

Living Physical Geography Instructor's Manual

PART I

Atmospheric Systems: Weather and Climate

PART SUMMARY

Part I consists of six chapters:

- Chapter 2 Portrait of the Atmosphere
- Chapter 3 Seasons and Solar Energy
- Chapter 4 Water in the Atmosphere
- Chapter 5 Atmospheric Circulation and Wind Systems
- Chapter 6 The Restless Sky: Severe Weather and Storm Systems
- Chapter 7 The Changing Climate

As a whole, this part provides thorough treatment of Earth's atmosphere and its weather and climate systems. The chapters are sequenced logically, cumulatively building on one another to provide a firm foundation in atmospheric science.

Chapter 2 provides an introduction to the atmosphere's chemistry, structure, and main pollutants. Chapter 3 delves into seasons and the energy budget resulting as Earth absorbs the Sun's radiation. Chapter 4 explores water in the atmosphere and the importance of water vapor. Chapter 5 builds on the previous chapters and introduces pressure gradients and resulting wind. This chapter uses the knowledge from previous chapters to explore wind systems. Chapter 6 is a culminating chapter where the basic building blocks presented in the previous chapters are applied to understand storm systems. Chapter 7 reports on the current scientific understanding of climate change, both natural and anthropogenic.

TEACHING CONTEXT

This is one of four parts in *Living Physical Geography*. The parts are based on energy flow in Earth's systems. All chapters in Part I have in common the theme of solar energy moving through and doing work on the atmosphere.

TEACHING TIPS

- One of the main challenges of teaching physical geography in a single semester or quarter is to select what to include and what to skip. It's simply not possible to cover everything. The atmosphere is the largest and perhaps most complex of the four parts of *Living Physical Geography*. There are two approaches to addressing this problem: teach a few topics in depth or teach many topics superficially. Either approach has its strengths and weaknesses. A strength of teaching a few well-chosen topics in depth is that the instructor can develop a sensible narrative that gives students a good (but incomplete) understanding of Earth's atmosphere. One of the pitfalls of teaching many topics quickly is that it can be difficult for

the instructor to create a context for the topics, and the material may be perceived by students as a laundry list of disarticulated facts.

- At a minimum, students should understand the chemical and physical structure of the atmosphere, the greenhouse effect (both natural and anthropogenic), how precipitation forms, why the wind blows, and global air circulation and precipitation patterns.
- Students generally enjoy learning about tornadoes and hurricanes. If possible, devote one or two lectures to these topics, using them to apply and reinforce material learned in earlier chapters.
- Students should have a firm grasp of the basic elements of anthropogenic climate change (Chapter 6). Students should understand the physical process causing it and the seriousness of the situation.

CHAPTER 2

Portrait of the Atmosphere

CHAPTER SUMMARY

This chapter provides an overview of the chemistry and structure of the atmosphere. Air pollution and the ozonosphere are major units in this chapter as well. The chemistry of the atmosphere can be broken down into two categories: permanent gases and variable gases that act as greenhouse gases. Over 99% of gases in the atmosphere are permanent gases, primarily nitrogen (78%) and oxygen (21%). The importance of the permanent gases is mainly that they create most of the mass and pressure of the atmosphere, and oxygen is essential for respiration.

The variable gases that act as greenhouse gases form the remaining 1% of atmospheric gases. Although they occur in minute amounts, greenhouse gases are particularly important because they regulate the atmosphere's temperature. Greenhouse gases absorb and emit longwave radiation emitted from Earth's surface. In so doing, they delay the heat loss from Earth's surface, keeping the atmosphere far warmer than it would be without them.

The atmosphere's pressure comes from the weight of the gases in the atmosphere. The weight of the atmosphere compresses the gases nearer the surface. Much like compressed air inside a car tire, as the air becomes more compressed the air pressure increases. The highest air pressure, therefore, is near Earth's surface, where it is most compressed.

The structure of the atmosphere consists of four major layers: the troposphere, the stratosphere, the mesosphere, and the thermosphere. Each of these layers is identified by how temperature changes with changes in altitude. In the troposphere and mesosphere, temperature decreases as altitude increases. In the stratosphere and thermosphere, the opposite is true. The troposphere is the most immediately important layer, as it is where all Earth's weather occurs and it is the layer we live in. The stratosphere plays the vitally important role of blocking harmful UV radiation from the Sun.

