Section 8.1 Energy Transfer in the Climate System

(Student textbook pages 311 to 322)

Specific Expectations

- **D1.1** analyse current and/or potential effects, both positive and negative, of climate change on human activity and natural systems
- **D2.1** use appropriate terminology related to climate change, including, but not limited to: *anthropogenic, atmosphere, carbon footprint, carbon sink, climate, greenhouse gases*, and *hydrosphere*
- **D2.4** investigate a popular hypothesis on a cause-and-effect relationship having to do with climate change, using simulations and/or time-trend data that model climate profiles
- **D2.5** investigate, through laboratory inquiry or simulations, the effects of heat transfer within the hydrosphere and atmosphere
- **D2.7** investigate, through research or simulations, the influence of ocean currents on local and global heat transfer and precipitation patterns
- **D3.1** describe the principal components of Earth's climate system and how the system works
- **D3.2** describe and explain heat transfer in the hydrosphere and atmosphere and its effects on air and water currents
- **D3.4** identify natural phenomena and human activities known to affect climate, and describe the role of both in Canada's contribution to climate change

In this section, students will learn about the major parts of Earth's climate system and how these parts interact in a series of feedback loops. Students will also learn about heat transfer between and among the different parts of the system, and consider Earth's energy budget. Students will explore climate events, such as El Niño and La Niña, as examples of heat transfer among systems.

Common Misconceptions

- Students may have difficulty recognizing the difference between closed and open systems, because many closed systems (such as a greenhouse) become open systems as soon as something is added or removed from inside. For example, the global system is the largest closed system, but it becomes an open system when spacecraft exit and meteors (and other debris) enter Earth's atmosphere.
- Students may note that the temperature is cooler when the Sun is not shining directly. However, this change in temperature is relatively small and is buffered by the temperature of the atmosphere. In comparison, the Moon does not have an atmosphere to hold in heat. The Moon's daily temperature reaches a high of 135°C and a low of −170°C.

Background Knowledge

The true definition of a closed system is one that is completely isolated from all other systems. This is a theoretical assumption, because no system can truly be isolated. However, the definition of a closed system as used here (where energy but not matter can be exchanged) is an idea from physics.

A global system includes those interrelated items, events, and forces that have a global or worldwide impact. The biosphere is the global system that includes all life on Earth. Some scientists define the biosphere as the regions of Earth inhabited by organisms, while others use a narrower definition and consider the biosphere to be made up of only Earth's living organisms themselves.

One of the most significant challenges of understanding climate change is quantifying and accurately predicting feedback loops. Both positive and negative feedback loops permeate every aspect of climate processes, and they are a major source of uncertainty. As with other climate features, very large-scale predictions of feedback loops (as shown in the student textbook) are possible, but smaller regional results are very hard to predict.

The temperature of ocean currents is a direct result of the varying quantity of solar heating around the globe. Because the equatorial regions consistently receive the most sunlight, they are the warmest. This, coupled with the prevailing winds, leads to the ocean currents described in Chapter 7.

The thermohaline circulation system is sometimes called the "Great Ocean Conveyer." In the 1980s, Wallace Broecker of Columbia University first recognized that changes in this conveyor could explain some of the great historical climate change mysteries, such as the sudden climate changes seen at the end of the last ice age. His studies indicate that large changes in thermohaline circulation may be triggered by the warming of Earth's atmosphere.

The density of seawater increases with temperature to a maximum of −2°C, which is its freezing point. The layers of warmer, less dense water and colder, more dense water are sharply separated at a transition called the thermocline. The salinity of the surface layers of water is increased via evaporation, but decreased by adding freshwater through rain or run-off.

The Sun is the only input of energy to Earth. It powers weather systems (allowing for wind power), provides energy for photosynthesis (allowing for storage of harvestable energy in fossil fuels and biomass), and powers the hydrologic cycle (allowing for hydroelectric power). The only forms of harvestable alternative energy not directly related to solar energy are tidal power (powered by the Moon's gravity), and geothermal energy (powered from Earth's molten core).

Literacy Support

Using the Text

- Students will be learning new concepts and Key Terms as they read this section. To keep track of this new information, encourage students to effectively organize it. They can make brief notes about what they have read. Have them identify the main ideas and state them in their own words.

