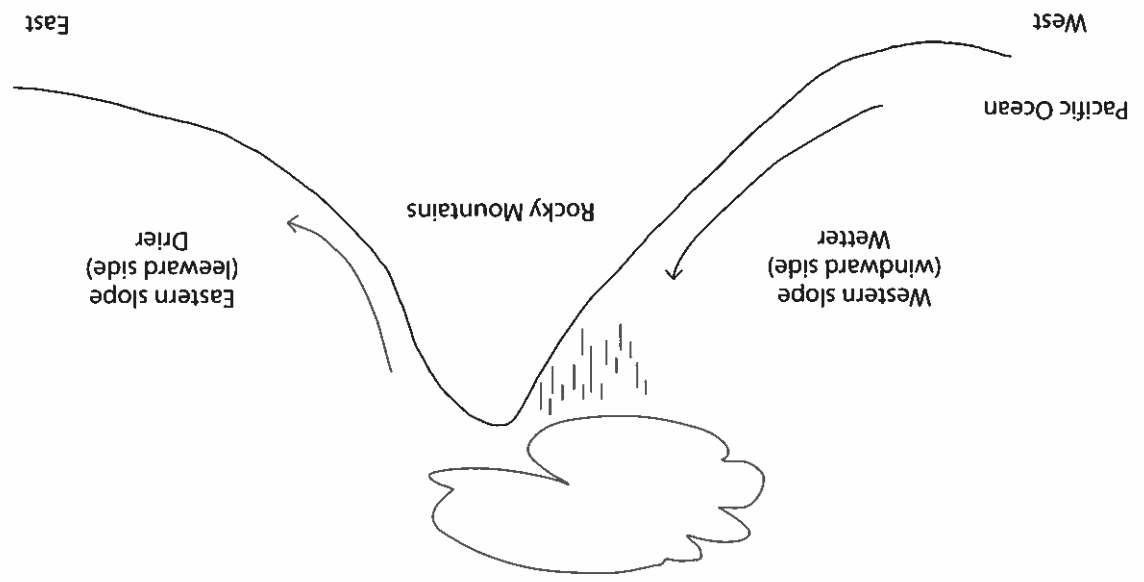


Figure 2.4 Formation of rain clouds on the windward side of the Rocky Mountains

Warm Pacific air flows east until it hits the Rocky Mountains, where it begins to rise. As it rises, it cools and loses moisture as rain and snow, making the west coast wetter than average. The air continues to move east over the mountains until it begins to fall on the eastern side of the mountain range in Alberta. There it warms up and absorbs moisture, making the eastern side drier. Sometimes during the winter this produces especially warm, dry winds called the "Chinooks" that flow into southern Alberta.

Support Question

11. Cold air cannot contain as much water vapour as warm air. Explain why there are areas of low rainfall east of the Rocky Mountain range, while at the same time there are large amounts of rainfall on the western slopes of the mountains.

Ecozones

Climate naturally affects the type of vegetation that will grow in a region—that's why you can't grow tropical plants in your backyard in Ontario. However, vegetation can also affect the climate by influencing how much radiant energy the earth's surface absorbs and how quickly the surface heats or cools. Vegetation also releases a tremendous amount of water vapour into the atmosphere, which plays a role in our climate.

The community of plants and animals found together is broadly categorized into ecological zones or "ecozones." An **ecozone** is a large natural area on the earth's surface having roughly the same land features, plants, and animals throughout. There are 15 terrestrial (land) ecozones and 5 aquatic (water) ecozones in Canada. These ecozones vary in size. Explore Canada's ecozones using the online interactive colour map available through the course web page.

Go to your course page on the ILC website and click on "Canada's Ecozones" under Lesson 2.

The Mixedwood Plains ecozone, lying along the southern part of Ontario and Quebec, is one of the smallest ecozones. However, approximately half of Canada's population lives in this ecozone, which contains two of Canada's largest cities, Toronto and Montreal. One of this ecozone's features is its mixture of deciduous trees (no leaves in winter) and evergreen trees (leaves in winter). Ecozones can be subdivided into smaller areas called ecoregions, which have more closely related features.

The Boreal Shield is Canada's largest ecozone. It includes parts of Newfoundland and extends across to northern Alberta. This ecozone generally has poor growing conditions, and its trees are stunted. Spruce trees are common in the northern part of this ecozone, while deciduous trees such as birch and maple can be found in the southern part.

The Southern Arctic ecozone is located in northern Canada. Because snow is often blown around in this windy area, there is an impression that this area receives a lot of precipitation; in fact, it receives very little. This ecozone contains the world's largest concentration of free-roaming large mammal, the caribou, which are now threatened by climate change and resource development.

Support Question

- For the following question, start your online search using keywords such as "ecozone & Canada." Useful websites include the Canadian Council on Ecological Areas, the Canadian Biodiversity website, and Environment Canada.
- 12. a)** Use the Internet to find the yearly average precipitation in the Southern Arctic and Mixedwood Plains ecozones, and compare the two results. Give your results in millimetres (mm).

- b)** Use the Internet to find the average temperature in the Mixedwood Plains during the winter, and the average temperature during the summer. Also, name four types of trees commonly seen in this ecozone.

Ecozones and Climate

Changes in the biological community can affect climate in many complex ways. For example, trees act like water pumps, using their roots to draw water up from deep in the ground and then releasing it as a water vapour through the pores in their leaves. So much water is pumped into the air this way that it can cause rain over wide areas. This is what happens in the Amazon rainforest. When large areas of forest are burned or cut down, this water pumping stops. The air gets drier, affecting everything from the soil to the large animals. It can even get so dry that it is hard for the trees to re-grow. In extreme cases, the climate over a wide area can change from being consistently warm and moist to extremely hot and dry. When this happens, crops fail, wells and rivers run dry, the soil blows away, and local economies can collapse (see Figure 2.5).



Figure 2.5 Soil cracks appearing during a severe drought

Source: iStockphoto.com

With changes in the vegetation cover come changes in the amount of solar radiation absorbed or reflected by the ground. As you saw in Lesson 1, bare rock and soil absorb more solar radiation, making the surface much hotter and drier. This can lead to faster melting of snow and ice, as well as changes in soil decomposition rates. In consequence, even more CO_2 and methane are released into the atmosphere. (You'll learn more about these gases in Lesson 3.)

Interactions

The climate in any area depends on the amount of solar radiation it receives, along with the pattern of prevailing winds and ocean currents bringing warm or cool air to it. It also depends on local geography and the type of ecozone present. All these factors combine in complex ways so that sometimes very small changes cause major shifts. This makes predicting climate responses very difficult. It also means that areas with similar latitudes can have dramatically different climates.

Can you figure out why there is a successful wine industry around Kelowna, B.C., but not near Kenora, Ontario, even though they share the same latitude?

Kelowna lies on the eastern side of the Rocky Mountain range, and receives warm, dry air. This gives it lots of sunshine during the growing season. As well, the prevailing winds deliver warm Pacific air to the region; the moderate winters and hot summers are ideal for growing wine grapes. This is also a desirable climate for people who like to avoid the extreme conditions of winter, thus Kelowna is a rapidly growing retirement community.

Meanwhile, Kenora receives air from the middle of the continent where there is no large body of water to moderate the temperatures. Summers may be hot, but winters tend to be very cold—too cold for grape plants to survive.

Conclusion

In the last two lessons, you have learned how the earth's climate system works. You have seen how solar radiation provides the heat necessary for all life and how the prevailing winds and ocean currents move that heat around the globe. Local climates are also determined by landforms, like mountains and large lakes, as well as through interactions with ecozones. In the next lesson you will apply your knowledge of climate regulation to see how the earth's climate system can be affected by changes in the heat transfer system—changes humans are bringing about through their use of fossil fuels.

Key Concepts

Prevailing winds: winds, such as the westerlies and trade winds, that blow predominantly from one direction and affect a large area

Convection cell: a circular flow of air in the atmosphere

Coriolis Effect: tendency for objects on a rotating surface to curve away from a straight line; causes air and ocean currents on earth to turn to the right in the northern hemisphere because of the earth's rotation

Trade winds: prevailing winds around the equator that blow in from the east

Westerlies: prevailing winds, blowing from west to east, that exist in the mid-latitudes (30°–60°)

Easterlies: polar convection current, blowing from east to west, that exists above 60°N latitude

Jet stream: a band of high-speed winds approximately 10 kilometres above the earth's surface

Ecozone: an ecological zone or ecozone is a large area that has roughly the same land features, climate, plants, and animals throughout

Key Questions

Save your answers to the Key Questions in your
Course Journal or e-Journal.

Total: 17 marks

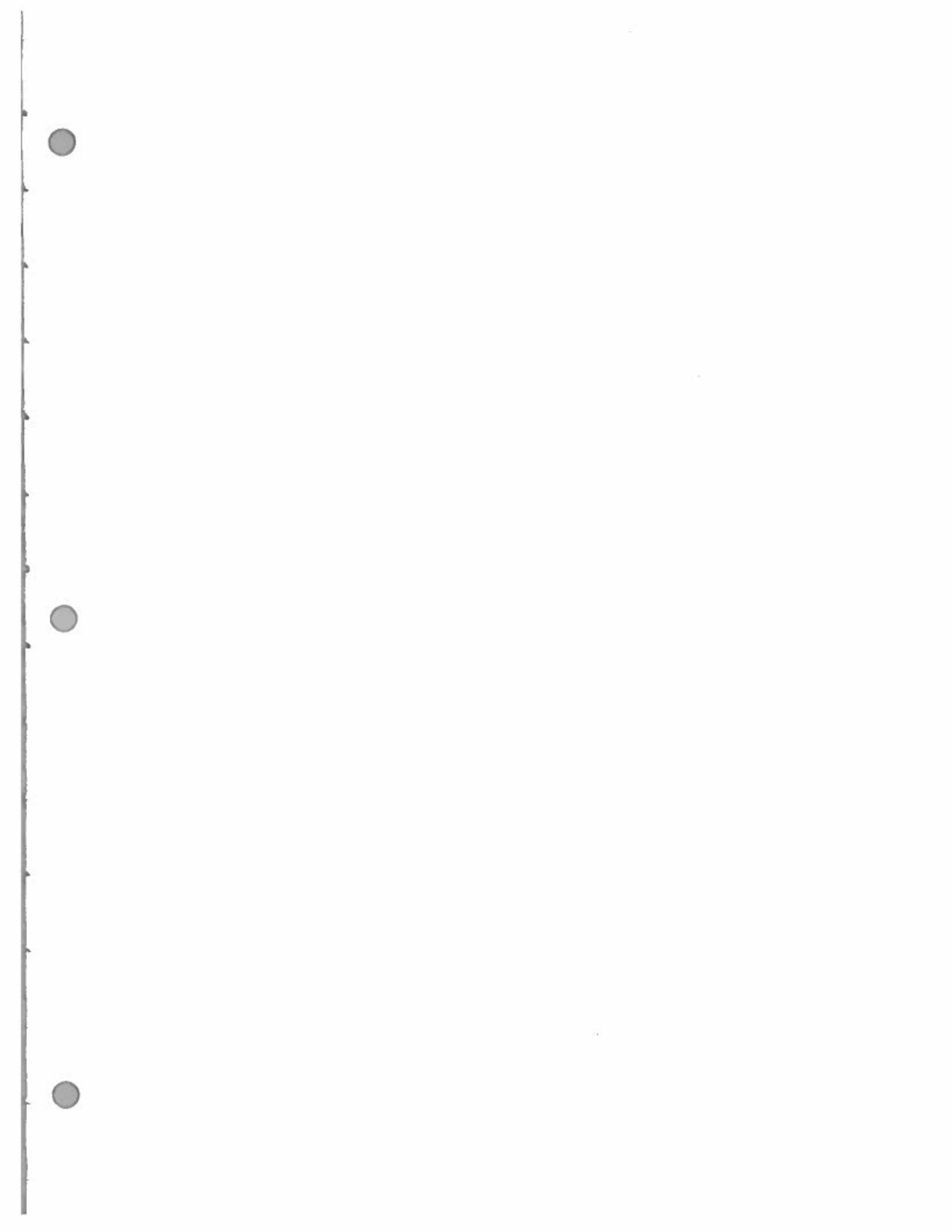
5. On a typical day in September, a flight from Halifax to Ottawa takes 1 hour and 13 minutes, while a return flight from Ottawa to Halifax takes 1 hour and 30 minutes. Based on your knowledge of the prevailing winds and the jet stream, explain the differing time required for the two trips. (4 marks)
6. Describe how mountain ranges can affect an area's climate. (4 marks)
7. Sara grew up in Timmins, Ontario, around 550 km north of Toronto. Last year she moved to St. John's, Newfoundland, on the Atlantic coast. Since both cities are close to the 48°N latitude, Sara expected the climate to be about the same as in Timmins. She was surprised to find that the average winter temperatures in St. John's were much warmer than in Timmins. However, this was not the case throughout the entire year. In the summer the average temperatures in St. John's were colder than Timmins. Explain why St. John's and Timmins have different climates. (5 marks)
8. Compare the amount of rainfall and snowfall in the Mixedwood Plains ecozone to that in the Southern Arctic ecozone. Explain why the pattern of snowfall in the Southern Arctic ecozone may seem misleading. (4 marks)

Now go on to Lesson 3. Remember, you do not send your journal to the Independent Learning Centre until you have completed Unit 1 (Lessons 1 to 5).



SNC2D-B

The Greenhouse Effect



- describe the greenhouse effect
 - explain how the greenhouse effect works to trap heat
 - recognize the main gases involved in the greenhouse effect
 - relate changes in carbon dioxide concentration to changes in global temperatures
- After completing this lesson, you will be able to

What You Will Learn

Suggested Timing for This Lesson (hours)	
The Greenhouse Effect	¾
How Heat is Trapped	½
Gases Involved in the Greenhouse Effect	¾
Optional Activity: Greenhouse Effect	1
Changes in Carbon Dioxide Levels	½
Key Questions	1

You may find this time grid helpful in planning when and how you will work through this lesson.

Planning Your Study

You have seen how the earth's climate is controlled by a balance between energy inputs from the sun and heat loss back into space. This balance is threatened by recent human activity, leading to what many people are calling the "greenhouse effect."

The greenhouse effect is a controversial topic that is often in the news. In this lesson you will learn what the greenhouse effect is and how it relates to climate change.

This is an issue not just for scientists, but for all of society. The greenhouse effect has an impact on the way you drive, the jobs you have, and the cost of your food. We all need to know the basic science behind this issue so that we can make environmentally wise choices.

