All living things on our planet need water and oxygen to survive. Plants need carbon dioxide as well. Most living things we know cannot survive extreme temperatures, nor can they live long if exposed to large doses of the sun's ultraviolet radiation. It is the atmosphere, the layer of air that surrounds the earth, that supplies most of the oxygen and carbon dioxide and that helps maintain a constant level of water and radiation in the earth system.

Although actually a thin film of air, the atmosphere serves as an insulator, maintaining the livable temperature we find on earth. Without the atmosphere, the earth would experience temperature extremes of as much as 260° C (500° F) between day and night. The atmosphere also serves as a shield, blocking out much of the sun's ultraviolet radiation, as well as protecting us from showers of meteors. At other times, the atmosphere is described as an *ocean* of air surrounding the earth. This description reminds us of the currents and circulation of the atmosphere – its dynamics – which create the changing conditions on earth that we know as weather.

For contrast, we can look at our moon, a celestial body with no atmosphere, in order to see the importance of our own atmosphere. Most obviously, a person standing on the moon without a space suit would not have any oxygen to breathe. Also, astronauts have recorded temperatures of upto 204° C (400° F) on the hot, sunlit side of the moon. On the dark side, the temperatures, which approach -121° C (- 250° F), would kill an unprotected human.

The next thing our astronaut on the moon might notice is the 'unearthly' silence. On earth, we can hear because sound waves travel by moving the molecules of the atmosphere. Since the moon has not atmosphere and no molecules to vibrate and carry the sound waves, the lunar visitor would not be able to hear any sounds. Also, the astronaut could not fly aircraft or helicopters, and it would be fatal to try to use a parachute. In addition, there is no atmosphere to other protection from the bombardment of meteors that fly through space and collide with the moon. Nearing the earth, most meteors burn up before reaching the surface because of friction with the atmosphere. And without an atmosphere for protection, a visitor might also be burned by the ultraviolet rays of the sun. On earth, we are protected to a large degree from ultraviolet radiation because the ozone layer of the upper atmosphere absorbs the major portion of this harmful radiation.

We can see that, in contrast to the stark lifelessness of the moon, the earth presents a hospitable environment for life, almost solely because of its atmosphere. All living things are adapted to its presence. For example, many plants reproduce by pollen carried by winds. Birds can fly only because of the air, and the water cycle of the earth is maintained through the atmosphere, as is the heat budget. The atmosphere diffuses sunlight as well, giving us our blue skies and the fantastic reds, pinks, oranges, and purples of sunrise and sunset. Without this diffusion, the sky would appear black, as it does from the moon.

Further, the atmosphere provides a means by which the systems of the earth attempt to reach equilibrium. Changes in weather are ultimately the result of the atmospheric effects that equalize temperature and pressure differences on the earth's surface by transferring heat, energy, and moisture through the earth's atmospheric and oceanic circulation systems.

CHARACTERISTICS OF THE ATMOSPHERE

The atmosphere extends as far as 9600 kilometers (6000 miles) above the earth's surface. Its density decreases rapidly with altitude, and, in fact, 97 percent of the air is concentrated in the first 29 kilometers (18 miles) or so. Since air has mass, the atmosphere exerts pressure on the earth's surface. At sea level, this pressure is about 1034 grams per square centimeter (14.7 lb per sq in.), but the higher the elevation, the lower the atmospheric pressure.

Composition of the Atmosphere

The atmosphere is composed of numerous gases. Most of these gases remain the same proportions regardless of the density of the atmosphere. About 78 percent of the atmosphere's volume is made up of nitrogen, and nearly 21 percent consists of oxygen. Argon comprises most of the remaining 1 percent. The percentage of carbon dioxide in the atmosphere varies but is about 0.03 percent by volume. There are traces of other gases as well: ozone, hydrogen, neon, xenon, helium, methane, nitrous oxide and krypton.

(a) Nitrogen, Oxygen, and Carbon Dioxide – Nitrogen makes up the largest proportion of air and is needed by plants. In addition, some of the other gases in the atmosphere are vital to the development and maintenance of life on earth. One of the most important of the atmospheric gases is, of course, oxygen, which all animals, including humans, use to oxidize (burn) the food they eat. Oxidation, which is technically the chemical combination of oxygen with other materials to create new products, occurs in situations outside animal life as well. Rapid oxidation takes place, for instance, when we burn fossil fuels or wood and thus release tremendous amounts of heat and light energy. The decay of certain rocks or organic debris and the development of rust are examples of slow oxidation and are processes that depend upon the existence of oxygen in the atmosphere.

