Chapter 3: Introduction to the Atmosphere

Learning Outcomes

Chapter 3: Introduction to the Atmosphere

Chapter Three introduces the reader to the structure and chemical composition of the atmosphere. Without an atmosphere, life as we know it on Earth would not be possible. Atmosphere is a vast but very shallow ocean of air with Earth at the bottom (more than 98% of it lies within 26 kilometers [16 miles] of Earth's surface). Atmosphere is held to Earth by gravitational pull, which is loose enough that the air can move on its own. Evaluating how gases mix and are sorted in the atmosphere is key to understanding how solar energy moves through the atmosphere. The relationship between atmospheric heating and air pressure is introduced. The chapter also evaluates the impact pollutants have on weather and climate.

Teaching Tip:

Before class have students read this article on how volcanic eruptions affect climate: http://www.scientificamerican.com/article/how-do-volcanoes-affect-w/. Consider offering credit for a short write-up, or give a short quiz on the article at the start of class to assess their understanding of the subject.

TOPICS

Size and Composition of the Atmosphere

- *Size of Earth's Atmosphere*
  - *Density decreases With Altitude*
- *Development of Earth's Modern Atmosphere*
- *Composition of the Modern Atmosphere*
- *Permanent Gases*
  - *Nitrogen and Oxygen*
- *Variable Gases*
  - *Water Vapor*
  - *Carbon Dioxide*
  - *Ozone*

Other Variable Gases
Particulates (Aerosols)
Vertical Structure of the Atmosphere
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Atmospheric Conditions and Air Pollution
Consequences of Anthropogenic Air Pollution
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The Elements of Weather and Climate
The Controls of Weather and Climate
Latitude
Distribution of Land and Water
General Circulation of the Atmosphere
General Circulation of the Oceans
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Topographic Barriers
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The Coriolis Effect
Significant Aspects of the Coriolis Effect
Important Consequences of the Coriolis Effect
People and the Environment: The UV Index
Global Environmental Change: Aerosol Plumes Circling the Globe
Energy for the 21st Century: Transitioning from Fossil Fuels

CHAPTER OUTLINE

I. **Size and Composition of the Atmosphere**

   A. *Air*

      1. **Air**—synonymous with atmosphere; is a mixture of gases, mainly nitrogen and oxygen.

   B. *Density Decrease with Altitude*

      1. The atmosphere could be considered a vast ocean of air surrounding Earth.
      2. It is held fast to Earth's surface by the planet's gravitational pull, but not so tightly that it cannot move as a fluid mass.
      3. Although the atmosphere extends outward to more than 10,000 kilometers, more than 50 percent of the atmosphere's mass is concentrated within about 600 meters of Earth's surface, and more than 98 percent of it lies within 26 kilometers of the surface.
      4. The atmosphere also extends downward into caves, rock, and soil, as well as being dissolved into water and in the bloodstreams of living organisms.

   C. *Development of Earth's Modern Atmosphere*

      1. Just after Earth's formation 4.6 billion years ago, Earth's atmosphere probably consisted of lighter elements such as hydrogen and helium.
      2. H_2O and CO_2 gradually increased, whereas lighter elements were lost.
      3. Water vapor from Earth's atmosphere condensed and formed the world's oceans.
      4. Early forms of life (bacteria) removed CO_2 and released O_2, and atmosphere was transformed into an O_2-rich and CO_2-poor atmosphere.
      5. Our modern atmosphere was influenced by life on Earth.

   D. *Composition of the Modern Atmosphere*

      1. Permanent *Gases*
      2. *Nitrogen and Oxygen*
         a) Nitrogen—78 percent
         b) Oxygen—21 percent
         c) Argon—nearly 1 percent
         d) Neon, helium, methane, krypton, and hydrogen are found in trace amounts.
      3. Variable *Gases*
      4. *Water Vapor*
         a) Is invisible in Earth's atmosphere, but determines the humidity of the atmosphere, is the source of all clouds and precipitation, and is intimately involved in the storage, movement, and release of heat energy.
         b) May be as much as 4 percent of the total volume of air over warm, moist surfaces (i.e., tropical oceans) and less than 1 percent within arid regions.
         c) The total amount of water vapor in Earth's atmosphere is nearly constant, so it is variable in location and not in time.
      5. *Carbon Dioxide*
         a) Only water vapor and carbon dioxide have a significant effect on weather and climate.

b) Water vapor and atmospheric carbon dioxide significantly affect the climate because they can absorb infrared radiation, keeping the lower atmosphere warm.
   (1) Proportion of carbon dioxide has been increasing at about the rate of 2 parts per million per year and is at present about 401 parts per million.
      (a) Most atmospheric scientists conclude that it will make the lower atmosphere warm up enough to cause significant, but unpredictable, global climatic changes.

6. *Ozone*
   a) **Ozone**—a molecule made up of three oxygen atoms (O_3); mostly concentrated in the **ozone layer** (between 15 and 48 kilometers above Earth's surface), where it helps to absorb deadly ultraviolet solar radiation and protect animal life.
   b) Proportion of carbon monoxide, sulfur dioxide, nitrogen oxides, and various hydrocarbons is also increasing from emissions from factories and cars.
   c) All are hazardous to life and may have an effect on climate.
7. *Other Variable Gases*
   a) Methane (CH_4) introduced naturally and anthropogenically absorbs long-wave radiation.
   b) Carbon monoxide, sulfur dioxide, nitrogen oxides, and hydrocarbons are also increasingly being introduced via anthropogenic sources.