Introduction

The Greenhouse Effect

The term **greenhouse effect** comes from the greenhouses used for gardening. Greenhouses are usually made of glass or plastic, which allows the sunlight to pass through and warm the ground inside it. This in turn warms the air inside the greenhouse. The warm air inside the greenhouse is trapped by the sealed structure that prevents the heat from escaping by convection or conduction.

The greenhouse effect in our atmosphere works a little differently. Like the glass in greenhouses, our atmosphere lets light pass through. Not all the radiant energy makes it all the way to earth's surface. About 30% of the sunlight is reflected back into outer space, mainly by the clouds. Of the remaining 70%, most is absorbed by the earth's surface and to a smaller extent by the air, as illustrated below.

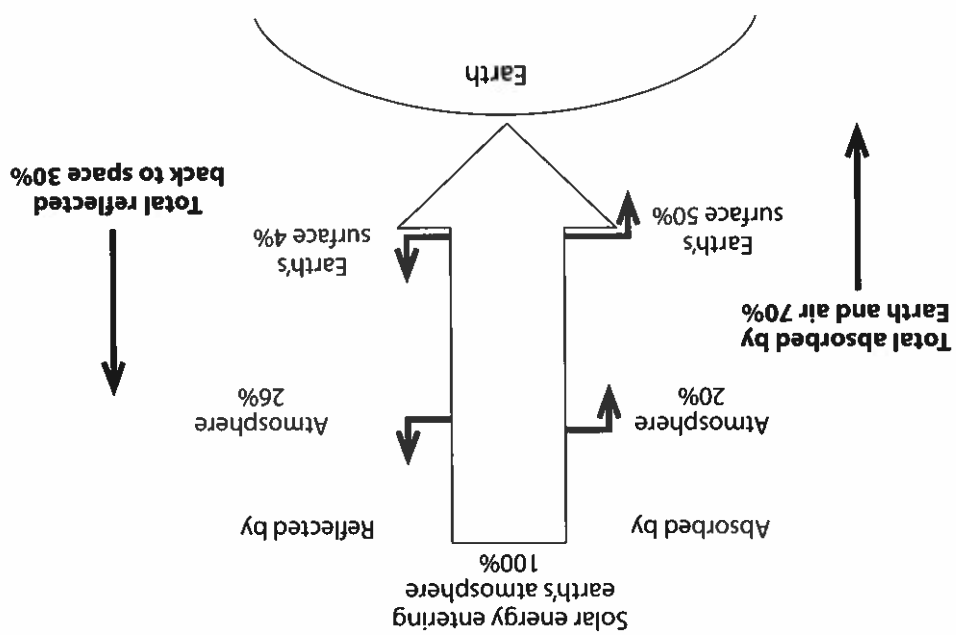


Figure 3.1 What happens to solar radiation hitting the earth

When absorbed by the earth's surface, radiant energy is transformed into **heat (thermal) energy**. As a result, the earth's surface and the air become warmer. Because warm things give off heat, the earth's surface radiates heat back towards outer space. However, as this heat energy passes through our atmosphere, it is absorbed by gases such as carbon dioxide (CO_2) and prevented from escaping. Since the atmosphere's retention of heat reminds us of what happens in a garden greenhouse, we refer to it as the greenhouse effect, even though the methods of trapping the heat are quite different. In a garden greenhouse, the heat is kept from escaping by the sealed enclosure, reducing loss due to convection. In the atmosphere, the heat is trapped mainly by carbon dioxide, which prevents heat radiation out into space.

Support Question

Do not send your answers in for evaluation.

13. Explain how the greenhouse effect can take place on a cold, sunny day inside a car with the windows up.

There are Suggested Answers to Support Questions at the end of this unit.

Importance of the Natural Greenhouse Effect

Without the atmospheric greenhouse effect, much of earth's heat would be lost to outer space. It has been estimated that without the greenhouse effect, the earth's average surface temperature would be much colder, around -18°C . The greenhouse effect is clearly necessary for the earth to support life.

But there can be too much of a good thing. Another planet in our solar system, Venus, has a size similar to earth's, yet has a very thick atmosphere of CO_2 that traps much more heat than the earth does. As a result, the surface temperature of Venus is around 460°C —far too hot to support life as we know it.

It is unlikely that earth could ever get as hot as Venus. However, as you will see, there has been an increase in the gases that produce the greenhouse effect. This is mostly the result of human activities. Scientists warn us that this will increase the earth's average temperature, with serious consequences.

How Heat is Trapped

The earth emits heat energy into outer space in the form of **infrared radiation**. Any warm object will emit infrared radiation, a form of electromagnetic wave similar to visible light. However, infrared waves are longer and have less energy than the waves of visible light. You cannot see infrared with your eyes, but you can feel it when you put your hand near a hot object, like a stove or a car seat in summer. You will learn more about the properties of electromagnetic waves in Unit 4.

As the long-wave infrared energy radiates away from the earth's surface up towards space, it may strike a carbon dioxide particle or another greenhouse gas in the atmosphere. Though the greenhouse gases do not absorb visible light, they do absorb the longer infrared waves. As a result, visible light passes through the atmosphere, but the infrared waves can be captured. This means that some of the infrared waves on their way to outer space are captured by the greenhouse gases in the atmosphere (see Figure 3.2). This causes the atmosphere to hold more heat, warming our planet.

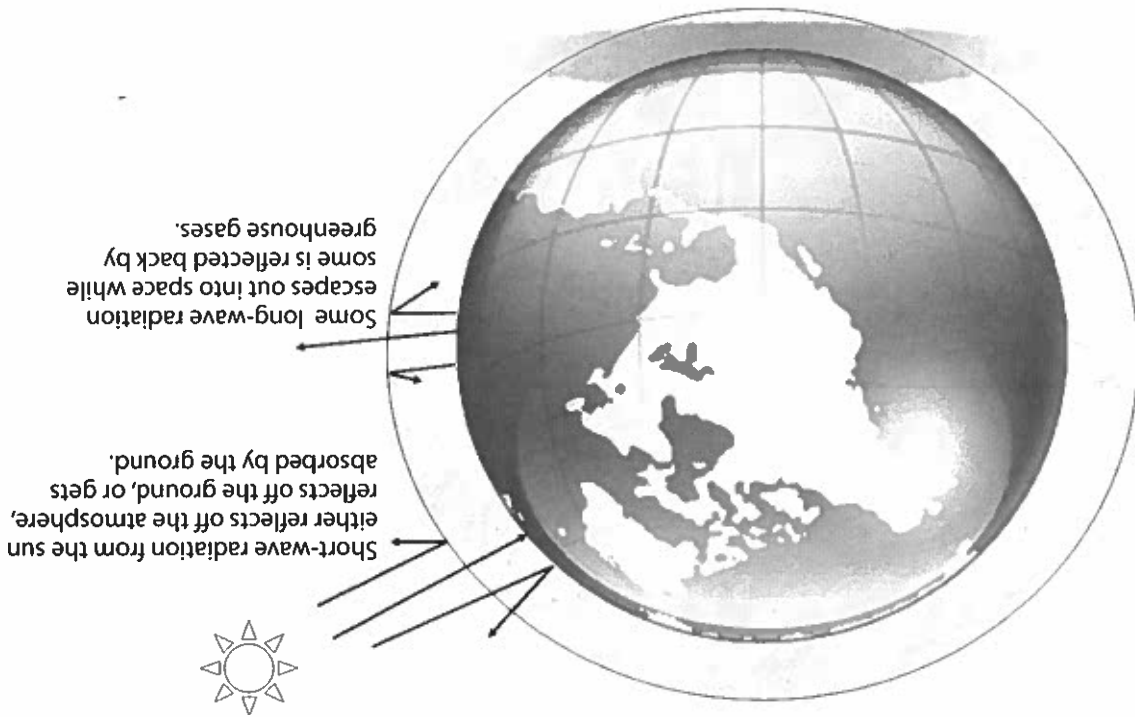


Figure 3.2 Greenhouse effect in earth's atmosphere

Support Question

14. Explain why infrared waves can be captured by greenhouse gases, while visible light waves cannot.

Gases Involved in the Greenhouse Effect

As you learned in the previous lesson, the atmosphere is mainly made up of nitrogen (78%), oxygen (21%), and small quantities of other gases (1%). These “other gases” are responsible for the greenhouse effect. Six of these gases create the biggest greenhouse effect:

1. carbon dioxide (CO_2)
2. methane
3. chlorofluorocarbons (CFCs)
4. ozone
5. nitrous oxides
6. water vapour

1. Carbon Dioxide

Although representing only approximately 0.03% of the air in our atmosphere, carbon dioxide (CO_2) is the most important of the greenhouse gases. Carbon dioxide plays an important role for green plants, which take in carbon dioxide through their leaves in order to make food and grow. In the process, plants release oxygen into the air.

Because plants take in carbon dioxide, scientists refer to vegetation as **carbon sinks**: plants hold carbon dioxide inside them just as a sink holds water. When a tree or other vegetation is burned, the carbon dioxide stored in it is released into the atmosphere. Scientists consider this burning a **carbon source**.

Carbon dioxide is normally produced when living things respire (breathe). You breathe out carbon dioxide when you exhale. However, carbon dioxide is also produced by the burning of **fossil fuels** such as coal, oil, and natural gas. That's because fossil fuels are really the remains of dead plants and animals that lived millions of years ago. Some of those remains got trapped at the bottom of lakes or oceans and became a thick, dark mud. Over time this mud became very compressed and concentrated, eventually turning into the oil and coal we burn today.

When we burn fossil fuels, we release the carbon that was trapped and removed from the atmosphere by plants millions of years ago. The amount of carbon dioxide in the atmosphere increases as more fossil fuels are burned throughout the world. Carbon dioxide is the main greenhouse gas; as the amount of carbon dioxide in the atmosphere increases, so does the greenhouse effect.

Other human activities also release large quantities of CO_2 into the atmosphere. The two main ones are cement production and the cutting down and burning of rainforests.

2. Methane

Methane (CH_4) is another type of carbon-based gas. It is normally produced when organic materials such as dead plants decompose over time. Landfills also produce methane from the buried organic material that is decomposing. The main human activities that produce methane include agriculture (especially rice production), cattle farming, and fossil-fuel extraction.

Methane can also be released when frozen soils begin to decompose. Much of the Arctic Region contains permanently frozen soil layers called **permafrost**. This soil contains carbon that was trapped ten of thousands of years ago. As the Arctic warms up, this soil starts to thaw and decompose, releasing large amounts of CO_2 and methane into the atmosphere.

Methane is also stored in vast quantities in the mud at the bottom of the ocean, where intense pressures and cold temperatures trap methane gas in the form of methane ice. As the ocean warms up, this trapped methane can be released, significantly adding to the methane levels already in the atmosphere.

3. CFCs

Chlorofluorocarbons (commonly referred to as “CFCs”) are man-made chemicals used in refrigerators, cleaning solvents, and in the making of plastic foam. There are many types of CFC gases, but all have similar greenhouse effects. They are released when they are used, burned, or decay in landfills.

Though they exist in much smaller quantities than carbon dioxide in the atmosphere, these gases are much more efficient than carbon dioxide at producing the greenhouse effect. In fact, CFC gas is 10 000 times more efficient at producing the greenhouse effect than carbon dioxide. This means it requires 10 000 times fewer particles to have the same effect. As a result, even at very low levels they can have a significant impact on the greenhouse effect. Fortunately, recent international agreements have led to a ban on the production of many types of CFCs, so their concentration in the atmosphere should gradually decrease over time.

4. Ozone

Ozone (O_3) is a naturally occurring molecule of oxygen that is normally found high up in the atmosphere. Because it is very good at blocking harmful UV radiation from the sun, ozone helps protect all life. However, ozone is also produced by the burning of fossil fuels. This ozone tends to stay near the ground and creates the orange pollution known as smog that blankets many cities. Ozone can also act as a potent greenhouse gas, blocking infrared radiation from escaping into space.

5. Nitrous Oxides

Nitrous oxides (N_2O) are molecules containing nitrogen and oxygen. They are produced by the burning of fossil fuels at high temperatures, such as in car engines. Nitrous oxide is also a very potent greenhouse gas, about 300 times more efficient than CO_2 . However, its concentration in the atmosphere is still very low, so its overall impact is not yet very significant.

6. Water Vapour

Water vapour is the gas form of water, seen most often as steam. Water vapour forms when water evaporates or boils. Because most of the earth's surface is covered with water, a lot of evaporation occurs. This puts a lot of water vapour up into the atmosphere, where the water acts as a strong greenhouse gas. As the planet warms up, there is more evaporation. This releases more water vapour into the atmosphere, which causes the planet to warm up even more. This pattern—the effect of a process amplifying that process—is called a **positive feedback loop**. Water is not as potent per molecule as the other greenhouse gases described here. However, the abundance of water in the atmosphere means that it plays a major role in regulating global temperatures. When ranked by their contribution to the greenhouse effect, the most important gases are

- water vapour, which contributes 36–70%
- carbon dioxide, which contributes 9–26%
- methane, which contributes 4–9%
- ozone, which contributes 3–7%

Of the human-produced greenhouse gases, carbon dioxide is the most significant.

Support Questions

15. In the tropics, much of forest destruction comes from burning. Describe two ways that this affects the carbon dioxide in the atmosphere.

16. Indicate how nitrous oxides are produced and how they are connected to the greenhouse effect.

Using airtight clear plastic bags and sunlight, you can examine the greenhouse effect for yourself in this optional activity. You can also determine how effective water vapour is as a greenhouse gas.

Optional Activity: Greenhouse Effect



Purpose

Investigate the greenhouse effect inside a clear plastic bag.

Materials

- 6 small or medium-sized clear plastic bags that you can seal (such as ZiplocTM)
- 6 medium-sized ice cubes
- 1 tablespoon of water
- a location, inside or outside, with direct sunshine and shade
- marker pen (or regular pen and masking tape or a sticky-note)

Procedure

1. Place two ice cubes in each of the three small plastic bags. Seal each bag so that it is airtight.
2. Place each ice-cube bag inside another plastic bag. Seal the outer bag so that it is also airtight. You will now have three sealed bags, each with a sealed package of ice in it.
3. Label each bag with a number—1, 2, or 3—using the marker pen (or a regular ink pen on masking tape or a sticky-note).
4. In Bag #2, add about 1 tablespoon of water to the outside bag.
5. Close Bag #2 tightly again.
6. Place Bags #1 and #2 in direct sunlight. Place Bag #3 in a nearby shady location, protected from direct sunlight.
7. Observe the condition of the ice in the bags every 5–10 minutes. For smaller ice cubes, check every 5 minutes; for larger ice cubes, check every 10 minutes.
8. Record the time it takes for the ice in each bag to completely melt.

