CLIMATE AND MAN'S ENVIRONMENT

AN INTRODUCTION TO APPLIED CLIMATOLOGY

JOHN E. OLIVER

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Preface

This text is the outcome of my varied experiences in teaching courses in climatology and applied climatology. While there are a number of excellent introductory texts covering the dynamics of climate and regional climatology, they frequently do not contain material concerning the varied applications of the concepts and principles expressed. Because of the multidisciplinary nature of applied climatology, it was necessary to scour the literature for appropriate readings so that a meaningful course could be taught. Unfortunately, such readings almost always assumed a basic knowledge of the subject to which climate is being related. In many instances, students do not have such a background and much valuable class time is spent in supplying the basic concepts needed. By bringing together much of this varied material, presenting it in a rational conceptual context, this void will hopefully be filled. Furthermore, the text should supply a suitable starting point for the discussion of the many fascinating aspects of applied climatology.

The impact of climate upon man and his environment crosses many disciplines; no one person can assume expertise in all these areas. Accordingly, I have drawn heavily upon the thoughts and ideas of numerous authors, have corresponded with many, and have belabored my colleagues with endless questions. To all of these persons I express my gratitude. I am also grateful to the many publishers who permitted me to use or adapt their diagrams; these are acknowledged in the text. Similarly, I would like to thank the following for granting permission to use their work: W. S. Broecker, Jen-hu Chang, J. F. Cronin, J. R. Goldsmith, L. Greenburg, P. P. Micklin, R. E. Munn, R. E. Murphy, W. R. D. Sewell, H. Suzuki, W. Van Royen, and especially A. N. Strahler who allowed me to use many of his excellent diagrams.

No author with a young family could possibly complete a manuscript without an enormous amount of patience and fortitude on the part of his wife; it is certainly to the credit of my wife that this book was ultimately completed.

John E. Oliver
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November 1972.

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Contents

Introduction

In the 1951 *Compendium of Meteorology*, Landsberg and Jacobs state: "If we consider climate as the statistical collective of individual conditions of weather, we can define *applied climatology* as the scientific analysis of this collective in the light of a useful application for an operational purpose. . . . The term operational is . . . broadly interpreted as any useful endeavor, such as industrial, manufacturing, agricultural, or technical pursuits." Such a definition still holds true and is, in part, followed in this text. However, in view of the current and growing interest in study of the environment as a functioning entity of many interacting systems, I have seen fit to extend the concept of "applied climatology." Few would deny that the study of the environment and environmental deterioration crosses the boundaries of established disciplines and that the modern environmental scientist needs a broad background in quite diverse disciplines. Climate-environment relationships certainly form part of this required background so that it is necessary to identify a wider scope of applied climatology than that defined previously. It might instead be considered as application of the principles and concepts of climatology to spheres of endeavor that concern man and his past and present environments. The aim of such study is to facilitate comprehension of the relationships that exist and to promote a rational interpretation of climatic concepts as they relate to both natural and man-modified environments.

In keeping with this aim, Part I treats relationships between climate and environment.[1] It essentially concerns the application of climatic principles and climatic interpretation to areas of study directly related to the natural environment. The approach used is systematic but it is hoped that the interconnectivity between each "Climate and . . ." chapter becomes clear. Part II covers applied climatology within the context of the Landsberg-Jacobs definition. It assesses the role of climate in the study of man and his pursuits, and the operational purposes including bioclimatology, industry, and agriculture.

Part III serves a dual function. First, it provides a summary of the changes in climate over time; second, it is an exercise in the utilization of applied climatology as it is defined here. To reconstruct climates of the past many interpretive tools are needed and, for the most part, the nature of past climates must be derived from their impact upon other environmental systems. Thus a reciprocal relationship exists; to interpret past climates one must understand other environmental systems—but to understand those systems it is necessary to comprehend the role of climate in shaping them.

