

Chapter 1

Earth's Atmosphere

Chapter Outline

The Atmosphere and the Scientific Method
Weather, Climate, and Meteorology
 Meteorology—The Study of the Atmosphere
 A Glimpse at a Weather Map
 Weather and Climate in Our Lives
 Focus on a Special Topic
Components of Earth's Atmosphere
 The Early Atmosphere
 Composition of Today's Atmosphere
Vertical Structure of the Atmosphere
 A Brief Look at Air Pressure and Air Density
 Layers of the Atmosphere
 Focus on an Observation
Summary
Key Terms
Questions for Review
Questions for Thought and Exploration

Learning Objectives

- 1.1. Outline the scientific method and describe how it can be applied to studying the atmosphere and weather.
- 1.2. Differentiate between weather and climate, and briefly discuss the history of meteorology and its most important milestones.
- 1.3. Interpret and describe a weather map, applying weather patterns and concepts such as low, high, front, and storm types.
- 1.4. List the positive and negative effects of climate and weather on human health, agriculture, infrastructure, environment, and economy.
- 1.5. Compare and contrast the composition of Earth's atmosphere over the course of its evolution.
- 1.6. Explain the role of gases (including water vapor, carbon dioxide, oxygen, and other greenhouse gases) and pollutants in Earth's atmosphere and assess their impact on Earth's climate.
- 1.7. State the terms and calculations for density and air pressure, and explain their importance with regard to Earth's atmosphere.
- 1.8. Label the layers of the atmosphere and their altitudes, and classify their respective temperatures, compositions, and functions.

Summary

This introductory chapter presents a broad overview of Earth's atmosphere and the many ways weather and climate influence our lives. We look briefly at the weather map and a satellite image so that we can observe that storms and clouds of all sizes and shapes are dispersed throughout the atmosphere. The movement, intensification, and weakening of these systems, as well as the dynamic nature of air itself, produce a variety of weather events that we describe in terms of weather elements. The sum total of

weather and its extremes over a long period of time is what we call weather. Although sudden changes in weather may occur in a moment, climatic change takes place gradually over many years. The study of the atmosphere and all of its related phenomena is called *meteorology*, a term whose origin dates back to the days of Aristotle. Weather and climate influence the clothes we wear, the food we eat, and many other parts of our lives. Extreme weather can cause severe damage and major disruption to society.

We learn that our atmosphere is one rich in nitrogen and oxygen as well as smaller amounts of other gases, such as water vapor, carbon dioxide, and other greenhouse gases whose increasing levels may result in additional global warming and climate change. We examine Earth's early atmosphere and found it to be much different from the air we breathe today.

We investigate the various layers of the atmosphere: the troposphere (the lowest layer), where almost all weather events occur, and the stratosphere, where ozone protects us from a portion of the sun's harmful rays. Above the stratosphere lies the mesosphere, where the air temperature drops dramatically with height. Above the mesosphere lies the warmest part of the atmosphere, the thermosphere. At the top of the thermosphere is the exosphere, where collisions between gas molecules and atoms are so infrequent that fast-moving lighter molecules can actually escape Earth's gravitational pull, and shoot off into space. Finally, we look at the ionosphere, that portion of the upper atmosphere where large numbers of ions and free electrons exist.