Your experimental set-up should look like this:

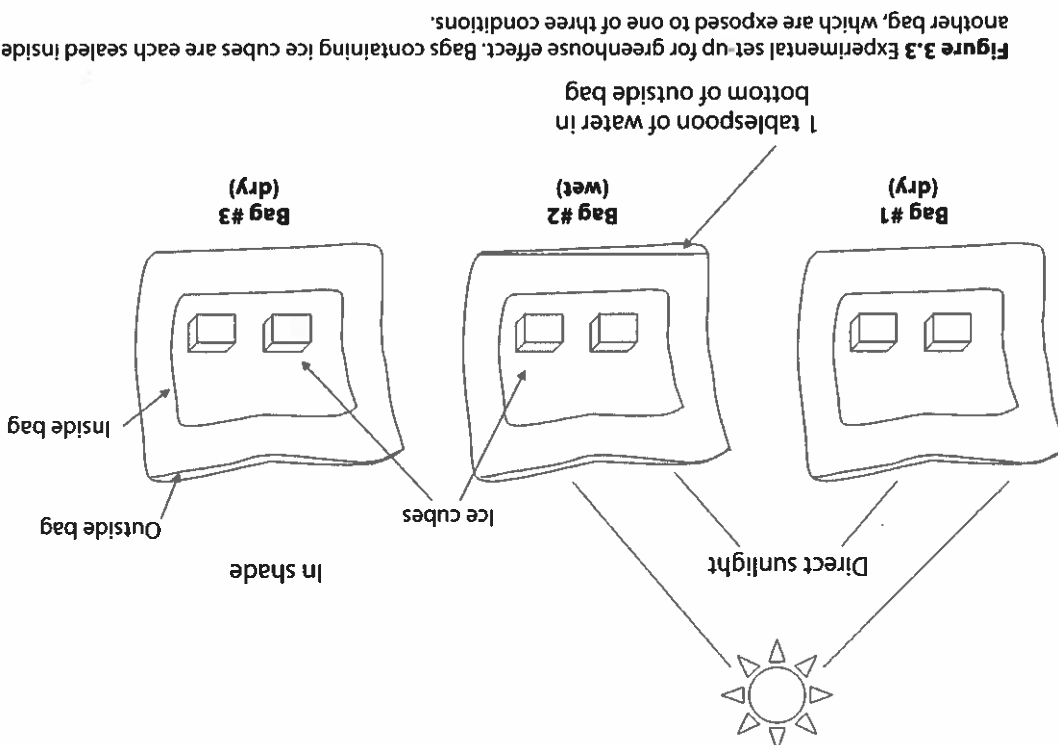


Figure 3.3 Experimental set-up for greenhouse effect. Bags containing ice cubes are each sealed inside another bag, which are exposed to one of three conditions.

Observations

Complete the following table.

Treatment	Bag #1: Sun-dry	Bag #2: Sun-wet	Bag #3: Shade-dry
Time until full melt (approximately)			

Analysis

Complete Support Question 17.

Conclusion

Complete Support Question 18.

Support Questions

17. a) Which bag melted the fastest?

b) Was there a difference in melting rate between Bag #1 (sun-dry) and Bag #2 (sun-wet)?

18. Explain the difference in melting rate among the three bags.

Runaway Greenhouse Effect

A runaway greenhouse effect occurs if positive feedback loops lead to the release of all greenhouse gases into the atmosphere. This may have happened on Venus, but it is unlikely to happen to that extent on earth. However, there is a real worry that as the earth warms up, more greenhouse gases will be released. This will increase the warming even more, leading to even more greenhouse-gas release.

The main concerns are the release of tremendous amounts of methane from melting Arctic permafrost, the release of methane from vast reserves of methane ice lying at the bottom of the Arctic Ocean, and increased water vapour caused by evaporation.

The potential for positive feedback loops such as these makes it difficult to predict the magnitude and speed of climate change.

Changes in Carbon Dioxide Levels

Carbon dioxide is an important greenhouse gas. It is also one that humans are directly adding to the atmosphere, resulting in our current problem of global climate change. To solve the climate change problem, we need to understand how carbon is added and removed from the atmosphere.

Carbon Cycle

As plants grow, they remove carbon dioxide from the air. Animals eat the plants, using the stored carbon for their own growth and survival. Carbon is released into the air as part of natural decay and normal respiration. This creates a natural carbon cycle as CO_2 continually enters the atmosphere and is removed. The amount of carbon dioxide in the atmosphere at any time is the result of a balance between the inputs and outputs.

You can explore the carbon cycle through an animation available from the link on the course page.

Go to your course page on the ILC website and click on “Carbon Cycle” under Lesson 3.



Past CO₂ Levels

Current levels of carbon dioxide in the atmosphere can be measured directly using satellites and ground-based measuring stations. But how can we know what CO₂ levels were like hundreds or even thousands of years ago? Fortunately the levels of CO₂ in the atmosphere are naturally recorded, sometimes year by year, in the ice found in glaciers.

When it snows, the fresh snow layer contains tiny air pockets that trap samples of air. If the snow does not melt, but keeps building up, layers of trapped air are laid down year after year. This process occurs naturally in glaciers near the North and South Poles. If you look closely, you will see tiny bubbles frozen in the ice. The deeper you look down into the ice, the older the air bubbles. In really deep glaciers, it is possible to take samples of ice that were laid down hundreds of thousands of years ago. By careful analysis of the air trapped in the bubbles, we can measure the composition of the atmosphere that existed when the bubble was formed.

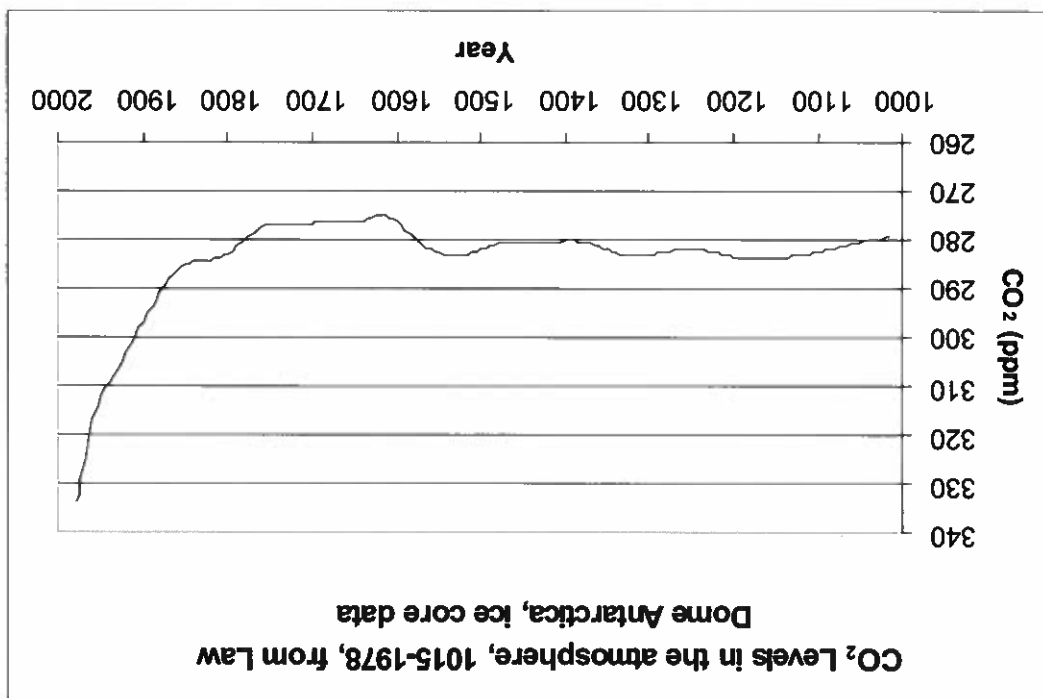
Scientists have been studying ice-core samples taken from Antarctica and Greenland glaciers. They have analyzed the concentration of carbon dioxide in the air bubbles trapped in the ice, and determined how the concentration has changed over thousands of years. For example, Figure 3.4 below depicts CO₂ concentrations obtained from samples of ice taken from the Law Dome site located in East Antarctica. This sample only looked at ice layers over the period from 1015 to 1978.

The concentration is reported in parts per million (ppm) instead of percent. We often talk about the percentage of carbon dioxide in the atmosphere, but when dealing with small percentages, scientists use ppm instead. In order to change ppm into percent, simply divide the ppm value by 10 000. In other words 335 ppm (335 ÷ 10 000) is equal to 0.0335%.

The graph indicates that there was a sharp rise in the amount of carbon dioxide around the year 1800. This coincides with the Industrial Revolution, which began around 1750. At this time, fossil fuels began to be burned in large quantities. The rate of increase in CO_2 levels then became steeper during the 1800s and 1900s as different types of engines and electric motors were developed. These allowed industries to produce goods in large factories, using machines that ran on energy from coal, oil, natural gas, and electricity. With all this industrial activity, the amount of carbon dioxide released into the atmosphere increased dramatically. But is the recent increase in atmospheric CO_2 really due to human activity? How can we tell? Maybe it's just part of a natural cycle. Are today's levels really much different from levels in the past?

You will look more closely at these important questions in the next lesson. One way to answer them is to look at a very long-term historical record. With this we can see whether today's levels are truly unusual or within the range of natural fluctuations. Recent data from deep Antarctic ice cores provides evidence from past atmospheres going back nearly 800 000 years. This data shows that today's CO_2 levels are the highest they have been in 800 000 years. Over this time period, the natural fluctuations in CO_2 levels ranged from 180 to 270 ppm. In Lesson 4, you will examine this kind of evidence in greater detail.

Figure 3.4 Carbon dioxide levels in the atmosphere over the past 1000 years.
Source: Data from the National Oceanic and Atmospheric Administration (NOAA), USA.



Support Question

19. The table below contains more recent data about the concentration of carbon dioxide in our atmosphere. The data was obtained from the Earth System Research Laboratory at the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

Atmospheric CO₂ levels over the last seven years

Year	Concentration (ppm)
2009	386
2008	384
2007	382
2006	380
2005	378
2004	376
2003	374

- a) Use the data to produce a line graph, with the year along the horizontal axis and the concentration (in ppm) along the vertical axis.
- b) What does the line in the graph indicate about what is happening to the concentration over these years?

Conclusion

In this lesson, you studied the greenhouse effect, which is responsible for keeping the earth warm enough to support life. But over the past 250 years, humans have been releasing carbon from long-term storage in fossil fuels back into the atmosphere. Carbon dioxide is an important greenhouse gas, along with water vapour and methane. The levels of carbon dioxide today are higher than they have been for at least 800 000 years. The consequences of these high levels for the earth's climate are predicted to be very significant, especially if positive feedback loops occur.

In the next lesson, you will examine in more detail some of the controversies around climate change. You will explore the role that CO_2 plays, how much climate change is likely to happen, and how fast it could occur.

Key Concepts

Greenhouse effect: Gases in the earth's atmosphere allow short-wave radiation from the sun to reach the earth, but block the outgoing long-wave radiation from reaching space. The result is a net increase in heat.

Heat (thermal) energy: form of energy; can be given off by objects that have been heated up by incoming solar radiation

Infrared radiation: a type of long-wave radiation given off by hot objects

Carbon sink: a storage material for carbon dioxide. Examples include very long-term storage in fossil fuels, and shorter-term storage in green plants.

Carbon source: a source of carbon dioxide in the atmosphere. Examples include burning fossil fuels, burning rainforests, and melting permafrost in the Arctic.

Fossil fuels: non-renewable fuels, such as coal, oil, and natural gas, that derive from the compressed remains of dead plants and animals

Permafrost: a type of frozen soil found in arctic regions. It is a long-term carbon sink, often trapping carbon for thousands of years.

Positive feedback loop: occurs when the effect of a process amplifies that process. For example, excess carbon dioxide in the atmosphere causes Arctic permafrost to melt, which causes the release of more carbon dioxide, which causes even more warming to occur, which melts even more permafrost.

Carbon cycle: the natural cycle of carbon from the atmosphere into living things and then back into the atmosphere

Key Questions

Save your answers to the Key Questions in your
Course Journal or e-Journal.

Total: 15 marks

9. When people cut down large parts of Canada's boreal forest, how does this influence the greenhouse effect? (4 marks)
10. Name two uses of chlorofluorocarbons (CFCs). How are CFCs associated with the greenhouse effect? (3 marks)
11. Match each item in column A with the corresponding item in column B. (5 marks: 1 mark for each pair)

Column A	Column B
i) large rainforests are considered a	a) is increasing
ii) the main greenhouse gas is	b) carbon source
iii) methane is considered a	c) carbon sink
iv) in recent years carbon dioxide	d) nitrous oxide
v) a hot object emits	e) greenhouse gas
	f) carbon dioxide
	g) visible light
	h) infrared radiation
	i) is decreasing

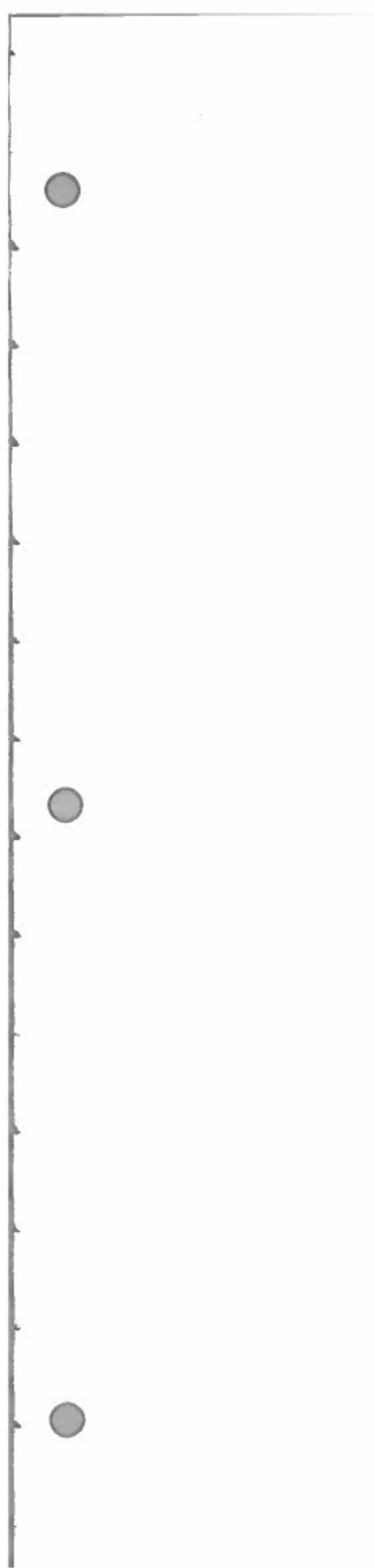
12. Explain why the amount of carbon dioxide in the atmosphere started to increase around 1800. (3 marks)

Now go on to Lesson 4. Remember, you do not send your Journal to the Independent Learning Centre until you have completed Unit 1 (Lessons 1 to 5).

