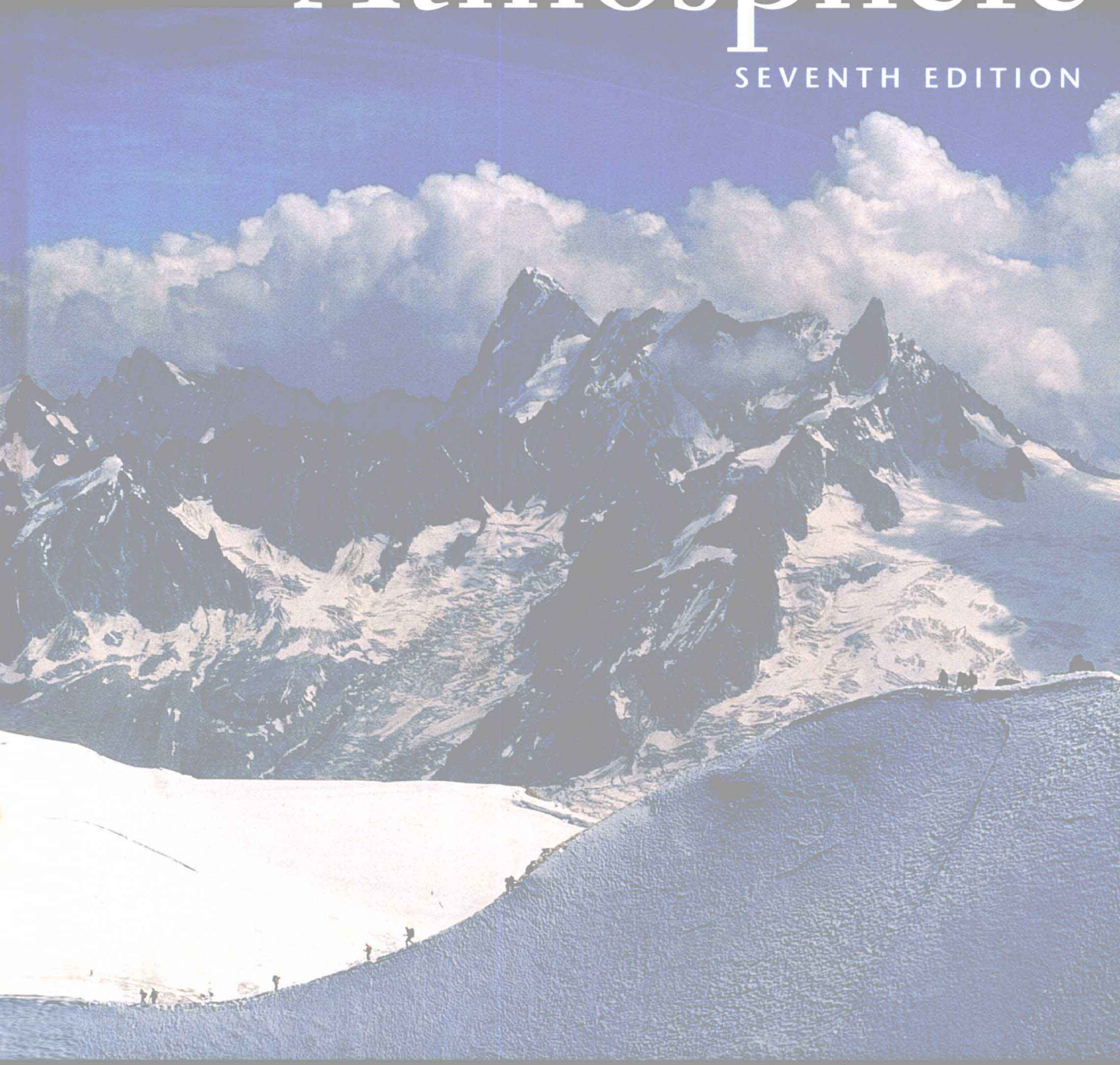
The Atmosphere

SEVENTH EDITION



Frederick K. Lutgens ▪ Edward J. Tarbuck

SEVENTH EDITION

The Atmosphere

An Introduction to Meteorology

Frederick K. Lutgens
Edward J. Tarbuck
ILLINOIS CENTRAL COLLEGE

Illustrated by
Dennis Tasa

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Preface

There are few aspects of the physical environment that influence our daily lives more than the phenomena we collectively call *weather.* Newspapers, magazines, and television stations regularly report a wide range of weather events as major news stories—an obvious reflection of people's interest and curiosity about the atmosphere. We also face important environmental problems related to the atmosphere. Such issues as air pollution, ozone depletion, and global warming require our attention. A basic meteorology course can take advantage of our interest and curiosity about the weather as well as our desire to understand the impact that people have on the atmospheric environment.

The Atmosphere: An Introduction to Meteorology, Seventh Edition, is designed to meet the needs of students who enroll in such a course. It is our hope that the knowledge gained by taking a class and using this book will encourage many to actively participate in bettering the environment, and others may be sufficiently stimulated to continue their study of meteorology. Equally important, however, is our belief that a basic understanding of the atmosphere and its processes will greatly enhance appreciation of our planet and thereby enrich the reader's life.

In addition to being informative and up-to-date, a major goal of *The Atmosphere* is to meet the need of beginning students for a readable and user-friendly text, a book that is a highly usable "tool" for learning basic meteorological principles and concepts.

The language of this book is straightforward and *written to be understood.* Clear, readable discussions with a minimum of technical language are the rule. When new terms are introduced, they are placed in **boldface** and defined. The frequent headings and subheadings help students follow discussions and identify the important ideas presented in each chapter. A list of key terms with page references is found at the end of each chapter, and a glossary is included at the conclusion of the text for easy reference to important terms. Review questions conclude each chapter to help the student prepare for exams and quizzes. Problems with a quantitative orientation are also found at the ends of many chapters. Most problems require only basic mathematical skills and allow students to enhance their understanding by applying scientific principles explained in the chapter. Useful information on metric conversions and weather maps is found in the appendices along with other helpful reference material.