E. *Particulates (Aerosols)*
1. **Particulates**—solid and liquid particles found in the atmosphere; can be both visible and invisible, and come from both natural and human-made sources.
   a) Larger particles are mainly water and ice.
2. Particulates affect the weather and climate in two ways:
   a) They are hygroscopic (they absorb water), and water vapor collects around them (termed *cloud condensation nuclei*), which contributes to cloud formation.
   b) They can either absorb or reflect sunlight, thus decreasing the amount of solar energy that reaches Earth's surface.

II. Vertical Structure of the Atmosphere

A. *Thermal Layers*
1. Most weather phenomena occur in the lower atmosphere.
2. There are five thermal layers in the atmosphere:
   a) Troposphere
   b) Stratosphere
   c) Mesosphere
   d) Thermosphere
   e) Exosphere
   f) *-sphere* is used when talking about the entire layer.
   g) When referring to just the upper portion of a layer or the boundary between two layers, *-pause* is used.

3. *Troposphere*—the lowest thermal layer of the atmosphere, in which temperature decreases with height.
    a) **Tropopause**—a transition zone at the top of the troposphere, where temperature ceases to decrease with height.
4. *Stratosphere*—atmospheric layer directly above the troposphere, where temperature increases with height.
    a) In comparison to the turbulent troposphere, the stratosphere could be considered stagnant.
    b) **Stratopause**—top of the stratosphere, elevation about 48 kilometers (30 miles), where maximum temperature is reached.
5. *Upper Thermal Layers*
    a) **Mesosphere**—atmospheric layer above the stratopause, where temperature again decreases with height as it did in the troposphere (note, this term also refers to the rigid part of the deep mantle, below the athenosphere).
        (1) **Mesopause**—transition zone at the top of the mesosphere.
    b) **Thermosphere**—the highest recognized thermal layer in the atmosphere, above the mesopause, where temperature remains relatively uniform for several kilometers and then increases continually with height.
        (1) **Exosphere**—the highest zone of Earth's atmosphere.
6. *Temperature Patterns in the Atmosphere*
    a) Temperature alternately decreases and increases from one layer to the next.
    b) The warm zones of the thermal layers each have their own specific source of heat. In the troposphere, it's the visible portion of sunlight. In the stratosphere and thermosphere, the Sun's ultraviolet (UV) rays serve as the heat source (the warm zone of the stratosphere is near the top of the ozone layer, which absorbs UV rays).

B. *Pressure*
1. Atmospheric pressure is basically the weight of overlying air. Thus air pressure is normally highest at sea level and rapidly decreases with altitude.

C. *Composition*
1. Principal gases of the atmosphere have a uniform vertical distribution in the lowest 80 kilometers (50 miles) of the atmosphere.
2. **Homosphere**—zone of homogeneous composition; in both the troposphere and stratosphere.
3. **Heterosphere**—zone of heterogeneous composition; begins in the mesosphere and continues through the exosphere, where gases tend to be layered according to their molecular masses rather than having the homogenous composition of the homosphere.
4. *Distribution of Water Vapor*
    a) Varies with vertical distribution, with most being found near Earth's surface and decreasing with altitude.
    b) Above 16 kilometers, water in the atmosphere is frozen.

5. *Ozone Layer*
    a) **Ozonosphere—ozone layer**; the zone of a relatively rich concentration of ozone in the atmosphere, between 15 to 48 kilometers (9 to 30 miles) high, that absorbs ultraviolet radiation.
6. *Ionosphere*—deep layer of ions (electrically charged molecules and atoms) in the mesosphere (middle and upper parts) and thermosphere (lower part) that aids in long-distance communication by reflecting radio waves back to Earth; also generates auroral displays.

III. Human-Caused Atmospheric Change

A. Pollutants, inefficient and wasteful fossil fuel use, and rapid population growth are all contributing to changes in Earth's atmosphere.

B. Consequences of global climate change have been a larger concern in recent years.

1. In February 2012, the U.S. Global Change Research Program issued a report building on its June 2009 report, *Global Climate Change Impacts in the United States*, in which it highlighted several concerns related to the phenomena:
    a) Climate change in the United States is now apparent.
    b) The changes are anthropogenic.
    c) Climate change poses significant risks for human and natural systems.
    d) Trends observed include rising temperatures, sea-level change, increasing heavy downpours, longer growing seasons, reductions in snow and ice, and changes in the amounts and timing of river flows.

C. *Depletion of the Ozone Layer*

1. Ozone is naturally produced in the stratosphere, and it serves to protect life on Earth by shielding it from the deadly UV rays of the Sun.
2. *Natural Formation of Ozone*
    a) Ozone is created in the upper atmosphere by the action of UV radiation.
    b) UV-C radiation splits oxygen molecules into free oxygen atoms that then combine with oxygen molecules to form ozone.
    c) In the stratosphere, ozone molecules are naturally broken down into oxygen molecules and free oxygen atoms by UV-B and UV-C radiation.
    d) The breakdown and formation of ozone is an ongoing process in this layer of Earth's atmosphere.
    e) About 90 percent of all atmospheric ozone is found in the stratosphere, where it forms a fragile shield by absorbing most of the potentially dangerous UV radiation from the Sun.
        (1) Prolonged exposure to UV radiation can cause cancer, suppress the immune system, diminish crop yields, and kill microscopic plankton on the ocean's surface.
3. When produced in the troposphere, ozone harms life, where it damages tissues in humans (eyes, lungs, noses); it also damages vegetation and corrodes buildings.
    a) Ozone is produced naturally in the stratosphere, whereas the combination of human activity such as automobile emissions and incoming solar radiation leads to its production in the troposphere.

