TOPIC 6

Insolation and the Seasons

What You Know About Incoming Solar Radiation

Where on Earth would you have to use blackout shades to get a good night's sleep in July?

Consider three different locations—Quito, Ecuador, near the equator, Syracuse, New York, and the North Pole. Where would you get the most daylight every year?

You might think the tropical equator is the place, with its 12 hours of daylight each day. But is that more than anyone in the other locations?

It certainly is for the winter residents of Syracuse, New York, who get only nine hours of daylight each day in late December. But in June, they have over 15 hours of daylight each day.

If you lived at the North Pole, you would have daylight 24 hours each day from March 21 until September 21! But during the other half of the year, you would have zero hours of daylight each day. But it all averages out, just like it does everywhere else on Earth. No matter where you are, you have one-half year's worth of daylight every year.

TOPIC 6

Insolation and the Seasons

Vocabulary

angle of incidence	greenhouse gases	ozone
deforestation	heat budget	sunspot
El Niño	ice ages	transpiration
global warming	insolation	

Topic Overview

Without energy from the sun, conditions on Earth would be drastically different. Energy from the sun drives global wind patterns, ocean currents, and the water cycle. Life processes of plants and animals also depend almost entirely on energy from the sun. Without solar energy, Earth would be a frozen wasteland, as all water and all the gases of Earth's atmosphere would exist only in the solid state. There would be no life and no rock cycle as it is now known. Very little weathering and erosion would occur. Both Earth and its moon would be almost totally dark.

Solar Radiation and Insolation

A body of matter that is not at absolute zero emits electromagnetic energy. This energy is radiated over a portion of the electromagnetic spectrum, with more of the energy radiated at some wavelengths than at others. The rate at which energy is radiated is called the intensity of radiation. In general, the higher the temperature of a body of matter, the shorter the wavelength at which the maximum intensity of radiation occurs. At the

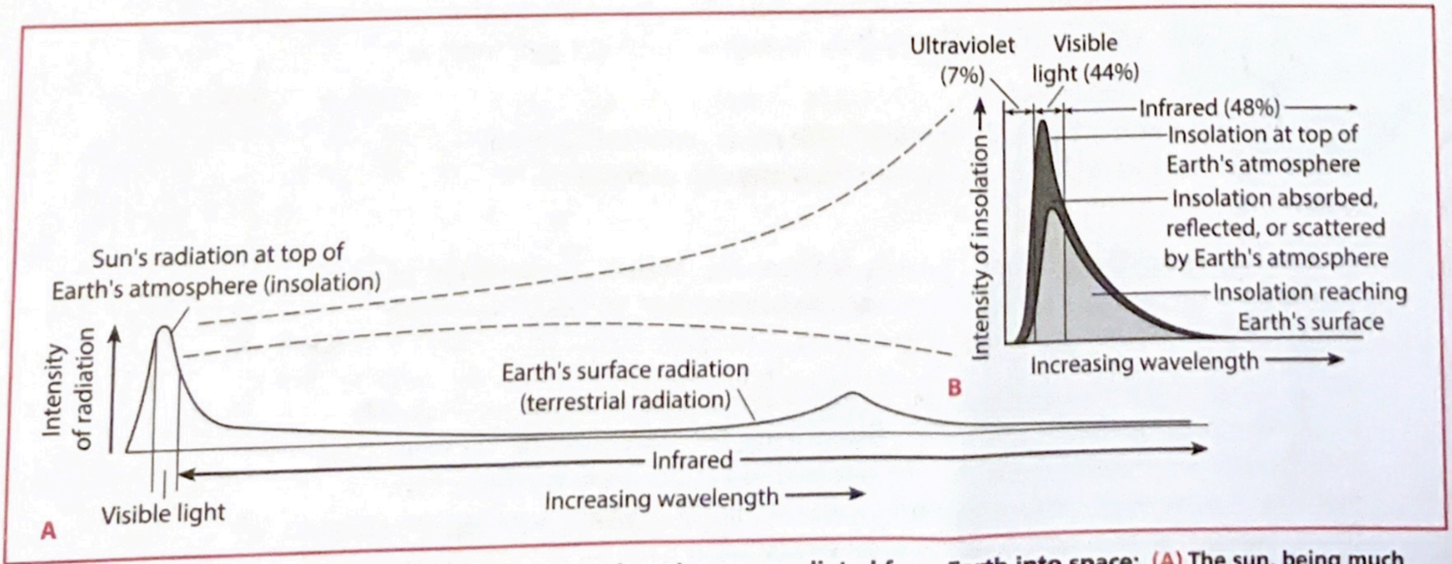


Figure 6-1. Intensity of insolation received by Earth and energy radiated from Earth into space: (A) The sun, being much hotter than Earth (sun 5800°C; Earth 15°C) emits shorter wavelengths of radiation than Earth does. Earth's surface emits only long wavelengths—infrared radiation. (B) The total amount of energy received by Earth's surface equals approximately 50 percent of the insolation that reaches the outermost part of Earth's atmosphere.

sun's temperature, the maximum intensity of radiation occurs in the range of visible wavelengths of electromagnetic energy. (See Figure 6-1.)

Insolation (**IN**coming **SOL**ar radi**ATION**) is the portion of the sun's output of electromagnetic radiation that is received by Earth at the outermost part of our atmosphere. The intensity of insolation is the relative strength of the sun's radiation that reaches a specific area of Earth in a specific amount of time. Figure 6-1 shows how the intensity of insolation varies with wavelength. The maximum intensity of insolation occurs in the range of wavelengths of visible light. However, approximately 48 percent of the total energy received at the outermost part of our atmosphere is infrared, a type of long-wave radiation.

Memory Jogger

Recall that a wavelength in an electromagnetic wave, as in other waves, is the distance between two successive peaks.

Effects of Earth's Atmosphere on Insolation

The insolation reaching Earth's surface is different from the insolation entering Earth's upper atmosphere, as shown in Figure 6-1. Since the atmosphere is mostly transparent to visible light, it transmits most of the visible light from the sun. However, insolation may be absorbed, reflected, or scattered before reaching Earth's surface. The atmosphere affects insolation in several ways as summarized in Figure 6-3.

Absorption of Ultraviolet and Infrared Most incoming ultraviolet radiation and other short wave radiation are absorbed by Earth's atmosphere. Nearly all ultraviolet radiation is absorbed in Earth's upper atmosphere (stratosphere) by **ozone** (O_3), a form of oxygen gas. In recent years, the amount of ozone in the upper atmosphere has been reduced by the chlorine and fluorine that have escaped into the atmosphere—mostly due to human activities. The result is that more ultraviolet radiation has been reaching Earth's surface. Ultraviolet radiation can be lethal to many forms of life and is a direct cause of skin cancer in humans. Regions in which the amount of ozone has been greatly reduced—popularly called "ozone holes"—occur near Earth's poles, especially the South Pole. (See Figure 6-2)

Other gases found in the atmosphere can absorb long-wave infrared radiation. Water vapor, carbon dioxide (CO_2), and methane (CH_4) are three gases that absorb much incoming infrared radiation.

Reflection and Scattering When clouds are present, much of the incident, or incoming, solar energy is reflected back into space. However, some of it, including some visible light, is reflected to the atmosphere or toward Earth's surface.

Random reflection, or scattering, of insolation is caused by aerosols—finely dispersed solids and liquids suspended in air. Besides ice crystals and water droplets, the dispersed materials include dust, bacteria, meteor fragments, volcanic ash, and various other air pollutants. As the concentration of aerosols increases, the scattering of insolation also increases, thus reducing the amount of insolation that reaches Earth's surface.

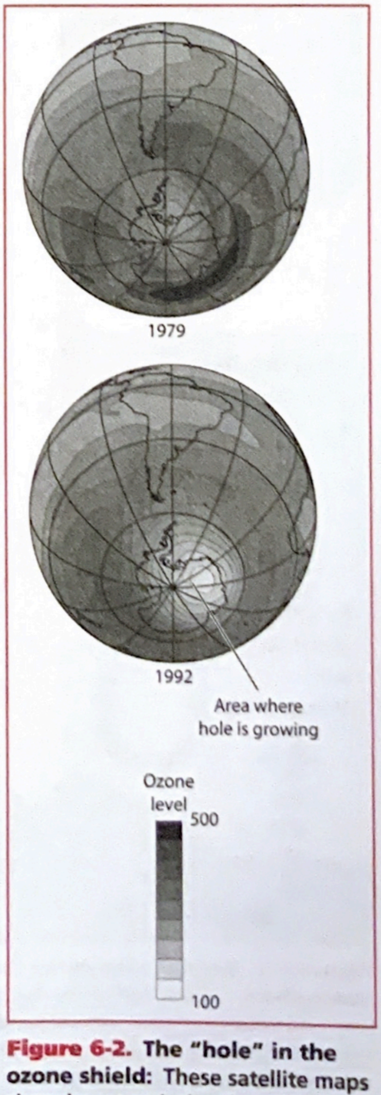


Figure 6-2. The "hole" in the ozone shield: These satellite maps show how much the "hole" in the ozone shield above the South Pole grew in just over a decade.

Balance of Energy from Insolation and Earth's Surface Radiation

About half of the insolation that strikes Earth's upper atmosphere reaches Earth's land and water surfaces, as shown in Figure 6-3. Some of the insolation is reflected and some is absorbed. Insolation that is absorbed by

Digging Deeper

On a typical day, it is estimated that approximately 25 percent of incident solar energy is reflected back into space by the cloud cover. This is the cause of the bright clouds seen in images of Earth taken from space.

Earth's surface is partly converted to heat and tends to raise the temperature of the surface. However, Earth's surface also radiates electromagnetic energy, thus tending to lower its temperature. Over time, the amount of energy absorbed from insolation is generally equal to Earth's surface radiation, and thus temperature and heat are balanced.

Factors Affecting Absorption and Reflection of Insolation

When insolation reaches Earth's surface, many factors affect whether it is absorbed or reflected. These factors include the angle at which the insolation reaches Earth's surface, the characteristics of the surface, and how the energy of the insolation interacts with Earth's surface materials and living things.

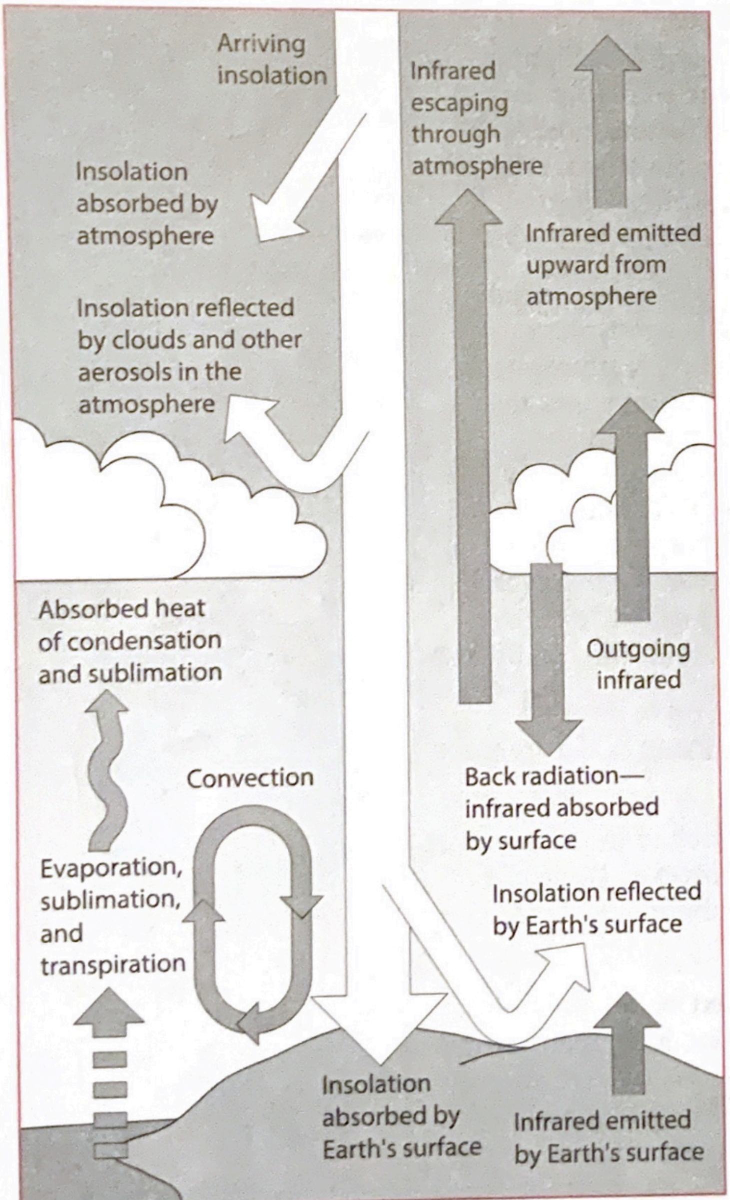


Figure 6-3. Energy balance for Earth's surface and atmosphere: About half of the insolation is absorbed by Earth's land and water surfaces. The remainder is reflected back into space or absorbed by Earth's atmosphere. Earth's surface and atmosphere also absorb energy from reradiation, which occurs as some of the infrared radiation emitted by Earth's surface is radiated back by greenhouse gases in the atmosphere.

Angle of Incidence One important factor affecting the absorption of insolation is the angle at which the insolation strikes Earth's surface—called the **angle of incidence.** The altitude of the sun—which varies with time of day, latitude, and season—determines the angle of incidence. The higher the sun is in the sky, the higher the angle of incidence, and the more insolation is absorbed. Generally, a lower angle of incidence means that more insolation is reflected and less is absorbed. (See Table 6-1.)