Carbon dioxide is an important atmospheric gas, since it absorbs heat from the earth. The atmosphere then emits about half of that heat energy back to the earth. This process helps maintain the warmth of the earth and is a factor in the earth's heat energy budget. However, human activity, largely the burning of fossil fuels, has greatly increased the amount of carbon dioxide in the atmosphere. There is concern that this will upset our current temperature structure.

Carbon dioxide is also involved in the system known as the carbon cycle. Plants, through a process known as **photosynthesis**, use carbon dioxide and water to make carbohydrates (sugars and starches) in which amounts of solar energy are stored. Oxygen is given off as a by-product. Animals then use the oxygen to oxidize the carbohydrates, releasing the stored solar energy. A by-product of this process in animals is the release of carbon dioxide, which completes the cycle when it is in turn used by plants in photosynthesis.

(b) Ozone – another vital gas in the earth's atmosphere is ozone. The ozone molecule (O_3) is a cousin of the oxygen molecule (O_2), as it is made up of three atoms of oxygen while regular oxygen is made up of only two. Ozone is formed in the upper atmosphere when an oxygen molecule is split into two atoms by short-wave solar radiation and the free unstable atoms join two other oxygen molecules to form two molecules of ozone consisting of three oxygen atoms each.

Ozone is important to climate because it is capable of absorbing large amounts of the sun's ultraviolet radiation. Without the ozone of the upper atmosphere, the ultraviolet radiation reaching the earth would severely burn human skin, increase the incidence of skin cancer, destroy certain microscopic forms of life, and damage plants. There is, therefore, increasing concern that human activity, especially the addition of chlorofluorocarbons (CFCs) to the atmosphere, may permanently damage this fragile ozone layer.

The small proportion of ultraviolet radiation that ozone allows to reach the earth does serve useful purposes. For instance, it is important in the production of certain vitamins, and it helps in the growth of some viruses and bacteria. It also has a function in the process of photosynthesis. Least important but most visible, ultraviolet radiation produces painful sunburns or beautiful tans, depending on individual skin tolerance and exposure time.

(c) Water vapour, Liquids and Solids – Water vapour is always mixed in some proportion with the dry air of the lower part of the atmosphere, although it varies from 0.02 percent by volume in a cold, dry climate to a high of nearly 5 percent in the humid tropics. The variation in this percentage over time and place are an important consideration in the examination and comparison of climates. In addition, water vapour absorbs heat in the lower atmosphere and so prevents its rapid escape from the earth. Thus, like carbon dioxide, water vapour plays a large role in the insulating action of the atmosphere. In addition to gaseous water vapour, liquid water also exists in the atmosphere as rain and as fine droplets in clouds, mist, and fog. Solid water is found in the atmosphere in the form of ice crystals, snow, and hail. Suspended in the atmosphere are many other solids such as dust, soil particles, pollen, microscopic animals, bacteria, smoke particles, seeds, spores, and salts from ocean spray, all of which can play an important role in absorption of energy and in the formation of raindrops.

Vertical Layering of the Atmosphere

Though people function primarily in the lowest levels of the atmosphere, there are times, as when we fly in aircraft or climb a mountain, when we leave our normal altitude. The thinness of the atmosphere at higher altitudes then may affect us if we are not accustomed to it. Visitors to Inca ruins in the Andes or high-altitude Himalayan climbers may experience 'altitude sickness', and even skiers in the Rockies near 'mile-high' Denver may need time to adjust. The air at these levels is much thinner than most of us are used to. In other words, there is more empty space between air molecules, and thus there is less oxygen and other gases in each breath of air inhaled.

The atmosphere can be divided into several layers according to differences in temperature and rates of temperature change. The first of these layers, lying closest to the earth's surface, is the **troposphere** (from Greek: *tropo*, turn, i.e., the turning or mixing zone), which extends about 10 to 16 kilometers (6 to 10 miles) above the earth. Its thickness, which tends to vary seasonally, is least at the poles and greatest at the equator. It is within the troposphere that people live and work, plants grow, and virtually all the earth's weather takes place.

The troposphere has two distinct characteristics that differentiate it from other layers of the atmosphere. One is that the water vapour and dust particles of the atmosphere are concentrated in this one layer; they are virtually non-existent in the atmospheric layers above the troposphere. The other characteristic of the layer is that temperature decreases with increased altitude.