Meteorology is highly visual. Therefore, photographs and artwork are a very important part of an introductory book. *The Atmosphere, Seven Edition,* contains dozens of new high-quality photographs that were carefully selected to aid understanding, add realism, and heighten the interest of the reader.

The seventh edition of *The Atmosphere: An Introduction to Meteorology* represents a thorough revision. However, it should be emphasized that the main focus of the new edition remains the same as that of its predecessors—to foster a basic understanding of the atmospheric environment. In keeping with this aim, the organization of the text remains intentionally traditional. Following an overview of the atmosphere in Chapter 1, the next 10 chapters are devoted to a presentation of the major elements and concepts of meteorology. Chapter 12 on weather analysis follows and serves to reinforce and apply many of the concepts presented in the preceding chapters. Chapter 13 is devoted to the important issue of air pollution.

The text concludes with two chapters on climate (Chapter 14 and 15), and one devoted to optical phenomena (Chapter 16). Chapter 14, "The Changing Climate," explores a topic that is the focus of much public interest as well as scientific research: Is global climate changing, and, if so, in what ways? How are people causing or contributing to these changes? The discussions in Chapter 14 have been carefully and thoroughly revised and updated to reflect the fast-changing nature of this sometimes controversial subject.

An examination of the seventh edition of *The Atmosphere* will reveal greater strength in the following areas:

- Quantitative emphasis: Although the text remains nontechnical in its basic approach, the book includes six boxes on quantitative topics. In addition, problems are a part of 10 chapters.
- Case studies: The seventh edition includes several case studies of specific weather events, including a late winter blizzard, a storm that spawned 55 tornadoes, and a devastating hurricane. These and other case studies serve to illustrate and apply basic concepts. Most include weather maps, charts, and tables.