Surface Characteristics Texture and color also affect the absorption of insolation by Earth's surfaces. When a surface has a rough or uneven texture, more insolation is absorbed and less is reflected. Surfaces with darker colors tend to absorb more insolation than they reflect. Surfaces with lighter colors tend to reflect more insolation than they absorb. For example, ice and snow reflect almost all of the insolation that strikes them. This is one reason the polar regions stay cool even during summer's six months of continuous sunshine.

Change of State and Transpiration When energy from insolation reaches Earth's surfaces, it interacts with the materials and living things found there. For example, energy from insolation can cause water to change state—melting of ice or snow into liquid water or evaporating liquid water to form water vapor. Energy from insolation also fuels plant growth and increases **transpiration**—a process by which plants release water vapor into the atmosphere as part of their life functions. When energy from insolation is involved in change of state and transpiration, it is not available to raise the temperature of Earth's surface. Instead, it is transformed into potential energy.

Land and Water Heating

With equal amounts of insolation, an area of Earth's surface made up of liquid water will heat up and cool off more slowly than an equal area of land. These rates in heating and cooling differ for the following reasons:

- Water has a much higher specific heat than the rocks and soil that make up land.
- Water is highly transparent to insolation. Some insolation penetrates up to 300 feet in clear water but usually to less than a foot in rocks and soil. Rocks and soil heat rapidly because the energy of insolation is concentrated in a thin zone.
- Water can flow freely, so convection can occur. Convection currents in water can distribute absorbed energy through a large volume.
- When insolation strikes water surfaces, much of its energy is converted to stored heat as some water evaporates. Thus, less energy is available to increase the water temperature.

The Greenhouse Effect

Although Earth's atmosphere allows much insolation to pass through to Earth's surface, most of the radiation from Earth's surface does not escape into outer space. Instead, it is absorbed by the atmosphere. This occurs because Earth's surface radiation consists mostly of long infrared radiation, which can be absorbed by carbon dioxide, water vapor, methane, and other gases in the atmosphere. These gases are called **greenhouse gases.** This absorption warms the atmosphere and causes it to act as a heat "blanket." This blanket reduces energy loss to outer space and makes Earth's surface about 59°F (33°C) warmer than it would otherwise be. Without any greenhouse gases, the average temperature of Earth would be about 0°F (–18°C).

Figure 6-4 models the process by which the atmosphere transmits short-wave radiation from insolation and absorbs long-wave reradiation called

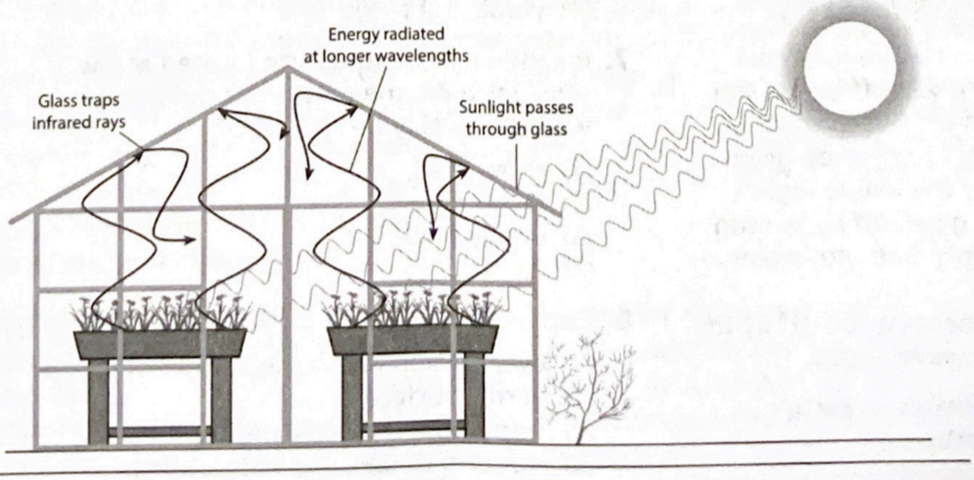


Figure 6-4. The greenhouse effect: Insolation is transmitted through the glass of a greenhouse, just as it is transmitted through Earth's atmosphere. Objects inside a greenhouse absorb energy from the insolation and are heated. The heated objects then give off long wave infrared radiation, which cannot pass outward through the glass. The infrared radiation is trapped by the glass, and is partly absorbed by the air and by objects inside the greenhouse—raising their temperatures. Comparatively, radiation emitted from Earth's surface is trapped in the atmosphere by greenhouse gases—increasing Earth's surface temperatures.

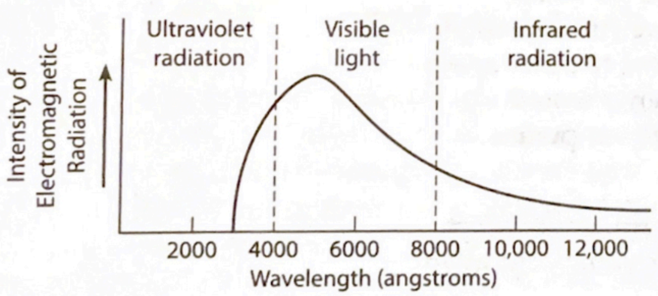
the greenhouse effect. In recent years there has been concern that the greenhouse effect may be causing **global warming**—an increase in average Earth temperatures. The burning of wood and fossil fuels releases additional carbon dioxide and other greenhouse gases into the atmosphere. This increase in carbon dioxide and other greenhouse gases is thought to intensify the greenhouse effect—thus raising Earth's surface temperatures. Global warming could result in environmental problems such as rising sea levels caused by melting glaciers and sea ice, and the shifting of Earth's climatic zones. (See Figure 6-12.)

Review Questions

1. Electromagnetic energy that reaches Earth from the sun is called

(1) insolation
(2) conduction
(3) specific heat
(4) terrestrial radiation

2. The graph below represents the relationship between the intensity and wavelength of the sun's electromagnetic radiation.



Which statement is best supported by the graph?

(1) The infrared radiation given off by the sun occurs at a wavelength of 2000 angstroms.
(2) The maximum intensity of radiation given off by the sun occurs in the visible region.
(3) The infrared radiation given off by the sun has a shorter wavelength than ultraviolet radiation.
(4) The electromagnetic energy given off by the sun consists of a single wavelength.

3. Water vapor and carbon dioxide in Earth's atmosphere are good absorbers of

(1) visible radiation
(2) infrared radiation
(3) ultraviolet radiation
(4) X-rays

4. If dust particles are added to the atmosphere, the amount of insolation reaching the ground will probably

(1) decrease
(2) increase
(3) stay the same
(4) increase, then decrease

5. Ozone is important to life on Earth because ozone

(1) cools refrigerators and air conditioners
(2) absorbs energy that is radiated by Earth
(3) absorbs harmful ultraviolet radiation
(4) destroys excess atmospheric carbon dioxide

6. Which form of electromagnetic energy is radiated from Earth's surface with the greatest intensity?

(1) X-rays
(2) infrared rays
(3) ultraviolet rays
(4) visible light rays

7. In land areas of equal size located at the same latitude, the most solar radiation would probably be reflected by a

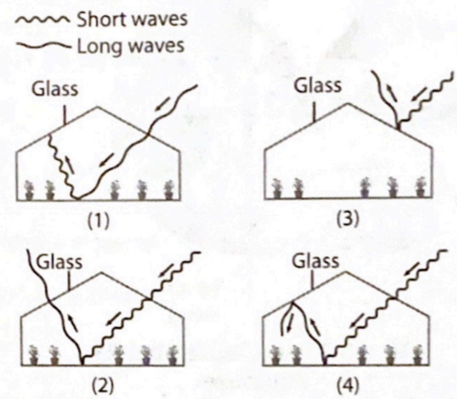
(1) snow field
(2) sandy desert
(3) grassy field
(4) forest

8. Insolation is changed into potential energy by

(1) evaporation and transpiration of water from Earth's surface
(2) formation of clouds and fog
(3) freezing of lake and ocean water
(4) rain and snow forming in clouds

9. How do the rates of warming and cooling of land surfaces compare to the rates of warming and cooling of ocean surfaces?
   (1) Land surfaces warm more quickly and cool more slowly.
   (2) Land surfaces warm more slowly and cool more quickly.
   (3) Land surfaces warm more quickly and cool more quickly.
   (4) Land surfaces warm more slowly and cool more slowly.

10. Which model best represents how a greenhouse remains warm as a result of insolation from the sun?



Variation of Insolation

Insolation varies from place to place on Earth's surface. It also varies in any given place over the course of a year. Insolation can vary in two general ways—by intensity (strength) and by duration (length of time).

Variation in Intensity and Angle of Insolation

The rate at which solar energy is received by a given area per unit time is the intensity of insolation. Intensity of insolation can be measured in joules per square meter per second. The intensity of insolation received at a particular area of Earth's surface varies for several reasons because of the angle of incidence. When insolation strikes a surface at an angle of 90°, or perpendicular, it has maximum intensity, because the insolation is concentrated in the smallest possible area. As the angle of incidence decreases from 90° toward 0°, the same amount of insolation is spread out over greater and greater areas, as shown in Figure 6-5. Therefore, at smaller angles of incidence, the intensity of insolation decreases the heating effect.

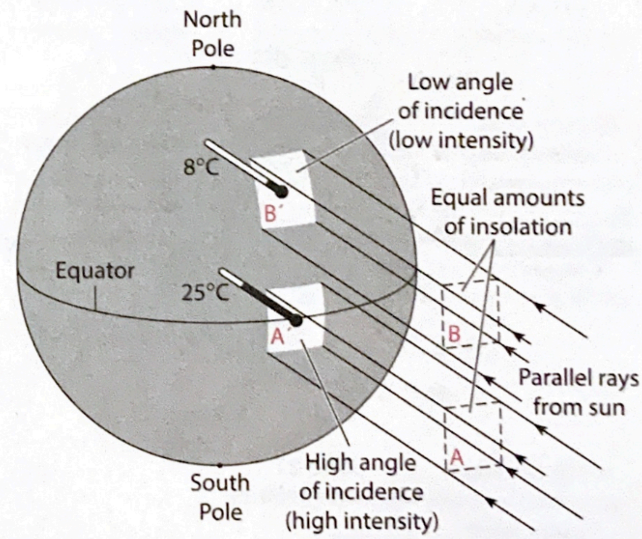


Figure 6-5. Earth's shape and the intensity of insolation: Because of Earth's spherical shape, the parallel rays from the sun strike different parts of Earth's surface at different angles. Near Earth's poles where the angle of incidence is smaller, the same amount of insolation spreads out over a larger area. As a result, the intensity of insolation is much less than that in regions with a higher angle of incidence of the sun's rays.

Effect of Earth's Shape and Thickness of the Atmosphere The sun's energy reaches Earth as a bundle of parallel rays. If Earth were flat and positioned perpendicular to these rays, the intensity of insolation would be the same everywhere on Earth's surface. However, Earth is shaped like a sphere. As a result, at any given time, there is just one place where insolation arrives perpendicular to Earth's surface. At all other places on Earth the angle of incidence is less than 90°. Generally, for each degree of latitude North or South of the place where insolation is perpendicular to Earth's surface, the angle of incidence is one degree less.

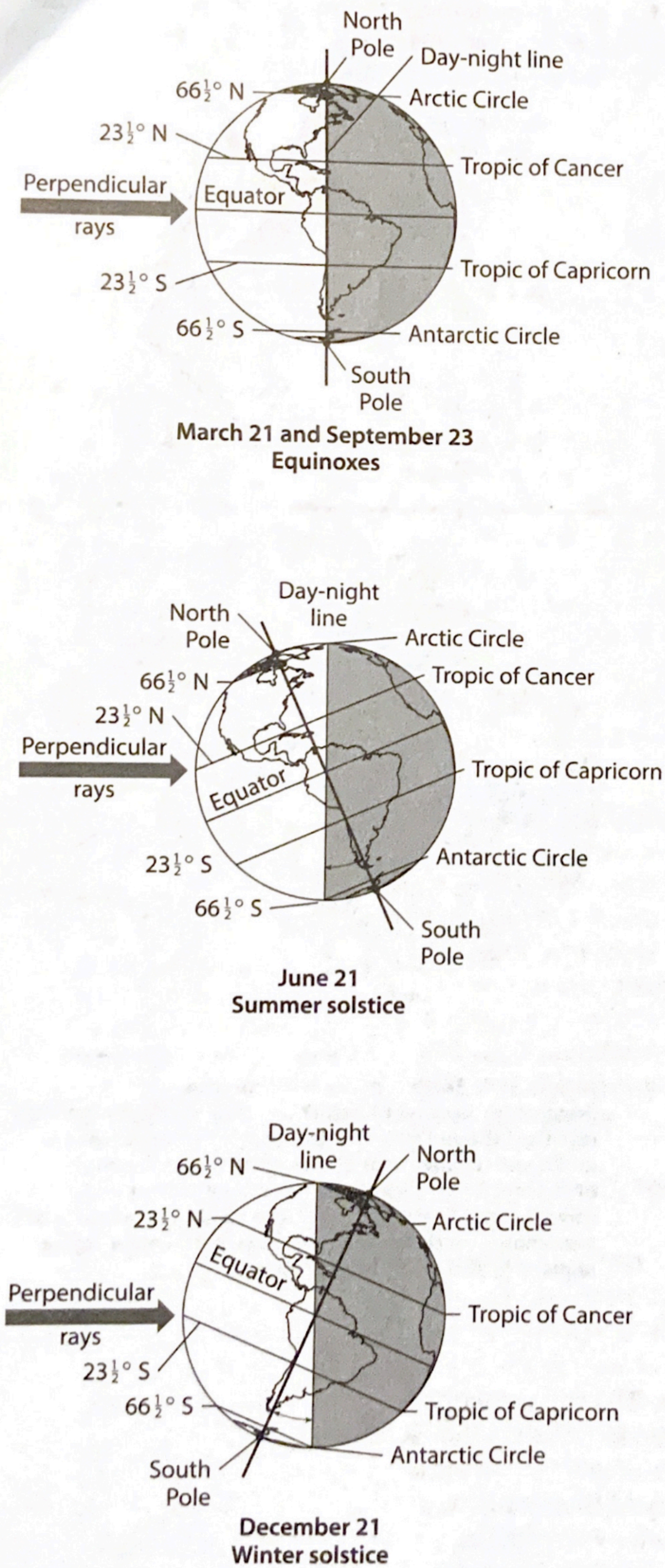


Figure 6-6. Seasonal changes in insolation at different latitudes: At any given time, the intensity of insolation is at a maximum at the latitude where the angle of incidence is 90°. The latitude of maximum intensity of insolation shifts with the seasons between 23½° N on June 21 to 23½° S on December 21.