With applied climatology so widely defined, its scope is obviously enormous. This poses problems concerning the selection of material presented and the level at which it is to be treated. When it is considered that entire journals may be devoted to a subject that is treated in a few pages here, the problem is clearly evident. To meet this, I have chosen to provide a survey of ideas and interpretations rather than select isolated examples and study them in depth. The value of this approach is that once basic principles are covered, follow-up studies can be completed more easily; to facilitate this approach an extensive bibliography is given.

I hope that the text will be useful in a number of ways. For students in climatology courses it provides a source that allows them to comprehend the significance of climatology beyond the basic coverage of the workings of climate, and why and where climatic regimes are so located. To students in other disciplines, ranging from geomorphology to human ecology, it provides a climatic viewpoint of aspects of their studies that may have been overlooked in a single-discipline approach. Finally, to the growing

[1] Since climate is, of course, environment, the relationship suggested here is one of emphasis; in effect, the climatic environment is viewed as one conditioner of the total environment and the nature of environmental interaction.

number of students studying environmental science, it provides a perspective on one of the most important inputs in their field of study.

In keeping with the survey nature of the text, statistics and mathematics have been kept to a minimum. Equations presented are, for the most part, symbolic representations of worldwide exchanges. Data presented in the text are given in metric units except where, in cited references, the original units are retained. For those interested in analytic use of climatic data, the Appendices include data sources and statistical methods.

PART I
Climate and Environment

CHAPTER 1

Climate and the Ecosphere

In recent years the necessity of treating environmental problems holistically has meant that problem solving has become both interdisciplinary and multidisciplinary. To facilitate such treatment, many ecological terms and concepts have become widely used in disparate disciplines. The concepts of the biosphere (that part of the earth-atmosphere system in which life exists) and the ecosystem (a self-sustaining community of organisms taken together with their physical environment) provide two widely used examples. To express a combination of these two concepts simultaneously, LaMont Cole (1958) introduced —in somewhat apologetic terms—the concept of the ecosphere. It has proved a useful addition to the literature, because, in essence, it provides a single concept that allows treatment of the worldwide system in ecologic terms.

The interaction between living (biotic) and nonliving (abiotic) components of the ecosphere can be represented in a variety of ways. Figure 1–1, for example, shows the basic components that combine to produce a terrestrial ecosystem. The system depends upon the nature of the climate, biota, and surface materials, and the manner in which they interact. To analyse such a system, Odum (1962) suggests that it is necessary to deal with both its structure and its function. The structure of the system involves:

1. The composition of the biological community.
2. The quantity and distribution of abiotic materials.
3. The range, or gradient, of conditions of existence, for example, that of temperature or light.

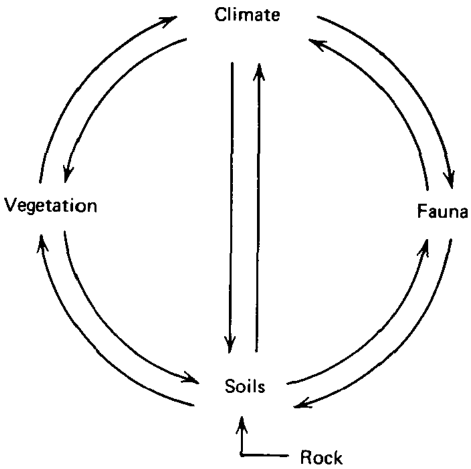


Figure 1–1. Components of a terrestrial ecosystem.

Used in conjunction with Figure 1–1, such a framework would allow a relatively static aspect of the system to be assessed. To explain how the system works, it is necessary to analyse the factors that allow it to function, where function concerns:

1. The rate of energy flow through the system.
2. The rate of material and nutrient cycling.
3. The environmental (e.g., varying day-length) and biologic (e.g., nitrogen fixation) regulations that occur.

Thus, to place both structure and function in perspective, it becomes necessary to redesign the schematic representation shown in Figure 1–1, for the active processes of, and inputs into, the system need to be explored.

Figure 1–2 represents, in schematic form, how this might be conceived; superimposed upon the original ecosystem are the realms that contribute toward its function. Comprising processes associated with the atmosphere, biosphere, and terresphere, the full complexity of the system becomes apparent. As indicated by the intersecting circles, each of the designated realms is both directly and indirectly related to the others.