(1) Depletion of stratospheric ozone increases the amount of tropospheric ozone.

4. *The "Hole" in the Ozone Layer*
   a) Ozone in the stratosphere, lying in the ozone layer, is being depleted through a combination of natural and human-produced factors.
   b) Largest human factor is the release of **chlorofluorocarbons (CFCs)**—synthetic chemicals that affect the ozone layer.
      (1) When UV radiation breaks down CFCs in the ozonosphere, the released chlorine then breaks down the ozone molecules, creating chlorine monoxide and oxygen molecules, which cannot filter solar radiation.
   (a) As many as 100,000 ozone molecules can be destroyed for every chlorine atom released.
   c) The layer has not only thinned, but it has disappeared entirely in some areas.
   d) Dramatic thinning of the ozone layer has been observed since the 1970s.
   e) The major thinning has been caused by the release of human-produced chemicals such as CFCs.
      (1) CFCs are used as refrigeration and cooling agents.
      (2) At least since 1979, a hole in the ozone layer developed over Antarctica. Although it ebbs and flows each year, it had been increasing in size and duration each year.
   (a) In the 1980s, a similar hole developed over the Arctic.
5. *Antarctic Polar Vortex*
   a) Depletion is more severe over polar regions (particularly Antarctica) because:
      (1) In winter, the polar vortex isolates air over Antarctica.
      (2) The formation of polar stratospheric clouds, which allow for the accumulation of chlorine compounds, accelerate the depletion process.
   b) Ozone depletion has been correlated with increased levels of UV radiation reaching ground surfaces in Antarctica, Australia, mountainous regions in Europe, central Canada, and New Zealand.
6. *The Montreal Protocol*
   a) In 1978, many countries began banning the use of CFCs, and by 1996 all countries of the industrial world had banned them.
   b) Developing nations had an extended deadline to assist with the implementation of alternatives.
7. It is estimated that the current reservoir of CFCs in the atmosphere may persist for 50 to 100 years, continuing to deplete stratospheric ozone long after they are no longer produced or used.
   a) Most research has predicted that recovery may not be well underway until 2050.
   b) The recovery of the hole is touted by many scientists as an environmental success story.
   c) It is estimated that without the ban on CFCs, by the year 2100, ozone levels over the tropics would have collapsed to the levels currently found over the Arctic and Antarctica.

D. *Air Pollution*
   1. Smoke has been a recognized pollutant for centuries.
      a) The burning of coal was prohibited in London by royal proclamation in the year 1300.
      b) Pollution became more widespread during the Industrial Revolution.
         (1) Industrial-related pollution led to several “episodes” causing human death and illness (e.g., Belgium’s Muese Valley and Donora, PA).
         (2) The greatest problem has been the concentration of people and automobiles.
         (3) Chemical impurities in the air have also contributed to pollution problems.
   2. *Primary and Secondary Pollutants*
      a) Primary pollutants are contaminants released directly into the air.
         (1) They include particulates, sulfur compounds, nitrogen compounds, carbon oxides, and hydrocarbons.
      b) Secondary pollutants are not released directly into the air but rather form from the chemical reactions and other processes in the atmosphere.
   3. *Carbon Monoxide*
      a) Carbon monoxide is the most abundant primary pollutant.
      b) Formed from the incomplete combustion of carbon-based fuels, especially automobiles.
      c) It is colorless and odorless and presents a hazard when humans are exposed to it in confined spaces.
      d) Carbon monoxide enters the bloodstream and decreases the amount of oxygen available to the brain and other organs.
   4. *Nitrogen Compounds*
      a) Nitric oxide can form naturally as a byproduct of biological processes.
      b) It can also form through high-temperature and high-pressure combustion.
      c) Nitric oxide can react in the atmosphere to form nitrogen dioxide.
         (1) A corrosive gas that gives polluted air a yellow or reddish-brown color.
         (2) Can also react with sunlight to form several different components of smog.
   5. *Sulfur Compounds*
      a) Most are of natural origin—from volcanic eruptions or hydrothermal vents.
         (1) Hydrogen sulfide is one example.
      b) Human activity during the past century has increased the release of sulfur compounds into the atmosphere.
         (1) Primarily from burning fossil fuels, which release compounds such as sulfur dioxide that can react in the atmosphere and form sulfur trioxide and sulfuric acid.
   6. *Particulates*
      a) Particulates (also known as aerosols) are tiny, solid particles or liquid droplets suspended in the air.

(1) Primary anthropogenic sources include dust and smoke from industrial combustion.
(2) Particulate concentration may increase through secondary processes.
(3) Health hazards from particulates are greatest when particles are <2.5 micrometers in diameter.
(4) In 1997, the U.S. Environmental Protection Agency (EPA) revised regulations to take into account the harmful effect of such fine particulates.