The thickness of Earth's atmosphere, which the Sun's rays have to pass through to reach Earth's surface, varies greatly during the day and year, and with changes in latitude. When the Sun is straight overhead at a 90 degree angle of insolation, the intensity of the insolation is about 80 times stronger than when the Sun is on the horizon at a zero angle of insolation. (See Table 6-1.) This is due partly to the changes in the thickness of atmosphere that the Sun's rays must pass through. The more atmosphere the Sun's rays must pass through, the greater the absorption, reflection, refraction, and scattering of the rays, and the less the transmission of the rays to Earth's surface.

Effect of Latitude The intensity of insolation is greatest at the equator at each equinox, and decreases with increasing latitude (north or south). As shown in Figure 6-6, insolation is perpendicular to Earth's surface at the equator at the time of each equinox. The spring equinox is March 21, and the fall equinox is September 23.

On the first day of summer in the Northern Hemisphere (summer solstice), insolation is perpendicular to Earth's surface at 23½° N latitude. The intensity of insolation is at its maximum at this latitude—the Tropic of Cancer. On the first day of winter in the Northern Hemisphere (winter solstice), insolation is perpendicular to Earth's surface at 23½° S latitude. The intensity of insolation is at its maximum at this latitude—the Tropic of Capricorn. (See Appendix 4.) A4

Effect of Seasonal Changes As Earth travels in its yearly orbit around the sun, the angle of incidence for insolation at any given latitude varies with the seasons. As shown in Figure 6-7, the lowest angle of incidence at 42° N latitude occurs at the winter solstice and the highest angle at the summer solstice. As shown in Table 6-2, the angle of incidence for insolation decreases by one degree for each degree of latitude away from the point of perpendicular insolation.

Effect of Time of Day On any given day, the altitude of the sun varies from zero at sunrise, to a maximum at apparent solar noon, and back to zero again at sunset. In a similar way, the angle of incidence and the intensity of insolation also vary during the day as shown in Figure 6-8. The maximum angle and intensity occur at solar noon. A4

Table 6-1. Effect of Sun's Altitude on Insolation Intensity		
Altitude of the Sun	Relative Length of the Path of Sun's Rays through Earth's Atmosphere	Relative Intensity of Insolation on a Horizontal Surface of Earth
90°	1.00	0.78
60°	1.15	0.65
30°	2.00	0.31
0°	45.00	0.00

Variation in Duration of Insolation

The length of time that insolation is received each day—or the time between sunrise and sunset—is called the duration of insolation. The duration of insolation at a given location corresponds to the number of hours that the sun is visible each day. As shown in Table 6-2, the duration of insolation varies with latitude and with the seasons. In the continental United States, duration of insolation is longest on the summer solstice (June 21) and shortest on the winter solstice (December 21). On the equinoxes (March 21 and September 23), the average duration of insolation is 12 hours.

Effects of Latitude and Season A review of Table 6-2 will reveal how duration of insolation varies with latitude and season. At the time of the summer solstice, northern areas of the contiguous United States have more hours of daylight than do southern areas. The reverse happens at the time of the winter solstice when southern areas of the contiguous United States have more hours of daylight than the northern areas. Only during the equinoxes is the duration of insolation the same everywhere—12 hours.

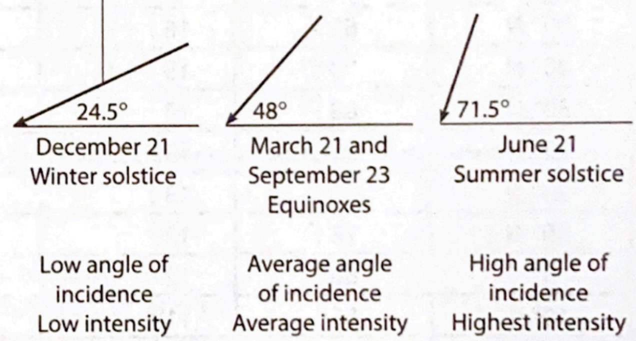


Figure 6-7. Maximum angles of incidence at 42° N latitude in different seasons: Values were measured at solar noon in New York State on the first day of each of the four seasons.

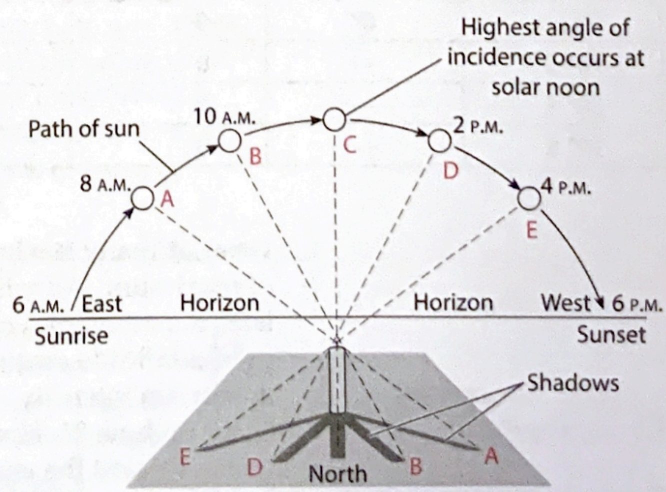


Figure 6-8. Changes in the altitude of the Sun during an average day and the resulting changes in the length and directions of shadows: The data is for an equinox day in the middle latitudes of the Northern Hemisphere. The time of day can be determined by observing the height and direction to the Sun's location in the sky. The shadow of a vertical post indicates how the angle of incidence of insolation varies throughout the day. A higher angle of incidence produces a shorter shadow and a greater intensity of insolation. The shortest shadow is at solar noon and it points directly north.

Relationship of Surface Temperatures to Insolation

The temperature of Earth's surface at a given location varies throughout the day. Similarly, the average daily temperature varies throughout the year. These variations depend on the balance between energy being gained from insolation and the energy being lost by Earth's surface radiation. When energy is being gained at a greater rate than it is being lost, Earth's surface temperature rises. When energy is being lost faster than it is being gained, Earth's surface temperature falls. Temperatures are generally higher when the intensity of insolation is greater. Temperatures also tend to be higher at a location for which the duration of insolation is longer.

Table 6-2. Variation in Insolation by Latitude and Season						
Latitude	Summer Solstice June 21		Equinoxes: March 21, September 23		Winter Solstice December 21	
	Angle of Incidence at 12:00 Noon	Duration of Insolation	Angle of incidence at 12:00 Noon	Duration of Insolation	Angle of Incidence at 12:00 Noon	Duration of Insolation
90° N	$23\frac{1}{2}^\circ$	24 Hours	0°	12 Hours	—	0 Hours
80° N	$33\frac{1}{2}^\circ$	24	10°	12	—	0
70° N	$43\frac{1}{2}^\circ$	24	20°	12	—	0
$66\frac{1}{2}^\circ$ N	47°	24	$23\frac{1}{2}^\circ$	12	0°	0
60° N	$53\frac{1}{2}^\circ$	$18\frac{1}{2}$	30°	12	$6\frac{1}{2}^\circ$	$5\frac{1}{2}$
50° N	$63\frac{1}{2}^\circ$	$16\frac{1}{4}$	40°	12	$16\frac{1}{2}^\circ$	$7\frac{3}{4}$
40° N	$73\frac{1}{2}^\circ$	15	50°	12	$26\frac{1}{2}^\circ$	9
30° N	$83\frac{1}{2}^\circ$	14	60°	12	$36\frac{1}{2}^\circ$	10
$23\frac{1}{2}^\circ$ N	90°	$13\frac{1}{2}^\circ$	$66\frac{1}{2}^\circ$	12	43°	$10\frac{1}{2}$
20° N	$86\frac{1}{2}^\circ$	$13\frac{1}{4}$	70°	12	$46\frac{1}{2}^\circ$	$10\frac{3}{4}$
10° N	$76\frac{1}{2}^\circ$	$12\frac{1}{2}$	80°	12	$56\frac{1}{2}^\circ$	$11\frac{1}{2}$
0°	$66\frac{1}{2}^\circ$	12	90°	12	$66\frac{1}{2}^\circ$	12
10° S	$56\frac{1}{2}^\circ$	$11\frac{1}{2}$	80°	12	$76\frac{1}{2}^\circ$	$12\frac{1}{2}$
20° S	$46\frac{1}{2}^\circ$	$10\frac{3}{4}$	70°	12	$86\frac{1}{2}^\circ$	$13\frac{1}{4}$
$23\frac{1}{2}^\circ$ S	43°	$10\frac{1}{2}$	$66\frac{1}{2}^\circ$	12	90°	$13\frac{1}{2}$
30° S	$36\frac{1}{2}^\circ$	10	60°	12	$83\frac{1}{2}^\circ$	14
40° S	$26\frac{1}{2}^\circ$	9	50°	12	$73\frac{1}{2}^\circ$	15
50° S	$16\frac{1}{2}^\circ$	$7\frac{3}{4}$	40°	12	$63\frac{1}{2}^\circ$	$16\frac{1}{4}$
60° S	$6\frac{1}{2}^\circ$	$5\frac{1}{2}$	30°	12	$53\frac{1}{2}^\circ$	$18\frac{1}{2}$
$66\frac{1}{2}^\circ$ S	0°	0	$23\frac{1}{2}^\circ$	12	47°	24
70° S	—	0	20°	12	$43\frac{1}{2}^\circ$	24
80° S	—	0	10°	12	$33\frac{1}{2}^\circ$	24
90° S	—	0	0°	12	$23\frac{1}{2}^\circ$	24

Times of Yearly Maximum and Minimum Temperatures Each year, the times of maximum and minimum temperatures in a given place occur somewhat later than the times of maximum and minimum insolation. For example, in mid-latitude areas of the contiguous United States (49° N to 25° N) the maximum intensity of insolation and the maximum duration of insolation occur on June 21. However, the period of highest daily temperatures occurs later—toward the end of July or early in August. (See Figure 6-9.)

The reason for this delay relates to the changing balance between energy gain from insolation and energy loss from Earth's surface radiation. During spring and early summer in the contiguous United States, the intensity and duration of insolation increase. Each day the surface receives more energy of insolation than it loses by radiation and the average temperature goes up slightly. After June 21, a little less energy is received, but the amount of energy received is still more than the amount lost. Therefore, the temperature continues to go up until the rate of incoming energy

MemoryJogger

Recall that the length of the sun's apparent path through the sky varies during the year. Day length, or duration of insolation, is proportional to the length of the sun's path. There is one hour of insolation for each 15° of path.

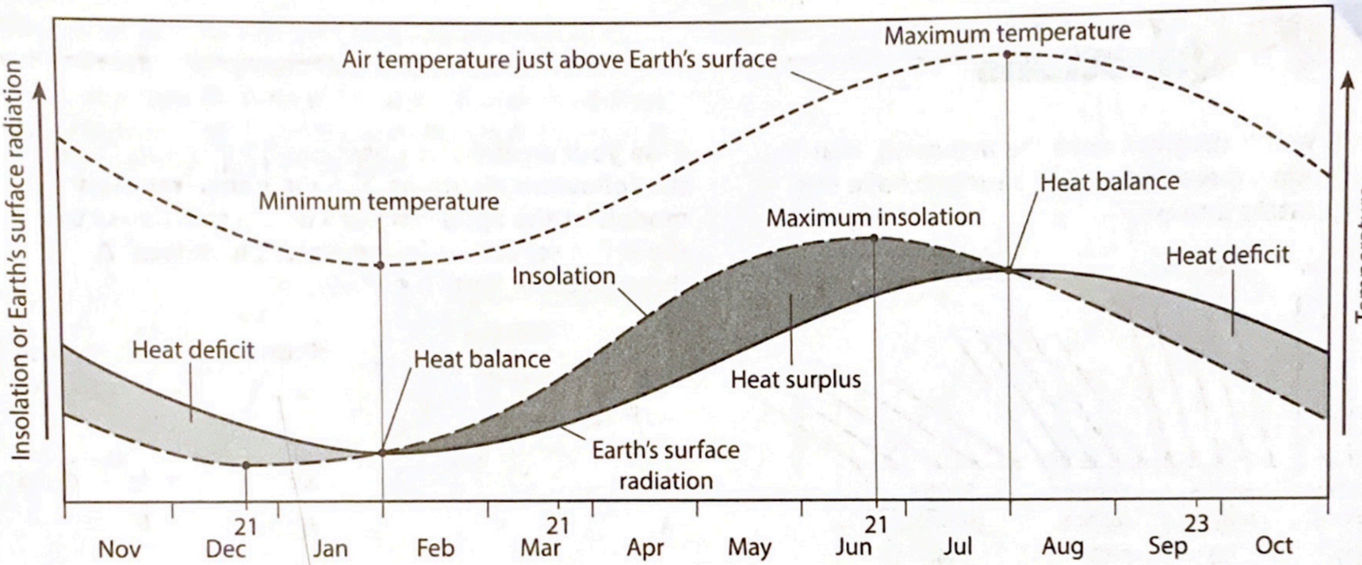


Figure 6-9. Average daily temperatures, insolation, and Earth's surface radiation for mid-latitudes of the Northern Hemisphere during a year

finally drops below the rate of energy loss by Earth's surface radiation. Similarly, mid-latitude areas of the contiguous United States are not at their coldest when the duration of insolation and angle of incidence are at their minimum on December 21. These areas continue to lose more energy from surface radiation than they gain by insolation until late January or early February—when the coldest temperatures occur.