It is clear that atmospheric processes, especially on a long-term climatological basis, form a significant part of the system, playing a role in both structural and functional aspects. Furthermore, it is evident that the system, be it a local

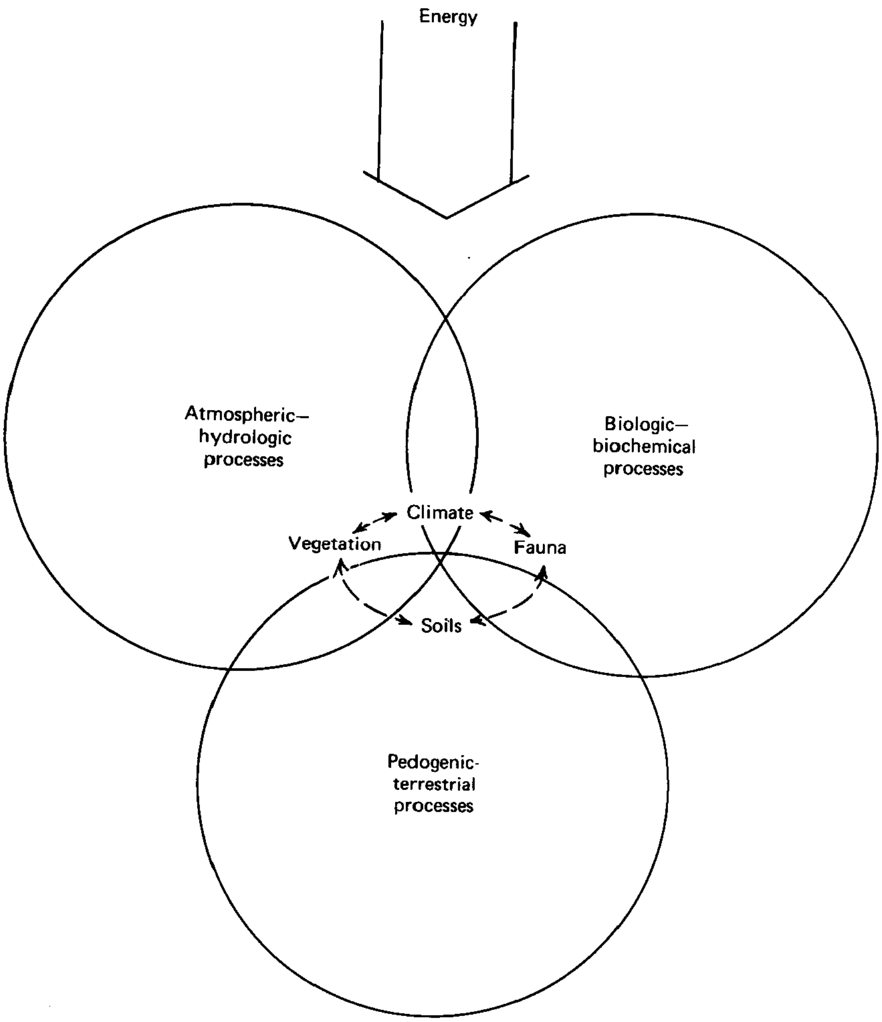


Figure 1–2. Ecosystem function shown as interacting sets of environmental processes.

ecosystem or the entire ecosphere, requires energy to function. Since this energy is almost totally derived from the sun, the study of solar radiation—its nature and its distribution over time and space—forms the very core of understanding the energetics of the ecosphere.