The altitude at which the temperature ceases to fall with increased altitude is called the **tropopause**, which separates the troposphere from the **stratosphere**, the second layer of the atmosphere. The temperature of the lower part of the stratosphere remains fairly constant (about – 57° C or – 70° F) to an altitude of about 32 kilometers (20 miles). It is in the stratosphere that we find that concentration of ozone that does so much to protect life on earth from the sun's ultraviolet radiation. Because of this ozone layer, however, temperatures increase in the upper parts of the stratosphere as the ozone absorbs ultraviolet radiation. Temperatures at the **stratopause**, which is about 56 kilometers (35 miles) above the earth, are about the same as temperatures found on the earth's surface, although little of that heat can be conducted because the air is so thin.

Above the stratopause are the **mesosphere**, in which temperatures tend to drop with increased altitude, and the **thermosphere**, where temperatures increase until they approach 1100° C (2000° F) at noon. However, the air is so thin at this altitude that there is practically a vacuum and little heat can be conducted.

The thermosphere was once called the ionosphere because of the ionization of molecules and atoms that occurs in this layer, mostly as a result of ultraviolet rays but also because of X-ray and gamma radiation. Ionization refers to the process whereby atoms are changed to ions through the removal or addition of electrons, giving them an electrical charge. The thermosphere merges gradually into the exosphere, the zone where the earth's atmosphere gives way to interplanetary space.

Definition of Weather and Climate

Weather refers to the condition of atmospheric elements at a given time and for a specific area. That area could be as large as the New York metropolitan area or a spot as small and specific as a weather observation station. Although the high-level atmospheric zones are important in such fields as space research, remote sensing, and telecommunications, it is the lowest layer, the troposphere that is of the greatest interest to physical geographers and weather forecasters who survey the changing conditions of the atmosphere in a study known as **meteorology**.

Many observations of the weather of a place over a period of years provide us with a description of its climate. **Climate** describes an area's average weather, but it also includes those common deviations from the norm or average that are likely to occur, as well as extreme situations, which can be very significant. Thus, we could describe the climate of the southeastern United States in terms of average temperatures and precipitation through a year, but we would also have to include mention of the likelihood of hurricanes during certain periods of the year. **Climatology** is the study of the varieties of climates, both past and present, found on our planet and their distribution over its surface.

Weather and climate are of prime interest to the physical geographer because they affect and are interrelated with other parts of the earth system. The changing conditions of atmospheric elements, such as temperature, rainfall, wind, etc. affect soils and vegetation, erode landforms, and cause flooding of towns and farms.

Elements of Weather and Climate

There are five basic elements of the atmosphere that serve as the 'ingredients' of weather and climate. They are (1) solar energy (or insolation), (2) temperature, (3) pressure, (4) winds and (5) precipitation (and moisture). We must examine these elements in order to understand and categorize weather and climate. Thus, a weather forecast will generally include the probably temperature range, the present temperature, a description of the cloud cover, the chance of precipitation, the speed and direction of the winds, and air pressure.

The amount of solar energy received at one place on the earth's surface varies during a day and throughout the year. The amount of insolation a place receives is the most important weather element, as the other four are in part dependent upon the intensity and duration of solar energy.

The temperature of the atmosphere at a given place on or near the surface of the earth is largely a function of the insolation received at that location. It is also influenced by many other factors such as land and water distribution and altitude. Unless there is some form of precipitation occurring, the temperature of the air may be the first element of weather we describe when someone asks us what it is like outside.

However, if it is raining, or the fog is in, or it is snowing, we will probably notice and mention that condition first. We are less aware of the amount of water vapour or moisture in the air (except in very arid or humid areas). However, moisture in the air is a vital weather element in the atmosphere, and its variations play an important role in the likelihood of precipitation.

We are probably least aware of variations in air pressure, although the fluctuation in the air pressure are basic to the development of winds and storms. However, there are some people who say they can feel a change in the weather 'in their bones' because they have arthritis and can probably sense the movement of fluids under pressure in their joints.

We all know that weather varies. It is the momentary state of the atmosphere at a given location, and it varies from time to time and from place to place. There are even variations in the amount that weather varies. In some places or at some times of year, the weather changes almost daily from rain to sunshine to clouds to rain to snow. And in other places, there may be weeks of uninterrupted sunshine, blue skies, and moderate temperatures and then weeks of persistent rain. There are a few places where there are only minor differences in the weather throughout the year. The language of the original people of Hawaii is said to have no word for weather because conditions there varied so little.

Controls of Weather and Climate

Variations in the elements of weather and climate over the earth's surface are caused by several controls. The major controls are (1) land and water distribution, (2) ocean currents, (3) altitude, (4) landform barriers, (5) human activity, and (6) latitude.