Times of Daily Maximum and Minimum Temperatures The hottest part of an average day is some time in mid-afternoon, not at solar noon when the intensity of insolation is greatest. (See Figure 6-10.) Each day, although insolation is greatest at solar noon, Earth's surface continues to gain more energy from the sun than it loses from surface (terrestrial) radiation until mid-afternoon. In a similar way, the coolest temperatures on an average day usually occur just slightly after sunrise. Earth's surface continues to lose heat throughout the night until after insolation begins at sunrise.

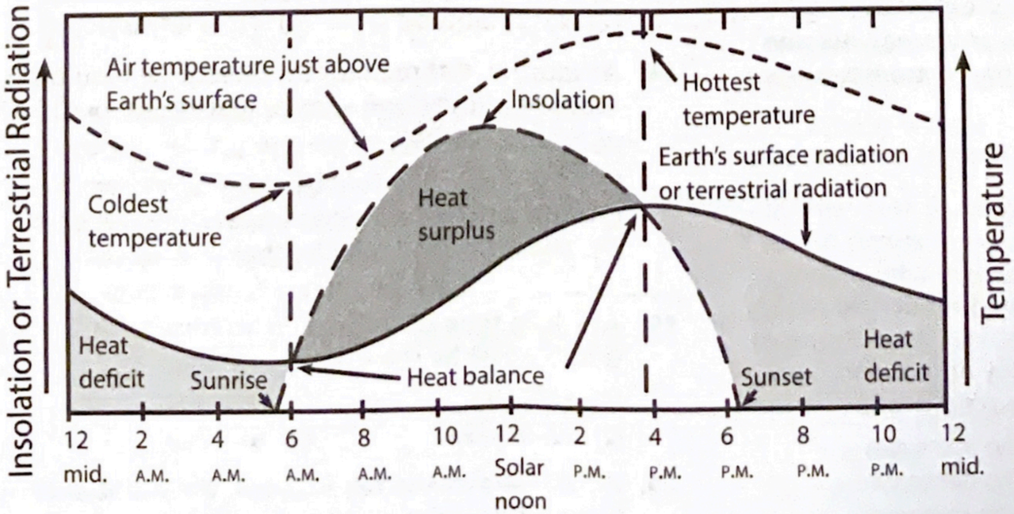
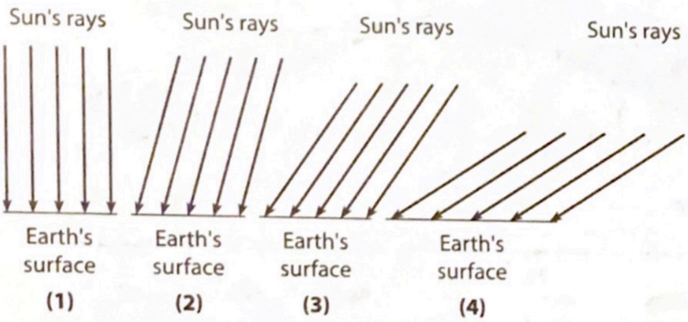


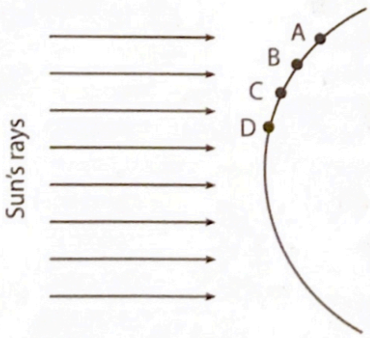
Figure 6-10. Typical daily variations in insolation, surface radiation, and near-surface air temperature

Review Questions

11. In which diagram does the incoming solar radiation reaching Earth's surface have the greatest intensity?



12. The following diagram represents a portion of Earth's surface that is receiving insolation. Positions A, B, C, and D are located on Earth's surface.



At which position would the intensity of insolation be greatest?

(1) A (2) B (3) C (4) D

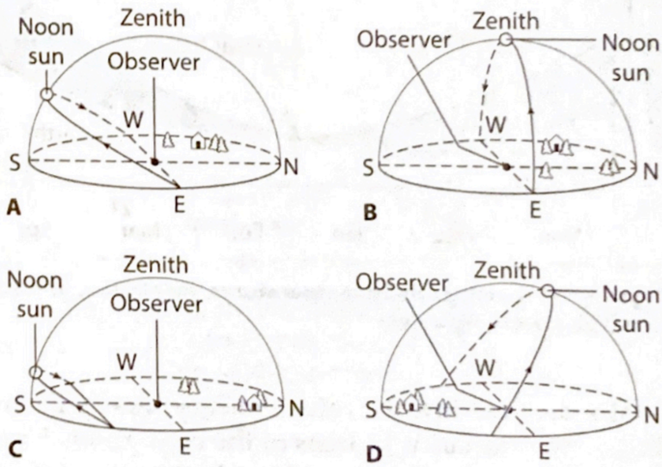
13. Over a period of one year, which location would probably have the greatest average intensity of insolation per unit area? Assume that there is equal atmospheric transparency at each location.

(1) Tropic of Cancer, $23\frac{1}{2}°$ N
(2) New York City, 41° N
(3) the Arctic Circle, $66\frac{1}{2}°$ N
(4) the North Pole, 90° N

14. The most logical conclusion that can be made from the relationship between the altitude of the sun throughout the day and the amount of insolation is that, as the sun's altitude

(1) increases, the insolation increases
(2) increases, the insolation decreases
(3) decreases, the insolation increases
(4) decreases, the insolation remains the same

Base your answers to questions 15 through 18 on the following diagrams. The diagrams represent models of the apparent path of the sun across the sky for observers at four different locations, A through D, on Earth's surface.



15. At location A, on which side would an observer's shadow cast by the sun fall at local noon?

(1) south side (3) east side
(2) north side (4) west side

16. If the model of location B represents the apparent path of the sun observed at the equator, what is the date at location B?

(1) March 21 (3) October 21
(2) June 21 (4) December 21

17. If the model of location D represents the apparent path of the sun on December 21, where is location D?

(1) the North Pole (3) the equator
(2) 45° N latitude (4) 45° S latitude

18. At location B three months later, how would the altitude of the noon sun compare to its present altitude?

(1) The altitude would be less than shown.
(2) The altitude would be greater than shown.
(3) The altitude would be the same as shown.

---

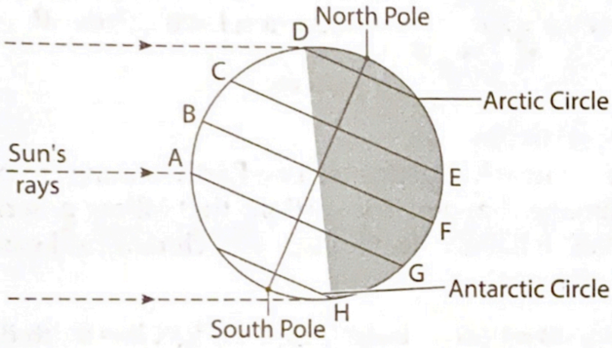
19. At which time of day would an observer's shadow cast by the sun be shortest?

(1) 6:00 A.M. (3) 3:00 P.M.
(2) 12:00 noon (4) 6:00 P.M.

20. At the time of the fall equinox, the number of hours of daylight in New York City is generally about

(1) 9 (2) 12 (3) 15 (4) 18

Base your answers to questions 21 through 25 on the following diagram. The diagram represents Earth at a specific time in its orbit. The dashed lines indicate radiation from the sun. Points A through H are locations on Earth's surface.



21. Which line represents the equator?

(1) AB (2) BF (3) CE (4) DH

22. What is the season in the Northern Hemisphere when Earth is in the position shown in the diagram?

(1) spring
(2) summer
(3) fall
(4) winter

23. When the sun is in the position shown in the diagram, how many hours of daylight would occur at the North Pole during one complete rotation?

(1) 0 (2) 8 (3) 12 (4) 24

24. In which direction would a person located at position H have to look to see the sun at the time shown in the diagram?

(1) north (2) east (3) south (4) west

25. Six months after the date indicated by the diagram, which point would receive the sun's vertical rays at noon?

(1) A (2) B (3) C (4) D

---

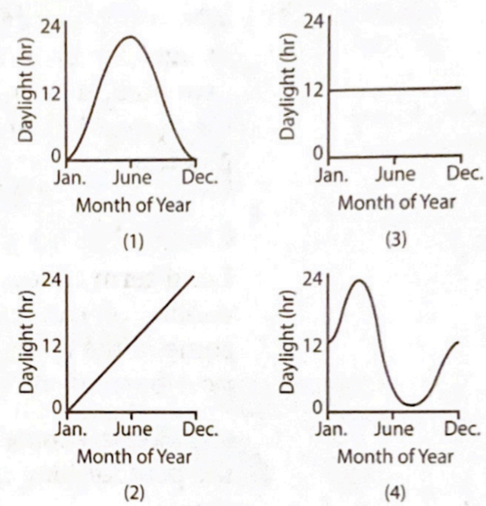
26. The length of time that daylight occurs at a location during one day is called the location's

(1) angle of incidence
(2) intensity of insolation
(3) duration of insolation
(4) eccentricity of insolation

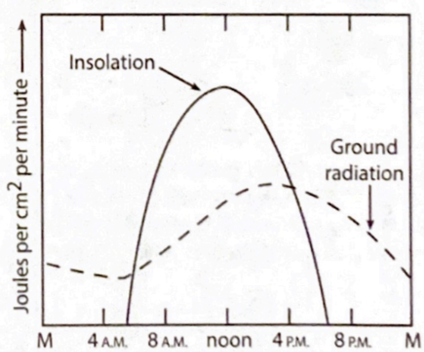
27. What is the primary reason New York State is warmer in May than in February?

(1) Earth is traveling faster in its orbit in February.
(2) The altitude of the noon sun is greater in February.
(3) The insolation in New York is greater in May.
(4) Earth is closer to the sun in May.

28. Which graph best represents the duration of insolation during the year at Earth's equator?



29. The following graph illustrates the relationship between insolation and Earth's surface radiation during a 24-hour period in New York State on March 21.



At what time did the maximum air temperature probably occur?

(1) 6 A.M.
(2) 12 noon
(3) 4 P.M.
(4) 6 P.M.

30. What is the usual cause of the drop in temperature that occurs between sunset and sunrise at most New York State locations?

(1) strong winds
(2) ground radiation
(3) cloud formation
(4) heavy precipitation

31. In New York State, the maximum total daily insolation occurs during June. Which statement best explains why the maximum annual temperature is usually observed about a month later, in July?

(1) Earth is closer to the sun in June than it is in July.
(2) Earth is farther from the sun in June than it is in July.
(3) New York State loses far more energy than it receives from the sun during most of July.
(4) New York State receives more energy from the sun than it loses during most of July.

Heat Budget and Climate Change

An object's **heat budget** is the result of the balance between the total amount of energy it receives and the total energy it emits or loses. Heat budget can be measured as the average temperature of an object. Earth's heat budget is the result of a radiation balance between the radiation from the sun and Earth's interior compared to the radiation Earth gives off to space.

Examples of Climate Change

Long-term changes in Earth's heat budget caused by Earth heating up or cooling off can result in climatic changes. The sections that follow describe some of the types of changes in Earth's heat budget and climate and some possible reasons for these changes.