SNC2D-B



Climate Change: Causes and Consequences



Introduction

So far in this unit, you have learned how the climate system works and how the greenhouse effect causes climate change. In this lesson, you will examine the evidence for climate change. You will learn how to distinguish natural variations in climate from changes due to human activities. To do this, you will examine patterns of past climates as revealed through a variety of natural indicators. Next you will examine the relationship between greenhouse-gas production and current climate change. You will evaluate the evidence linking carbon dioxide levels to global temperature increases and to changes in ice and sea-level conditions. Finally, you will learn about the possible consequences of climate change and how these may affect all life on the planet—including yours.

Planning Your Study

You may find this time grid helpful in planning when and how you will work through this lesson.

Suggested Timing for This Lesson (hours)	
Measuring Past Climates	½
Possible Causes of Climate Change	½
Is Climate Change Happening Now?	¾
Activity 1: Expansion of Water	¾
Activity 2: Melting Icebergs	½
Consequences of Climate Change	¾
Key Questions	1

What You Will Learn

- After completing this lesson, you will be able to
- analyze different kinds of evidence for past climate change to separate natural from human-caused effects
- analyze the cause-and-effect relationship for human-caused climate change
- identify and describe indications that climate change is occurring
- assess current and potential impacts of climate change

Climate Change: Examining the Evidence

The term **climate change** refers to the increase over time of average global temperatures and its influence on natural processes. Science provides powerful ways to study natural processes and understand their causes. The science of climate change is no different. However, as you have learned, there are many factors that determine our climate. These factors interact in complex ways, making it hard to establish clear cause-and-effect relationships. This has led some people to argue that climate change is part of a natural cycle that humans have little to do with. That is why scientists are trying to find out how and why our climate has changed in the past and what this tells us about possible future changes.

Measuring Past Climates

One way to distinguish human-caused climate change from natural change is to look at past climates. If current climate and atmospheric conditions were found to exist in the past before people began to burn fossil fuels, humans are not necessarily responsible for current climate change. But how can you measure past climates? Weather stations are a recent invention, giving us data going back only about 120 years. We need data going back thousands of years. Fortunately, scientists have discovered natural processes that have preserved records of past climates. Some of these are used to look back in detail over a few hundred years, while others reveal patterns going back nearly 800 000 years.

Tree Rings

To look at more recent climates, scientists can examine trees that are hundreds or even thousands of years old. Each year a tree grows a new layer of wood under its bark called a growth ring or **tree ring**. The ring's thickness depends on temperature and precipitation during the year it formed. So each growth ring preserves a record of the climate for that year. By analyzing growth patterns in living trees, scientists can directly relate growth pattern to the climate patterns that occurred during the tree's life. The picture below shows the growth rings in a tree that was about 25 years old when it was cut down. Each year's growth is indicated by the width of the white band between dark bands. You can see from the variation in the width of growth rings that this tree experienced patterns of very good growth (wide rings) followed by some years when it grew very little (narrow rings).



Figure 4.1 Cross-section of a 25-year-old tree showing growth rings
Source: iStockphoto.com

Many trees live to be hundreds of years old, and some live for thousands of years. The oldest trees on earth are the bristlecone pines, many of which are found in California. The average age of these trees is 1000 years, and a few are more than 4000 years old. The rings of dead, fossilized trees can also provide evidence of climate changes.

Sea-Floor Sediments

Another way to reconstruct past climates uses material found on the sea floor. Sea-floor sediments contain the shells of tiny organisms that once lived at the surface of the oceans. When they died, their shells sank to the ocean floor and settled into the mud. The type and number of these organisms alive at the surface depended on the water temperature. By studying the type and number of shells found in the sediments, scientists get an idea of changes in ocean temperatures over time. Scientists use the chemical makeup of these shells to get more accurate readings of temperature. The shells contain oxygen atoms that were drawn out of the ocean water as the shell grew. Some oxygen atoms (referred to as isotopes) are heavier than others. Since a water particle (H_2O) is made up of two hydrogen atoms and one oxygen atom, these heavier oxygen atoms are also present in some water particles. When ocean water evaporates, the water particles with the heavier oxygen atom tend to evaporate last. When temperatures are higher, there is greater evaporation, so there will be an increase in the proportion of water molecules in the ocean containing the heavier oxygen atoms. The ratio of the two oxygen isotopes in the shells can be used to determine the temperature of the water at the time the shell was growing. This is known as **oxygen isotope analysis**.

Like tree rings, ocean sediments are laid down in layers, with the recent years at the top and the older layers at the bottom. Scientists can take a core sample out of the sediment and pull out shell fragments from along the length of the core. This gives them a continuous temperature record going back thousands of years.

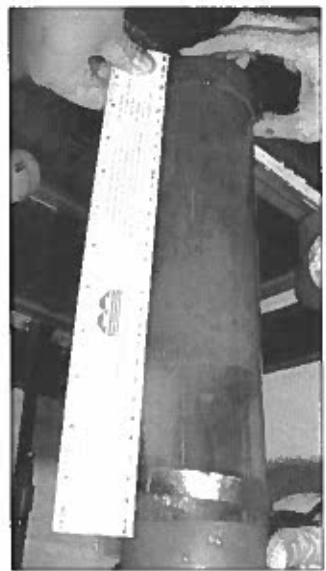


Figure 4.2 Core sample of ocean floor sediment

Source: National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce

Ice Cores

As you learned in Lesson 3, past climate can also be revealed by studying the air bubbles trapped in samples of very old ice. This involves taking **ice core** samples from ice that has been around for many thousands of years, such as in the glaciers of Greenland and Antarctica.

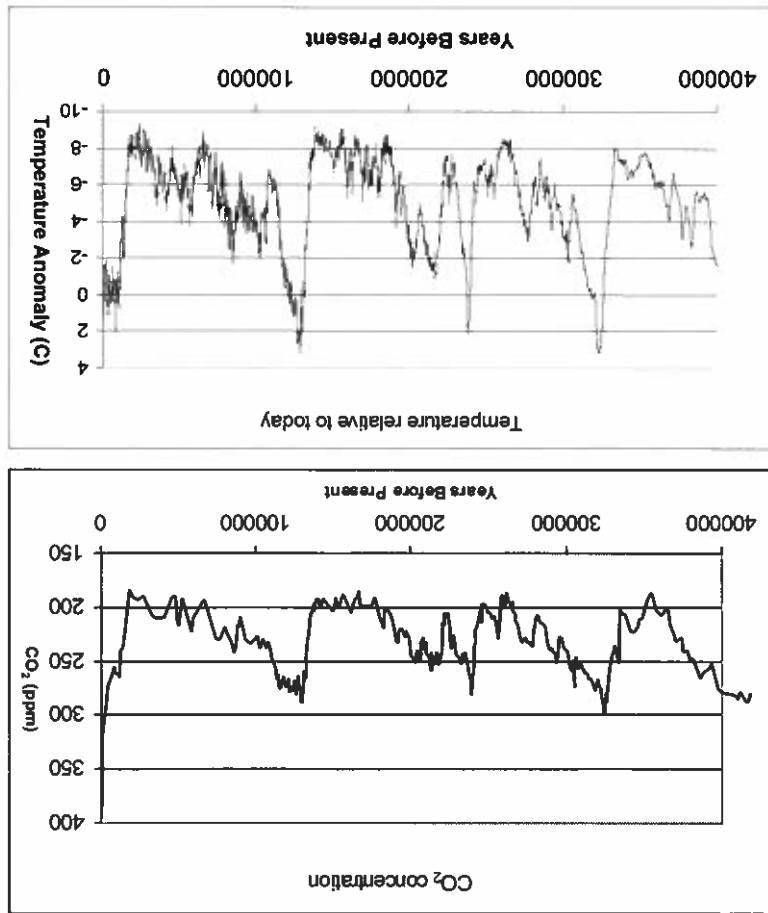
Some of the best records of past climates have come from analysis of ice cores. Because the glaciers are very old and deep, it is possible to get core samples that date back nearly 800 000 years. The ice contains air bubbles that trapped tiny samples of the atmosphere when the bubble was formed. Analyzing the contents of the bubbles is like sampling the actual air that existed up to 800 000 years ago. Using ice cores, we can get a measure of the temperature (from isotope ratios) as well as the amount of CO_2 and other greenhouse gases present in the atmosphere. For example, the graphs below show changes in the levels of CO_2 as well as the average annual temperature for the past 400 000 years. The data come from the Vostock Antarctic ice cores. Added to each graph are annual data collected from the Mauna Loa observatory in Hawaii, which covers the last 50 years in detail.

Other Sources of Long-Term Climate Data

Scientists have discovered that many other natural materials contain a record of past climates. For example, soil layers can be examined for changes in pollen abundance, which indicates changes in vegetation that relate to climate. Other examples include corals, fossils, lake sediments, and the growth rings in fish bones.

Note that the pattern of temperature changes matches almost exactly the changes in CO_2 levels. Note too that the levels of CO_2 recorded recently (384 ppm) are far higher than at any time in the past 400 000 years. Evidence like this strongly indicates that the recent surge in CO_2 levels is not part of normal variation and that increasing CO_2 levels are associated with higher global temperatures.

Figure 4.3 Graphs of CO_2 concentration and temperature changes over 400 000 years



Support Question

Do not send your answers in for evaluation.

20. One method of studying climate change is to examine the shells of organisms that lived long ago. What can the type of shells and their distribution on the ocean floor tell us about past climates?

There are Suggested Answers to Support Questions at the end of this unit.

Possible Causes of Climate Change

The causes of climate change are not fully understood because of the complex interactions between the components of climate. Also, positive feedback loops can turn relatively small changes in one component into big climate outcomes. What is certain, however, is that climate change can result from either natural or anthropogenic (human-influenced) causes.

Natural Causes

The earth's climate has changed many times over its four-billion-year history. There have been periods of extreme heat and extreme cold. The reasons probably include changes in the earth's orbit, movement of the continents, changes in solar radiation levels, and collisions with asteroids and comets. The earth's motion may cause climate changes because the shape of the earth's orbit changes slightly over a period of about 100 000 years. Also the tilt of the earth's axis varies a few degrees over a time period of 41 000 years, and the earth's axis of rotation wobbles a bit with a repetition of 23 000 years. If you watched these motions in a speeded-up video, the earth would look like a wobbling top as it orbits the sun. This motion alters the way the sun's energy is distributed to different parts of the planet. In Lessons 1 and 2, you learned how this can alter heat transfer patterns and so change climate. However, because these changes take place over tens of thousands of years, they cannot be the cause of recent climate change.

Another long-term cause of climate change is **continental drift** or **plate tectonics**. Sections of the earth's crust, called plates, move up to a few centimetres a year. Even though the amount moved each year is small, over millions of years the plates can move a great distance. For example, scientists believe that Greenland once had a warmer climate because it was located closer to the equator. The changes in the position of the continents affect wind patterns, ocean currents, and the amount of solar radiation reflected back into space. All of this would affect climate. But again, these changes happen over millions of years and so can't be responsible for the climate changes over the last century.

Some scientists think that **sunspots** can be a short-term cause of climate change. Sunspots are regions on the sun's surface that are at a slightly lower temperature. The number of sunspots changes over an 11-year cycle. The amount of energy given off by the sun increases very slightly when the number of sunspots increases. If the sun emits more energy, more energy available to reach earth, and this could potentially affect climate. But the sunspot cycle on its own is unlikely to be the cause of major climate change because global temperatures show a steady increase, not an 11-year cycle of ups and downs.

Volcanic eruptions can be another short-term cause of climate change. Large eruptions release a huge amount of gases and volcanic ash into the atmosphere. Sometimes there is enough material to create thick clouds that block incoming solar radiation. This cools the planet for a few years. Some volcanic activity in the past may have also released large amounts of carbon dioxide into the atmosphere, leading to a greenhouse effect and warmer global temperatures. However, there has not been enough volcanic activity in the past century to account for the sudden increase in greenhouse gases in the atmosphere.

A comet or asteroid striking the earth's surface would cause a disruption in the climate. Depending on the size of the object, the impact could devastate continents and throw a tremendous amount of material into the atmosphere. This would lead to global cooling that could last for centuries. The extinction of the dinosaurs was likely caused by climate change brought on by a large asteroid hitting the earth. Luckily we have not been hit recently by a large asteroid, so this is not the reason for recent climate changes.

Anthropogenic Causes

Two important ways that humans can affect the climate are by altering the atmosphere through addition of greenhouse gases and by removing vegetation (deforestation). Changes in these two climate components can also lead indirectly to changes in other components, resulting in rapid and significant climate change.

Greenhouse-Gas Levels

Humans alter the atmosphere by adding greenhouse gases, especially carbon dioxide. This is the result of burning fossil fuels, which started about 250 years ago. The atmospheric concentration of CO_2 has increased by 31% since 1750, when it was about 280 ppm. It continues to increase by about 1.5 ppm or 0.4% per year. Today it is about 384 ppm. About 80% of the anthropogenic emissions of CO_2 during the past 20 years is due to fossil-fuel burning and cement production. The rest is due to deforestation.

The graph below shows the concentration of carbon dioxide levels in the atmosphere each year for the period 1959–2007, obtained by the Mauna Loa observatory in Hawaii, USA.