7. *Photochemical Smog*
   a) A number of gases react to UV radiation in strong sunlight to produce secondary pollutants, making up what is known as **photochemical smog**.
   b) Nitrogen dioxide and hydrocarbons (also known as *volatile organic compounds*, or VOCs) generated from incomplete combustion of fuels are major contributors to photochemical smog.
      (1) For example, nitrogen dioxide breaks down under UV radiation and forms nitric oxide.
         (a) This then may react with VOCs to form peroxyacetyl nitrate (PAN).
         (b) PAN has been a significant cause of crop and forest damage in some areas.
      (2) Can also form ozone, which is the main component of photochemical smog.
   c) The conditions within the atmosphere can also determine air pollution levels.
      (1) Stagnant air can cause pollutants to accumulate in a region, whereas rapid and frequent movement allows pollutants to be more readily dispersed.
8. *Consequences of Anthropogenic Air Pollution*
   a) Carbon monoxide, sulfur dioxide, and particulates can contribute to cardiovascular disease, whereas prolonged exposure to some particulates may promote lung cancer.
   b) Nitrogen oxides and sulfur dioxide are the principal contributors to acid rain.
   c) Tropospheric ozone damages crops and trees and is now the most widespread air pollutant.
   d) The EPA reports that perhaps one-fifth of all hospital cases involving respiratory illness in the summer are a consequence of ozone exposure.
   e) In the past few decades in the United States, there has been a downward trend in the emission of all pollutants except nitrogen oxides and ozone.
   f) This is mostly because of increasingly stringent emission standards imposed by the EPA.

E. *Energy Production and the Environment*
   1. Release of CO_2 is still on the rise despite reductions of many air pollutants.
   2. Much of this increase and the challenges associated with it are from the production of energy.

IV. Weather and Climate

A. *Weather*—short-run atmospheric conditions that exist for a given time in a specific area.

B. *Climate*—the pattern or aggregate of day-to-day weather conditions over a long period of days, encompassing both the average characteristics and the variations and extremes.

C. *The Elements of Weather and Climate*

1. There are four main elements, or variables, of weather and climate:
   a) Temperature
   b) Pressure
   c) Wind
   d) Moisture
      (1) All are measurable, vary frequently (if not continuously) in time and space, and provide the key to deciphering the complex mechanisms and processes of weather and climate.

D. *The Controls of Weather and Climate*

1. There are seven principal controls (semipermanent attributes of Earth) that cause or influence the elements of weather and climate:
   a) Latitude
   b) Distribution of land and water
   c) General circulation of the atmosphere
   d) General circulation of the oceans
   e) Altitude
   f) Topographic barriers
   g) Storms
2. There is often much overlap and interaction among these controls, with widely varying effects on weather and climate.
   a) *Latitude*—influences the element of temperature, as the basic function of heat over Earth from sunlight is a function of latitude.
   b) *Distribution of Land and Water*—influences both temperature and moisture, with continental climates and maritime (oceanic) climates differing greatly.
      (1) For example, Seattle, Washington, and Fargo, North Dakota, are at about the same latitude, but their average January temperatures differ by 34°F (18°C), with Seattle being much warmer because maritime areas experience milder temperatures than do continental areas in both winter and summer.
      (2) Maritime climates also are normally more humid than continental climates.
   c) *General Circulation of the Atmosphere*—influences most elements of weather and climate. Although the atmosphere is in constant motion, the troposphere displays a semipermanent pattern of major wind and pressure systems.
      (1) Simplifying the actual circulation shows that general surface wind direction varies according to latitude, with most surface winds in the tropics coming from the east, whereas those in middle latitudes flow mostly from the west.

d) *General Circulation of the Oceans*—influences most elements of weather and climate in a similar fashion as the atmosphere, through the horizontal transfer of heat, but not to the same extent that atmosphere does.
   (1) Like the atmosphere, oceans are in constant motion, but they indicate broad general pattern of currents.
      (a) For example, eastern coasts of continents have warmer currents, whereas western coasts have cool currents.

e) *Altitude*—influences temperature, pressure, and moisture content, with each generally decreasing with increasing altitude.

f) *Topographic Barriers*—influence wind flow by diverting it.
   (1) Windward and leeward sides of mountains and large hills experience different climates because the first faces the wind, while the other is sheltered from it.
      (a) This has a major impact on moisture and average rainfall, with one side being very wet and the other very dry.

g) *Storms*—result from interaction of the other climate controls, but then create their own specialized weather circumstances like other controls.

E. *The Coriolis Effect*

1. *Cause of the Coriolis Effect*
   a) It is a result of Earth's rotation beneath moving objects.
2. *Significant Aspects of the Coriolis Effect*
   a) Can significantly influence long-range movements.
   b) Four basic points to remember:
      (1) A free-moving object appears to deflect to the right in Northern Hemisphere and to the left in the Southern Hemisphere.
      (2) The apparent deflection is strongest at the poles, decreasing progressively toward the equator, where there is zero deflection.
      (3) Fast-moving objects seem to be deflected more than slower ones because the Coriolis effect is proportional to the speed of the object.
      (4) The Coriolis effect influences direction only, not speed.
3. *Important Consequences of the Coriolis Effect*
   a) The Coriolis effect influences winds and ocean currents, in particular serving as an important component of the general circulation of oceans.
   b) It does not affect the circulation pattern of water draining out of a washbowl—the time involved is too short and water speed too slow; instead, draining direction is determined by the characteristics of the plumbing system, shape of the washbowl, and pure chance. You can test this for yourself.

V. People and the Environment: The UV Index

A. The UV Index (UVI) was developed in the 1990s by the EPA and National Weather Service.

1. Designed to inform the public of harmful UV radiation levels near Earth's surface.
2. The UVI forecasts the next day's radiation using scale of 1–11+.
   a) One represents low exposure, and levels increase as numbers increase.
      (1) Level 8 and above indicate very high exposure.