Ice Ages and Long, Warm Periods on Earth Earth's heat budget has shifted in the past for long periods of time. Some of these shifts in heat balance

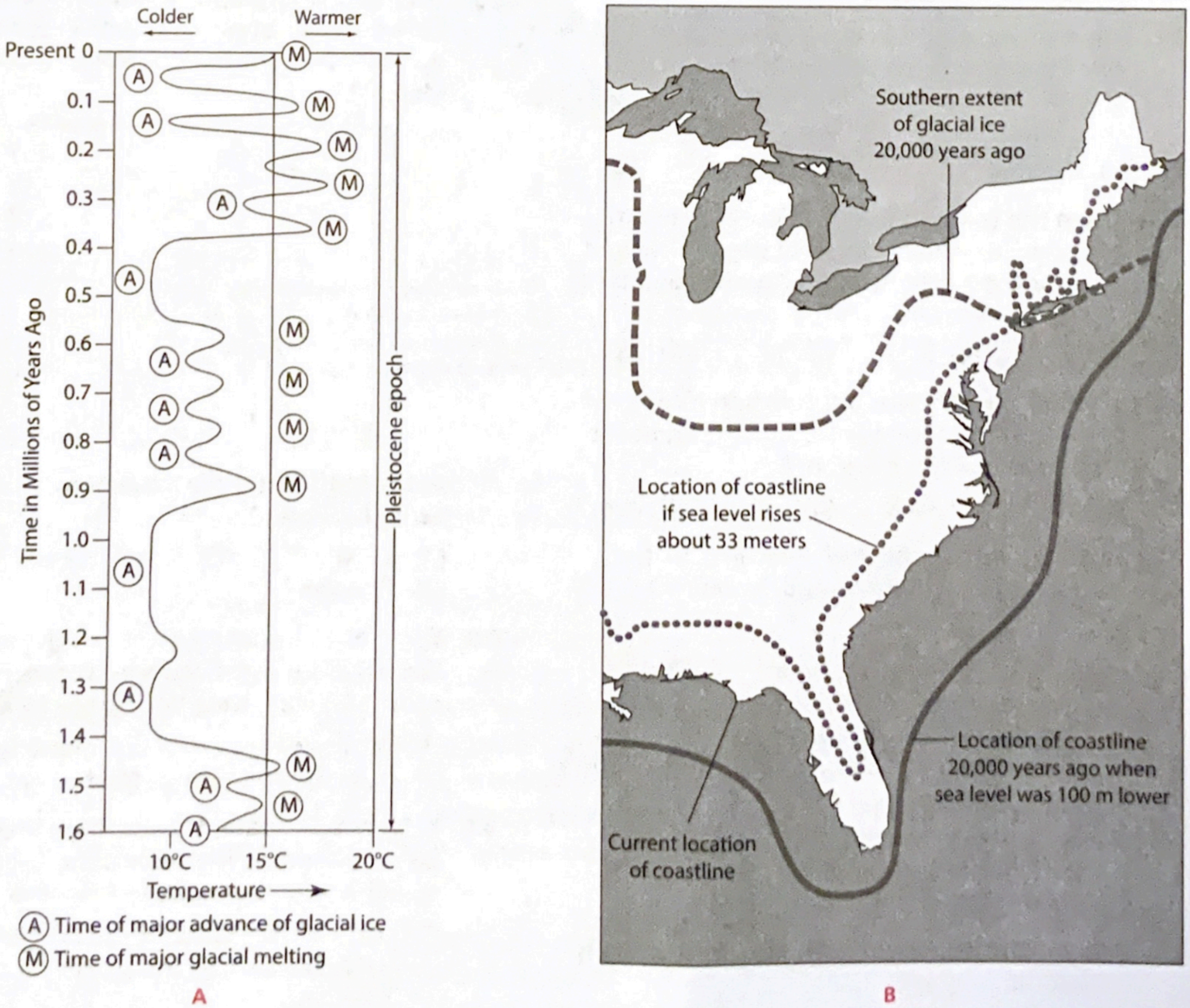


Figure 6-11. Changes in temperature, sea level, and position of glaciers associated with the Pleistocene Ice Age and present times: Diagram A shows estimated temperature variations from today's average Earth temperature of 15°C. Times of advances and melting of glaciers are estimates. Diagram B shows the maximum extent of glaciation about 20,000 years ago and the extended coastline of the area that is now the eastern United States. Sea levels 20,000 years ago were 100 meters lower, due to the large amounts of water stored as ice. Diagram B also shows how sea levels would rise if global warming continues—melting today's glaciers and ice caps.

A **El Niño Conditions in Eastern Pacific Ocean**

B **Some Changes in Climate and Weather That Can Result From El Niño**

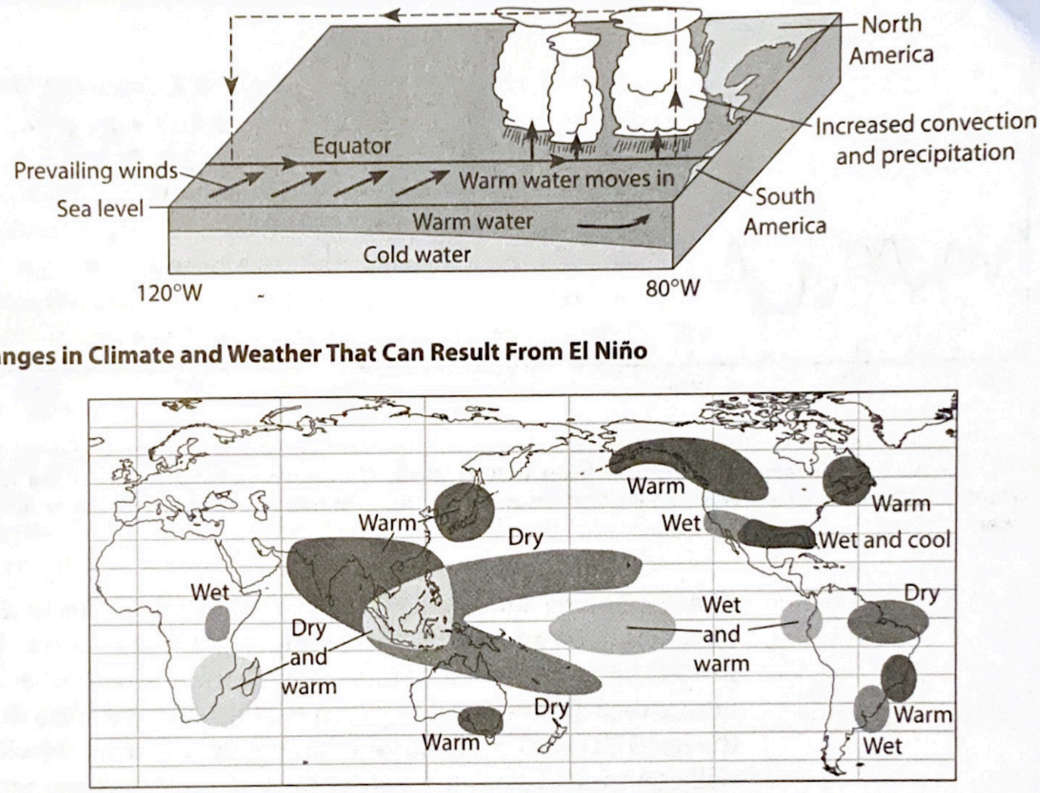


Figure 6-12. El Niño conditions: Diagram A shows how every 2 to 10 years, changes in prevailing winds push a huge mass of warm ocean water toward the west coast of South America—replacing the normally cold waters of the eastern Pacific Ocean. The influx of warm water results in a temperature rise and an increase in air convection currents and precipitation in a region with a normally cool and dry climate. Map B shows some of the worldwide conditions linked to El Niño events, such as major flooding in southern California and droughts in southern Africa.

produced warm periods when Earth probably had few or no glaciers. Other shifts in heat balance produced periods called **ice ages** when glaciers advanced into the middle latitudes.

According to Geologic History of New York State in the *Earth Science Reference Tables,* the last ice age—the Pleistocene—lasted from about 1.8 million to approximately 10 thousand years ago. During the Pleistocene, glaciers advanced and retreated 10 or more times as shown in Figure 6-11. At times between the advances of the glaciers, there were warm interglacial periods when Earth was warmer than today. (See Figure 6-11.) Some scientists think that Earth is presently in one of these interglacial periods, but that in the future glaciers will again advance into the middle latitudes.

El Niño and La Niña Events Every 2 to 10 years, the normally cold waters of the eastern Pacific Ocean off western South America are replaced with a vast area of warmer waters. This warming event, known as **El Niño,** causes major climatic repercussions around the world. As shown in Figure 6-12, flooding, droughts, and heat waves are known to occur during an El Niño. Recently it has been noted that there are also periods of exceptionally cold water—called La Niña events—in the eastern Pacific Ocean, which also affect worldwide climate.

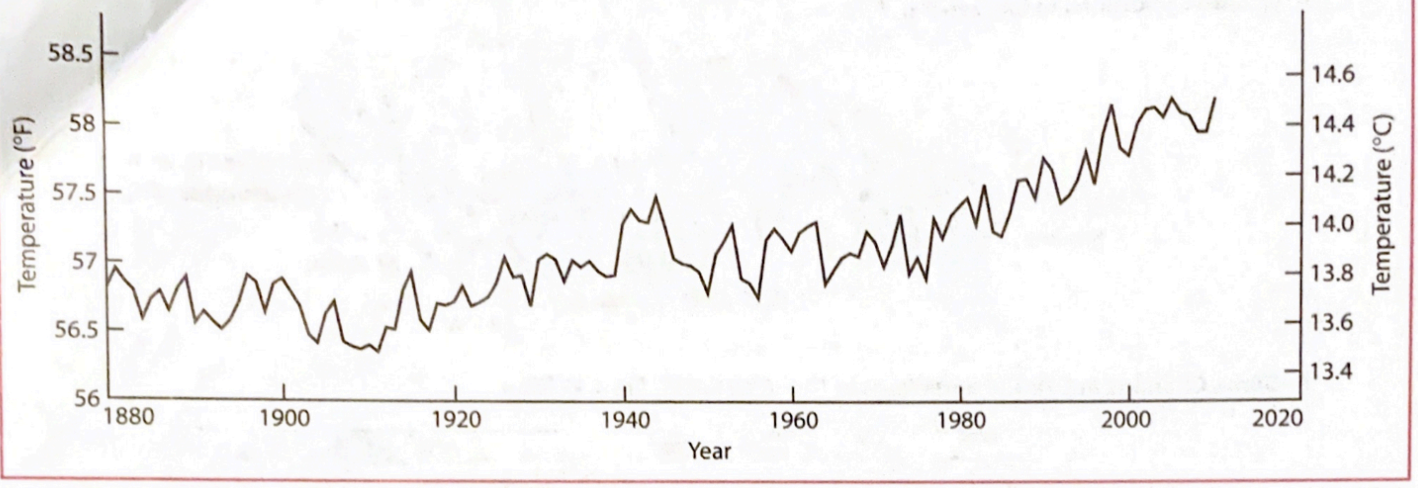


Figure 6-13. Worldwide average temperatures from 1880 to 2010: The increasing temperatures of the 1980s and 1990s have convinced many scientists that global warming is occurring and may worsen as human activities continue to add greenhouse gases to the atmosphere.

Global Warming and Heat Waves From the early 1980s to the present time, there has been a trend of rising temperatures known as global warming. In 1998, worldwide temperatures were the warmest ever recorded. Figure 6-13 shows the changes in Earth's average surface temperature over the last 120 years. It remains to be seen whether worldwide temperatures will continue to rise, or whether they just reflect a temperature fluctuation similar to the one that occurred during the 1930s and 1940s.

Many scientists believe that there are many weather consequences of global warming including increased numbers and strength of violent storms like hurricanes and tornadoes and an increase in heat waves. A heat wave is a series of days with abnormally and uncomfortably hot and unusually humid weather that lasts two or more days. Heat waves can make it difficult for humans to effectively cool their bodies, especially if they do not live in a normally hot and humid climate. Heat waves can result in hyperthermia (heat stroke) leading to death. In most years in the United States, more humans die of heat waves than any other weather event. On average, 170 heat-related deaths occurred each year from 1998 to 2007. That average decreased from the early 2000s, when the 10-year average was 237, perhaps due to increased awareness of the dangerous potential of heat waves. To protect yourself during a heat wave, don't over exercise outside, stay in shady areas, drink plenty of water, and try to stay in an air-conditioned location.

Causes of Heat Budget Shifts

There are many possible explanations for the shifts in Earth's heat budget that produce climate change. Some possible causes are described in the following paragraphs.

Changes in Solar Energy The sun's energy output and related sunspot activity follow an 11-year cycle, as shown in Figure 6-14. A **sunspot** is a darker region of the sun's visible surface. When there are large numbers of sunspots, the sun emits from 0.1 to 1.0 percent more electromagnetic energy. As a result, Earth receives more insolation at these times. Note that the high temperatures of the 1990s, shown in Figure 6-13, show a correlation with an increase in the number of sunspots as indicated in Figure 6-14.

Changes in Earth's Orbit and Axis Tilt Changes in Earth's axis and orbit over many thousands of years may be a major influence in climate change. Over periods of thousands of years, the tilt of Earth's axis changes a few degrees. The season during which Earth passes closest to the sun varies from its present winter occurrence in the Northern Hemisphere to a summer occurrence. The amount of eccentricity of Earth's orbit also changes a minor amount. When the cycles of these factors occur at the same time, summers may be cooler and winters warmer with more precipitation. The times of such occurrences seem to correspond with the advances of the glaciers during the Pleistocene Ice Age. (See Figure 6-11.)

Volcanic Eruptions and Climate Changes In the early 1990s, Earth's atmosphere underwent cooling that was probably related to the eruption of the Pinatubo volcano in the Philippines. (See Figure 6-13.) When there are major volcanic eruptions, aerosols such as volcanic ash and sulfur compounds are propelled into the stratosphere and stay there for months or years. The aerosols make Earth's atmosphere less transparent to insolation and reflect a greater than normal amount of insolation back into space. As a result, less energy arrives at Earth's surface, and cooler temperatures occur.

Memory Jogger

Recall that the amount of eccentricity of Earth's orbit refers to the amount of deviation from a circle, or the flattening of its elliptical shape.