Teaching Suggestions, Demonstrations, and Visual Aids

1. A large classroom demonstration vacuum chamber can be used to show that sound does not travel through a vacuum (place an alarm clock or buzzer in the vacuum chamber). Heat can't be transported via conduction and convection through a vacuum either. The rates of cooling of a warm object inside and outside the vacuum chamber could be compared to reinforce this fact (a third object could be placed in a large container of water at room temperature to illustrate the higher thermal conductivity of water). Students might become more aware of the importance of radiant energy transport between Earth and sun.
2. Chapter 1 in *Hands-On Meteorology* by Zbigniew Sorbjan (American Meteorological Society, 1996, ISBN 1-878220-20-9) discusses some of the early theories about air and early determinations of the chemical composition of air.
3. Place a candle in the center of a dish and partially fill the dish with water. Light the candle and then cover it with a large jar or beaker. The flame will consume the oxygen inside the jar and reduce the pressure. Water will slowly flow into the jar to re-establish pressure balance. The change in volume should be close to 20%, the volume originally occupied by the oxygen in the air. This demonstration can be used to illustrate the concept of partial pressure, which is later used in the chapter on humidity. The students should also be asked what they think the products of the combustion might be and why these gases do not replace the oxygen and maintain the original pressure in jar. One of the combustion products is water vapor, which condenses as the air in the jar cools. Another combustion product is carbon dioxide, which presumably goes into solution. Students should be asked what effect the heat generated by the burning candle might have on the results of the experiment.
4. Students often confuse water vapor with liquid water. Students should understand that water vapor is an invisible gas. Haze, fog, clouds, and the steam from a boiling pot all become visible when water vapor condenses and forms small drops of liquid water.

5. Some of the atmospheric pressure demonstrations described in Chapter 6 could be performed here also.
6. Fill a wine glass completely with water and cover it with a piece of plastic (such as the lid from a margarine container), being careful to remove any air. Invert the glass. The water remains in the glass because the upward force on the cover due to the pressure of the air is much stronger than the downward gravitational force on the water. The demonstration can be made much more convincing if a 4000 mL flask is used instead of the wine glass. When full of water, the flask weighs approximately 10 pounds.
7. Photographs showing the flat tops of thunderstorms taken from the ground or an airplane often mark the top of the troposphere. Shadows will often be apparent on visible satellite photographs taken when the sun is at a low angle in the sky. This creates the appearance of depth reinforces the fact that Earth's atmosphere is thin.
8. The discussion of surface air motions in Chapter 1 is a good place to introduce satellite images, loops, and surface weather maps. Being able to observe and understand weather phenomena on their own may heighten students' interest in the subject.
9. Challenge students to speculate on how we know the chemical composition of Earth's early atmosphere.
10. Use the University of Wyoming's Department of Atmospheric Science's website ([Atmospheric Soundings](#)) to demonstrate that most of the water vapor in the entire atmosphere is in the lower half of the troposphere. (Look at the "MIXR" column—this is water vapor mixing ratio, with units of g/kg—grams of water vapor per kilogram of dry air.)

Student Projects

1. Have the students mark the positions of fronts and pressure systems for each day on an outline map of the United States. (This information can be obtained, among other places, from the [NOAA Advanced Hydrologic Prediction Service](#).)
2. Have students compose a one-week blog or journal, including daily weather maps and weather forecasts. Have the students provide a commentary for each day as to the coincidence of actual and predicted weather.
3. Have students keep a daily record of weather observations, especially significant changes in the weather. Then, periodically, the instructor can supply mean daily data such as high and low temperatures, pressure, dew point, wind speed, cloud cover, and precipitation amounts. The students should plot these data and annotate the graph with their observations. Students can use their graphs to experimentally test concepts developed in class. After studying Chapter 1, for example, students might try to determine whether periods of stormy weather really are associated with lower-than-average surface pressure.
4. Students could attempt to repeat some of the experiments in *Hands-On Meteorology*.
5. Use the University of Wyoming's Department of Atmospheric Science's website ([Atmospheric Soundings](#)) to identify the altitude of the tropopause at locations on three different continents.