- Readability: Improved readability was achieved by reducing sentence and paragraph length, omitting unnecessary details, examining chapter organization and flow, and writing in a more personal style. In the seventh edition, Chapters 1, 2, 3, 4, 5, 14, and 15 were substantially rewritten in an effort to make the material more understandable and the text more "user friendly".
- Environmental issues: Many of the serious environmental issues that face humanity are related to the atmosphere. The new edition includes expanded and updated treatment of air pollution, ozone depletion, global warming, and more.
- Special-interest boxes: Boxes allow us to explore applications, interesting examples, and related scientific principles without significantly disrupting the flow of basic text discussions. This popular feature has been expanded in the seventh edition. There are now an average of nearly four boxes per chapter.

Acknowledgments

Writing a college textbook requires the talents and cooperation of many individuals. Working with Dennis Tasa, who is responsible for all of the outstanding illustrations, is always special for us. We not only value his outstanding artistic talents and imagination, but his friendship as well. Once again we benefited from the skills of our Developmental Editor Fred Schroyer. He helped us make the seventh edition a more readable, user-friendly text.

We also acknowledge the contributions of Professor Gregory J. Carbone at The University of South Carolina. In addition to his numerous insightful comments, he prepared eight special interest boxes and many chapter-end problems. He has also prepared a new edition of the excellent laboratory manual that is available to accompany this text.

Our students remain our most effective critics. Their comments and suggestions continue to help us maintain our focus on readability and understanding.

Special thanks goes to those colleagues who prepared in-depth reviews. Their critical comments and thoughtful input helped guide our work and clearly strengthened the text. We wish to thank:

Christopher R. Church, *Miami University*
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We also want to acknowledge the team of professionals at Prentice Hall. Thanks to Editor-in-Chief Paul Corey. We sincerely appreciate his continuing strong support for excellence and innovation. Thanks also to our editor Dan Kaveney. His strong communication skills and energetic style contributed greatly to the project. The production team, led by Ed Thomas, has done an outstanding job. They are true professionals with whom we are very fortunate to be associated.

Frederick K. Lutgens

Edward J. Tarbuck

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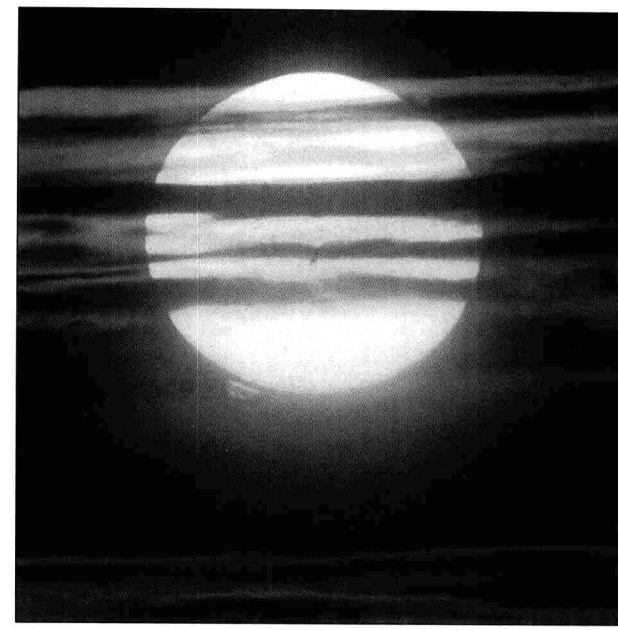