Human Causes Many scientists who study climate have found evidence that human activities have an impact on climate change. For example, the expansion of deserts at the cost of grasslands—called desertification—is often related to overgrazing by livestock such as sheep and cattle. Since deserts heat up faster than grasslands, the temperature of these areas increases.

The cutting down of forests—called **deforestation**—in many tropical areas has resulted in these regions becoming hotter and drier. When deforestation occurs, the insolation once absorbed by the trees and converted into potential energy instead goes into heating Earth's surface. Additionally, without the trees, there is less transpiration of water vapor to increase the humidity of the atmosphere—resulting in less precipitation.

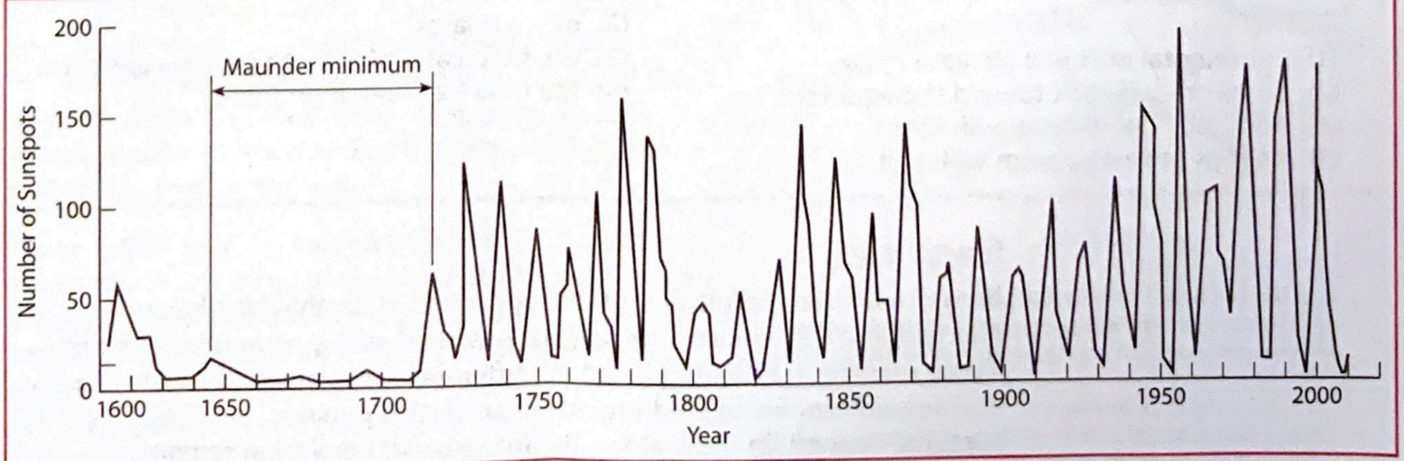


Figure 6-14. Graph of sunspot numbers for the years 1600–2010: This diagram shows the number of sunspots varies through a solar cycle of approximately 11 years.

As discussed previously, human activities that produce greenhouse gases may be a major reason for the present global warming. For example, the increase in atmospheric carbon dioxide in recent years is largely due to the burning of fossil fuels. Another human factor is the building of cities—urbanization—which results in clearing land of plants and trees to construct buildings. Cities also increase carbon dioxide because of an increased use of fossil fuels.

Review Questions

32. Between the years 1850 and 1900, records indicate that Earth's mean surface temperature showed little variation. This would support the inference that

(1) Earth was in heat balance
(2) another ice age was approaching
(3) Earth was gaining more energy than it was losing
(4) the sun was emitting more energy

33. Air temperature is regulated partly by the percentage of carbon dioxide (CO_2) in the air. Which of the following statements is correct?

(1) The CO_2 content of the air during the glacial period was very high because cold water absorbs more CO_2 than warm water.
(2) During periods of great volcanic activity, the CO_2 content of the air decreases because the clouds reduce plant growth.
(3) The CO_2 content of the air is increasing due to the burning of fossil fuels.
(4) The CO_2 content of the air is increasing due to the deposition of limestone from groundwater.

34. Some scientists predict that an increase in atmospheric carbon dioxide would cause a worldwide increase in temperature. Which of the following could result if a worldwide temperature increase occurred?

(1) Continental drift will increase.
(2) Isotherms will shift toward the equator.
(3) Additional landmasses will form.
(4) Ice caps at Earth's poles will melt.

35. A heating of the normally cold ocean waters of the eastern Pacific Ocean off the coast of South America is called

(1) the greenhouse
(2) El Niño
(3) ozone effect
(4) global warming

36. Which event would most likely cause a new ice age in North America?

(1) a decrease in the energy produced by the sun
(2) a decrease in the light reflected by Earth's surface
(3) an increase of carbon dioxide in Earth's atmosphere
(4) an El Niño event

37. When were large parts of North America covered by ice sheets?

(1) only once, early in Earth's geologic history
(2) only once, in the recent geologic past
(3) once early in Earth's geologic history and once in the recent geologic past
(4) many times during Earth's geologic history

38. Another ice age would probably result in a change in

(1) sea level
(2) moon phases
(3) the speed at which Earth moves in its orbit
(4) the time between high tides

Seasons

New York State and other mid-latitude areas of Earth's Northern Hemisphere experience four seasons—winter, spring, summer, and fall. These seasons are distinguished by differences in temperature, moisture, and vegetation. Some land regions near Earth's equator have little seasonal change. In these areas, the intensity of insolation remains relatively high, and the duration of insolation is about 12 hours per day throughout the year.

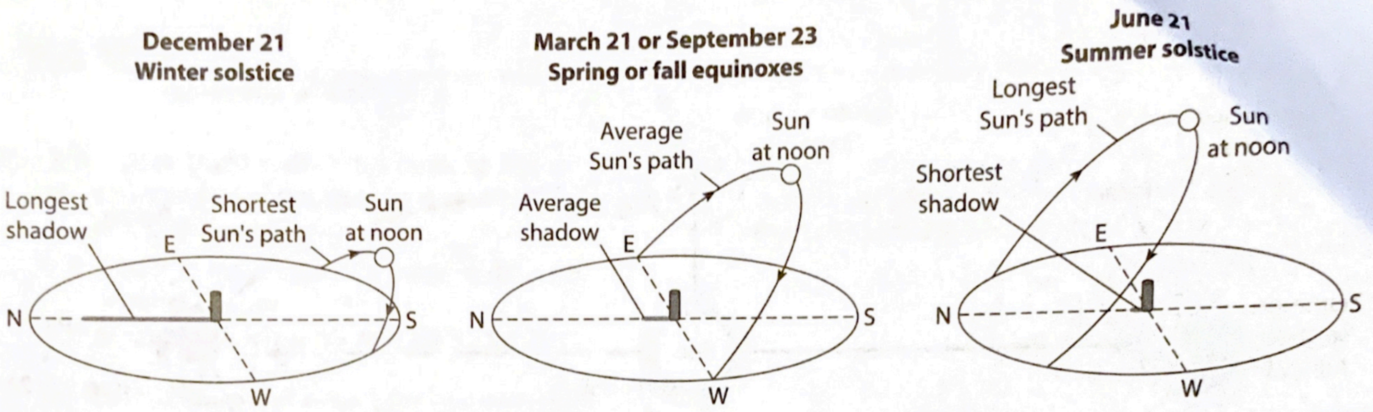


Figure 6-15. The direct causes of seasons: Shown for the mid-latitudes of the northern hemisphere include changes in angle of incidence or height of the sun in the sky and the changes in duration of the sun's daily motion path. Note how the length of the shadow of the sun at noon changes with the seasons.

Direct Causes of the Seasons

Seasonal changes in temperature, moisture, and other weather conditions result from the cyclic variations in the angle of incidence and the intensity and duration of insolation that occur during the year. (See Figure 6-15 and Appendix 4.) Generally the seasons follow the north-south shift in the direct rays of insolation. This shift, caused by the tilt of Earth's axis, occurs between $23\frac{1}{2}°$ N latitude and $23\frac{1}{2}°$ S latitude as discussed previously. This shifting of the sun's rays results in the seasons being the opposite of each other in the Northern and Southern Hemispheres. A4

Climate zones, and their associated wind patterns and surface ocean currents, also shift in a north-south pattern. However, this shift lags about a month behind the shift of direct rays of insolation. Figure 6-16 shows the effects of the shifting rays of the sun on the seasonal positions of the wind and moisture belts on Earth.

Astronomical Causes of the Seasons

The variations in insolation that directly cause the seasons are themselves the result of factors that may be called the astronomical, or indirect, causes of the seasons. These indirect causes of seasons include the tilt and parallelism of Earth's axis and Earth's revolution around the sun.

Tilt of Earth's Axis As shown in Figure 6-17, Earth's rotational axis is tilted at an angle of $23\frac{1}{2}°$ with respect to a line perpendicular to the plane of its orbit of the sun. This tilt, coupled with the other reasons described here, means that perpendicular insolation from the sun shifts between $23\frac{1}{2}°$ N and $23\frac{1}{2}°$ S latitudes. If the tilt of Earth's axis were greater, perpendicular insolation would reach farther

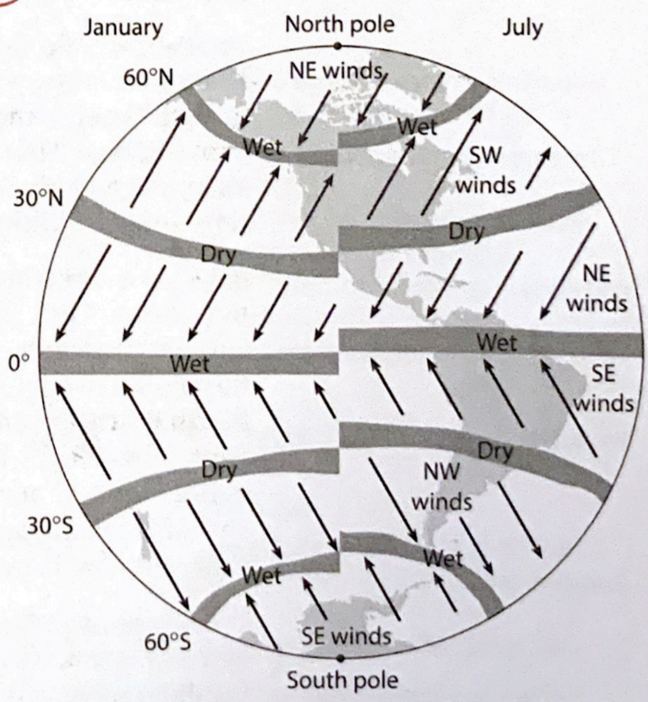


Figure 6-16. Seasonal shifting of Earth's wind and moisture belts: By comparing the latitudes of the wind and moisture belts in January and July, you can see how the wind and moisture belts shift north and south during the year following the direct rays of insolation. Also, look at the diagram Planetary Wind and Moisture Belts in the Troposphere in the *Earth Science Reference Tables* that represents conditions near the time of the equinoxes.

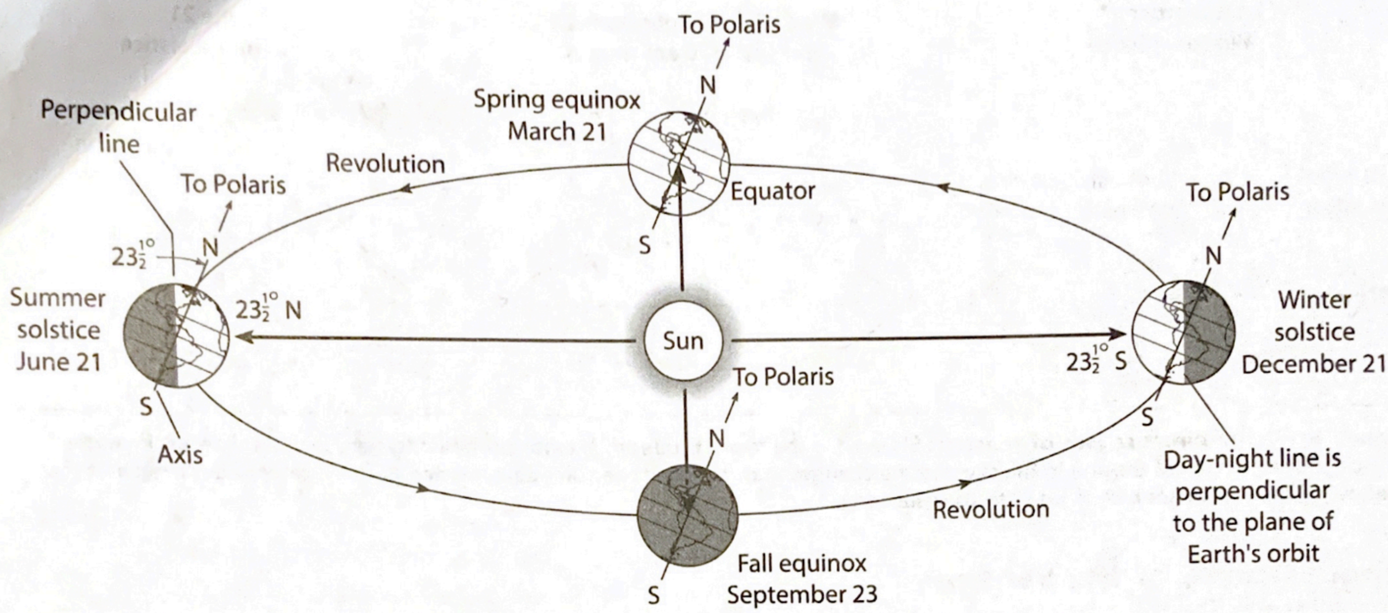


Figure 6-17. Indirect causes of the seasons: The astronomical, or indirect, causes for the seasons described in the text, result in the changes in angle, intensity, and duration of insolation.

north and south, resulting in generally warmer summers and colder winters for much of Earth. If the tilt of Earth's axis were less than $23\frac{1}{2}°$, then perpendicular insolation would not shift as much. As a result, seasonal effects would be less pronounced—there would be cooler summers and warmer winters.