(1) Land and Water Distribution – Not only do the oceans and seas of the earth serve as storehouses of water for the whole system, but they also store tremendous amounts of energy. Their widespread distribution makes them an important atmospheric control that does much to modify the atmospheric elements.

All things heat at different rates. On the earth's surface, bodies of water heat and cool more slowly than do land surfaces. Water is less dense, and heat passes through it to the layers below. In more dense materials like soil or rock, the heat is concentrated on the surface. Thus, a given unit of heat energy that is warming the land only works on the surface layer, while the same amount of energy striking water affects a greater volume of water. Since liquid water flows, it is able to transfer heat to other layers and portions. In addition, being essentially transparent, water allows heat and light energy to penetrate to deeper levels than do various opaque land surfaces. So a given unit of heat energy will be spread through a greater volume of water than of land. Finally, the specific heat of water is greater than that of land, which means that water surfaces must absorb more heat energy than land surfaces in order to be raised the same number of degrees in temperature. In fact, the specific heat of water is over four times that of earth or rock.

For these same reasons, water cools off more slowly than does land. The result is that as summer changes to winter, the land cools more rapidly than bodies of water, and as winter becomes summer, the land heats more rapidly. Since the air gets much of its heat from the surface with which it is in contact and which it overlies, the differential heating of land and water surfaces sets up inequalities and variations in the temperature of the atmosphere.

The mean temperature in Seattle, Washington in July is 18° C (64° F), while the mean temperature during the same month in Minneapolis, Minnesota is 21° C (70° F), although the two cities are located at similar latitudes. Much of this difference in temperature can be attributed to the fact that Seattle is near the Pacific Coast, while Minneapolis is in the heart of a large continent and far from the moderating influence of an ocean. Consequently, Seattle stays cooler than Minneapolis in the summer because the surrounding water warms up slowly, keeping the air relatively cool. Minneapolis, on the other hand, is in the center of a large landmass that warms very quickly and in turn warms the layer of air above it. In the winter, the opposite is true. Seattle is warmed by the water while Minneapolis is not. The mean temperature in January is 4.5° C (40° F) at Seattle and -15.5° C (4° F) at Minneapolis.

Not only do water and land heat and cool at different rates, but so do various land surfaces. Soil, forest, grass, and rock surfaces all heat differentially and set up variations in the overlying temperatures of the air, which in turn can affect the other climatic elements.

2. Ocean currents – Surface ocean currents are large movements of water pushed by the winds. They may flow from a place of warm temperatures to one of cooler temperatures or vice versa. These movements result, from the attempt of earth systems to reach a balance, in this instance of temperature and density.

The rotation of the earth affects the movements of both the winds and ocean currents. It causes the currents to move generally in a clockwise direction in the Northern Hemisphere and in a counterclockwise direction in the Southern Hemisphere. The reason for this movement is the Coriolis Effect.

Since the temperature of the ocean greatly affects the temperature of the air above it, an ocean current that moves warm equatorial water toward the poles or cold polar water toward the equator can significantly modify the air temperatures of those locations into which it flows. If the currents pass close to the land and are accompanied by onshore winds, they can have a significant impact upon the coastal climate.

The Gulf Stream, with its extension, the North Atlantic Drift, is an example of an ocean current that moves warm water northward, keeping the coasts of Great Britain and Norway ice-free in wintertime and moderating the climates of nearby land areas. We can see the effects of the Gulf Stream if we compare the winter conditions of the British Isles with those of Labrador in northeastern Canada. Though both are at the same latitude, the climate of the British Isles is moderated by the effects of the Gulf Stream (North Atlantic Drift). For example, the average temperature in Glasgow, Scotland, in January is 4° C (39° F), while during the same month it is -21° C (- 7° F) in Nain, Labrador.

The California Current is a current off the west coast of the United States that helps moderate the climate of the coast as it brings cold water south to relatively warm areas. As the current swings southwest from the coast of central California, cold bottom water is brought to the surface, causing further chilling of the air masses above. San Francisco's cool summers (July average, 14° C or 58° F) reflect the effect of this current.

3. Altitude as a Control – As we have seen, temperatures within the troposphere decrease with increasing altitude. In Southern California, you can find snow for skiing if you go to an altitude of 2400 to 3000 meters (8000 to 10,000 feet). Mount Kenya, 5199 meters (17,085 feet) high and located at the equator, is cold enough to have glaciers. Anyone who has hiked upward 500, 1000, or 1500 meters in midsummer has experienced a decline in temperature with increasing altitude. Even if it is hot on the valley floor, you may need a sweater if you climb a few thousand meters. Quito, Ecuador, only 1° south of the equator, has an average temperature of only 13° C (55° F) because it is located at an altitude of about 2900 meters (9500 feet).