ENERGY FOR THE SYSTEM

The ultimate source of almost all energy available on earth is the sun. A giant nuclear fission device, converting hydrogen to helium, the sun radiates energy to surrounding space. As electromagnetic radiation, solar energy is described in terms of wavelike disturbances that, like any wave, are characterized by wavelength (the distance separating successive crests—or troughs—of the wave) and wave frequency (the number of waves passing a fixed point each second). The relationship between these two is given by

$$c = \lambda v$$

where c = the speed of the wave [equals the speed of light 299,800 km (186,000 miles)/sec]
v = wave frequency
λ = wavelength

Because the product of wavelength and wave frequency equal a constant, it follows that short wavelengths are characterized by high frequency and long wavelengths by low frequency (Figure

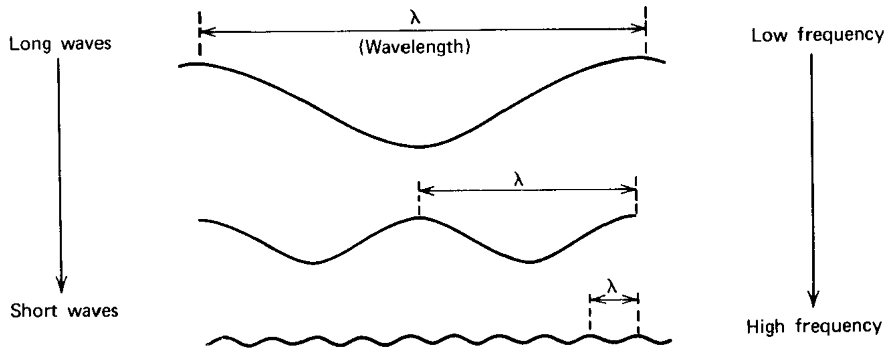


Figure 1–3. Relationship between wavelength and wave frequency.

1–3). Wavelengths can be measured in centimeters (cm), microns (μ), with 1μ equal to 10^{-4} cm or Angstrom units (Å), where 1 Å equals 10^{-8} cm.

Since waves may have a wide range of lengths, an entire spectrum of electromagnetic radiation can be identified. Figure 1–4 shows the spectrum and indicates how different bands are characterized by different types of radiation. The diagram shows that solar radiation is confined to a limited portion of the spectrum, with a peak occurring in the part comprising visible light. The reason for this localization is explained through examination of the laws governing radiation.

All bodies, not at absolute zero (−273°C, (0°K), the temperature at which all molecular motion ceases), radiate energy to surrounding space. The efficiency at which they radiate is highly variable, with the perfect radiator being a blackbody. This has the property of absorbing all radiation that falls upon it and then emitting radiation in a manner that depends solely upon its temperature. Blackbody radiation is the highest value that a body can theoretically emit at a given temperature.

The sun may be considered a blackbody and, through analysis of the solar beam, it can be established that the wavelength of maximum emission (λ_{max}) is about 0.5 μ. Using Wien's displacement law, given as

$$\lambda_{max} = K/T$$

(T = absolute temperature, K = constant = 2897), the surface temperature of the sun is calculated to be about 6000°C. The flux of energy of a blackbody at this temperature is derived using Stefan's formula, which relates the flux to the fourth power of the temperature of the radiating body:

$$F = \sigma T^4$$

where F = flux of radiation [ly (langley)/min]
T = absolute temperature
σ = Stefan-Boltzmann constant, 0.813×10^{-10} cal/cm²/min (°K)⁴

The flux is evaluated at 100,000 ly/min (langleys are radiation units where 1 ly = 1 cal/cm²).

The earth, at a mean distance of 93,000,000 miles (149.5×10^6 km) from the sun intercepts but a minute fraction of this output, about 0.0025%. In fact, the amount of radiation falling on a surface perpendicular to the solar beam, at the outer edge of the atmosphere, is estimated at 2.0 ly/min. This value, although it does vary, is called the solar constant. Note that this value refers to solar energy incident on a plane; the earth is a sphere with only half its surface exposed to solar radiation at any one time. The value must be decreased accordingly.[1]

As a sphere, rotating on an inclined axis at a variable distance from the sun, the earth's surface (excluding the effects of the atmosphere for the moment) receives energy that is highly variable over both time and space. Effects of these

[1] The incident solar radiation averaged over the globe will be given by

$$\text{solar constant} \times \frac{\text{area of circular plane}}{\text{area of sphere}} = \text{solar constant} \times \frac{\pi R^2}{4\pi R^2}$$

that is, ¼ of the value.