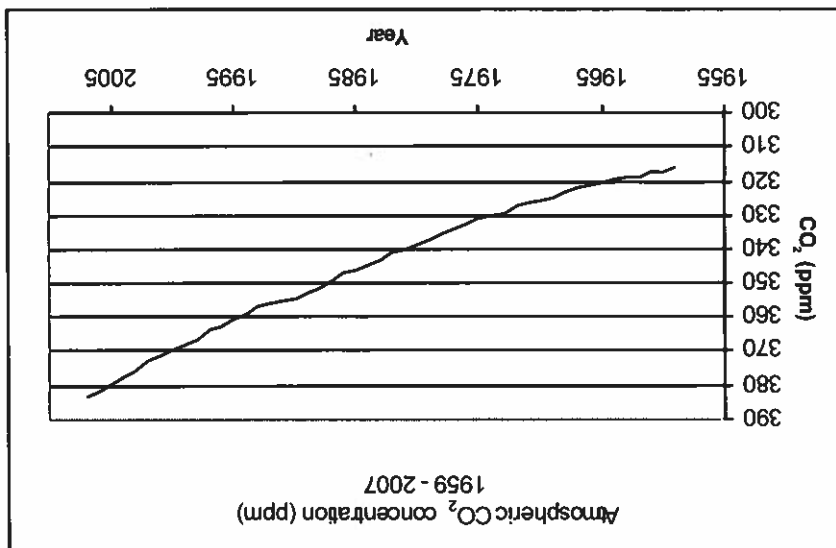


Figure 4.4 CO_2 concentration by year, 1959–2007

Note that the level of CO_2 has increased every year. There is no indication that the rate of increase in CO_2 level is slowing down, despite recent awareness of the issue of climate change.

The atmospheric concentrations of other major greenhouse gases like methane (CH_4) and nitrous oxide (N_2O) have also increased since 1750. Methane (+151%) is released through agriculture, while most nitrous oxide (+17%) comes from the burning of gasoline in car engines.

Deforestation

Humans have always cut down trees. But in the last 50 years, forests all over the world have been clear-cut at an incredible rate. This is particularly true in tropical regions, where rainforests have been almost wiped out in many areas. This deforestation contributes to climate change in two main ways.

First, the wood is often burned or decomposes, releasing large amounts of carbon dioxide into the atmosphere. Second, the cleared land is usually not reforested, so there is no way for the vegetation to capture and store carbon dioxide for long periods. This means that less CO_2 is being removed from the atmosphere. Deforestation also changes the albedo of the land, the water cycle, the amount of methane released through soil decay, and many other factors that indirectly contribute to climate change.

Support Question

- 21.** Explain why high levels of carbon dioxide are considered an anthropogenic cause of climate change.

Is Climate Change Happening Now?

It is clear that the concentration of important greenhouse gases in the atmosphere, like carbon dioxide and methane, has increased dramatically since the burning of fossil fuels began. It is also clear that more greenhouse gases in the atmosphere can lead to an increased greenhouse effect and global warming. The big question is whether the levels of greenhouse gas in the atmosphere now are large enough to cause detectable climate change.

Scientists are tackling this question by looking at three main types of evidence: global temperatures, ice, and sea-level rise.

Global Temperature

There is no single thermometer measuring the global temperature. Instead, individual temperature measurements are taken every day at several thousand stations over the land areas of the world. These are combined with thousands more measurements of sea-surface temperatures taken from ships. This information is then used to produce a value representing the global average temperature for a specific period of time.

As you know, temperature varies a lot day to day. Scientists need to analyze temperature changes in order to discern trends. One method uses **temperature anomalies**. A temperature anomaly is a temperature value obtained by comparing the measured temperature to some average temperature.

In Figure 4.5 below, scientists from NASA's Goddard Space Flight Center in the USA combined temperature data from land and sea to create an annual global temperature measure. They then converted these to temperature anomalies to better reveal the overall trend. The values above the zero line represent above-average temperatures, and the values below the zero line represent below-average temperatures.

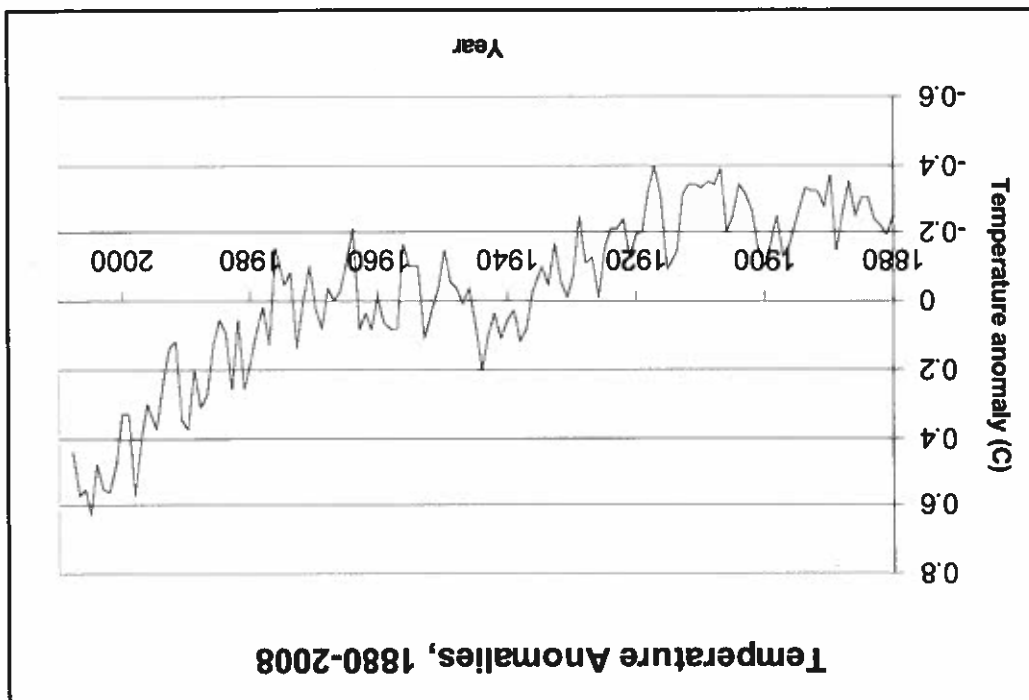


Figure 4.5 Temperature anomalies by year, 1880–2008

From this graph you can see that global temperatures are on an upward trend; in the last 30 years, they have all been above the global average.

The global temperature increase from the 1850s to 2005 is 0.76°C . This may not seem like much, but since this is a global increase, it represents a significant change. For example, in 400 000 years, the global temperature has never been more than 3°C higher than it is today. Remember, the global temperature is an average of the temperatures across all regions. Individual regions, especially the Arctic and Antarctic, have experienced much more heating.

Some people argue that the increases in global temperature are not caused by human activities, but rather occur naturally. For example, weather conditions in many areas of the world are affected by El Niño. El Niño is a shift in the ocean currents, temperatures, and winds in the Pacific Ocean. It occurs every few years and its duration varies. Also, the way we take temperature measurements has changed over the years, and some argue that the older data is not as accurate. Others argue that the earth is just going through a natural warming period, similar to the periods between ice ages.

There has been so much controversy around the evidence for climate change that an international science panel was created in the 1980s to provide definitive scientific answers to many of these questions. The **United Nations Intergovernmental Panel on Climate Change (IPCC)** compiles science reports from all around the world and works with thousands of scientists to write status reports on the progress of climate change. The IPCC has concluded that there has been a real increase in global temperatures and that this has been caused by human activities.

Support Question

22.

The table below lists the global average temperatures for every 10 years during the last century. Using this data, create a line graph with year along the horizontal axis (x-axis) and temperature along the vertical axis (y-axis). What general trend can you see in the graph?

Average global temperatures by decade in the last century

Year	Average Temperature (°C)
1900	13.95
1910	13.85
1920	13.97
1930	14.07
1940	14.23
1950	14.09
1960	14.19
1970	14.09
1980	14.33
1990	14.47
2000	14.69

Ice

If the world is heating up, one of the most noticeable effects should be the melting of ice. In fact, scientists have found that the amount of ice at the poles, in Greenland, and in glaciers around the world is decreasing rapidly. Most of earth's 160 000 glaciers have been shrinking and thinning, and this is happening faster every year. Data from approximately 30 reference glaciers in nine mountain ranges indicate that the average rate of melting has more than doubled in recent years. These findings come from the World Glacier Monitoring Service (WGMS), a centre based at the University of Zurich in Switzerland, which is supported by the United Nations Environment Programme (UNEP).

In Canada, the Athabasca Glacier in Alberta is receding at a rate of three metres per year. It has lost over half of its volume because of climate change.



Figure 4.6 This part of the Athabasca Glacier in Alberta used to fill the valley only 100 years ago.

Source: iStockphoto.com

Other kinds of ice besides glaciers have also shown signs of decrease. The Arctic Ocean is usually covered in ice, but in the last 30 years the area covered by sea ice has shrunk dramatically. The rate of loss is so fast that researchers predict that within 50 to 100 years, the North Pole may be ice-free for the first time in three million years. Ice loss is equally dramatic in Antarctica. In the past decade, large areas of sea ice that took thousands of years to form have broken up dramatically over a period of only a few days.

Sea-Level Rise

Another indicator of climate change is changes in sea level. Sea levels can rise for two reasons. The first is that water expands as it warms up, as you will see in Activity 1. As the oceans heat up, their volume expands. This is called **thermal expansion**. Since the earth is mostly covered by oceans, thermal expansion of the water accounts for a significant increase in the sea level. The second reason for sea-level rise is as ice melts on land, water flows into the ocean. Scientists estimate that if all the land ice in the polar regions were to melt, sea levels could go up by about 25 metres. In Activity 2, you will see that the melting of land ice increases sea levels more than the melting of sea ice.

As a result of global warming, sea levels have risen during the past 50 years at the rate of around two millimetres per year. However, recent satellite measurements of sea levels show that they are rising even faster now. Figure 4.7 below shows sea-level rise for the period 1993–2008. The average increase now is three millimetres per year. This is due to both thermal expansion and land-ice melting.



Activity 1: Expansion of Water

Purpose

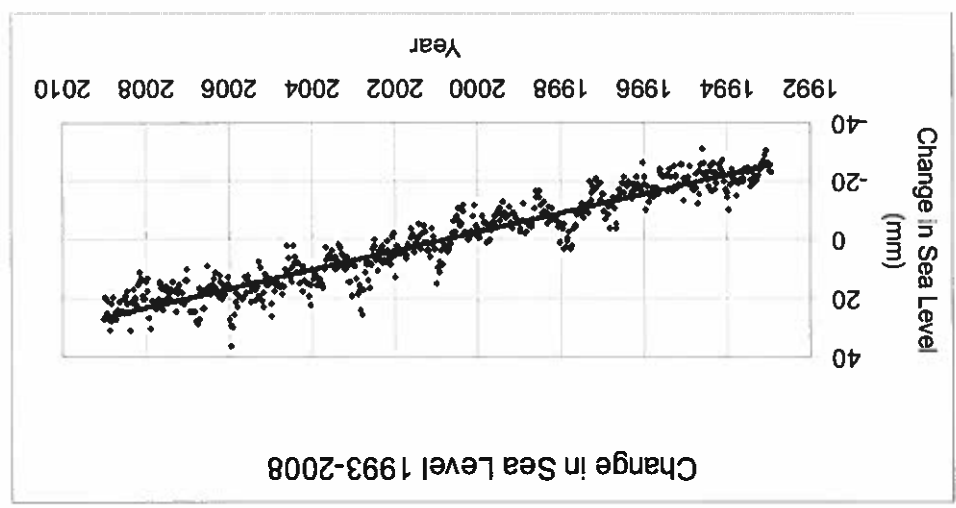
Examine the effect of heat on the expansion of water.

Materials

- a stove
- a cooking pot
- water
- a plastic bottle
- measuring spoons

A few millimetres a year may not seem like much. But tides and storms can amplify that increase, producing waves and storm surges that are much higher. Many coastal cities in the world are located only one to two metres above sea level and could experience massive flooding with only a small increase in sea levels.

Figure 4.7 Change in sea level, 1993–2008



Procedure

1. Fill a small pot about half full of water. It should be about 10 cm deep.
 2. Heat the pot on the stove until it is hot but not boiling. Turn off the heat source.
 3. Fill an empty plastic bottle with water right to the brim. (You can use a 500 mL water bottle or a 2 L pop bottle, depending on the size of the pot.)
 4. Place the plastic bottle in the pot of hot water. Make sure it can stand up without tipping over. (Be careful not to burn yourself.)
 5. Add more water to the bottle if any spilled out while you moved it. It should be completely full.
 6. Leave the bottle in the water for at least 10 minutes.
 7. Carefully take the bottle out of the water and let it cool.
 8. Now use a measuring spoon to measure how much water you need to add back into the bottle in order to fill it up again.
- Your experimental set-up should look like this:

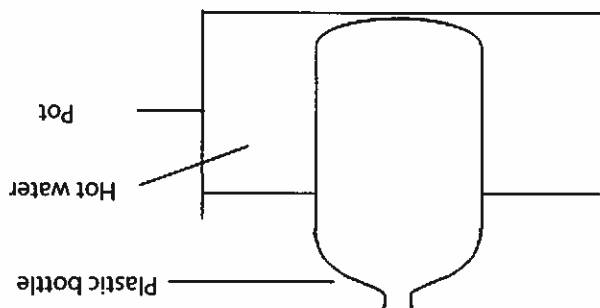


Figure 4.8 Experimental set-up with water-filled plastic bottle being heated in a pot

Analysis

Why did you have to add water to the bottle after it cooled in order to fill it back to the top again? When the water in the bottle was heated, it expanded and overflowed out of the full bottle. The amount of water you added replaced the lost water. In a 500 mL bottle, approximately 2 mL will spill out (depending on the temperature of the hot water). This means the hot water expanded about 0.4%.



Activity 2: Melting Icebergs

Purpose

Examine any changes in water level due to the melting of floating ice.

Materials

- glass or cup
- ice cubes
- water (at room temperature)
- paper towel

Procedure

1. Place a dry piece of paper towel under an empty glass.
 2. Place three ice cubes in the glass.
 3. Carefully fill the glass with water up to the very top of the glass, without letting the water spill over the edge of the glass.
 4. If the paper towel gets wet during the pouring, replace it with a dry piece.
 5. Let the ice cubes melt completely. It will take about 15 minutes.
 6. After the ice cubes have melted, examine the paper towel to see if any water has spilled over the glass.
- Your experimental set-up should look like this:

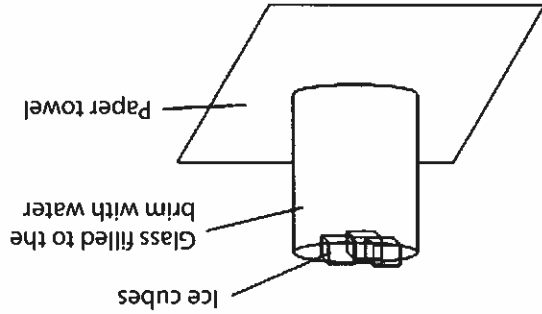


Figure 4.9 Experimental set-up with water-filled glass and ice cubes

Analysis

Did the melting ice increase the water level? If it did, the paper towel would have gotten wet because water would have spilled over the sides of the full glass. If the paper towel stayed dry, the water level did not rise.