Answers to Questions for Review

1. Radiant energy from the sun.
2. Investigators use the scientific method by posing a question, putting forth a hypothesis, predicting what the hypothesis would imply if it were true, and carrying out tests to see if the prediction is accurate. To be accepted, a hypothesis has to be shown to be correct through a series of quantitative tests. Studying atmosphere, however, is somewhat different, because our Earth has only one atmosphere. Despite this limitation, scientists have made vast progress by studying the physics and chemistry of air in the laboratory (for instance, studying the way in which molecules absorb energy) and by extending those understandings to the atmosphere as a whole. Observations using weather instruments allow us to quantify how the atmosphere behaves and to determine whether a prediction is accurate. If a particular kind of weather is being studied, such as hurricanes or snowstorms, a field study can gather additional observations to test specific hypotheses.
3. Seven common weather elements are:
(1) *air temperature*—the degree of hotness or coldness of the air; (2) *air pressure*—the force of the air above an area; (3) *humidity*—a measure of the amount of water vapor in the air; (4) *clouds*—a visible mass of tiny water droplets and/or ice crystals that are above Earth's surface; (5) *precipitation*—any form of water, either liquid or solid (rain or snow), that falls from clouds and reaches the ground; (6) *visibility*—the greatest distance one can see; (7) *wind*—the horizontal movement of air.
4. Weather describes the condition of the atmosphere at any particular time and place. Climate describes weather conditions averaged over a region or over a time period.
5. *Meteorology* is the study of the atmosphere and its phenomena. The term itself goes back to the Greek philosopher Aristotle who, about 340 B.C., wrote a book on natural philosophy entitled *Meteorologica*.
6. Middle-latitude cyclonic storm, hurricane, thunderstorm, and tornado.
7. From the south.
8. From west to east.
9. High and low-pressure systems, fronts, wind speed and direction, cloud cover, and temperatures.
10. Low-pressure systems: counterclockwise. High-pressure systems: clockwise.
11. Weather and climate dictate the type of clothing we buy and wear, the types of crops we plant and harvest, and homes we build. Even if we have appropriate clothing and shelter weather and climate can greatly impact and affect our comfort, well-being, and overall health (e.g., arthritic pain is linked to high humidity and falling air pressures, heart attack incidences are higher after the passage of warm fronts, when rain and wind are common, and after the passage of cold fronts, when an abrupt change takes place as showery precipitation is accompanied by cold gusty winds, and headaches are common on days when we are forced to squint, often due to hazy skies or a thin, bright overcast layer of high clouds). Weather and climate can have dramatic economic impacts, either by saving heating costs in warm winters or by increasing them in cold years.

Cold weather, coupled with snow and ice typically affects commuter traffic, air travel, schools, and can lead to major power outages. Droughts can result in food shortages, starvation, heat strokes, dehydration, and very destructive wild fires. Strong winds, such as hurricanes, thunderstorms, and tornadoes, can lead to destruction and flash flooding.

12. Earth's first atmosphere (some 4.6 billion years ago) was most likely *hydrogen* and *helium*—the two most abundant gases found in the universe—as well as hydrogen compounds, such as methane and ammonia. A second, denser atmosphere gradually enveloped Earth as gases from molten rock within its hot interior escaped through volcanoes and steam vents. We assume that volcanoes spewed out the same gases then as they do today: mostly water vapor (about 80%), carbon dioxide (about 10%), and up to a few percent nitrogen. As millions of years passed, the constant outpouring of gases from the hot interior (outgassing) provided a rich supply of water vapor, which formed into clouds. Rain fell upon Earth for many thousands of years. Large amounts of CO₂ were dissolved in the oceans. The atmosphere gradually became rich in nitrogen (N₂). Oxygen (O₂), the second most abundant gas in today's atmosphere, probably began an extremely slow increase in concentration as energetic rays from the sun split water vapor (H₂O) into hydrogen and oxygen during a process called *photodissociation*. The hydrogen, being lighter, probably rose and escaped into space, while the oxygen remained in the atmosphere. After plants evolved, the atmospheric oxygen content increased more rapidly, probably reaching its present composition about several hundred million years ago. Today's atmosphere consists mostly of molecular nitrogen (N₂), which occupies about 78%, and molecular oxygen (O₂), which makes up about 21% of the total volume of dry air; argon, neon, helium, hydrogen, and xenon make up the remaining 1%. If the latter gases are removed, the percentages for nitrogen and oxygen hold fairly constant up to an elevation of about 80 km (or 50 mi).
13. Nitrogen, oxygen, argon, and water vapor.
14. Water vapor.
15. Ozone and oxygen filter out damaging ultraviolet radiation from the sun, greenhouse gases keep the planet warm, and the atmosphere provides water to drink and oxygen to breathe.
16. Water forms precipitation, releases latent heat, and is a greenhouse gas. Water vapor is extremely important for Earth's heat-energy balance.
17. CO₂ enters the atmosphere through vegetation decay, volcanic eruptions, exhalations of animal life, and through burning of fossil fuels and deforestation. CO₂ removal occurs through photosynthesis, *chemical weathering*, and with the help of phytoplankton, by deposition into Earth's oceans. The amount of CO₂ in the atmosphere has increased over the course of the last 100 plus years due to burning of fossil fuels and deforestation.
18. Soil, dust, salt from ocean waves, forest fire smoke, volcanic ash particles and gases, and pollutants.
19. Water vapor and carbon dioxide.
20. (a) Air is surprisingly heavy, and the more molecules are packed into an air column, the denser an air column becomes, and the more the surface pressure increases. On the other hand, when fewer molecules are in the air column, the air weighs less, and the surface pressure goes down.