   3. Research indicates that UV-induced skin damage is cumulative.
      a) Children especially should take precautions by using SPF 30 or higher sunscreen.
B. UV forecasts are based on the quantity of ozone in the atmosphere as well as cloud cover and elevation of the location.
   1. Lower ozone concentrations indicate higher potential for UV exposure.
   2. Data are generated via satellites.

VI. Global Environmental Change: Aerosol Plumes Circling the Globe

A. Air pollution is not a local problem; computer models suggest aerosol plumes can circle Earth in about 3 weeks.
B. To study the impact of aerosol plumes, the National Center for Atmospheric Research is using a modified Gulfstream V aircraft (HIAPER [High-performance Instrumental Airborne Platform for Environmental Research]).
   1. HIAPER collects data on the chemical composition and size of aerosol particles within a plume.
   2. Data are then analyzed to determine the impact on the local environment.
C. Plumes contain sulfate aerosols that are highly reflective.
   1. Reflective aerosols likely mask some of the warming caused by global climate change.
D. Plume aerosols enhance cloud formation because of an abundant supply of condensation nuclei.
   1. Long-term impacts will likely include modified precipitation patterns and storm tracks through diminished rain and snow events and suppressed precipitation in some areas.

VII. Energy for the 21st Century: Transitioning from Fossil Fuels

A. Before fossil fuels, humans completed mechanical work through their own labor and animal labor.
   1. Historically, development has allowed the world to derive as much as 80% of its energy from fossil fuels.
B. Fossil fuels also come with a high cost.
   1. Combustion of coal, oil, and gas produces pollution.
   2. Sulfur dioxide (SO_2) causes acid rain.
      a) Clean Air Act required removal of SO_2 emissions and largely alleviated the problem.
   3. All fossil fuels emit carbon dioxide (CO_2), the primary human-produced greenhouse gas driving global climate change.
   4. Uneven global distribution of fossil fuels also causes geopolitical conflict.
   5. Support for alternative energy is growing among various sectors.
      a) The transportation sector runs on liquid fuel derived from crude oil.
         (1) The only liquid alternative is biofuel, which competes with food production.
   6. Nuclear power is the largest alternative energy source but comes with grave risks, as seen in the Fukushima Daiichi disaster in 2011.
   7. Hydroelectric power uses dams and the power of falling water to generate electricity, but these dams can degrade ecosystems and displace people.

8. Geothermal and tidal power are often limited to locations away from large populations.
9. Wind power is the fastest growing alternative energy but is limited by when the wind is blowing.
10. Solar energy harnesses sunlight to generate electricity through photovoltaic cells or by generating steam but is also limited to sunny days.
11. Main barriers to an “energy transition” toward alternative energy remain economic and political.
    a) Support for carbon emission pricing that includes the damage done through these emissions may help to accelerate the transition.

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Learning Check 3-1

What generally happens to the density of the atmosphere with increasing altitude?

As altitude increases, the atmospheric density decreases.

Learning Check 3-2

What is the most abundant gas in the atmosphere? Does this gas play an important role in processes in the atmosphere? What role does ozone play in the atmosphere?

Nitrogen is the most abundant atmospheric gas. It has a minimal effect on weather and climate.

Learning Check 3-3

What generally happens to the temperature of the atmosphere from the surface of Earth to the tropopause? What happens to the temperature above the tropopause in the stratosphere? Why do these changes in temperature occur?

The temperature decreases as altitude in the troposphere increases. The temperature increases with altitude in the stratosphere.

Learning Check 3-4

Is ozone the most abundant gas in the stratospheric ozone layer? Explain.

No. The statospheric ozone layer still contains an abundance of the permanent gases (nitrogen, oxygen, and argon). It is called the ozone layer because this is the layer of Earth’s atmosphere where the concentration of ozone relative to other gases is at its maximum.

Learning Check 3-5

What is the explanation for the thinning of the ozone layer that has been observed since the 1970s?

The ozone layer has been thinned by the use of chlorofluorocarbons (CFCs). When CFCs escape to the stratosphere, UV radiation breaks apart this anthropogenic compound and releases a chlorine atom that "robs" ozone of one of its oxygen atoms. This converts O_3 into O_2, which allows UV radiation to pass through unimpeded.

Learning Check 3-6

How does photochemical smog form, and what are some of its effects on human health?

It is a secondary pollutant. Photochemical smog consists of a number of gases that react to UV radiation in strong sunlight. Photochemical smog can damage sensitive body tissue like the eyes, lungs and nose.

Learning Check 3-7

What is the difference between weather and climate?

Weather is the short-run atmospheric conditions that exist for a given time in a specific area. *Climate* is the aggregate of day-to-day weather conditions over a long period of time.

Learning Check 3-8

What is the relationship of the "controls" of weather and climate to the "elements" of weather and climate? What is the most fundamental control of weather and climate? Why?

The controls of weather and climate could be considered to be variations (in many instances, spatial) in the elements of weather and climate. Latitude is the most fundamental control of weather and climate.

Learning Check 3-9

Describe the Coriolis effect and its cause.

The Coriolis effect is the apparent deflection of moving objects on or over Earth's surface. These objects are deflected to the right of their paths in the Northern Hemisphere and to the left of their paths in the Southern Hemisphere. This force can significantly influence long-range movements. There are four basic points to remember regarding the Coriolis effect:

1. A free-moving object appears to deflect to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

2. The apparent deflection is strongest at the poles, decreasing progressively toward the equator, where there is zero deflection.