Before Reading

- Have students flip through the section to preview the text features and the headings. Have them look at the Key Terms and consider if they are already familiar with any of the words. This will help them identify the main ideas in the section.
- ELL To help English language learners use the text features to navigate the section, have a scavenger hunt. Ask students to find a feature that
  - helps to explain the meaning of a word (boxes in the margin)
  - explains a diagram (a caption)
  - tells a big idea (a head or subhead)
  - summarizes important information (the section summary)

During Reading

- Have students work in pairs and check each other's comprehension. Have them stop at every subsection and ask each other two questions about the content. Once they agree on the best answer for each question, they can proceed to the next subsection of text.
- Have students compile a list of questions as they read the text. This will help focus their reading and will serve as an organizer for information they still need to learn.

After Reading

- To consolidate their learning, have students create a graphic organizer to show the relationship between two key concepts they learned about in the section. They can use this organizer as a starting point for the graphic organizer they develop in the Chapter Review. Provide students with **BLM G-41 Cause-and-Effect Map, BLM G-42 Concept Map, BLM G-43 Flowchart, BLM G-44 Main Idea Web, BLM G-45 Spider Map** or **BLM G-47 Venn Diagram**.

Using the Images

- DI Encourage spatial learners to summarize the illustrations throughout the section as a preview to the material.
- Have students look at the photos in Table 8.1. Ask students to think of other types of photos that could have been used to illustrate each of the three types of energy transfer.
- Use Figure 8.8 to illustrate the fate of the spectrum of energy reaching Earth. Depending on the wavelength of the energy, the light will be reflected, absorbed or emitted.

Assessment FOR Learning		
Tool	**Evidence of Student Understanding**	**Supporting Learners**
Learning Check, pages 314, 317	Students explain why Earth is considered a close system. They provide examples of feedback loops. Students describe processes by which heat is transferred. Answers to question 2 on page 314 will be based on information in Figure 8.3. Look for paraphrasing or summaries of the information. Answers to question 4 on page 314 may include simple feedback loops (for example, the Sun came out and I took off my sweater) or they may show multiple steps.	Allow students to answer the questions using alternative methods of presentation (i.e., using diagrams, models or manipulatives). For example, allow students to make models or use manipulatives to show their understanding of question 2 on page 314. Provide students with **BLM 8-2 Climate Feedback Loops.**
Activity 8-2 What Heats the Atmosphere?, page 315	Students calculate changes in temperature of the air and soil, and use their calculations to correctly identify that Earth's surface heats Earth's atmosphere more than the Sun does. They explain how the results would differ if the air were over water or ice instead of soil.	Students may benefit from using the Math Skills Toolkits in the student textbook appendix when calculating their answers.
Section 8.1 Review Questions, page 322	Answers demonstrate an understanding of the components of Earth's climate system, feedback loops, thermal energy transfer, thermohaline circulation, El Niño and La Niña events, and Earth's energy budget.	Provide students with the opportunity to make models or use other manipulatives to demonstrate their understanding. Use **BLM A-40 Scientific Drawing Rubric** to assess students' answers to question 4.

Instructional Strategies

- DI Have students complete **BLM 8-3 Thermal Energy Transfer.** Students could also perform skits to demonstrate different types of energy transfer.
- ELL Use a variety of concrete and visual aids to help with this material. Models and manipulatives will be helpful to all students.
- Enrichment—Students can complete **BLM 8-4 Thermohaline Circulation** to research and then illustrate what happens to the water at the points where it sinks or rises. Use **BLM A-40 Scientific Drawing Rubric** to assess students' work.
- Remind students that Earth is a system of interrelated parts, including the atmosphere, hydrosphere, biosphere, and geosphere (or lithosphere). As a class, construct a model biosphere using a small terrarium or aquarium. The components of the model will include an energy source (for example, light), an atmosphere (trapped gases in the container), a lithosphere (for example, soil or rocks), a hydrosphere (water vapour, condensation, trapped water in the geosphere, etc.), and a biosphere (plants and/or animals). Students can observe events over the course of the unit. Challenge them to discuss what makes it an open versus a closed system. Unless you can make a model that takes ethical treatment of animals into account, do not use them, arthropods included. Provide students with **BLM G-17 Using Models and Analogies in Science**.
- Have students use **BLM 8-5 Heating the Air** to help them summarize the mechanisms that heat the atmosphere based on information in the figures and text.
- To demonstrate specific heat capacity, leave a few substances of similar mass in the Sun, or in a bath of ice water. Be sure that both objects have surfaces that absorb energy to the same extent. After a few minutes, substances with a low specific heat capacity will have temperatures close to their surroundings. Substances with a high specific heat capacity will take longer to approach the temperatures of their surroundings.