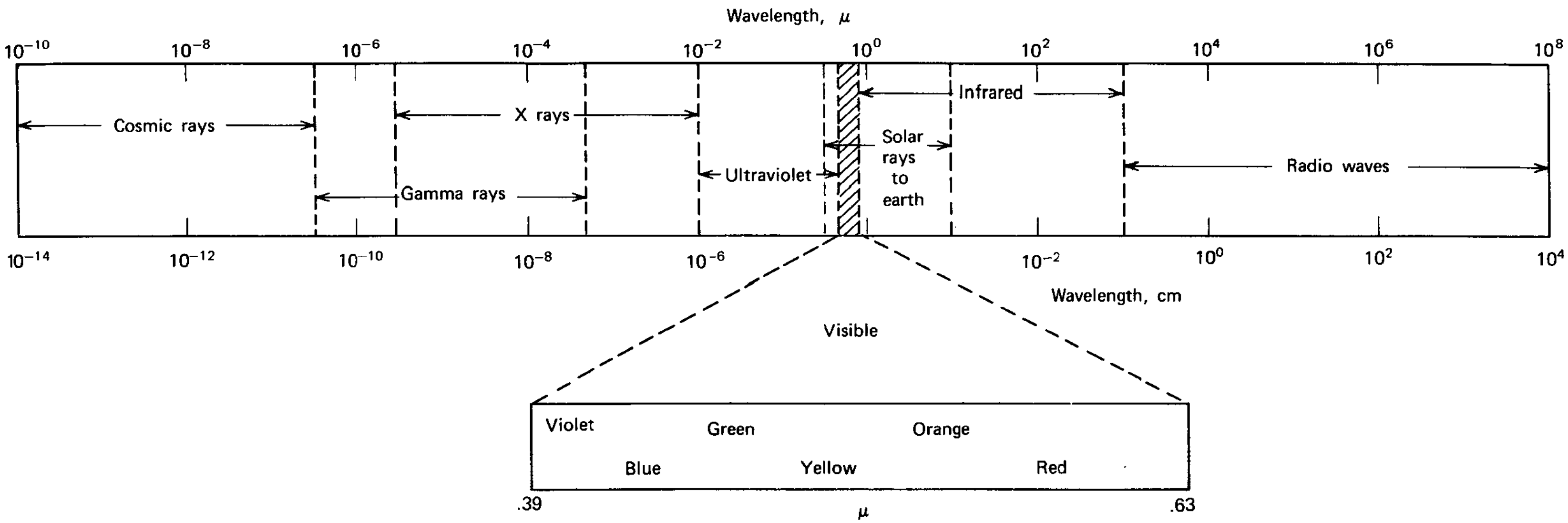


Figure 1–4. The electromagnetic spectrum.

astronomical features are summarized in Figure 1–5. In revolving around the sun, the earth is in its closest position on January 3 (perihelion), while it is most distant on July 4 (aphelion). This variable earth-sun distance means that the amount of solar radiation intercepted by the earth in January (perihelion) is about 7% more than in July.

A spherical earth also means that only one point on earth can have the sun directly overhead at any one time. That is, assuming no atmosphere, the intensity of radiation on a surface (I_h) is equal to that incident radiation (I_o) when the sun is at an elevation of 90°. As the angle between the surface and the overhead sun decreases, so I_h will decrease. The relationship is given by

$$I_h = I_o \sin a$$

where a is the sun's altitude, that is, the angle between the surface (horizon) and the overhead sun. The significance of this relationship is best seen by example.

If the sun is directly overhead, then $a = 90°$, and

$$I_h = I_o \sin 90°$$

The sine of 90° is 1; thus

$$I_h = I_o$$

Consider now the intensity of insolation at 60°N at noon on the day of the equinox. The angle of the sun in the sky is 30°.

$$I_h = I_o \sin 30,$$

the sine of 30° is 0.5, so

$$I_h = 0.5 I_o$$

The value of radiation intensity is decreased by half. The altitude of the sun in the sky at different times of the year, a function of latitude, plays a very important role in determining the amount of radiation received.