3. Fast-moving objects seem to be deflected more than slower ones because the Coriolis effect is proportional to the speed of the object.

4. The Coriolis effect influences the direction only, not the speed.

The Coriolis effect influences winds and ocean currents, in particular serving as an important component of the general circulation of oceans. Contrary to the belief of many, the Coriolis effect does not affect the circulation pattern of water draining out of a washbowl. The time involved is too short and water speed too slow. Rather, the draining direction is determined by the characteristics of the plumbing system, the shape of the washbowl, and pure chance.

Chapter 3 Learning Review
After studying this chapter, you should be able to answer the following:

Size and Composition of the Atmosphere (p. 56)
1. What is meant by the terms *permanent gases* and *variable gases* in the atmosphere?

Constant, or permanent, gases are those that remain in relative constant quantities in time and space throughout the lower layers of Earth's atmosphere. Examples of constant or permanent gases (from largest to smallest percentages, as illustrated in Figure 3-3) include nitrogen, oxygen, argon, neon, helium, krypton, and hydrogen.

Variable gases are those that possess highly variable quantities in Earth's atmosphere. Examples of variable gases (from largest to smallest percentages, as illustrated in Figure 3-3) include water vapor, carbon dioxide, carbon monoxide, methane, ozone, sulfur dioxide, and nitrogen dioxide. The most important variable gases are water vapor, carbon dioxide, methane, and ozone. While found in significantly smaller quantities than the permanent gases, these variable gases are nonetheless important because of their role in affecting weather and climate.

2. Describe the most important permanent gases of the atmosphere.

The most important constant, or permanent, gases include nitrogen, oxygen, and argon. These gases make up 78 percent, 21 percent, and 0.9 percent of the atmosphere, respectively.

3. Briefly describe some of the roles that **water vapor**, **carbon dioxide**, **ozone**, and **particulates** (**aerosols**) play in atmospheric processes.

Water vapor is invisible in Earth's atmosphere but determines the humidity of the atmosphere and is the source of all clouds and precipitation. It is intimately involved in the storage, movement, and release of heat energy. Water vapor may constitute as much as 4 percent of the total volume of air over warm, moist surfaces (i.e., tropical oceans), and less than 1 percent within arid regions. The total amount of water vapor in Earth's atmosphere is nearly constant, so it is variable in location and not in time.

Carbon dioxide, like water vapor, has a potent ability to absorb infrared radiation, which keeps the lower atmosphere warm. Because the proportion of carbon dioxide has been increasing yearly since the Industrial Revolution, there is much speculation and concern that higher concentrations of carbon dioxide in the atmosphere will lead to the lower atmosphere heating up too much, thus causing global climatic changes.

Ozone has a role in the stratosphere filtering out ultraviolet rays. In the lower atmosphere, ozone has negative impacts on plants and human tissue.

Particulates are solid and liquid particles found in the atmosphere. They can be both visible and invisible and come from both natural and human-made sources. Particulates affect the weather and climate in two ways: They are hygroscopic (they absorb water), and water vapor collects around them, which contributes to cloud formation; and they can either absorb or reflect sunlight, thus decreasing the amount of solar energy that reaches Earth's surface.

4. How has the burning of **fossil fuels** over the last 200 years changed the composition of the atmosphere?

The lower layers of the atmosphere have seen steadily increasing concentrations of carbon dioxide due to the increased burning of fossil fuels. The proportion of carbon dioxide in the atmosphere has increased at a rate of more than 0.0002 percent per year.

5. Describe both the vertical distribution of water vapor in the atmosphere and its horizontal (geographic) distribution near Earth's surface.

Water vapor is variable in both its vertical and horizontal distribution. The vertical distribution has most water vapor being near Earth's surface, and the amount decreases with increasing altitude. Above 16 kilometers (10 miles), it is too cold for water vapor—any moisture present would have frozen—thus there are no clouds above this altitude.

Water vapor is variable in how it is distributed horizontally near Earth's surface. It is most abundant in air overlying warm, moist surfaces such as tropical oceans (where water vapor may amount to as much as 4 percent of the total volume of air). It is least abundant over deserts and in polar regions (where it may amount to but a tiny fraction of 1 percent).

Vertical Structure of the Atmosphere (p. 59)

6. Discuss the size and general temperature characteristics of the **troposphere** and **stratosphere**.

Beginning at sea level, air temperature first decreases with increasing altitude through the first thermal layer of the atmosphere, the troposphere. It then remains constant despite altitude increases through the tropopause and the lower portion of the stratosphere. Then, at about 20 kilometers (12 miles) in altitude, air temperature begins increasing with increasing altitude to about 48 kilometers (30 miles). This vertical variation, with its alternating pattern of increasing and decreasing air temperature, is a complex pattern that's very different from what was originally assumed until about a century ago, when it was thought that air temperature continued to decrease with increasing altitude.

7. Describe how atmospheric pressure changes with increasing altitude.

Normally, air pressure is highest at sea level (where there is more air above it to cause compression), and it diminishes rapidly with increasing altitude (with air in upper layers being subjected to less compression). By 5.6 kilometers (3.5 miles) above sea level, air pressure is at

50 percent the level it was at sea level. By 16 kilometers (10 miles) above, it is only 10 percent, and by 32.3 kilometers (20 miles) above, only 1 percent.