Human activity creates air pollutants that can be harmful to human health. Air pollutants can be divided into primary and secondary pollutants. Primary pollutants, like carbon monoxide and sulfur dioxide, are emitted directly from a source, such as a car or smokestack. Secondary

pollutants, such as ground-level ozone, are a by-product of chemical reactions of primary pollutants. One class of ozone-depleting pollutants, called chlorofluorocarbons or CFCs, threatens the ozonosphere, our protective shield from UV radiation. This problem was successfully addressed with ratification of the Montreal Protocol.

TEACHING CONTEXT

The purpose of this chapter is to provide a general introduction to fundamental aspects of the atmosphere—its chemical composition, its physical structure, and the pollutants found in it. These topics will carry over to the other chapters in Part I. For example, the physical structure of the atmosphere is essential for understanding weather-related processes. Similarly, the environmental lapse rate helps to create convection in the troposphere. Convection in the troposphere is a fundamentally important topic in Part I. Fossil fuels and greenhouse gas pollutants are also important in the context of anthropogenic climate change.

TEACHING TIPS

- Prioritize covering gases in the atmosphere, both permanent and variable gases. The most important gases are nitrogen, oxygen, water vapor, carbon dioxide, and methane.
- Be sure students understand the major characteristics of the troposphere and stratosphere. Students should be particularly familiar with the environmental lapse rate. This concept is important later when discussing precipitation (Chapter 4) and air movement (Chapter 5).
- Emphasize that, from the standpoint of the long-term greater good of society, the benefits of clean air are greater than the costs of cleaning up the air.

CHAPTER LEARNING GOALS

After reading the chapter and working through the study guide, students should understand the five learning objectives for the chapter:

- 2.1 Describe the gases and other materials that make up the atmosphere.
- 2.2 Explain what causes air pressure and how air pressure changes vertically within the atmosphere.
- 2.3 Name and describe the atmosphere's layers.
- 2.4 Identify major atmospheric pollutant types and discuss their effects on human health.
- 2.5 Assess the effects of anthropogenic pollutants in the ozonosphere and the anticipated condition of the ozonosphere in the coming decades.

CHAPTER FEATURES ANSWER KEY

Picture This: The Tropopause

Consider This

1. The anvil of this cumulonimbus cloud occurs at what boundary line? The troposphere.

2. **Given the latitude of this cloud, what is the altitude of the anvil structure?** About 18 kilometers.

Picture This: Particulate Matter Haze

Consider This

1. **Assume that the sea-level photo was taken in an urban area on the small island of Maui. What types of particulate would you expect to find there? Explain.** Answers may vary. Responses can include black carbon from burning fossil fuels, vehicle exhaust, fine volcanic ash, salt particles from ocean spray.
2. **Do astronauts in orbit see an aureole around the Sun? Why?** Astronauts would not observe an aureole because they are above the atmosphere and particulate matter that would produce sun haze.

Chapter Study Guide

Concept Review

The Human Sphere—China’s “Airpocalypse”

1. Why do urban areas in eastern China have such poor air quality? Eastern China is experiencing large economic growth, with industrial factories, vehicular emissions, coal-burning power plants, and previously very loose environmental regulations.

2.1 Composition of the Atmosphere

2. What are the three major permanent gases in the atmosphere? What are some of the variable gases? Nitrogen, oxygen, and argon are the three major permanent gases. The variable gases are many, but this chapter covered water vapor, carbon dioxide, methane, nitrous oxide, ozone, and CFCs and HFCs.

3. What are sources and sinks for gases? Give examples. Gases enter the atmosphere through sources. Gases exit the atmosphere through sinks. Burning vegetation and burning fossil fuels are sources of carbon dioxide. Absorption by plants through photosynthesis and absorption by the oceans are carbon dioxide sinks. Each gas has different sources and sinks.

4. What are aerosols? Give examples. Aerosols are microscopic solid or liquid particles suspended in the atmosphere. Dust, pollen, and cloud droplets are examples of aerosols.

2.2 The Weight of Air: Atmospheric Pressure

5. What is air pressure, and how much is there at sea level, in kilograms per square centimeter? In PSI? Air pressure is the force exerted by molecules of air against a surface. At sea level, there is approximately 1 kg pressing on every square centimeter of all objects (or 14.7 pounds pressing on every square inch).

6. Why is air pressure greater near Earth's surface than at higher altitudes? Because the molecules are compressed and denser near the surface. They are compressed by their own weight. Greater molecular density in the atmosphere creates higher pressure.