You should find that neither the sides of the glass nor the paper towel was wet, indicating that the water level did not change as the ice melted. This is because the volume of water created by the melting ice equalled the volume of water occupied by the ice. So, as the ice melts, there is no change in overall water level.

Support Question

23. At gasoline stations a sign at the pumps indicates that the amount of gas delivered is adjusted to a temperature of 15°C. Why do you think it is necessary to indicate the temperature?

Consequences of Climate Change

Almost everything can be affected, either directly or indirectly, by climate change. The most significant changes to us will probably come from changes in the oceans, land, weather, and biodiversity.

Oceans

The water in the ocean is expected to heat up several degrees as a result of climate change. This will increase sea levels due to thermal expansion. Sea levels will also rise because of the melting of land ice. This melting of ice will also change the salt content of the ocean, which can change ocean currents.

Sea-Level Rise

Predicted values for sea-level rise by 2100 have a large range, but most scientists think they will rise by at least 300 millimetres (or 0.3 metre). The reason for this uncertainty is that the increase is highly dependent on what happens to the land ice in the Antarctic and Greenland. For example, it has been estimated that if just the West Antarctic Ice Sheet were converted to water and spread evenly across the oceans, the sea level would rise by five metres. On the other hand, the melting sea ice in the Arctic will not cause the sea levels to rise since that ice is already floating in the water.

The rising sea level is expected to cause flooding in many coastal cities. It has been estimated that as much as half of the world's population lives in coastal areas. Many of the largely populated cities throughout the world—such as New York, London, and Tokyo—have been built near the ocean. As the water level rises, massive engineering will be needed to keep the water out; in many cases it will be necessary to relocate and redevelop. For many coastal cities, the fresh water supply will also be at risk of contamination from sea water.

Coastal erosion is already a widespread problem along the coast of some countries. It is expected to increase as cliffs and beaches are further eroded by the increase in sea levels. Rising seas bring higher tides, larger waves, and more violent storms, which can rapidly destroy coastlines, sometimes in a few hours.

Ocean Currents

Cold water is slightly heavier than warm water. Also, salty water is heavier than fresh water. This means that cold, salty water is heavier than warm, fresh water. These properties help drive a global ocean current known as the **Great Ocean Conveyor Belt**.

This big current starts when water near the poles gets cooled down and then becomes saltier as ice formation pulls fresh water out of the ocean water while leaving behind the salts. As the ocean water near the poles gets colder and saltier, it sinks to the bottom. This downward push is the pump that drives the circulation. The cold, heavy water flows along the ocean floor in deep ocean currents towards the equator. Meanwhile, the warm water at the equator gets pushed towards the poles in surface currents. The result is a huge ribbon of water that flows around the globe, moving warm water towards the poles and sending cold, salty water down to the equator. The movement of this big global current sets up the motion of smaller regional currents.

If ocean currents are disrupted, the world climate would be greatly affected. For example, northern Europe could get much colder if the Gulf Stream current were to stop sending warm water north. This could happen with climate change

Land

because rapid melting of the polar ice would add more fresh water to the polar sea, reducing its salt concentration and causing less sinking. This would cause the Gulf Stream current to slow down or even stop. There is some evidence that this has occurred in the past, causing mini-ice ages in Europe. So even if the world warms up overall, some areas could actually get colder.

As you learned in Lesson 2, ocean currents are also responsible for the rich fishing areas that occur where two main currents meet. If currents slow down or change direction, this would dramatically change ocean biodiversity and reduce the amount of fish available to catch.

Climate change will affect life on land in many ways, mostly related to water, fire, and changes in biodiversity. This will have an impact on our uses of the land, especially for agriculture, forestry, and control of pest species.

Agriculture

The availability of water strongly influences agriculture of any kind. Climate change will modify rainfall, evaporation, runoff, and soil moisture. For example, in Canada's prairie region, wheat production may be reduced. In Saskatchewan, farmers are already struggling with less water. This central region is a key food-producing area that currently produces most of the planet's surplus food supply. Increased temperatures will cause droughts and crop failures. Food production in other agricultural areas in the world will also be affected, creating potential food shortages. Such changes could affect the world's political stability.

The demand for water for irrigation will increase in a warmer climate because hotter air increases evaporation from the soil. At the same time, less rainfall, falling water tables, and the resulting increase in the energy needed to pump water up from deeper in the ground will make irrigation more expensive. As a result, some land may be taken out of production. Also, with the increased evaporation, the hazard of salt accumulation in the soil will increase, reducing the number of crops that can be grown.

Forestry

Warmer and drier conditions will also increase the risk of drought and forest fires in many areas. Canada's Boreal Forest is especially at risk because the trees burn easily and the soil can get very dry very quickly. Lightning strikes cause most fires, and climate change is expected to increase the number of thunderstorms. Fires caused by lightning can grow very quickly in the Boreal Forest, and within a few hours can threaten communities and the forest their economy is based on.

Biodiversity

A further problem for agriculture and forestry comes from the possible infestation of new pests and diseases as well as an increase in some of the established insects. Cold winters often act as a barrier to the spread of insect pests. This barrier is being removed as the temperature in the mid latitudes increases. For example, the pine beetle has devastated large sections of the pine forests in British Columbia, causing billions of dollars in damage. Pine beetles generally die off during Canada's cold winters, but the recent warm temperatures have helped the beetle survive winter so that their population is growing rapidly.

Ecosystems across the world will be under stress as they attempt to adapt to climate change. In many cases, seasonal patterns are altered. For example, in the middle and high latitudes, spring comes earlier now. Plants are flowering earlier and insects are emerging sooner. While this may sound like a good thing, it can be devastating for many species as they are no longer in synchrony with their natural food supply. For example, Arctic birds have evolved to hatch their young at the peak of the insect abundance. If the insects emerge earlier and the birds can't speed up their egg-laying, then the young birds will hatch too late to get enough to eat.

Animals that live in the polar regions are especially threatened because those regions are changing most quickly. For example, the loss of Arctic ice is severely affecting the polar bear. Polar bears spend most of their time hunting seals and raising their young on the sea ice. When the sea ice melts in spring, they come ashore and can't feed again until the ice forms. The ice now melts earlier and freezes later, meaning the bears spend more weeks a year without food. Many are starving. There is concern that as the ice disappears, so will the polar bears. Nature has adapted to climate change before, but past changes occurred over hundreds or thousands of years. This gave the species a chance to find new habitats and adapt to new diets and diseases. Climate change is happening much faster now; changes that used to occur over a thousand years now take only decades. This is too fast for many species to adjust to, and so many will be lost.

Pollution

Climate change can also have a direct impact on your own health. For example, rising temperatures are expected to increase ground-level ozone production. Combined with other pollutants in the air, ozone can sometimes be seen as a haze over cities, forming **smog**. Smog can irritate the eyes, nose, and throat, and make it difficult for some people to breathe. In places where the local air quality is already

poor, the pollution will be made much worse by higher temperatures. Environment Canada weather forecasters issue “smog alerts” whenever the pollution levels in hot city air become unhealthy. The number of smog alerts issued every summer has been growing steadily.

Weather

As the earth warms up, the convection currents in the air that transfer heat speeded up. This can lead to more extreme weather conditions such as hurricanes, droughts, and heavy thunderstorms with local flooding. Storms will occur more often and with greater intensity. This may already be happening. In the United States, there has been an increase in the number of hurricanes, and the strongest hurricanes (categories 4 and 5) have become more common. In 2005, there was a record number of major hurricanes; the financial losses have run into the tens of billions of dollars.

Support Questions

24. How will climate change affect people with respiratory problems?

25. Explain how climate change could affect coastal cities.

26. Explain how climate change could affect grain production in the prairies.

Climate Change and Canada

Even though scientists can now predict with some confidence how fast the global temperature will increase, predicting climate changes for a particular region is more difficult. Many climate components can produce conflicting responses depending on local changes in ice, soil, water cycles, wind currents, and vegetation. However, in general climate scientists have predicted that the wet areas of the world will become wetter and the dry areas will become drier.

The effect on Canadians depends on where they live and what they do for a living. In the Arctic, the warming trend is starting to affect the traditional lifestyles of the Inuit. Faster-melting ice is causing a decrease in hunting days each year. Coastal erosion has forced people to move further inland, away from their main food supply. Because the ice forms later and melts earlier, people who need ice roads to drive big trucks across the land and lakes in winter have a shorter trucking season. This means less industrial development can take place.

On the east and west coasts, the number and intensity of tropical storms are expected to increase as the warmer ocean waters provide more energy for tropical storms. In the interior regions of Canada, especially in the prairies, it is predicted there will be less snow in winter, but heavier flooding in summer. Many areas will lose their spring and summer supply of water, which now accumulates as snowfall over the winter months. But the heavy summer rainstorms won't help restore that water since most of it will immediately run off the land, causing severe flooding along the small rivers.

Conclusion

In this lesson, you learned the causes of climate change and explored some its consequences. Humans have been adding greenhouse gases, like carbon dioxide and methane, to the atmosphere since the start of the Industrial Revolution in the late 1700s. As the concentration of greenhouse gases increases, so does global temperature. Evidence of past climates obtained from ice cores indicates that today's levels of greenhouse gases are the highest they have been in nearly 800 000 years. Humans have caused this increase.

The effects of climate change will depend on where you live. Almost everything in life could be affected, in land and sea. Nature has been able to cope with these kinds of changes in the past, but only when they occurred gradually, over a period of a few hundred to thousands of years. The rate of climate change now is so fast that natural mechanisms are unlikely to have time to adapt.

In the next lesson, you will explore some of the ways that people are proposing to limit climate change and adapt to its effects.

Key Concepts

Climate change: refers to the increase over time of average global temperatures and its influence of natural processes

Tree ring: a light coloured band of tissue laid down every year by a tree. Its width represents the growing conditions during that year and hence reflects the local climate.

Oxygen isotope analysis: establishes the ratio of heavier oxygen atoms to lighter oxygen atoms in a sample to determine the temperature of the water the isotopes came from

Ice core: a cylinder of ice drilled out of a glacier. The top layer represents the most recent snowfalls and the deeper layers represent older snowfalls. Air bubbles trapped in the ice can be used to recreate climate conditions that existed when the bubble was formed.

Anthropogenic: resulting from human activities

Continental drift (or plate tectonics): slow movement of plates (sections of the earth's crust)

Sunspots: regions on the sun's surface that are at a slightly lower temperature

Temperature anomaly: a way to analyze temperature data by converting temperatures to differences from some average value

United Nations' Intergovernmental Panel on Climate Change (IPCC): an international science organization that works with thousands of scientists around the world to write status reports on the progress of climate change

Thermal expansion: the increase in the volume of water as it is heated

Great Ocean Conveyor Belt: a huge flow of water running around the globe that moves cold water towards the equator and warm water towards the poles

Smog: air pollution caused by ground-level ozone

Key Questions

Save your answers to the Key Questions in your
Course Journal or e-Journal.

Total: 18 marks

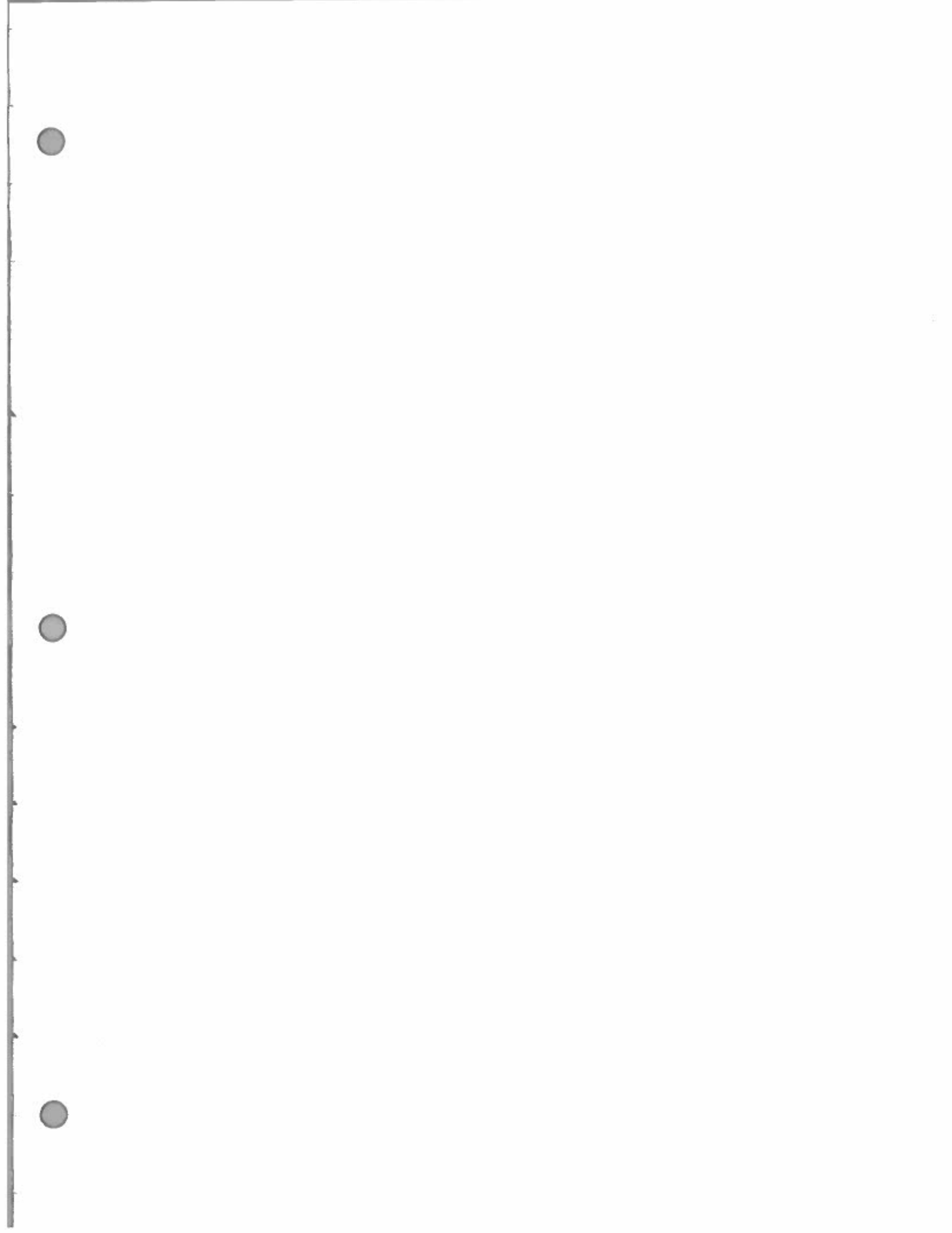
13. Explain how tree rings can be used to study past climates. (3 marks)
14. How does deforestation contribute to the greenhouse effect? (3 marks)
15. When filling a container with a liquid, explain why it is a good idea to leave an air space at the top, especially when storing the container in a warm area. (3 marks)
16. Explain why ground-level ozone is a problem. (3 marks)
17. Explain how climate change can affect food production in North America. (3 marks)
18. Describe two problems coastal cities may face as a result of climate change. (3 marks)

Now go on to Lesson 5. Remember, you do not send your journal to the Independent Learning Centre until you have completed Unit 1 (Lessons 1 to 5).