8. What is the **ozone layer**, and where is it located?

Ozone is a molecule of three oxygen atoms. Mostly concentrated in a layer about 15 to 48 kilometers (9 to 30 miles) above Earth's surface, it shields life on Earth from the deadly impact of ultraviolet solar radiation by absorbing, or filtering, those solar rays.

Human-Caused Atmospheric Change (p. 62)

9. How is ozone formed and why is it important in the atmosphere?

Ozone, or O_3, is a gas comprising molecules consisting of three atoms of oxygen. Ozone is formed when UV photons split oxygen molecules (O_2) into two oxygen atoms. The freed oxygen atom then bonds with an oxygen molecule to form an ozone (O_3) molecule. Ozone is important for the atmosphere because, unlike oxygen molecules, which do not absorb UV radiation, ozone efficiently absorbs UV radiation and therefore impedes the passage of the harmful radiation to Earth's surface. The largest portion of ozone is concentrated in the stratosphere and therefore is the layer of the atmosphere where the wealth of the UV radiation is intercepted. When ozone is in high enough quantities in the troposphere, it is harmful in that it is a major component of photochemical smog. When found in the troposphere, it is likewise a greenhouse gas.

10. What is meant by the "hole" in the ozone layer and what role have **chlorofluorocarbons (CFCs)** played in this?

The hole in the ozone layer is really a reduction of the amount of ozone in the stratosphere. Both naturally occurring phenomena and human-produced factors have been thinning the ozone layer and therefore reducing its capacity for shielding life from biologically destructive solar rays. The natural factors include an oscillation of the stratospheric winds that occurs about once every 2.3 years, the 11-year sunspot cycle, lingering debris from volcanic eruptions, and the El Niño ocean current effect every 3 to 5 years. In addition, human-made chemicals called chlorofluorocarbons (CFCs) are affecting the ozone layer; when CFCs break down in the atmosphere, their chlorine molecules cause a chemical reaction that breaks down ozone molecules to become oxygen molecules.

11. Describe and contrast **primary pollutants** and **secondary pollutants** in the atmosphere.

Primary pollutants are contaminants that are released directly into the air. Examples include particulates, sulfur compounds, nitrogen compounds, carbon oxides, and hydrocarbons. Secondary pollutants are not released directly into the air, but rather are formed as a consequence of chemical reactions or other processes in the atmosphere. Photochemical smog is an example of a secondary pollutant.

12. Describe and explain the causes of **photochemical smog**.

A number of gases react to ultraviolet radiation in strong sunlight to produce secondary pollutants, making up what is known as photochemical smog. For example, nitrogen dioxide and hydrocarbons (also known as *volatile organic compounds*, or VOCs)—generated from incomplete combustion of fuels—are major contributors to photochemical smog. Also, nitrogen dioxide breaks down under UV radiation and forms nitric oxide (NO). The nitric acid then may react with VOCs to form peroxyacetyl nitrate (PAN). PAN has been a significant cause of crop and forest damage in some areas. The breakdown of nitrogen dioxide into NO also frees an oxygen atom, which can react with O_2 to form ozone, which is the main component of photochemical smog. While ozone in the stratosphere is critical to life on Earth, ozone in the troposphere is hazardous to living organisms.

Weather and Climate (p. 67)

13. What is the difference between **weather** and **climate**?

Weather and climate are related, not synonymous, terms. Both are generated in the atmosphere, but *weather* refers to the short-term dynamics involved in momentary states of the atmosphere, whereas *climate* consists of long-term atmospheric conditions. In addition to differing in their time frame, they differ in spatial context: weather can vary greatly within a small region, whereas climate refers to larger expanses. Finally, one needs weather information over an extended period and area in order to describe climate.

14. What are the four **elements of weather and climate**?

The four main elements of weather and climate are temperature, pressure, wind, and moisture.

15. Briefly describe the seven dominant **controls of weather and climate**.

Certain semipermanent attributes, or controls, are latitude, distribution of land and water, general circulation of the atmosphere, general circulation of the oceans, altitude, topographic barriers, and storms. These either cause or influence the four main elements, often with much overlap and interaction. For example, distribution of land and water, general circulation of atmosphere, altitude, and topographic barriers all affect moisture in a region.

16. Describe the **Coriolis effect** and its cause.

The Coriolis effect is the apparent deflection of moving objects on, or over, Earth's surface. These objects are deflected to the right of their paths in the Northern Hemisphere and to the left of their paths in the Southern Hemisphere. This force can significantly influence long-range movements. The four basic points to remember regarding the Coriolis effect are as follows:

1. Free-moving objects appear to deflect to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

2. The apparent deflection is strongest at the poles, decreasing progressively toward the equator, where there is zero deflection.

3. Fast-moving objects seem to be deflected more than slower ones because the Coriolis effect is proportional to the speed of the object.

4. The Coriolis effect influences the direction only, not the speed.
The Coriolis effect influences winds and ocean currents, in particular serving as an important component of the general circulation of oceans. Contrary to the belief of many, the Coriolis effect does not affect the circulation pattern of water draining out of a washbowl. The time involved is too short and water speed too slow. Rather, the draining direction is determined by the characteristics of the plumbing system, the shape of the washbowl, and pure chance.

STUDY QUESTIONS

1. What prevents the atmosphere from "escaping" into space?

Earth's gravitational pull.