- To demonstrate that visible and infrared light, have different transmission capabilities, use a remote control device that uses infrared light (test this in advance to ensure the remote is using an infrared signal). Turn the television on and off with the remote control. Infrared waves are transmitted through the air. Place a glass of water in front of the sensor and attempt to turn on the television. The television will not respond because infrared waves are absorbed by water just as they are by the water droplets in Earth's atmosphere.
- Have students compare the illustration of thermohaline currents (deep currents) with the illustration of surface ocean currents shown in Chapter 7. Have them consider how these two systems work together to move water and heat around Earth.

Activity 8-2 What Heats the Atmosphere? (Student textbook page 315)

Pedagogical Purpose

Students perform calculations to investigate the amount of energy that reaches Earth and its effect on temperature.

Planning	
Time	20–30 min

Background

Specific heat capacity is the amount of heat required to raise the temperature of 1 g of a substance by 1°C. The specific heat capacity of different substances is variable. Water has one of the highest specific heat capacities, meaning it takes a relatively long time to heat up and cool down. Water, both as liquid and as vapour in clouds, can sometimes move from one location to another far faster than it can change temperature.

The atmosphere, land and water are differentially heated by the Sun because of their ability to absorb energy. The atmosphere does not readily absorb heat directly from the Sun, but heats primarily as the result of conduction and radiation from the land or the water beneath it. The albedo of a landform or water will determine how much heat it absorbs and can eventually transfer to the air above it.

Activity Notes and Troubleshooting

- Specific heat capacity is a universal phenomenon, but students may have difficulty grasping that different substances have different specific heat capacities.
- Circulate amongst students as they work on the activity, in case students have difficulty with beginning the calculations.
- Write the formula $Q=mc\Delta T$ at the front of the class. Discuss strategies for using this equation, including how to identify the different variables and how to rearrange the equation before substituting numbers for variables.
- Remind students that they will have to convert units. You may need to quickly review how to convert seconds to hours, for example.

Additional Support

- DI Have students work in pairs or groups if they are too challenged by the math. Ensure that the logical-mathematical learners are distributed among the groups.
- DI Encourage students who are having difficulty to ask for assistance from peers, particularly if they are not working in groups or if there is not a logical-mathematical learner in their group.
- Have students explain verbally what they are to do, to ensure comprehension.
- Use the sample equation at the front of the class as a visual support for students.
- Provide students with **BLM G-38 The Metric System and Scientific Notation** and **BLM G-39 Significant Digits and Rounding** for support.

Procedure Answers

1. Energy $= 1367 \frac{\text{J}}{\text{m}^2\text{s}} \times \frac{1.0 \text{ h}}{1} \times \frac{3600 \text{ s}}{\text{h}}$
   $= 492120 \frac{\text{J}}{\text{m}^2\text{s}}$
   $\approx 4.92 \times \frac{10^6 \text{ J}}{\text{m}^2\text{s}}$
2. Energy absorbed by the atmosphere $= 0.19 \times 4.921 \times \frac{10^6 \text{ J}}{\text{m}^2\text{s}}$
   $= \frac{93503 \text{ J}}{\text{m}^2\text{s}}$
   $\approx 9.4 \times \frac{10^5 \text{ J}}{\text{m}^2\text{s}}$
3. Energy absorbed by the atmosphere $= 0.51 \times 4.92120 \times \frac{10^6 \text{ J}}{\text{m}^2\text{s}}$
   $= 2.5098 \times \frac{10^6 \text{ J}}{\text{m}^2\text{s}}$
   $\approx 2.5 \times \frac{10^6 \text{ J}}{\text{m}^2\text{s}}$
4. $Q = mc\Delta T$
   $\Delta T = \frac{Q}{mc}$
5. (a) Assuming it is for the entire column (10 000 kg, or 1.0×10^7 g), the increase in air temperature is:
   $\Delta T_{air} = \frac{Q}{mc}$
   $= \frac{93503 \cancel{\text{J}}}{(1.0 \times 10^7 \cancel{\text{g}})}(1.00 \cancel{\text{J}}/\cancel{\text{g}}°\text{C})$
   $= 0.093503°\cancel{\text{C}}$
   $\approx 0.094°\text{C}$