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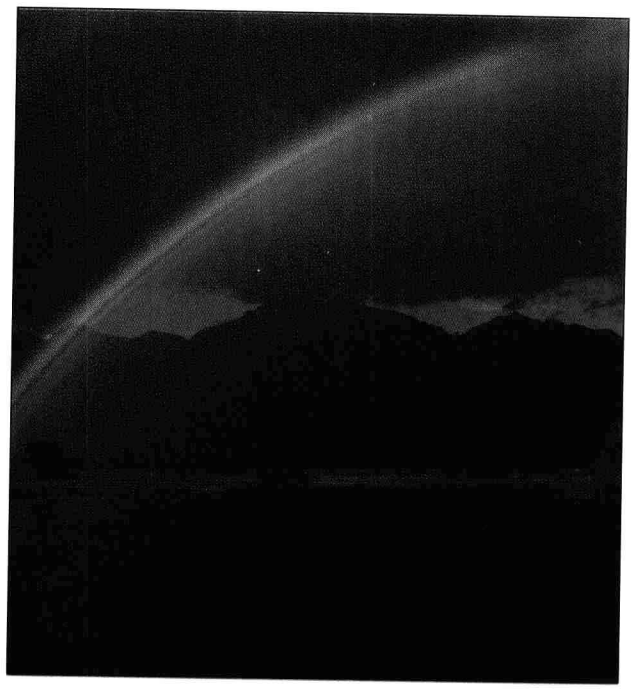
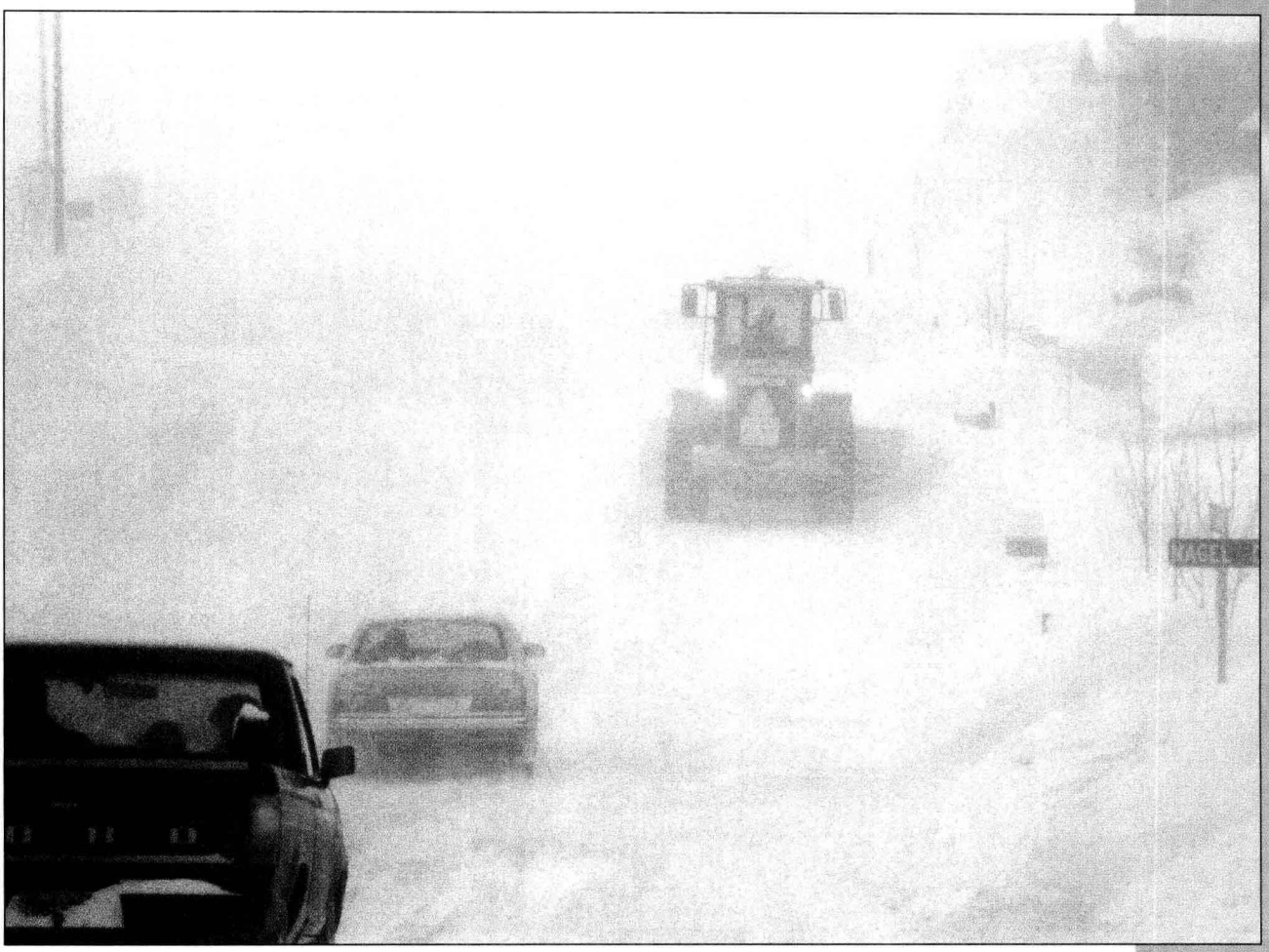