2. Why is the question "How deep is the atmosphere?" difficult to answer?

The atmosphere has no definite top, with no true boundary between it and outer space. Although most of its mass is concentrated at very low altitudes (more than 50 percent below 6.2 kilometers [3.8 miles] and more than 98 percent within 26 kilometers [16 miles]), traces of atmosphere extend for thousands of kilometers above Earth. Moreover, air expands to fill empty spaces, so it penetrates into caves and crevices in rocks and soil, thus extending down into Earth.

3. In what ways was life on Earth responsible for the composition of our modern atmosphere?

Early forms of life (bacteria) took in CO_2 from Earth's ancient atmosphere and gave off O_2 as a byproduct. The O_2 that accumulated, under reactions with UV radiation, formed O_3, which served to decrease the amount of UV radiation reaching Earth's surface, and the troposphere in general. Furthermore, O_2 is a highly reactive gas and aided in the evolution of more complex organisms (e.g., mammals, reptiles, amphibians, and avian species).

4. Why are you likely to get out of breath more easily when hiking in the mountains than at sea level?

Atmospheric pressure decreases with altitude. As one climbs a mountain, because of the reduced atmospheric pressure, less oxygen is available to be forced into the alveoli of the lungs, thus causing less oxygen to reach the bloodstream.

5. Why does the altitude of the tropopause vary from summer to winter and from the equator to the poles?

Because the atmosphere is a fluid mass, its density, and therefore its altitude, is affected by heating and cooling. In the summer at a given location, the atmosphere is subject to more heating, and therefore its density decreases and its altitude increases. During winter, because of less stimulation, the density of the atmosphere increases and its altitude decreases. Because the equator is subjected to more heating (because of a higher sun angle and constant day length), as compared with the poles, the density of the atmosphere is lower and its altitude is higher. At the poles, the situation is reversed because of the constant low sun angle and a 6-month period of constant darkness.

6. Why should humans be concerned about the depletion of the ozone layer?

Ozone blocks harmful UV radiation from reaching Earth's surface. If there is less ozone in the stratosphere, then the amount of UV radiation reaching the surface increases and poses a threat to human health and life in general.

7. Why is it inaccurate to talk about a change in climate from last year to this year?

Climate data are constructed from weather data gathered from a period that spans at least the previous 30 years. Changes in climate are discerned by examining trends in these long-term data. To make a generalization about climate change by looking only at a couple of years' data is poor statistical sampling.

8. In our study of physical geography, why do we concentrate primarily on the troposphere rather than on other zones of the atmosphere?

First, the troposphere is the life layer of the atmosphere. The entire biosphere exists in this layer. Second, all weather occurs in the troposphere (and climates are classified based on the characteristics of this layer).

9. Why does the Coriolis effect influence the direction of ocean currents but not the direction of water draining down in a kitchen sink?

Because the Coriolis effect is an apparent force generated from the rotation of Earth beneath moving objects, it only affects objects that move over long distances, such as ocean currents, atmospheric motions, and the movement of airplanes and missiles.

EXERCISES

1. Using Figure 3-3: how much more nitrogen is there in the atmosphere than oxygen?

3.7 times

2. Using Figure 3-3: how much more oxygen is in the atmosphere than carbon dioxide?

530.38 times

3. Use Figure 3-8:

a. If you are on top of Pikes Peak in Colorado at an altitude of 4.3 kilometers (2.7 miles; 14,110 feet), what is the approximate percentage of surface atmospheric pressure?

Approximately 53 percent

4. Use Figure 3-8: If you were in an unpressurized balloon at an altitude of 10 kilometers (6.2 miles; 33,000 feet), what is the approximate percentage of surface atmospheric pressure?

Approximately 23 percent

Answers to Seeing Geographically (p. 54)

Questions:
This composite satellite image of southern Africa and the southern Indian Ocean was captured on April 9, 2015, by the NASA/NOAA Suomi NPP spacecraft. What evidence of life on the surface of Earth is visible in this image? How does the pattern of clouds around tropical cyclone Joalane (at the top of the image) differ from those in the ocean west of southern Africa? How thick does the atmosphere appear relative to Earth's diameter?

Answers:
Lush vegetation is seen on the eastern coast of Madagascar and on the coastline of South Africa. Tropical cyclone Joalane shows the cyclonic pattern of a dominant low-pressure system drawing in surrounding air. Because of the height from which the image is depicted, the atmosphere appears to be very thin relative to the size of the Earth.

Answers to Seeing Geographically (p. 75)

Questions:
Look again at the satellite image at the beginning of the chapter (p. 54). Is the presence of a storm such as tropical cyclone Joalane an example of weather or climate? Why? The clouds shown in this image are likely to be found within which layer of the atmosphere? If that is the case, what is the maximum altitude of the tops of those clouds?

Answers:
The presence of a short-term phenomenon like a hurricane is an example of weather. The clouds are likely in the troposphere, so their maximum height is likely below 12 kilometers.

Suggested Resources:
- More on the ozone layer:
http://www.ozonelayer.noaa.gov/science/basics.htm

- How we measure background CO_2 levels on Mauna Loa:
http://www.esrl.noaa.gov/gmd/ccgg/about/co2_measurements.html

The following media are available for this chapter in MasteringGeography for student self study and for teachers to assign with assessments:

Geoscience Animations:
- Ozone Depletion
- Coriolis Effect

Videos:
- Ozone Hole
- Coriolis Effect Merry Go Round