SNC2D-B



What Can Be Done About Climate Change?



- describe probable impacts of climate change and their chances of occurring
 - assess different viewpoints on the issue and evaluate sources of bias
 - assess initiatives to combat climate change and suggest other possible solutions
- After completing this lesson, you will be able to

What You Will Learn

Suggested Timing for This Lesson (hours)	
Predicting Future Climate	1
Information and Misinformation	1
What Can Be Done About Climate Change?	1
Steps towards a Solution: Global Action	½
Key Questions	1

You may find this time grid helpful in planning when and how you will work through this lesson.

Planning Your Study

So far in this unit, you have learned how the climate system works and how human activities are enhancing greenhouse effects. You have also examined the evidence indicating that climate change is already happening. But how bad can it get? What amount of climate change is possible? What amount is likely?

In this lesson, you will learn how scientists make predictions about future climates, and you will examine some of the controversies around the issue. You will also investigate some possible solutions and the ways that societies around the world are beginning to tackle the problem.

Some people may feel that their actions will not change anything. However, even though the changes made by each individual seem small, they have significant effects when multiplied by millions of people. People have created this problem and people can solve it.

Introduction

Predicting Future Climate

How much will the climate change, given the amount of greenhouse gas in our atmosphere now? What will happen if we add even more greenhouse gases in the future?

These are difficult questions to answer. Reconstructing past climates is hard enough; predicting future ones is even harder. As you've seen, climate depends on many interrelated factors. Scientists are working hard to understand the climate system and predict future climates based on different levels of greenhouse gases in the atmosphere.

Like all science, this process involves collecting and analyzing data, determining relationships, and making predictions. These predictions are then tested against new evidence. If the new evidence doesn't support the prediction, then the scientists collect more data, re-analyze the relationships in the data, and revise the predictions.

This process of science is not controversial. The process of making predictions, testing them, and if necessary revising them based on new data, is called the **scientific method**. This same scientific method has produced medical cures, sent humans into space, and created cell phones. But because climate change is such a political and emotional issue, some people challenge the scientific process behind it.

To understand the controversy, you must know how scientists make climate predictions.

Modelling Climate Change

As the concentration of greenhouse gases increases, the amount of heat trapped by the atmosphere also increases. More heat means more transfer of heat around the globe. The result is climate change. But how much will it change, how fast, and where will the change be most dramatic?

To answer questions like these, **climatologists** (scientists who study climate) use sophisticated computer programs to model the earth's climate. These

computer programs use quantitative methods to simulate the interactions of the atmosphere, oceans, land surface, clouds, and ice.

These computer programs are called models because they represent the structure and function of the process in a simplified way that allows us to examine how the system works. You may be familiar with physical scale models—small versions of a real object. Engineers often build scale models of airplanes and cars to test

out how they might handle before building the real thing. Architects build scale models of proposed buildings to explore how they might look and interact with the surrounding landscape. Computer models perform a similar function. But instead of building a physical object to test out possible scenarios, the computer model uses equations to connect parts of the system.

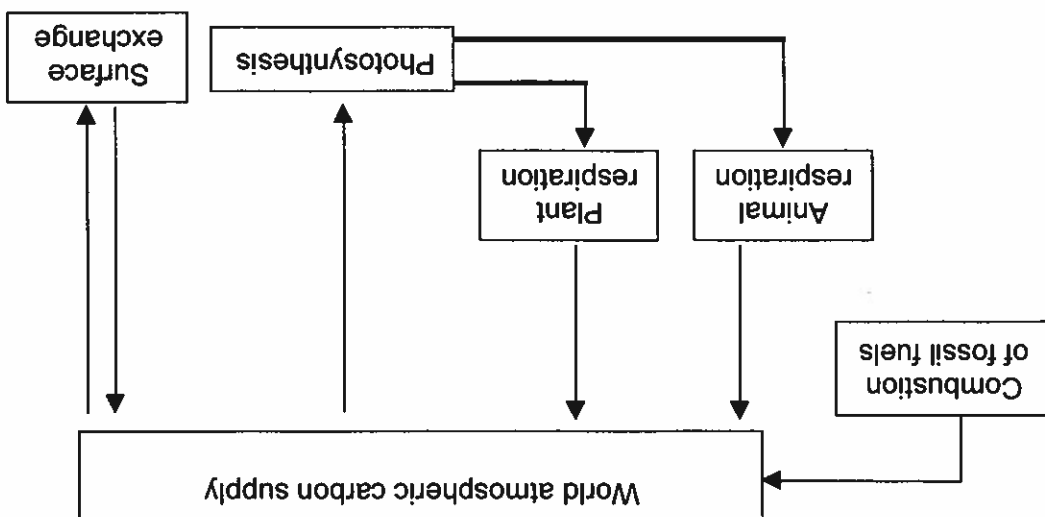


Figure 5.1 Simple computer model of the global carbon cycle

For example, Figure 5.1 represents a simplified model of the global carbon cycle. Each box represents a carbon source or sink, and each arrow represents a flow. In the model, carbon naturally enters the atmosphere through respiration from animals and plants as well as through surface exchange (chemical processes with the rocks, water, and soil). Carbon is removed from the atmosphere by plants during photosynthesis and is also absorbed by some surface materials. Carbon is also now entering the atmosphere through our burning of fossil fuels that used to be stored underground in long-term carbon sinks. Computer models are built using these flowchart structures. Equations are given for each flow rate based on research. The equations make it possible to determine how much the carbon dioxide concentration in the atmosphere will increase, based on changes in the inputs and the amount removed by photosynthesis. Real computer models of the carbon cycle are much more complex than the one above, with each box containing many boxes, and more arrows connecting them.

Computer models are now widely used. They are especially helpful when the system is too complex to be physically built or operates on time scales too long or too short to be easily seen. For example, computer models of hurricane formation help weather forecasters warn residents if a serious storm is likely to be headed their way. Airline pilots train on flight simulators that model what it is like to fly a new airplane so they can learn to handle emergencies without putting real planes and people at risk. When you play any video game, you are actually playing a computer model that simulates the actions in the game. As you know, some of these computer models can create experiences nearly identical to the real thing.

Climate Models

Climate models use computer programs to help us understand how the components of climate will react to changes in the other components. The components are connected using complicated mathematical equations. These equations take into account factors like the amount of each greenhouse gas, the ability of the oceans and atmosphere to store and exchange heat, and the effect of cloud formation on sea ice or evaporation. There are hundreds of variables to consider. Due to the complexity of the calculations, costly advanced computers are required. Using these models, scientists can explore many climate outcomes based on different starting conditions.

It seems hard enough to forecast the weather correctly a few days in advance. So how can climate be predicted 10 or even 100 years in the future? Part of the answer lies in climate being the average of weather conditions over time. Fortunately, it is not necessary to predict future daily weather conditions in order to predict future climate. For a climate model to be successful at making predictions, it must consider the interactions among the many components of the climate system. Modelling these interactions can be complicated because of **positive feedback loops** and **multiple effects**.

Positive Feedback Loops

In positive feedback loops, the effect of a process amplifies that process. In Lesson 3, you saw an example involving water vapour: as the planet warms up, evaporation puts more water vapour into the atmosphere; in turn, this water vapour further warms up the planet.

27. How do changes in the amount of snow cover contribute to rapid climate change in the Arctic?

Do not send your answers in for evaluation.

Support Questions

Sometimes one action can have multiple effects. For example, the average albedo of a snow-covered forest (35%) is about half that of a snow-covered field (70%); the field is nearly completely covered in snow, while many of the dark forest branches are left exposed and can still absorb sunlight. This means that the removal of forests at high latitudes should increase the albedo in winter and so help cool the earth. Some people have even suggested that this is one way to fight climate change.

However, there is more to this story. Trees are carbon sinks because they remove carbon dioxide from the air. If the trees were cut down, more carbon dioxide would be left in the atmosphere and global temperature would increase. So does cutting down the trees cool the air or heat it up? Because both effects happen at the same time, the climate model has to be able to combine the multiple effects of cutting down the trees. And this example involves only two effects from one factor. Often many factors need to be combined, each with its own series of multiple effects. This can make it hard to establish clear cause-and-effect relationships in the model.

Multiple Effects

Another example of a positive feedback loop comes from the albedo produced by snow and ice. The snow on the ground in the Arctic produces an overall cooling effect because it reflects sunlight back into space. However, if an increase in global temperature causes more Arctic snow to melt, then that albedo effect decreases. Also, the exposed ground is darker than the snow, so it absorbs more heat from the sun, causing even more melting. This creates a positive feedback loop: a small amount of melting creates bare ground that causes even more melting. In this way, small changes in the amount of albedo in the Arctic can trigger rapid large-scale changes. Because of these feedback loops and triggers in the climate system, climate models can be very sensitive to small changes in conditions.

28. Describe two features of the climate system that make it hard to develop predictive climate models.

There are Suggested Answers to Support Questions at the end of this unit.

What Makes a Good Climate Model?

Climate models are judged on their ability to represent current climate patterns and match past climate changes. If the model can closely replicate what we know already happened, then we have greater confidence that it can accurately predict what will happen. Though climate models are getting better, they still have some significant limitations. One is the way they model the dynamics of clouds. Clouds are an example of how multiple combined effects plus feedback loops can create complicated situations. The amount of cloud cover depends on many factors, including evaporation, sunlight, ozone features, temperature, and precipitation. But cloud cover can also be involved in feedback loops with each factor, at the same time, each factor is also interacting with the other factors in complex ways. This intertwined series of interactions makes it hard to establish clear cause-and-effect relationships. Because the amount of cloud cover is very important in determining how much radiant energy gets reflected back into space, this complexity leads to larger uncertainties in climate prediction. Despite the difficulties, climate models are powerful tools that are constantly improving. As more information becomes available and faster computers are developed, climate models get better at predicting future climates. This usually means they give a narrower range for their estimates or can predict climate over smaller scales (for example, Southern Ontario vs. Eastern North America). Like a good telescope, a model is considered better if it produces a clearer result. The best climate models available predict that global average temperature will increase approximately 3°C within the next 50 years. The heat will not be spread

evenly over the globe. Tropical regions will experience less heating, while the polar regions may heat up 4 to 5°C. If you want to learn more about climate modelling and explore what future climates may look like, visit Environment Canada's website and follow the links to the Canadian Centre for Climate Modelling.

Support Question

29. Describe two ways to judge the quality of a climate model.

Information and Misinformation

Why the Controversy?

Climate change is one of the most important environmental issues facing society today. To solve it, we will have to reduce our use of fossil fuels and switch to alternative energy sources. This will probably cost money, at least in the short term. Because this is a serious environmental issue, there is public passion, and because there is a lot of money involved, there is politics. When passion, politics, and money meet science, the result is often controversy.

As with all scientific analyses, scientists use climate models to predict climate change within a range of estimates (sometimes called a confidence interval). Some people argue that having a range of estimates means the science behind the models isn't very strong because they can't predict exactly what will happen. This is not true. Scientists always report a confidence interval around their predictions. Only if the interval is very large does it mean that the model is not much good at making predictions. As more research is done, the climate models improve; the boundaries around their predictions are getting smaller with every new analysis. Another reason some people doubt the existence of climate change is that climate varies naturally. They argue that whatever climate change we are experiencing now is only part of a natural cycle, so we don't have to take any expensive action.

Reliable Sources of Information

This is a healthy debate, and one that objective scientific investigation can resolve. But this debate is no longer confined to just the scientific community. Because this is such an important issue with economic, social, and political consequences, the debate is being carried out on TV talk shows, in political campaigns, at work, and within families. So much information and misinformation is being spread around that it is not easy to get the facts straight.

There is a lot of scientific work being done on climate change. Most of it is published in technical journals that the general public doesn't read. To provide an authoritative source of information on climate change science that is available to everyone, in 1988 the United Nations set up the **Intergovernmental Panel on Climate Change (IPCC)**. The IPCC is a scientific intergovernmental body run by the World Meteorological Organization (WMO) under the United Nations Environment Programme (UNEP). The IPCC is made up of scientists from around the world who summarize the best available scientific research and then prepare status reports on the state of global climate change.

The IPCC publishes updates and small reports on developments in climate change several times each year. About every five years, the IPCC releases large status reports called Assessment Reports that summarize all the climate change science known to that point. The IPCC's most recent Assessment Report was released in 2007 (called the "Fourth Assessment Report" or "AR4"). This report conclusively states that climate change in recent decades is not a natural occurrence, but rather the result of human activity. The report is very detailed and is available for free on the Internet (search using keywords such as "IPCC assessment reports").

For its efforts, the IPCC was awarded the 2007 Nobel Peace Prize, shared with former U.S. Vice-President Al Gore for his work on climate change and the documentary *An Inconvenient Truth*.

Are Scientists Undecided?

Scientific organizations, like the Canadian Meteorological and Oceanographic Society and the Canadian Foundation for Climate and Atmospheric Sciences, agree with the IPCC's conclusion that climate change in the last 50 years is mostly the result of human activity. But do all scientists agree? Some in the media have tried to show that climate change is very controversial in the scientific community, with little agreement about its causes or impacts. They argue that until the scientists reach consensus, there is no point taking expensive actions that may not be justified. But how divided is the scientific community on this issue?