   (b) For the 150 kg (150 000 g) of soil:
   $\Delta T_{soil} = \frac{Q}{mc} = 2.5098 \times \frac{\cancel{10^6}\text{J}}{(1.5 \times \cancel{10^6} \text{ g})}(0.8\cancel{5}\text{J}/\text{g}°\text{C})$
   $= 19.968°\text{C}$
   $\approx 20°\text{C}$

Answers

1. The soil warmed to about 20°C. The atmosphere only warmed by less than 0.1°. The atmosphere warmed more by absorbing heat at the surface than by absorbing solar energy directly. These numbers are fairly accurate for incoming solar radiation.
2. Water has a much higher albedo that soil, so it would likely reflect much of the solar energy back to the air. Consequently, the increase in the temperature of water would be less than for soil.

Learning Check Answers (Student textbook page 314)

1. Earth is considered a closed system because although solar energy can enter and heat can leave, only a very small amount of matter can enter or leave.
2. An example of a negative feedback loop occurs when an increase in global warming leads to an increase in evaporation of water, which leads to an increase in cloud cover and an increase in albedo, and, finally, to a decrease in global warming.
3. In a positive feedback loop, each factor strengthens the effects of the next. For example, small changes in climate can lead to larger and larger changes until the system achieves a new balance.
3. It is a positive feedback loop because each factor strengthens the effects of the next.
4. Answers may vary. Example: When my body is cold, I shiver, which burns energy, creates heat, and warms my body. This is a negative feedback loop.

Learning Check Answers (Student textbook page 317)

5. Conduction involves the transfer of thermal energy between two objects that are in direct physical contact. Convection is the transfer of thermal energy by molecules moving from one place to another. It can occur in liquids or gases, but not solids.
6. Example: Solar energy produces wind, causes evaporation and precipitation, drives ocean currents, and powers photosynthesis.
7. Heat is transferred in the atmosphere by conduction, convection and radiation. In the ocean, energy is transferred as water moves as a result of density differences that are caused by differences in the temperature and salinity of ocean water.
8. Energy could reach your hand directly via radiation or conduction because the air that is in contact with the stove would warm up. It could also heat your hand by convection because the air would move upward to your hand.

Section 8.1 Review Answers (Student textbook page 322)

Please also see **BLM 8-6 Section 8.1 Review (Alternative Format).**

1. atmosphere, hydrosphere, living things, rocks
2. As polar ice melts, ice and snow are replaced by water and rock. The water and rock have lower albedos, so they will absorb more energy, causing them to warm more rapidly. This energy, in turn, would cause more melting, which causes more ice to melt, lowering the polar albedo, causing more energy to be absorbed.
3. Earth absorbs ultraviolet light, visible light, and infrared energy, but it emits only infrared light.
4. Student answers should illustrate the sinking and rising of cold, salty, deep currents and warm, less salty, surface currents.
5. During an El Niño event, winds blowing west become weaker and can reverse. Warm waters in the western Pacific move eastward and this prevents cold water from upwelling. Global weather patterns change as a result.
6. El Niño and La Niña illustrate what happens when feedback loops of the ocean-atmosphere system are disrupted. Changes to the temperature of the ocean surface in the Pacific Ocean impact the transfer of thermal energy and climate change.
7. The oceans have a greater mass than the atmosphere, and the water in the oceans absorbs more energy than the gases in the atmosphere do.
8. Earth's energy budget is a balance between incoming and outgoing energy. To maintain a stable average global temperature, it must be balanced. Humans have introduced more greenhouse gases into the atmosphere. increasing the amount of thermal energy the atmosphere can absorb. Some of this thermal energy will return to the Earth's surface, increasing the average global temperature of Earth.