Change in altitude has a direct bearing on another atmospheric element, air pressure, which, like temperature, decreases with increasing altitude. As a result, the air pressure on top of a 4000-meter (13,000 feet) mountain will be less than in the plain fair below, and it will affect many everyday things. Water boils at 85° C (185° F) instead of 100° C (212° F), making it nearly impossible to make a good cup of tea. Automobile carburetors do not work effectively, and people travelling rapidly up or down the mountain have a popping sensation in their ears because of the change in pressure.

4. Landform Barriers – Landform barriers, especially large mountain ranges, can block movements of air from one place to another and thus affect the weather and climate of an area. For example, the Himalayas keep cold, winter, Asiatic air out of India, giving the Indian subcontinent a year-round tropical climate.

If the prevailing winds are from the west, and if they tend to bring rain and moisture with them, then a mountain range that runs north-south will generally have a wet climate on its west-facing, windward slop and a dry one on its east-facing, leeward (sheltered) slope. Although mountain ranges that run north-south, like the Rockies, Cascades, or Sierra Nevada in North America, block the movement of moisture carrying air from the western oceans to the interior of the continent, thus helping create and maintain desert areas on their eastern sides, they do little to block the movement of cold polar air toward the equator. Therefore, because they are not protected by an east-west mountain range to the north, areas in the southern United States can be subjected to unusual cold spells from the invasion of polar air.

5. Human Activities – Human beings, too, may be considered 'controls' of weather and climate. Such activities as building cities, burning fossil fuels, large-scale destruction of forests, draining swamps, or creating large reservoirs can significantly affect local climatic patterns and possibly world climatic patterns as well. In addition, people have tried to modify weather almost since the beginning of time. Though we have had only slight success, our potential for influencing weather and climate is considerable.

6. Latitude – Latitude is the most important control of weather and climate. Earlier we noted that insolation is considered the most important element, since it influences all the other elements. A location's latitude is the primary factor controlling the amount of insolation the location will receive on a daily, seasonal, and annual basis. Recall that the earth's axis is inclined from the plane of the ecliptic and remains parallel to itself as the earth revolves around the sun. These factors cause a constant, but systematic, variation in the amount of insolation received at a location on the earth's surface. In general, the more poleward a location, the greater the variation in insolation from season to season and the lower the total annual insolation received. Because solar radiation is a prime factor in an explanation of air temperature, we would expect to see lower mean (average) annual temperatures as we move poleward from the equator. This poleward decrease in temperature is true for these locations, all of which are within a hundred meters or so of sea level. The exception is near the equator itself. Due to the heavy cloud cover in the equatorial regions, average annual temperatures there tend to be lower than at places slightly to the north or south, where skies are clearer.

Another very simple way to see this general trend of decreasing temperatures as we move toward the poles is to think what clothes we would take along for one month, say January, if we were to visit Ciudad Bolivar, Venezuela; Raleigh, North Carolina; or Point Barrow, Alaska.

THE SEASONS

As we have just noted, latitudinal changes in solar radiation are a direct result of the inclination of the earth's polar axis as the earth annually orbits the sun and are the primary cause of our seasons. About June 22, the earth is in a position in its orbit so that the northern tip of its axis is inclined toward the sun at an angle of 23 ½ ° from a line perpendicular to the place of the ecliptic. This is called the summer **solstice** (from Latin: *sol*, sun; *sistere*, to stand) in the Northern Hemisphere. The Northern and Southern Hemispheres receive unequal amounts of light from the sun. That is, as we imagine rotating the earth under these conditions, a larger portion of the Northern Hemisphere than the Southern Hemisphere remains in daylight. Conversely, a larger portion of the Southern Hemisphere than the Northern Hemisphere remains in darkness.

A person living at Repulse Bay, Canada, north of the Arctic Circle, has a full 24 hours of daylight at the June solstice and can go hunting at 1:00 A.M. We can also see that someone living in New York City will experience a longer period of daylight than of darkness. And someone living in Buenos Aires, Argentina, will have a longer period of darkness on that day. This day is called the winter solstice in the Southern Hemisphere.