- (b) Atmospheric pressure decreases with increasing height, because as we climb in elevation, fewer air molecules are above us and a greater number is below us.
21. (a) 29.92 in. Hg, (b) 1013.25 mb, (c) 1013.25 hPa.
22. Troposphere, stratosphere, mesosphere, and thermosphere.
23. Generally, temperature decreases from Earth's surface to the tropopause (i.e., boundary between the troposphere and stratosphere at around 11 km or 36,000 ft.). It then increases throughout the stratosphere, but decreases again in the mesosphere. The top of the mesosphere (i.e., the mesopause) represents the coldest part of Earth's atmosphere. In the thermosphere temperature increases again.
24. (a) Troposphere, (b) Stratosphere; thermosphere.
25. Antarctica
26. Since the air in the upper stratosphere is extremely thin and the atmospheric pressure is low mesospheric air contains far fewer oxygen molecules than a breath of tropospheric air.
27. The **ionosphere** is not really a layer, but rather an electrified region within the upper atmosphere where fairly large concentrations of ions and free electrons exist.

Answers to Questions for Thought and Exploration

1. Climate: It's currently winter so I should wear warm clothing. Weather: It's warmer today than yesterday, so I can wear a lighter coat.
2. Answers may vary, but the student should point out that a newspaper weather map typically simplifies information. Cold fronts are often represented in different shades of blue (the darker the blue, the colder the temperature), and warm fronts are shown in shades of red. Cyclones are color-coded with the colors representing different intensities. Professional weather maps will comprise a lot more detailed information, and symbols are different. Cold fronts are displayed by blue triangles drawn on to a blue line (triangle point indicates the direction the cold front is moving), and warm fronts are represented by red half circles along a red line. Isotherms are used to display temperatures and temperature gradients, and isobars to show high and low-pressure systems. Isobars would show a middle latitude cyclone as a circular low-pressure system.
3. (a) Climate, (b) weather, (c) climate, (d) weather, (e) climate, (f) climate, (g) weather, and (h) climate.
4. The student first needs to be able to pose the right question, and in this case, the question would be "In which direction do weather systems move in the middle latitudes?" Subsequently, the student will come up with a hypothesis, and since the idea is to disprove the friend's hypothesis, it will be "Weather systems in the middle latitudes move from west to east." The student will then investigate potential experiments and tests that could be used to support this hypothesis. For example, s/he could look at wind maps from the middle latitudes that were put together over a period of times. If the student lives in the middle latitudes, s/he could put up a wind sock or wind vane to measure the wind direction. The idea is to design a series of quantitative tests that are accepted by the scientific community to prove his hypothesis and disprove the friend's hypothesis.

5. The student will draw an outline of North America, and using different colors, will mark daily positions of cold and warm fronts, and pressure systems over a period of several weeks. The student will be able to conclude in which direction the weather patterns are moving (west to east due to the jet stream), and how North America is affected by cold fronts moving in from the Arctic Circle and warm fronts from the Gulf of Mexico. In addition, s/he should be able to point out that middle latitude cyclones are daily phenomena, which drive the weather and produce a wide range of weather phenomena.
6. The student will compose a journal over a one-week period, which will list forecasts, weather maps, and weather-related newspaper articles, and will compare and contrast the forecasted weather with the actual weather of each day. The student will need to understand overall weather patterns, but also the difficulties associated with predicting the weather in certain regions (e.g., mountainous regions).