2.3 The Layered Atmosphere

7. What is the Karman line, and why is it significant? The Karman line refers to the "top" of the atmosphere at an altitude of roughly 100 km. Above the Karman line the atmosphere is so thin that aircraft can no longer rely on lift and instead must orbit the planet to remain aloft.

8. List the four layers of the atmosphere, based on changes in temperature with altitude, and give the major characteristics of each. The troposphere, the stratosphere, the mesosphere, and the thermosphere. Temperature drops with an increase in altitude in the troposphere and mesosphere. Temperature rises with altitude in the stratosphere and thermosphere.

9. What are the two layers of the atmosphere that block harmful solar radiation? At what altitudes in the atmosphere are they found? The ionosphere (60 to 1,000 km) and the ozonosphere (12 to 50 km).

10. What are the major characteristics of the troposphere? How do its temperature and pressure change with altitude? In the troposphere temperature and pressure decrease with height, there is vertical mixing, and all weather occurs there. The troposphere also has the greatest air pressure.

11. What is the tropopause? What is the altitude of the tropopause at midlatitudes? What is its altitude at the equator and at the poles? The tropopause is the boundary between the troposphere and the stratosphere. It is found at 12 km (7.5 mi) above Earth's surface at midlatitudes. At the equator, the tropopause is 18 km (11 mi) high, and at the poles it is 8 km (5 mi) high.

12. What is the range of altitudes for the stratosphere? How does temperature change with altitude in the stratosphere? The stratosphere is about 12 km to 50 km (7.5 to 30 mi) in altitude. Temperature increases with height. There is a permanent temperature inversion in the stratosphere.

13. Compare and contrast airflow in the stratosphere with that of the troposphere. The troposphere can develop strong vertical mixing. The stratosphere always flows horizontally in sheet-like layers. In other words, the troposphere can be strongly unstable, and the stratosphere is always stable, with a permanent temperature inversion.

14. What are auroras? Where do they occur in the atmosphere? Over what regions? What causes them? Auroras are the northern and southern lights. They occur mostly near the poles. The Sun's solar wind streams into Earth's upper atmosphere and energizes molecules in the ionosphere, causing them to glow.

15. Why don't clouds from the troposphere extend up into the stratosphere? Above the tropopause, the stratosphere is warmer than the cool, dense clouds.

2.4 Air Pollution

16. What is the source of most anthropogenic atmospheric pollutants? Fossil fuels are the most polluting source of energy we use.

17. Cite examples of primary pollutants, their sources, and their effects on human health. A primary pollutant enters the air or water directly from the source, such as a car's tailpipe or factory smokestack. Carbon monoxide and nitrogen dioxide are examples of primary pollutants. Generally, they can cause respiratory disease and cancer.

18. What are secondary pollutants? Which secondary pollutants are discussed in this chapter? A secondary pollutant is not directly emitted, but instead forms in the air or water through chemical reactions of primary pollutants. Ground-level ozone is the one focused on in this chapter.

19. How is the ozone molecule both beneficial and harmful to people? Explain. It is an anthropogenic secondary pollutant on the ground that causes respiratory ailments. In the stratosphere, naturally occurring ozone blocks UV radiation.

20. How is particulate matter hazardous to human health? Particulate matter consists of liquid and solid particles (aerosols) suspended in the atmosphere. There are many sources of particulate matter, both natural and anthropogenic. Any inhaled particles less than 10 microns may enter deep into the lungs and then the bloodstream, where they can cause or worsen physical ailments, including bronchitis, asthma, various cancers, and heart disease.

21. What atmospheric and topographic factors make air pollution worse? Topographic valleys and basins do not allow for winds to remove pollution, and temperature inversions help to trap pollution into topographic lows.

22. What is the U.S. Clean Air Act? When was it enacted? Has it been successful? How? The Clean Air Act imposed strict regulations on pollution emissions beginning in 1970. The program has been successful. The Clean Air Act has been effective at reducing air pollution in the United States, saving lives, and reducing long-term national health care-related costs.

2.5 Geographic Perspectives: Refrigerators and Life on Earth

23. What are CFCs and what are they used for? CFCs are a class of ozone-depleting compounds used mainly as refrigerants, aerosol propellants, and fire retardants.

24. How long do CFCs last in the troposphere? What happens when they reach the stratosphere? They last from 60 to 200 years or more. Some types of CFCs last more than 1,000 years. UV radiation breaks them apart when they reach the stratosphere.