Now let us imagine the movement of the earth from its position at the June solstice toward a position a quarter of a year later in September. As the earth moves toward that new position, we can imagine the changes that will be taking place in our three cities. First, in Repulse Bay, from no darkness at all on the June solstice there will be an increasing amount of darkness through July, August and September. In New York, sunset will be getting earlier, although it will still be light enough to play softball after dinner. And in Buenos Aires, the situation will be reversed. As the earth moves toward its position in September, we can see that the periods of daylight in the Southern Hemisphere will begin to get longer, the nights shorter.

Finally, on or about September 23, the earth will reach a position known as an **equinox** (Latin: *aequus*, equal; *nox*, night). On this date, day and night will be of equal lengths at all locations on the earth. Thus, on the equinox conditions are identical for both hemispheres.

Imagine again the revolution and rotation of the earth while moving from September 23 toward a new position another quarter of a year later in December. We can see that in Repulse bay, the nights will be getting longer and longer until on the winter solstice, which occurs on or about December 22, this northern town will experience 24 hours of darkness. The only natural light at all in Repulse Bay will be a faint glow at noon refracted from the sun below the horizon. And in New York, too, the days will get shorter and the sun will set earlier, until by the time you do your Christmas shopping, it is dark at 5:30 before the stores close. Again, we can see that in Buenos Aires, the situation is reversed, and on December 22, that city will experience its summer solstice and conditions will be much as they were in New York City in June. It may be a sweltering day in Buenos Aires, and everyone will go to the beach for the Christmas holidays.

Moving from late December through another quarter of a year to late March, Repulse Bay will have longer and longer periods of daylight, as will New York, while in Buenos Aires, the nights will be getting longer, though they still will not be as long as the days. Then on or about March 21, the earth will again be in equinox position similar to the one in September. Again, days and nights will be equal all over the earth. In other words, it will be 12 hours from sunrise to sunset and from sunset to sunrise. Finally, moving through another quarter of the year toward the June solstice where we began, Repulse Bay and New York City are both experiencing longer periods of daylight than of darkness, and the sun is setting earlier and earlier in Buenos Aires, until on or about June 22, Repulse Bay and New York City will have their longest day of the year, Buenos Aires its shortest. Further, we can see that on June 22, a point on the Antarctic Circle in the Southern Hemisphere will experience a winter solstice similar to that which Repulse Bay had on December 22, with no daylight in 24 hours except what will appear at noon as a glow of twilight in the sky.

Lines related to Earth revolution

Looking at the diagrams of the earth in its various positions as it revolves around the sun, we can see that the angle of inclination is important. For, on June 22, because the earth's axis is tilted 23½° toward the sun with respect to a line drawn perpendicular to the plane of the ecliptic, the sun's rays can reach that far (23½°) beyond the North Pole. The **Arctic Circle**, an imaginary line drawn around the earth 23½° from the North Pole (or 66½ °north of the equator), marks this limit. We can see from the diagram that all points on or north of the Arctic Circle will experience no darkness on the June solstice, and, further, that all points south of the Arctic Circle will have some darkness on that day. The **Antarctic Circle** in the Southern Hemisphere (23½° north of the South Pole, or 66½ ° south of the equator), marks a similar limit.

Furthermore, it can be seen from the diagrams that the sun's **vertical**, or **direct rays** (rays that strike the earth's surface at right angles) also shift position in relation to the poles and the equator as the earth revolves around the sun. At the time of the June solstice, the sun's rays are vertical, or directly overhead, at noon at all points located 23½° north of the equator. This imaginary line around the earth marks the northernmost position at which the solar rays will ever be directly overhead during a full revolution of our plant around the sun. The imaginary line marking this limit is called the **Tropic of Cancer**. Six months later, at the time of the December solstice, the solar rays are vertical and the noon sun is directly overhead at all points 23½° *south* of the equator. The imaginary line marking this limit is known as the **Tropic of Capricorn**. At the times of the March and September equinoxes, the vertical solar rays will strike directly only at the equator, and the noon sun is directly overhead at all points on that line.

Note also that on any day of the year the sun's rays will strike the earth at a 90° angle at only one position either on or between the two tropics. All other position that day will receive the sun's rays at an angle of less than 90° (or will receive no sunlight).

Insolation and the Seasons

Solar radiation received by the earth system is known as **insolation** (for *incoming solar radiation*), and it is the main source of energy on our planet. The seasonal variations in temperature that we experience are due primarily to fluctuations in insolation.

What causes these variations in insolation and thus in the seasons? One logical answer might be that the radiation given off by the sun fluctuates greatly and on a regular basis throughout the year. But it would be improbably for such cycles to correspond exactly to the time that it takes for the earth to revolve around the sun. Also, any fluctuations in solar radiation are not very large. We must thus look elsewhere for the causes of changes in amounts of insolation.