In the same way, the fact that the earth's axis maintains a fixed tilt causes the lengths of day and night to vary over the globe. Obviously, long hours of darkness decrease the amount of radiation, with the result that the seasonal variation in length of day and night over the earth's surface plays a significant part in determining radiation received.

The result of the interplay of these factors is shown in Figure 1–6, which gives the latitudinal distribution of solar radiation over a year. Note the highest values occur at perihelion and that annual variation is least in equatorial latitudes. At the poles, the values are most extreme. In the winter season, no radiation is received; in the summer, despite the low angle of the sun in the sky, the values are quite large, reflecting the fact that the sun is in the sky continuously.

The Role of the Atmosphere

The envelope of gases that encircle the earth modify the amount of solar radiation that is received at the surface. At about 88 km (55 miles) above the earth's surface, the solar beam differs little from its original form. At this level, irradiation of oxygen causes photodissociation of the oxygen molecule:

$$O_2 \rightarrow O + O$$

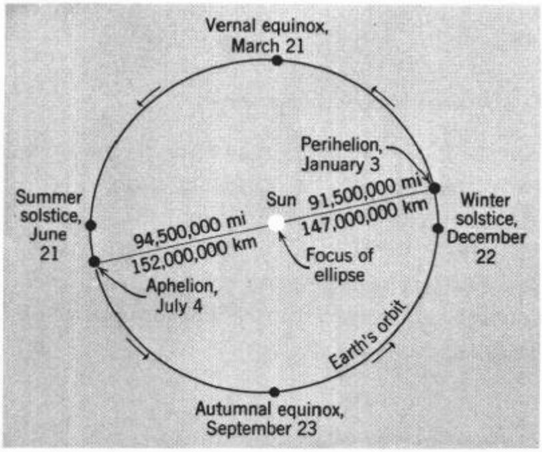
At this altitude, low atmospheric density means that little recombination occurs. This takes place largely between 30 and 60 km above the surface where ozone is formed:

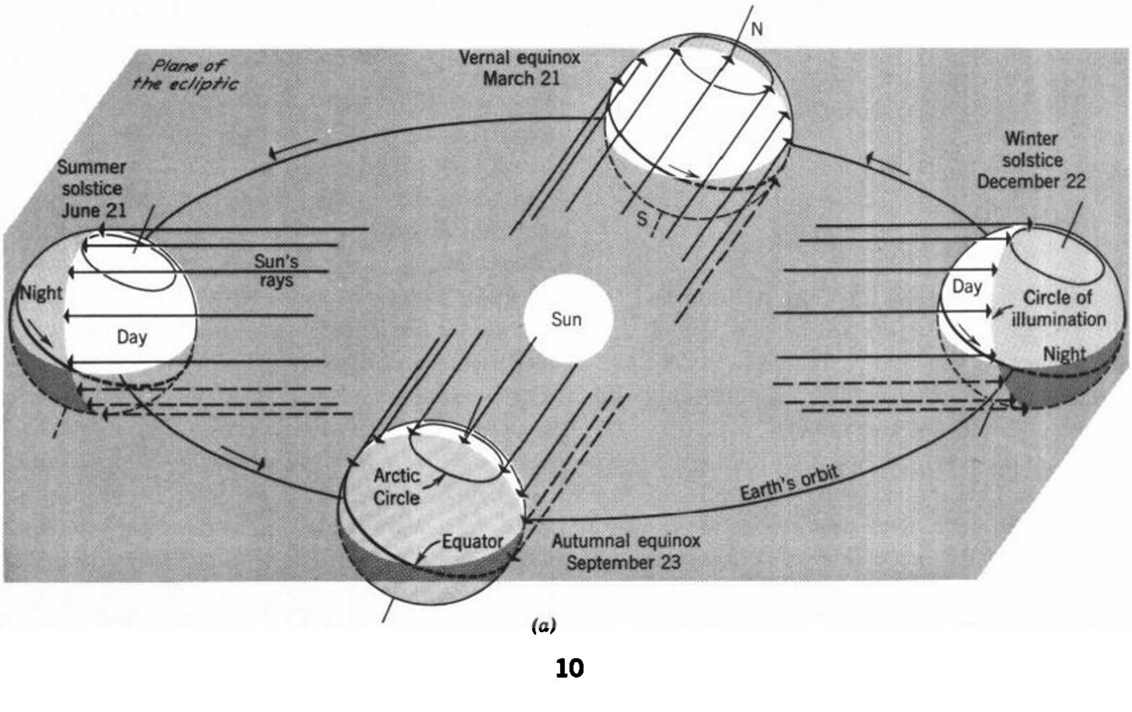
$$O_2 + O \rightarrow O_3$$

Below this level, wavelengths less than 0.29 μ have been absorbed and the ozone reverts again to oxygen. The formation of the ozone layer plays an exceptionally important role in the ecosphere, for it acts to screen out much of the ultraviolet light, a form of radiation that is harmful to life on earth.

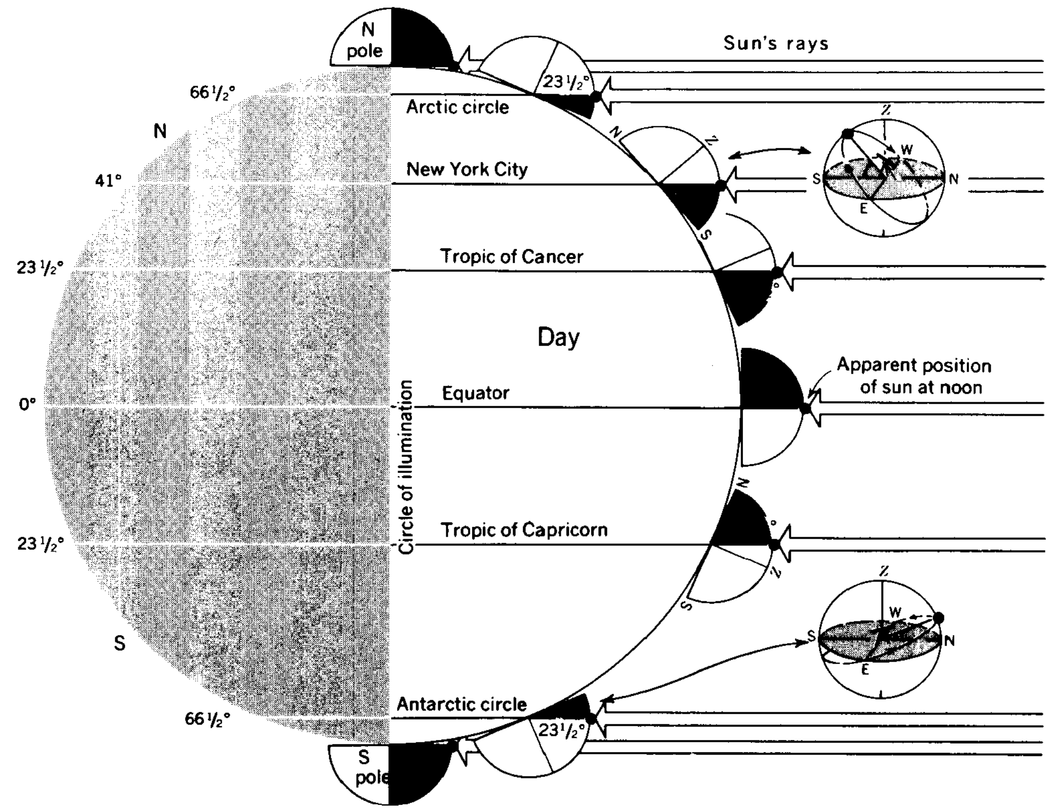
In the denser parts of the atmosphere, many other modifications occur. A small amount of solar radiation in the longer wavelength band is absorbed by water vapor and carbon dioxide. Gas molecules, dust, and clouds in this part both scatter and reflect solar radiation. Scattering occurs from very small particles and is most effective for short wavelengths. Were it not for this scattering effect, the sun would appear as a fiery ball in a black sky, for selective scattering of shorter wavelengths is responsible for the blue color of the sky. Larger atmospheric particles reflect rather than scatter the solar beam, with less discrimination as to wavelength.