25. What is the ozonosphere, and how do CFCs affect it? The ozonosphere is a concentrated layer of ozone molecules found in the stratosphere. Ozone molecules block ultraviolet radiation. This is important because UV rays give people cancer and reduce plant photosynthesis. CFCs break apart in the ozonosphere into chlorine. Chlorine reacts with and destroys ozone molecules. This lets more UV rays pass through to Earth's surface and cause harm to biological systems.

26. What are the projected trends in stratospheric chlorine levels for this century? By about 2040 stratospheric chlorine is anticipated to be back down to 1980 levels.

27. What are nacreous clouds, and how are they related to ozonosphere thinning over Antarctica? Why has there been less ozonosphere loss over the Arctic than over Antarctica? Nacreous clouds form where the stratosphere is very cold, mostly over Antarctica. These clouds assist in the reactive process that breaks ozone down. There are fewer nacreous clouds over the North Pole because the stratosphere is not as cold.

28. What are the connections between CFC production and human and ecological health? CFC production reduces the integrity of the ozonosphere. This allows more UV radiation to reach Earth's surface, which causes increased rates of human health problems and affects photosynthetic organisms.

29. When was the Montreal Protocol enacted, and what was its initial aim? Ratified in 1987, and going into effect in 1989, the Montreal Protocol banned CFC production outright in some countries and mandated phase-outs in other countries.

30. What recent amendment has been added to the Montreal Protocol, and why? In 2015, an amendment was added to the Montreal Protocol with the aim of phasing out hydrofluorocarbons by the mid-twenty-first century.

Critical-Thinking Questions

1. Why is air pollution in the United States and Canada decreasing even though the population, the number of cars, and energy consumption are all increasing? The U.S. Clean Air Act is credited with improving the air quality. Stricter vehicular, factory, and power plant emissions controls have reduced emissions and cleaned the air even though population and energy consumption have grown.

2. What is the general air quality where you live? If you do not know the answer, how can you find it? Answers will vary. There are many websites that give this information. AirNow.gov is one. Many local newspapers also report pollutant levels.

3. Acid rain is naturally produced by volcanoes. Given that acid rain is natural, why is natural acid rain not a hazard by anthropogenic acid rain is? Anthropogenic acid rain is more concentrated and more persistent than acid rain produced by volcanic emissions.

4. Construct an argument between critics and supporters of clean air regulations, with one side stating that these regulations are too costly to enact and the other side stating that it is too costly not to enact them. With which side do you identify more? Answers will vary. Students can take the business approach and put short-term profit and economic growth over long-term human health. Or students can put long-term human health over short-term gains in the profit and the economy.

5. Can you think of other pressing global environmental problems besides ozonosphere thinning that the world currently faces? Explain. The idea here is to segue into climate change. Climate change is also a global problem.

Test Yourself

1. True or false? The atmosphere is composed mostly of nitrogen. (answer: true)

2. True or false? Aerosols are gases in the atmosphere. (answer: false)

3. True or false? Air density and air pressure decrease as altitude increases. (answer: true)

4. True or false? In the stratosphere, temperature decreases with an increase in altitude. (answer: false)

5. True or false? The size of the hole in the ozonosphere peaked in the 1970s and has since been declining. (answer: false)

6. Multiple choice: Which pollutant is most deadly in high concentrations?

- a. Ozone
- b. Carbon monoxide
- c. Sulfur dioxide
- d. Particulate matter

Answer: B

7. Multiple choice: In which atmospheric layers is most ultraviolet radiation from the Sun absorbed?

- a. The troposphere
- b. The stratosphere
- c. The mesosphere
- d. The thermosphere

Answer: B

8. Multiple choice: In which layer of the atmosphere do auroras form?

- a. Troposphere
- b. Mesosphere
- c. Thermosphere
- d. Ionosphere

Answer: D

9. Fill in the blank: The _____ mandated the phase-out of CFCs by all industrialized countries. (answer: Montreal Protocol)

10. Fill in the blank: The vast majority of anthropogenic air pollutants originate from usage of _____. (answer: fossil fuels)

Picture This. YOUR TURN

The Atmosphere's Thermal Divisions

Fill in the blanks on the diagram below using each of the following terms only once. In addition, indicate, using the boxes below, whether the temperature is increasing or decreasing with altitude.

- | | |
|-----------------|-----------------|
| 1. Mesopause | 5. Thermopause |
| 2. Mesosphere | 6. Thermosphere |
| 3. Stratopause | 7. Tropopause |
| 4. Stratosphere | 8. Troposphere |