Parallelism of Earth's Axis Regardless of the position of Earth in its orbit, Earth's axis always points in the same direction in space. The north end of Earth's axis—the North Pole—always points to the present-day North Star—Polaris. Figure 6-17 shows that as Earth orbits the sun, the position of its axis at any given time is always parallel to its position at any other time—this condition is called parallelism.

Revolution of Earth Around the Sun As Earth revolves around the sun, the direction of Earth's axis with respect to the sun varies because of its tilt and parallelism. For example, on June 21, the North Pole is inclined toward the sun at an angle of $23\frac{1}{2}°$ from the perpendicular. On December 21, the North Pole is inclined away from the sun at this angle. On March 21 and September 23, the axis is still inclined $23\frac{1}{2}°$ from the perpendicular, but neither toward nor away from the sun. This cycle of variations causes variations in angle of incidence and duration of insolation throughout the year and results in seasonal changes. (See Figures 6-15 and 6-17.)

Small Seasonal Effect of Earth's Elliptical Orbit Because of Earth's slightly elliptical orbit, there is a variation in distance between Earth and the sun as Earth revolves around the sun. The small changes in distance between Earth and the sun during the year are too small to have a significant effect on the seasons. For example, winter in the Northern Hemisphere occurs at a time when Earth is actually nearest the sun. Earth as a whole receives about seven percent more energy when it is closest to the sun than it does when it is farthest away. This seven percent difference would only be significant if Earth's axis was not tilted at an angle of $23\frac{1}{2}°$.

Review Questions

39. The factor that contributes most to the seasonal temperature changes during a year in New York State is the changing

(1) speed at which Earth travels in its orbit around the sun
(2) angle at which sun's rays strike Earth's surface
(3) the distance between Earth and the sun
(4) energy given off by the sun

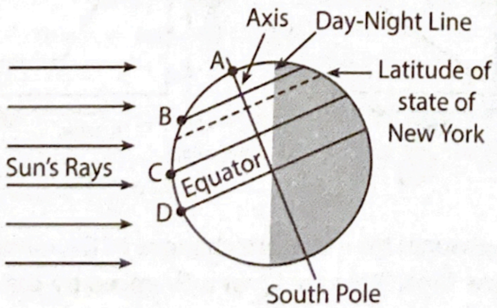
40. On which two dates could all locations on Earth have equal hours of day and night?

(1) September 23 and December 21
(2) December 21 and March 21
(3) March 21 and June 21
(4) March 21 and September 23

41. At which latitude does Earth receive the greatest intensity of insolation on June 21?

(1) 0°
(2) $23\frac{1}{2}°$ S
(3) $23\frac{1}{2}°$ N
(4) 90° N

Base your answers to questions 42 and 43 on the following diagram, which shows Earth as viewed from space. The shaded side represents Earth's nighttime side.



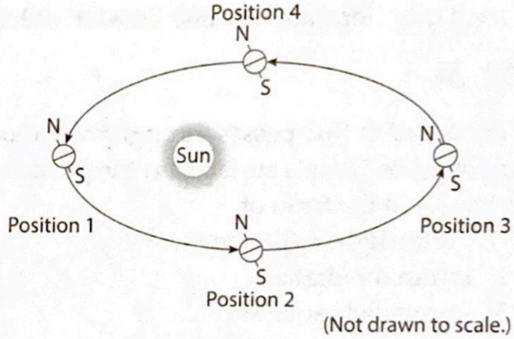
42. Which point on Earth's surface is receiving the greatest intensity of insolation?

(1) A (2) C (3) B (4) D

43. The total number of hours of daylight received by New York State on the days represented in the diagram is closest to

(1) 9 hr (2) 12 hr (3) 15 hr (4) 20 hr

44. Which position in the following diagram best represents Earth on the first day of summer in the Northern Hemisphere?



(1) 1
(2) 2
(3) 3
(4) 4

45. At which latitude would the duration of insolation be greatest on December 21?

(1) $23\frac{1}{2}°$ S
(2) 0°
(3) 10° N
(4) $23\frac{1}{2}°$ N

46. Which change would occur if Earth's axis were inclined at an angle of $33\frac{1}{2}°$ instead of $23\frac{1}{2}°$?

(1) The equator would receive fewer hours of daylight on June 21.
(2) The sun's perpendicular rays would move over a larger area of Earth's surface.
(3) The average duration of insolation would be less at the equator.
(4) There would be less seasonal effect on Earth.

47. Which of the following is the best description of parallelism?

(1) Earth's daily rotation
(2) position of the moon with respect to Earth
(3) positions of Earth's axis as it revolves around the sun
(4) arrangement of galaxies in the universe

48. Which does NOT cause the changes of Earth's seasons?

(1) Earth's revolution
(2) inclination of Earth's axis
(3) variation of the distance to the sun
(4) parallelism of Earth's axis

Practice Questions
for the New York Regents Exam

Directions

Review the Test-Taking Strategies of this book. Then answer the following questions. Read each question carefully and answer with a correct choice or response.

Part A

1 The radiation that passes through the atmosphere and reaches Earth's surface has the greatest intensity in the form of
(1) visible light radiation
(2) infrared radiation
(3) ultraviolet radiation
(4) radio-wave radiation

2 Compared with the temperature of land surfaces, temperatures of water surfaces change
(1) faster because water has a higher specific heat
(2) faster because water has a lower specific heat
(3) slower because water has a higher specific heat
(4) slower because water has a lower specific heat

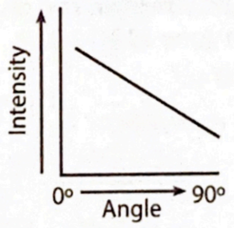
3 Most of the energy radiated by Earth's surface at night is in the form of
(1) infrared rays
(2) ultraviolet rays
(3) visible light rays
(4) X-rays

4 Under which conditions will the greatest amount of cooling by Earth's surface radiation occur?
(1) a clear night with low humidity
(2) a clear night with high humidity
(3) a cloudy night with low humidity
(4) a cloudy night with high humidity

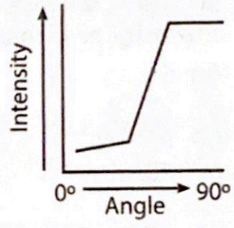
5 The sun's rays have a greater effect on land temperature than they have on water temperature. This difference can be explained partly by which of the following?
(1) Some energy from the sun is used to evaporate ocean water.
(2) Less energy is reflected by the water's surface than by the land's surface.
(3) Land materials have a higher specific heat than water has.
(4) Land materials require more heat energy than water does to raise their temperature 1°C.

6 Adding more carbon dioxide to the atmosphere increases the amount of
(1) radiant energy reflected by Earth
(2) radiation from the sun absorbed by the oceans
(3) radiation from Earth absorbed by the atmosphere
(4) ultraviolet rays striking Earth

7 Which graph best illustrates the relationship between the intensity of insolation and the angle of incidence?



(1)



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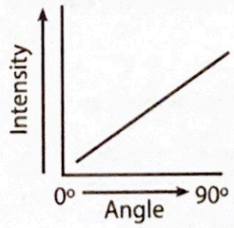
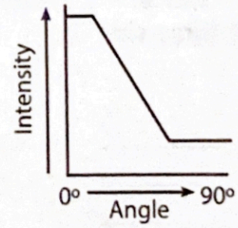


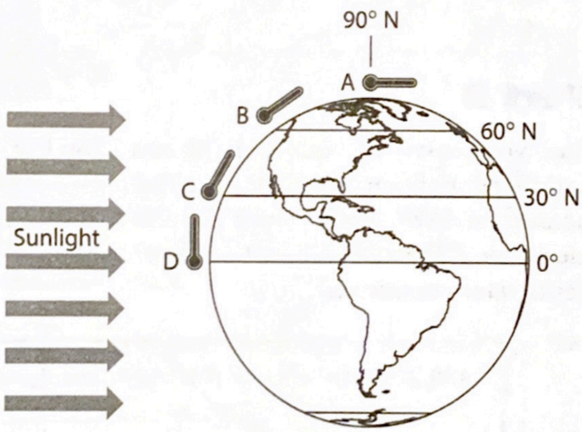
(2)



(4)

8 The seasonal temperature changes in the climate of New York State are most influenced by the changing
(1) CO_2 content of the air
(2) angle of incidence at which the sun's rays strike Earth's surface
(3) distance from the sun to Earth
(4) speed at which Earth revolves around the sun

9 The activity shown in the following diagram was used to test the effect of the angle of incidence on temperature. A student placed four thermometers—A, B, C and D—on a large globe. The bulb of each thermometer was placed against a black plastic square directly on a line representing latitude. The thermometers were then exposed to direct sunlight for 10 minutes at the angles shown.

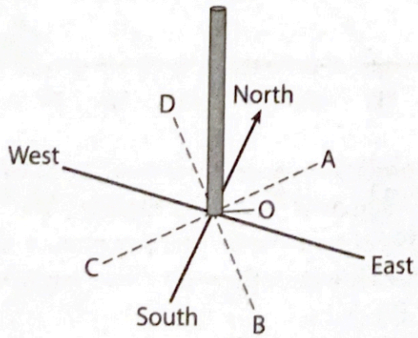


(Not drawn to scale.)

Which thermometer will show the greatest increase in temperature?

(1) A (2) B (3) C (4) D

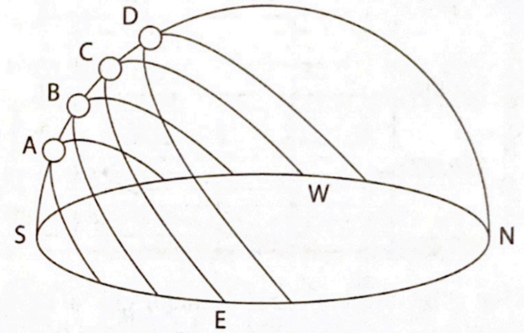
10 In New York State at 3 P.M. on September 21, the vertical pole shown on the following diagram casts a shadow.



Which line best approximates the position of that shadow?

(1) OA (2) OB (3) OC (4) OD

11 The following diagram represents a model of the sun's apparent path across the sky in New York State for selected dates.



For which path would the duration of insolation be greatest?

(1) A (2) B (3) C (4) D

12 Which two factors determine the number of hours of daylight at a particular location?

(1) longitude and season
(2) longitude and Earth's average diameter
(3) latitude and season
(4) latitude and Earth's average diameter

13 When do maximum surface temperatures usually occur in the Northern Hemisphere?

(1) early June to mid-June
(2) mid-July to early August
(3) late August to mid-September
(4) mid-September to early October

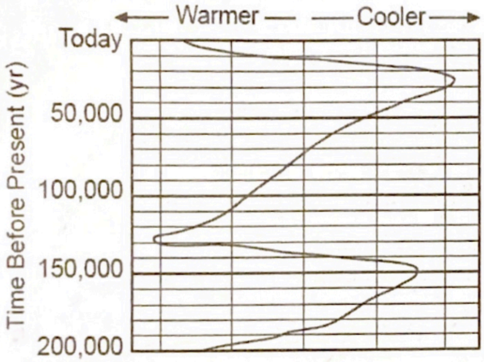
14 Earth loses heat energy to outer space mainly by

(1) radiation (3) convection
(2) reflection (4) conduction

15 An increase in carbon dioxide in the atmosphere may lead to an increase in global temperatures because carbon dioxide

(1) absorbs infrared radiation, thus preventing it from escaping Earth's atmosphere
(2) blocks harmful ultraviolet radiation from reaching Earth's surface and being absorbed
(3) interferes with the formation of clouds that block sunlight and cause cooling
(4) enters the atmosphere at a high temperature from combustion and respiration

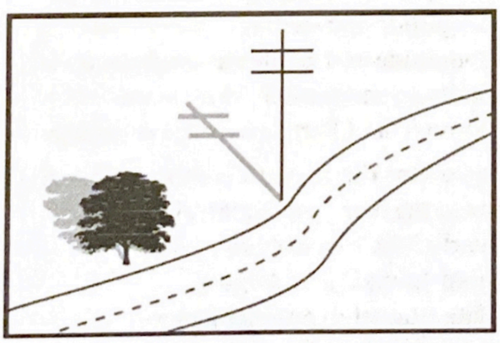
16 The diagram below shows trends in the temperature of North America during the past 200,000 years, as estimated by scientists.



What is the total number of major glacial periods that have occurred in North America in the last 200,000 years?

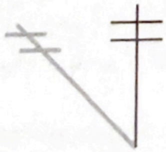
(1) 5 (2) 2 (3) 3 (4) 4

17 The diagram below shows the shadow cast by a telephone pole on March 21 at solar noon at a location in New York State.



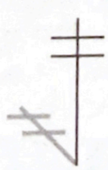
Shadow Cast on March 21

Which shadow was cast by the same telephone pole on June 21 at solar noon?