CHAPTER

1

Introduction to the Atmosphere



In January, 1997, many parts of the northern Great Plains experienced paralyzing blizzards. This one struck Bismarck, North Dakota on January 9, 1997. (Photo by Mike McCleary/Bismarck Tribune)

Weather influences our everyday activities, our jobs, and our health and comfort. Many of us pay little attention to the weather unless we are inconvenienced by it or when it adds to our enjoyment of outdoor activities. Nevertheless, there are few other aspects of our physical environment that affect our lives more than the phenomena we collectively call the weather.

In August 1992, the winds of Hurricane Andrew devastated portions of south Florida and Louisiana. Although the loss of life was relatively small, 250,000 people were left without homes. Losses in Florida alone exceeded $20 billion. Seven months later, in March 1993, a giant blizzard swept northward from the Gulf of Mexico up the east coast and into the maritime provinces of Canada. Many observers, including the National Weather Service, referred to this huge atmospheric upheaval as the "storm of the century." Nearly 300 deaths were attributed to the storm. Just a few months later, during the summer of 1993, torrential rains in the Midwest led to record flooding. Portions of the Mississippi and Missouri river systems experienced floods that have a probability of occurring only once every 500 years. For weeks, scenes of sandbaggers working to hold back the rising rivers were daily features on the evening news. Meanwhile, portions of the Southeast were suffering a record heat wave and drought. It was a summer of contrasts. Whereas many Midwest farmers had to contend with waterlogged or flooded fields, many of their counterparts in the South saw their crops wither and die for lack of adequate rain.

Although the foregoing weather events may have been especially striking or severe, they are not unusual. They serve to illustrate the fact that the United States has the greatest variety of weather of any country in the world (Figure 1–1). Severe weather events such as tornadoes, flash floods, and intense thunderstorms, as well as hurricanes and blizzards, are collectively more frequent and more damaging in the United States than in any other nation. Beyond its direct impact on the lives of individuals, the weather has a strong effect on the world economy as well as by influencing agriculture, energy use, water resources, transportation, and industry.

Weather clearly influences our lives a great deal. Yet, it is also important to realize that people influence the atmosphere and its behavior as well. There are and will continue to be significant political and scientific

Figure 1–1 The United States has the greatest variety of weather of any country. Severe weather events are frequent and costly occurrences. The flooding Tuolumne River, west of Modesto, California created this scene in January 1997. Record–breaking floods struck parts of California, Nevada, and the Pacific Northwest during the winter of 1996–97. (Photo by Ted Benson/*The Modesto Bee*/SYGMA)