One scientist, Dr. Naomi Oreskes of the University of California, decided to take a scientific approach to answering this question. She reviewed the 928 research articles on global climate change that were published in major scientific journals between 1993 and 2003. She wanted to see how many scientific articles disagreed with the view that human activity is causing climate change. If there really were a scientific controversy, it would show up in the journals.

She reported the results of her study in an article she wrote in 2004 entitled “Beyond the Ivory Tower.” In her study, she found that *no* scientific articles disagreed with the view expressed by the IPCC that the climate warming is mainly the result of human activities.

Scientists may disagree on exactly how much climate change will happen over the next 100 years, but all agree that humans are responsible for it. So there is no scientific controversy, despite what some journalists, politicians, and business groups may be telling you.

If the scientists are in agreement, why do we hear media reports of a controversy? Some of this is due to misinformation supplied by groups with a political agenda. For example, some organizations have hired lobbyists to provide the media with stories that suggest climate-change science is controversial. Such media releases are one source of confusion. Web blogs, political campaign ads, and reports from “think tanks” can also spread misinformation. It is important to be sceptical of all information and always consider its source, especially with an issue as politically charged as climate change.

Support Question

30. What is the main conclusion reached by the Intergovernmental Panel on Climate Change (IPCC) regarding the cause of recent climate change?

What Can Be Done About Climate Change?

About 30 gigatonnes (equals 30 billion tonnes) of carbon dioxide are released into the atmosphere by the burning of fossil fuels each year. That works out to an average of about five tonnes per person on earth.

It is predicted that the carbon dioxide level currently at 385 ppm will reach 550 ppm around the year 2050. Depending on population and economic growth, it could even exceed 1000 ppm by the year 2100. Remember that the ice-core data show the level has not been higher than about 300 ppm for hundreds of thousands of years. These new levels could push the climate into conditions never experienced before.

In order to decrease the amount of carbon dioxide released, we need to decrease the use of fossil fuels. Once the amount of carbon dioxide released is reduced, it will take time for the natural carbon cycle to remove the excess carbon dioxide from the atmosphere. It has been estimated that it would take approximately 50 years for half of the extra carbon dioxide to be absorbed. The climate system is capable of healing itself, given time. But to allow this to happen we have to stop adding carbon to the atmosphere.

Reducing Carbon Dioxide Emissions

How can we reduce the amount of carbon dioxide and other greenhouse gases put into the atmosphere? Here are some of the main approaches.

Energy Efficiency

If we use energy more efficiently, less fossil fuel is needed to meet our energy needs. Burning less fossil fuel means the amount of carbon dioxide entering the atmosphere does not rise as quickly. Improvements in energy efficiency come from hundreds of innovations available today. They not only reduce the amount of greenhouse gas produced, but also usually save money. Ways to conserve energy include

- using fluorescent light bulbs to reduce the electricity required for lighting
- improving insulation for houses and commercial buildings to reduce the amount of fossil fuels required for heating and cooling
- driving more fuel-efficient cars
- making more efficient power plants

The biggest contributors to carbon dioxide emissions are power plants and transportation. For example, in 2000 the power plants using coal produced about 25% of all global carbon emissions. Substituting natural gas or nuclear for coal power plants could reduce the amount of carbon emissions per unit of electricity by half. Any efficiency gains here will have significant benefits.

The easiest way to be energy efficient is to stop wasting energy when it isn't required. Little things like turning off lights and computers when you no longer need them, using less air conditioning, and driving less can all add up to significant energy savings.

Renewable Energy

Switching to renewable forms of energy will decrease the use of fossil fuels. Sources of **renewable energy**—such as solar, wind, tidal, hydroelectric, biomass, and geothermal—can be used to produce electricity and heat energy with no net increase in atmospheric carbon dioxide. All these renewable energy technologies are available today and are continually being improved.

These forms of energy are called renewable because their source of the energy is constantly being replaced. Non-renewable sources, like the fossil fuels created millions of years ago and the uranium mined for nuclear reactors, get used up and are not replaced.

No single renewable energy system has proven it can completely replace the energy provided today by fossil fuels. Probably many renewable energy sources will be used. In future, you may have solar panels on the roof of your house and car, a wind generator nearby, and a furnace using heat from the ground.

Biofuels (such as ethanol) produced from non-food plant products could also be used. Even though burning biofuels releases carbon dioxide, there is no net increase in the atmosphere because the plants used to create the biofuel pulled the same amount of carbon dioxide out of the atmosphere for their growth.

Increase the Number of Trees

Trees remove carbon dioxide from the atmosphere as they grow and store the carbon in long-term sinks in their wood. Adding more trees will help bring down the levels of CO_2 in the atmosphere. Unfortunately, today humans are cutting down more forests than ever, especially in the tropics. This deforestation reduces the carbon dioxide being removed from the atmosphere, and the burning of the wood adds significant amounts of new carbon dioxide.

The solution is to decrease deforestation and plant new trees to speed up the removal of carbon dioxide. Canadians have a large role to play in this because our Boreal Forest ecozone is one of the largest areas of intact natural forest left in

the world. It will need greater protection from development to continue to be an effective carbon sink.

Carbon Capture and Storage

Carbon capture and storage (CCS) is an experimental technology that promises to prevent about 90% of the carbon dioxide released from fossil fuels from reaching the atmosphere. The CO₂ is captured after the fuel is burned. It is compressed and then stored deep underground in the same places that hold natural gas and oil. The hope is that it will remain trapped there for thousands of years. However, this technology has yet to be proven and no one knows yet how much it will cost to remove and store the CO₂.

Support Questions

31. Explain why solar, wind, and tidal are considered renewable energy sources while fossil fuels are considered non-renewable.

32. It is expected that there will be two billion cars in the world by 2050 (roughly four times as many as today). If cars still use gasoline as the fuel, what can the car makers do to reduce the carbon dioxide emissions?

What Can You Do?

The carbon dioxide problem can only be solved by everyone working together, from governments and industry down to the level of the individual. You may not think you can do much about this problem, but when you multiply each person's contribution by the population, the effects become significant.

The first thing to do is to become aware of how much carbon dioxide your activities release. Once you know how much you are responsible for and where it comes from, you can start taking action to reduce it.

A **carbon footprint** is one way to measure your impact on climate. It is an indicator of the amount of greenhouse gases each of your main activities produces. It is often measured in kilograms (or tonnes) of carbon dioxide emissions. It's called a footprint because it's like the mark you leave on earth as you go about your daily activities. When you walk on a sandy beach, you leave a footprint. When you participate in an activity or use an item that emits greenhouse gases, you leave behind a carbon footprint. By reducing the energy requirements in those areas, you can leave a smaller footprint.

Many websites help you to calculate your carbon footprint. Use an Internet search engine and keywords like "carbon footprint calculator." For most Canadians, the three major contributors to their footprint are transportation, home heating, and electricity. That means the car, furnace, and major household appliances like refrigerators, clothes driers, and ovens contribute the most.

Canadians have one of the largest carbon footprints in the world, partly because we live in a cold climate and use fossil fuels for heating. But our high standard of living is also very dependent on fossil fuels. For example, when you buy fresh fruit in winter or a bag of ice in summer, a lot of fossil fuels were used to create, transport, and store these products.

To conserve energy at home, look at heating (furnace) and cooling (air conditioner) since they are the major users of energy. Hot water heating also uses a significant amount of energy. Adjust your thermometer settings to keep your room a bit cooler in winter and a bit warmer in summer. Even a difference of 1 to 2°C can add up to significant energy savings.

Next look at your major appliances. Whenever you get a new appliance, make sure it is energy efficient. New refrigerators, for example, use 40% less energy than models made just 10 years ago. Replacing incandescent bulbs with compact fluorescents can save you 60% of the energy used for lighting.

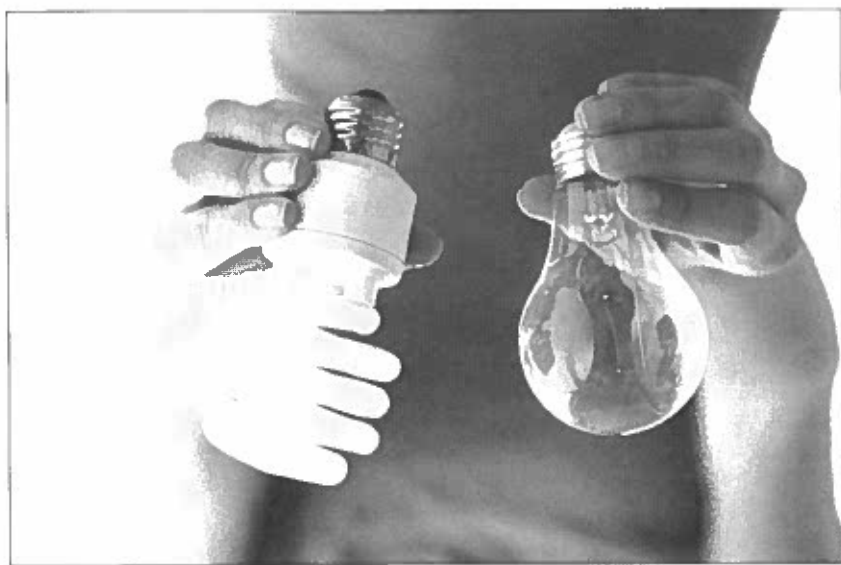


Figure 5.2 Replace old-style incandescent light bulbs with energy-efficient compact fluorescent bulbs.

Source: iStockphoto.com

Planting a tree helps remove carbon dioxide from the atmosphere. A single tree will absorb one tonne of carbon dioxide over its lifetime, and the shade it provides can reduce the air conditioning requirements of a house by 10%.

Support Questions

33. Do you think that everyone on earth has about the same size of carbon footprint? Explain your reasoning.

34. Suggest two ways you could reduce your carbon footprint.

Steps towards a Solution: Global Action

Climate change is a global problem requiring a global solution. Because the atmosphere flows everywhere on the planet, places that don't produce a lot of carbon dioxide still experience the problems it causes. The international nature of the problem was recognized decades ago. Since the 1980s, international meetings sponsored by the United Nations have been examining the problem and proposing solutions.

One of the most famous proposals came out of a UN-sponsored conference in 1997 in Kyoto, Japan. An agreement among the leading industrialized nations, the **Kyoto Protocol** called for every industrialized nation to reduce its output of greenhouse gas emissions by 6% below their 1990 levels by 2012. Canada signed this agreement, but the federal government has recently admitted that there is no way it can meet its target. In fact, both Canada and the United States are now emitting greenhouse gases at much higher rates than they were in the 1990s, so meeting the reduction targets is getting harder every year.

Despite the Kyoto Protocol's failure to reduce greenhouse-gas emissions, there are signs of progress. In the 1980s and 1990s, many governments and businesses simply denied that the problem was real and urgent. This frustrated the climate scientists and voters concerned about the issue. Now most governments and businesses recognize the problem and are developing policies to deal with it. But time is running out and it may already be too late to stop some of the impacts of climate change. The hope is that we can stabilize carbon dioxide levels before they reach critically dangerous levels.

In Canada, both the federal and provincial governments have recently adopted policies to address the causes of climate change. Most of these are related to reducing energy consumption. For example, some promote the international ENERGY STAR program. The ENERGY STAR symbol helps consumers select appliances that use less energy.

Governments around the world are promoting energy efficiency, developing renewable energy sources, and creating economic incentives for people and businesses to move away from fossil fuels. To find out what your government is doing about the issue, do an Internet search using terms like "climate change," and "renewable energy" combined with the name of your government. Most governments now have several websites devoted to their programs and policies concerning climate change.

Conclusion

In this lesson, you learned how both science and society are dealing with the issue of climate change. You learned how climatologists use computer models to predict the consequences of increased greenhouse gases in the atmosphere. You also learned of some potential strategies for reducing carbon dioxide emissions and ways to remove CO₂ permanently from the atmosphere. But the issue is not just confined to science.

In order for society to act on solutions to climate change proposed by the scientists, it must first recognize the problem. Then people must be willing to face the potential costs and risks involved with switching to alternative energy sources. These changes in attitude and behaviour are not easy, and many people are resistant. As a result, there has been much misinformation and bias surrounding the debate.

Fortunately, the controversy around the existence of climate change is beginning to die down. Governments and businesses around the world now recognize the problem and are working towards solving it. You also have an important role to play in this solution. Changes you make in your daily life can and will make a difference.

Key Concepts

Scientific method: the process of making predictions, testing them, and revising them if necessary

Climatologist: a scientist who studies climate

Climate model: a climate system represented by mathematical equations to simulate what happens as different factors of the climate are changed

Positive Feedback Loop: occurs when the effect of a process amplifies that process. For example, excess carbon dioxide in the atmosphere causes Arctic permafrost to melt, which causes the release of more carbon dioxide, which causes even more warming to occur, which melts even more permafrost.

Multiple effect: one action producing two or more effects that combine in ways that make prediction difficult

IPCC: Intergovernmental Panel on Climate Change. A scientific intergovernmental body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP) to investigate climate change

Renewable energy: a source of energy that does not run out. Examples include solar, wind, tide, and hydroelectric.

Carbon footprint: the amount of carbon dioxide produced by a person or group as a result of normal activities

Kyoto Protocol (or Accord): an international agreement made in 1997 that requires industrialized countries to cut emissions of carbon dioxide and other greenhouse gases

Key Questions

Save your answers to the Key Questions in your
Course Journal or e-Journal.

Total: 17 marks

19. Using one paragraph for each, briefly explain the terms “positive feedback loop” and “multiple effects” and how they can affect the predictability of climate models. Provide one example for each.
(6 marks: 3 marks for each term)

20. In one sentence, describe what the Intergovernmental Panel on Climate Change (IPCC) has said about the cause of climate change in the last 50 years. (2 marks)

21. People in Canada have one of the highest carbon footprints in the world. Suggest four ways individual Canadians can reduce it.
(4 marks: 1 mark for each way)

22. List four sources of renewable energy. (4 marks: 1 mark for each example)
23. Why is uranium, the fuel used in nuclear power plants, considered to be a non-renewable resource? (1 mark)

This is the last lesson in Unit 1. When you are finished, do the Evaluation work in your Course Journal or e-Journal for Unit 1. Follow any other instructions you have received from ILC about submitting your journal, then send it to ILC. A teacher will mark your work, and ILC will send it back to you as soon as possible.