(1)

(3)



(2)

(4)

18 It is known that less ozone in Earth's stratosphere can result in

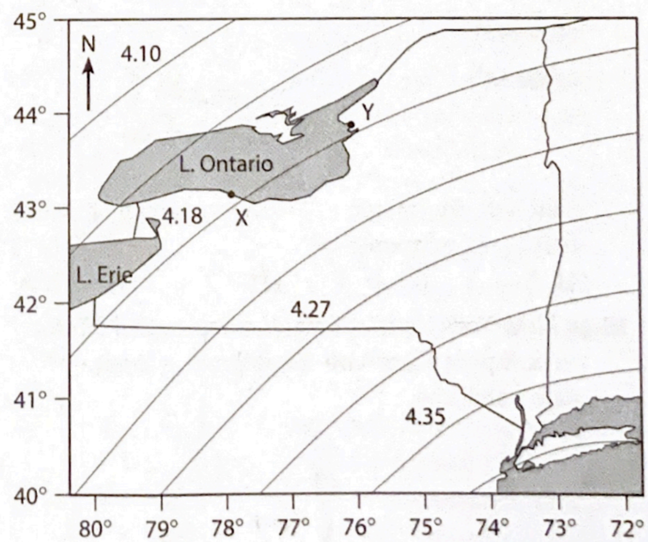
(1) ice ages
(2) an increase in carbon dioxide
(3) an increase in skin cancer
(4) a decrease in rock weathering caused by ultraviolet rays

19 Which angle of the sun above the horizon produces the greatest intensity of sunlight per unit area?

(1) 25°
(2) 40°
(3) 60°
(4) 70°

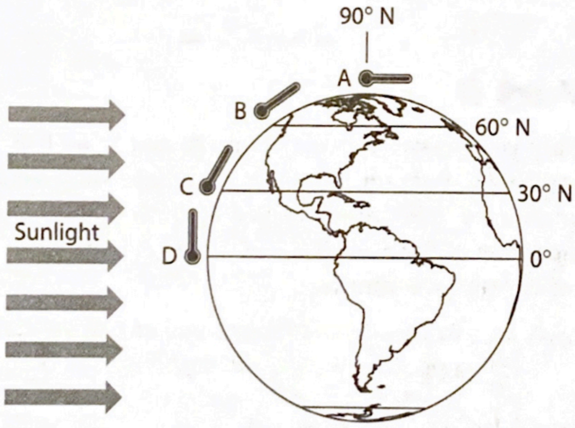
Part B

Base your answers to questions 20 and 21 on the following diagram. It represents a field showing the amount of insolation received at Earth's surface on a clear day in the morning—in joules per square centimeter per minute.



20 If the insolation value at the outer edge of Earth's atmosphere over New York State equals 7.75 joules per square centimeter per minute, why are the values lower at the surface in New York State? [1]

9 The activity shown in the following diagram was used to test the effect of the angle of incidence on temperature. A student placed four thermometers—A, B, C and D—on a large globe. The bulb of each thermometer was placed against a black plastic square directly on a line representing latitude. The thermometers were then exposed to direct sunlight for 10 minutes at the angles shown.



(Not drawn to scale.)

Which thermometer will show the greatest increase in temperature?

(1) A (2) B (3) C (4) D

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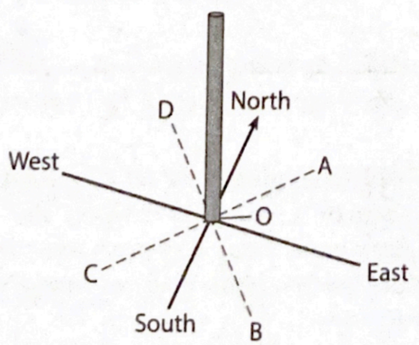

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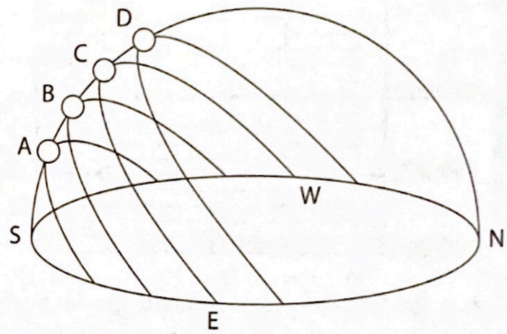

For which path would the duration of insolation be greatest?

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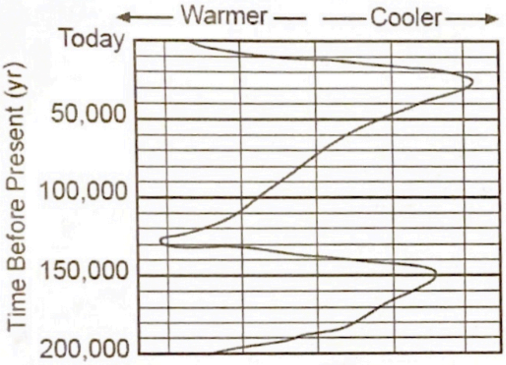

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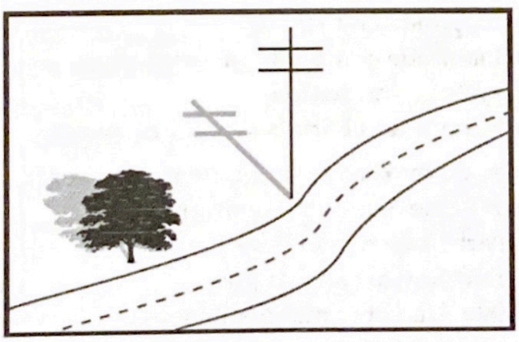

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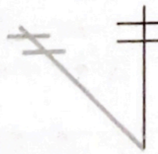
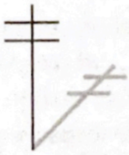
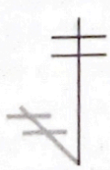


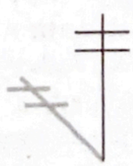
(1)



(3)



(2)



(4)

18 It is known that less ozone in Earth's stratosphere can result in

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Part B

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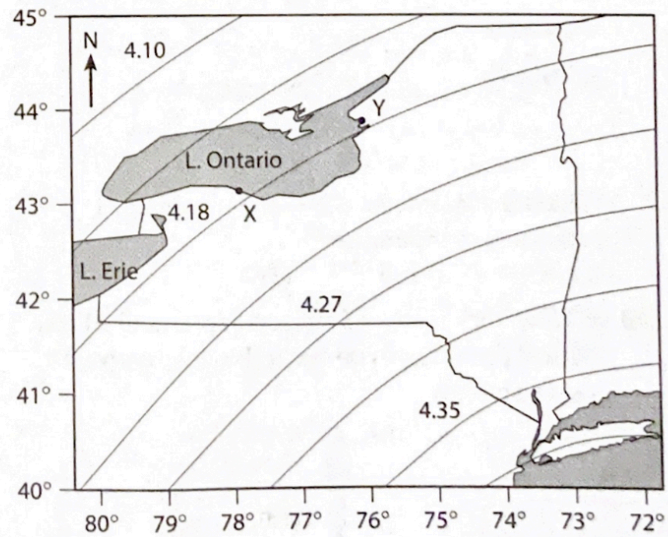
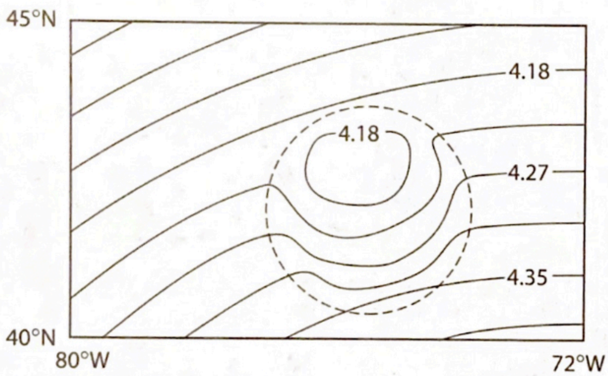


20 If the insolation value at the outer edge of Earth's atmosphere over New York State equals 7.75 joules per square centimeter per minute, why are the values lower at the surface in New York State? [1]

21 What change in atmospheric conditions within the dashed circle could cause the different pattern of isolines as indicated in that area in the following diagram? [1]



Base your answers to questions 22 and 23 on the table below, which provides information about several gases and their relationship to the greenhouse effect.

22 State one reason that a scientist would recommend restricting the emission of chlorofluorocarbon CFC-12 into the atmosphere. [1]

23 State which of the following actions would contribute more to the greenhouse effect and give a reason for your answer. [2]
(1) releasing 1 kilogram of methane directly into the atmosphere, OR
(2) burning 1 kilogram of methane, resulting in the release of about 3 kilograms of carbon dioxide into the atmosphere

24 Why is reflectivity of insolation at high latitudes greater in winter than in summer? [1]

25 In New York State, ski trails on a slope that faces north usually retain their snow later in the spring than those on a slope that faces south. Why does this occur? [1]

26 Why are equatorial areas equal in size to Earth's polar regions heated much more intensely by the sun? [1]

27 How does the way that noontime shadows are cast in New York State change with the approach of the summer solstice? [1]

28 In late summer 1991, Mt. Pinatubo, a volcano in the Philippines, exploded and sent thousands of tons of volcanic dust into the atmosphere. According to scientists, what effects did this event have on Earth's average temperatures in the months that followed? [1]

Part C

Using information from the following paragraph and your knowledge of earth science, answer questions 29 through 33.

Recent data from the study of tree rings and gases trapped in Greenland ice indicate that much of the Northern Hemisphere experienced a warm period—the Medieval Warm Period—from approximately 1000 A.D. to 1350 A.D. The data also indicate a much colder period—the Little Ice Age—which lasted from 1350 A.D. to approximately 1850 A.D. Thermometer readings from 1850 to the present indicate an overall temperature rise, often called global warming.

29 What human activities could have caused the overall change in temperature after 1850 and how could these activities cause the temperature change? [2]

Name of Gas	Symbol	Concentration in Troposphere (parts per billion)	Relative Greenhouse Effect per Kilogram of Gas (in equal concentrations)	Decay Time (years)
Carbon dioxide	CO_2	353,000	1	120
Methane	CH_4	1700	70	10
Ozone	O_3	10–50	1800	0.1
Chlorofluorocarbon	CFC-11	0.28	4000	6.5
Chlorofluorocarbon	CFC-12	0.48	6000	120

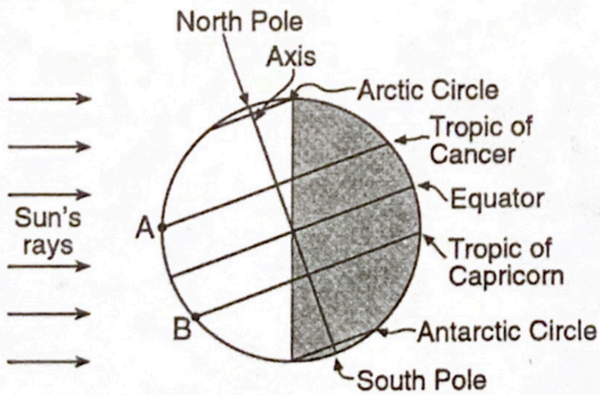
30 Propose two methods of slowing down or reversing the changes in temperature that have occurred since 1850 and explain how these methods might accomplish the goal. [2]

31 At the end of the Medieval Warm Period, Vikings abandoned their settlements in North America and Greenland. What are two possible natural climate-related causes and their effects that might explain this action by the Vikings? [2]

32 Some scientists propose that the Little Ice Age was in part the result of a few exceptionally cold winters increasing the ice and snow coverage in the Northern Hemisphere. How is it possible that more ice and snow would make it colder for such an extended number of years? [1]

33 Some scientists have suggested that an increase in solid aerosols—produced by burning wood and coal—deposited on Earth's surface from the atmosphere, at least in part, resulted in the end of the Little Ice Age. Explain how the deposited aerosols might produce the end of the Little Ice Age. [1]

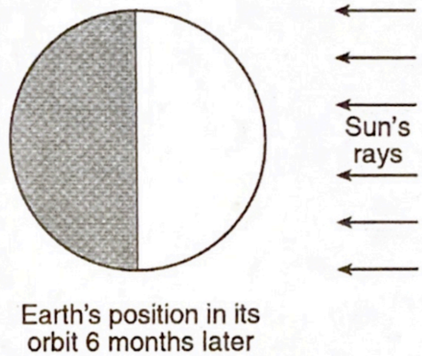
Base your answers to questions 34 through 36 on the diagram below, which represents Earth at a specific position in its orbit as viewed from space. The shaded area represents nighttime. Points *A* and *B* are locations on Earth's surface.



34a State the month in which Earth is at the position shown in the diagram. [1]

34b State the latitude that receives the most intense radiation from the Sun when Earth is at this position in its orbit. [1]

35 Describe the length of daylight at point A compared to the length of daylight at point B on the day represented by the diagram. [1]



Earth's position in its orbit 6 months later

36 The model of Earth provided *above* represents Earth in its orbit *6 months later*. On the model provided above:

- draw the position of Earth's axis and label the axis [1]
- label the North Pole [1]
- draw the position of Earth's Equator and label the Equator [1]

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37 The diagram below shows a view of the ground from directly above a flagpole in New York State at solar noon on a particular day of the year. The flagpole's shadow at solar noon is shown. Draw the position and relative length of the shadow that would be cast by this flagpole three hours later. [2]