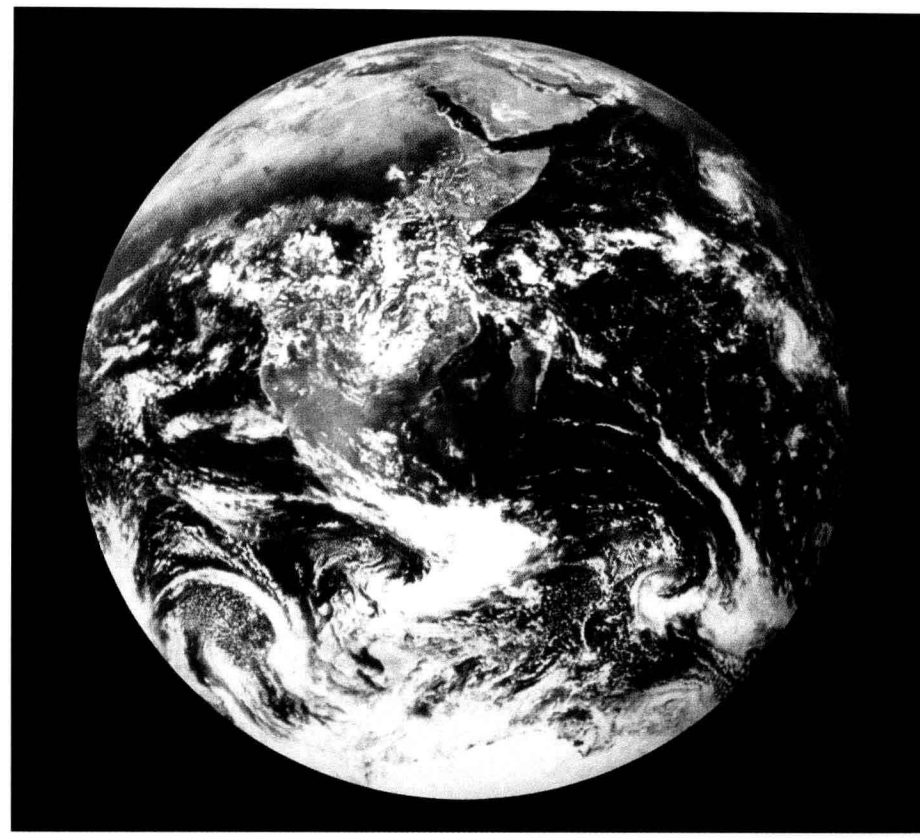


Figure 1–2 Africa and Arabia are prominent in this image of Earth taken from Apollo 17. The tan cloud-free zones over the land coincide with major desert regions. The band of clouds across central Africa is associated with a much wetter climate that in places sustains tropical rain forests. The dark blue of the oceans and the swirling cloud patterns remind us of the importance of the oceans and the atmosphere. Antarctica, a continent covered by glacial ice, is visible at the South Pole. (Courtesy of NASA)

decisions to make involving these impacts. Answers to questions regarding air pollution and its control and the effects of various emissions on global climate and the atmosphere's ozone layer are important examples. So there is a need for increased awareness and understanding of our atmosphere and its behavior.

Earth's Four Spheres

A view of Earth from space affords us a unique perspective of our planet (Figure 1–2). At first it may strike us that Earth is a fragile-appearing sphere surrounded by the blackness of space. It is, in fact, just a speck of matter in a vast universe. As we look more closely, it becomes apparent that Earth is much more than rock and soil. Indeed, the most conspicuous features are not the continents, but the swirling clouds suspended above the surface and the vast global ocean. These features emphasize the importance of water to our planet.

From such a vantage point, we can appreciate why Earth's physical environment is traditionally divided into three major parts: the solid Earth; the water portion of our planet, the hydrosphere; and Earth's gaseous envelope, the atmosphere. It is this last portion of our physical environment, the atmosphere, that is the primary focus of this text. It should be emphasized, however, that our environment is highly integrated and is not dominated by rock, water, or air alone. Rather, it is characterized by continuous interactions as air comes in contact with rock, rock with water, and water with air. Moreover, the biosphere, the totality of life-forms on our planet, is associated with each of the three physical realms and is an equally integral part of Earth. The interplay and interactions among the spheres of Earth's environment are uncountable (see Box 1–1).

The Solid Earth

The solid Earth is divided into three principal units: the dense core, the less dense mantle, and the crust, which is the light and very thin outer skin of Earth (Figure 1–3). The term **lithosphere** refers to a rigid outer layer of Earth that includes the crust and uppermost part of the mantle.

The crust averages only about 20 kilometers in thickness and varies from less than 5 kilometers in the ocean basins to more than 35 kilometers on the continents. When we consider the fact that the distance from Earth's surface to its center is about 6400 kilometers, this thin layer may seem relatively insignificant. However, the crust is of supreme importance. It is from this outermost layer that we derive the energy and

Box 1–1
Earth as a System

A *system* is a group of interrelated, interacting, or interdependent parts that form a complex whole. Most of us hear and use the term frequently. We may service our car's cooling *system*, make use of the city's transportation *system*, and be a participant in the political *system*. A news report may inform us of an approaching weather *system*.