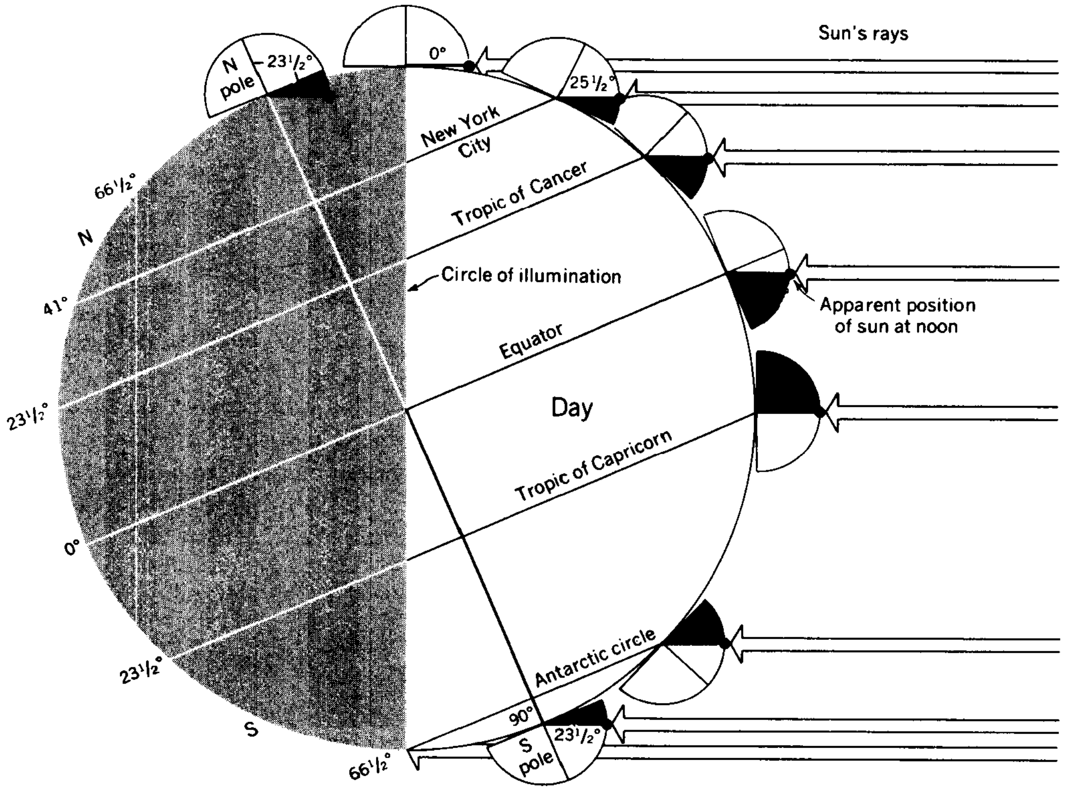
Figure 1–5. Earth-sun relationships. (*a*) Earth's orbit around the sun and illumination characteristics at the equinoxes and solstices. (*b*) The angle of the sun in the sky at different latitudes at the equinox (upper) and the northern hemisphere winter solstice (lower). (From Strahler, A.N., *Physical Geography*, Copyright © 1969 by John Wiley and Sons. Reproduced by permission.)





(*a*)


N pole
Sun's rays
66 1/2°
23 1/2°
Arctic circle
N
New York City
41°
Z
W
S
N
E
23 1/2°
Tropic of Cancer
Day
Apparent position of sun at noon
0°
Equator
Circle of illumination
23 1/2°
Tropic of Capricorn
S
Antarctic circle
66 1/2°
23 1/2°
S pole


N pole
23 1/2°
0°
Sun's rays
25 1/2°
New York City
66 1/2°
N
Tropic of Cancer
Circle of illumination
41°
Apparent position of sun at noon
Equator
23 1/2°
Day
Tropic of Capricorn
0°
Antarctic circle
23 1/2°
S
90°
23 1/2°
S pole
66 1/2°

(b)