It is true that the earth's atmosphere affects the amount of insolation received. Heavy cloud cover, for instance, will keep more solar radiation from reaching the earth's surface than will a clear blue sky. However, cloud cover is irregular and unpredictable, and it affects total insolation to only a minor degree over long periods of time.

Two major phenomena vary regularly for a given position on the earth as our planet rotates on its axis and revolves around the sun: the duration of daylight and the angle of solar rays. The amount of daylight controls the duration of solar radiation, and the angle of the sun's rays directly affects the intensity of solar radiation received. Together, the intensity and the duration of radiation are the major factors that affect the amount of insolation.

This situation is like an oven in which a roast is being cooked. The roast will cook faster and get browner if (1) the temperature is turned up and/or (2) someone leaves the oven on longer than usual. Likewise, a spot on the earth will receive more insolation if (1) the sun shines more directly, or (2) the sun shines longer, or (3) both. One reason that places along the Tropics of Cancer and Capricorn are so hot during their summer solstice is that the sun's rays are intense and the day is long (there are many hours of daylight).

The intensity of solar radiation received at any one time varies from place to place because the earth presents a spherical surface to insolation. Therefore, only a portion of the earth's surface can receive radiation at right angles. Solar energy that strikes the earth at a vertical angle covers less area than an equal amount striking the earth at an oblique angle. The closer to a right angle that the sun's rays strike the earth, the smaller will be the area covered. Since the amount of energy is the same no matter what kind of angle the rays make with the surface, it follows that the smaller the area that is struck, the greater will be the intensity per unit area. Conversely, the more oblique the angle at which the sun's rays strike the earth, the greater the area over which those rays will be spread, and so less energy will strike the earth per unit area. In addition, the atmosphere limits to some extent the amount of insolation that reaches the earth's surface, and oblique rays must pass through a greater thickness of atmosphere than vertical rays.

The duration of solar energy is related to the length of daylight received at a particular point on the earth, since no insolation is received at night. Obviously, the longer the period of daylight, the greater the amount of solar radiation that will be received at that location. And, as we have seen, periods of daylight vary in length through the seasons of the year as well as from place to place on the earth's surface.

Variations of Insolation with Latitude

Neglecting for the moment the influence of the atmosphere on variations in insolation during a 24-hour period, a place will receive its greatest insolation at solar noon when the sun has reached its zenith or highest point in the sky for that day. At any location, no insolation will be received during the hours of darkness. The amount of energy received after daybreak increases as the earth rotates until the time of solar noon. The amount of insolation then decreases until the next period of darkness begins.

We also know that the amount of daily insolation received at any one location on the earth varies with the seasons. There are three distinct patterns in the distribution of the seasonal receipt of solar energy in each hemisphere. These patterns serve as the basis for recognizing six latitudinal zones, or bands, of insolation and temperature that circle the earth.

If we look first at the Northern Hemisphere, we may take the Tropic of Cancer and the Arctic Circle as the dividing lines for three of these distinctive zones. The area between the equator and the Tropic of Cancer can be called the north **tropical zone**. Here, insolation is always high but is greatest at the two times during the year that the sun is directly overheat at noon. These dates vary according to latitude. The north **midlatitude zones** is the wide band between the Tropic of Cancer and the Arctic Circle. In this belt, insolation is greatest on the June solstice, when the sun reaches its highest noon altitude and the period of daylight is long and it is least when the sun is low in the sky and the period of daylight is short at the December solstice. The north **polar zone**, or **Arctic zone**, extends from the Arctic Circle to the pole. In this region, as in the midlatitude zone, insolation is greatest at the June solstice, but it ceases during the period that the sun's rays are blocked entirely by the tilt of the earth's axis. This period lasts for 6 months at the North Pole, but it is as short as 1 day directly on the Arctic Circle.

Similarly, there are the south tropical zone, the south midlatitude zone, and the south polar or **Antarctic zone**, separated by the Tropic of Capricorn and the Antarctic Circle in the southern Hemisphere. These areas get their greatest amounts of insolation at opposite times of the year from the northern zones.

Despite various patterns in the amount of insolation received in these zones, there are generalizations that we can make. For example, total annual insolation at the top of the atmosphere at a particular latitude remains constant from year to year. Furthermore, annual insolation tends to decrease from lower latitudes to higher latitudes. And the closer to the poles a place is located, the greatest will be its seasonal variations caused by fluctuations in insolation.