We know that Earth is just a small part of a large system known as the *solar system*. As we study Earth, it also becomes clear that our planet can be viewed as a system with many separate but interacting parts or subsystems. The hydrosphere, atmosphere, biosphere, and solid Earth and all of their components can be studied separately. However, the parts are not isolated. Each is related in some way to the others to produce a complex and continuously interacting whole that we call the *Earth system*.

The parts of the Earth system are linked so that a change in one part can produce changes in any or all of the other parts. For example when a volcano erupts, lava from Earth's interior may flow out at the surface and block a nearby valley. This new obstruction influences the region's drainage system by creating a lake or causing streams to change course. The large quantities of volcanic ash and gases that can be emitted during an eruption may be blown high into the atmosphere and influence the amount of solar energy that can reach the surface. The result could be a drop in air temperatures over the entire hemisphere. Where the surface is covered by lava flows or a thick layer of volcanic ash, existing soils are buried. This causes the soil-forming processes to begin anew to transform the new surface material into soil (Figure 1–A). The soil that eventually forms will reflect the interaction among many parts of the Earth system. Of course, there would also be significant changes in the biosphere. Some organisms and their habitats would be eliminated by the lava and ash, while new settings for life, such as the lake, would be created. The potential climate change could also impact sensitive life-forms.

The Earth system is powered by energy from two sources. The sun drives external processes that occur in the atmosphere, hydrosphere, and at Earth's surface. Weather and climate, ocean circulation, and erosional processes are driven by energy from the sun. Earth's interior is the second source of energy. Heat remaining from when our planet formed and heat that is continuously generated by radioactive decay, powers the internal processes that produce volcanoes, earthquakes, and mountains.

Humans are *part of* the Earth system, a system in which the living and nonliving components are entwined and interconnected. Therefore our actions produce changes in all of the other parts. When we burn gasoline and coal, build breakwaters along the shoreline, dispose of our wastes, and clear the land, we cause other parts of the system to respond, often in unforeseen ways. In this book you will learn about some of Earth's subsystems: the hydrologic system and the climate system, for example. Remember that these components *and we humans* are all part of the complex interacting whole we call the Earth system. ■

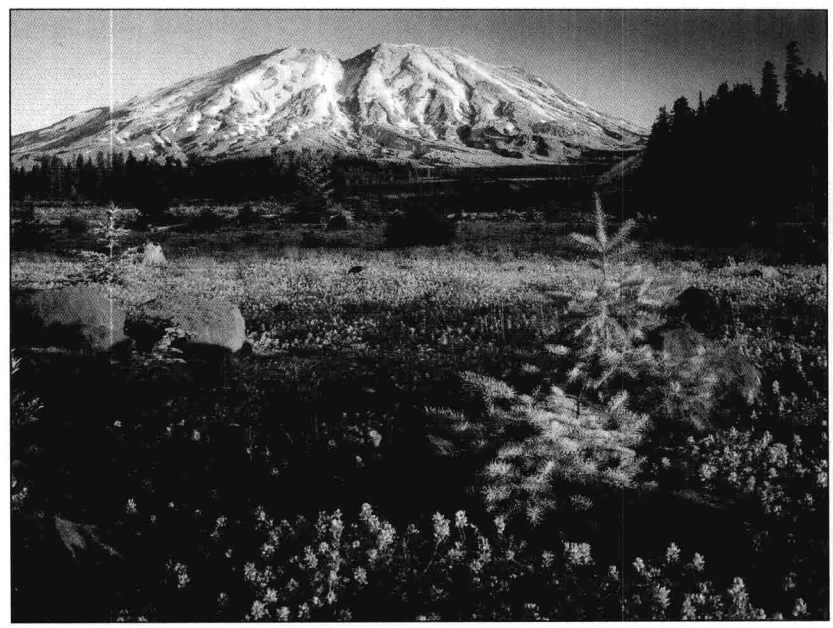


Figure 1–A When Mount St. Helens erupted in May 1980, the area shown here was buried by a volcanic mudflow. Now, plants are reestablished and new soil is forming. (Photo by Jack Dykinga)