The amount of insolation received by the earth is an important concept in understanding atmospheric dynamics and the distribution of climate and vegetation. Such climatic elements as temperature, precipitation, and winds are controlled in part by the amount of insolation received by the earth. People depend on certain levels of insolation for physical comfort, and plant life is especially sensitive to the amount of available insolation. You may have noticed plants that have wilted in too much sunlight or that have grown brown in a dark corner away from a window. Over a longer period of time, deciduous plants have an annual cycle of budding, flowering, leaving, and losing their leaves. This cycle is apparently determined by the fluctuations of increasing and decreasing solar radiation that mark the changing seasons. Even animals respond to seasonal changes; some animals hibernate, while many North American birds fly south toward warmer weather as winter approaches, and many animals breed at such a time that their offspring will be born in the spring, when warm weather is approaching.

SOLAR ENERGY AND ATMOSPHERIC DYNAMICS

Like all the other stars in the universe, the sun is a self-luminous mass of gases that emit radiant energy. A slightly less than average-sized star, our sun is the major source of energy, either directly or indirectly, for the entire earth system. The earth does receive very small proportions of energy from other stars and from the interior of the earth itself (volcanoes and geysers provide certain amounts of heat energy). However, when compared with the amount received from the sun, these other sources are insignificant.

Energy from the Sun

The energy emitted by the sun comes from nuclear reactions that take place in its interior. There, under high pressure, hydrogen is changed into helium through nuclear fusion in a process similar to that in a hydrogen bomb. This nuclear reaction releases tremendous amounts of energy that radiate out from the sun in all directions at the speed of light.

Energy emitted by the sun is in the form of **electromagnetic energy**, which travels in a spectrum of waves of varying lengths. It takes slightly more than 8 minutes for these waves to reach the earth. About 41 percent of this spectrum of waves is in the form of visible light rays, but much of the sun's energy cannot be seen by the human eye. About half of the sun's radiant energy is in waves that are longer than visible light rays, and these include some **infrared waves**. While these cannot be seen, they can sometimes be sensed by the human skin. The remaining 9 percent of solar energy is made up of X-rays, gamma rays, and **ultraviolet rays**, all of which are shorter in length than those of visible light. These also cannot be seen but can affect other tissues of the human body (thus the danger in absorbing too many X-rays). Collectively, visible light, ultraviolet rays, X-rays, and gamma rays are known as **short waves**.

We have learned to harness some of these energy waves for communications (radio, microwave transmission, television), health (X-rays), and use in the field of remote sensing (photography, radar, infrared imagery).

Energy is radiated into space by the sun at a steady rate. The earth's atmosphere intercepts an amount of energy equivalent to 1.97 calories per square centimeter per minute. A **calorie** is the amount of *energy* required to raise the temperature of 1 gram of water 1° C. This can also be expressed in units of power, in which case it would be 1367 watts per square meter. The rate of emission is known as the **solar constant** and has been measured with great precision outside the earth's atmosphere by orbiting satellites. The atmosphere affects the amount of solar radiation received on the surface of the earth because some energy is absorbed by clouds, some is reflected, and some is refracted. If we could remove the atmosphere from the earth, we would find that the solar energy striking the surface at a particular location for a particular time would be a constant value determined by the latitude of the location.

Of course, the measured value of the solar constant varies with distance from the sun as the same amount of energy radiates out into larger and larger areas. Because of this, if we measured the solar constant for the planet Mercury, it would be much higher than that for the earth. When the earth is closest in its orbit to the sun, its solar constant is slightly higher than the yearly average, and when it is farthest away, the solar constant is slightly lower than average. However, this difference does not have a significant effect on the earth's temperatures. When the earth is at aphelion in July and the solar constant is lowest because of the distance from the sun, the Northern Hemisphere is in the midst of a summer with temperatures that are not significantly different from those in the Southern Hemisphere 6 months later. The solar constant also varies slightly with changes in activity on the sun (during intense sunspot or sunstorm activity, for example, the solar constant will be slightly higher than usual). However, these variations are not even as great as those caused by the earth's elliptical orbit.

The Role of Water

As it penetrates our atmosphere, some of the incoming solar radiation is involved in energy exchanges, as water in our earth system is altered from one state to another. Water is the only material that can exist in all three states of matter – as a solid, as a liquid and as a gas – within the normal temperature range of the earth's surface. In the atmosphere, water exists as a clear, odorless gas called **water vapor**. It is a liquid in the atmosphere, in the oceans and other water bodies of the earth, in vegetation and animals, and underground. Water is found as solid snow and ice in the atmosphere as well as on and under the surface of the colder parts of the earth.

Not only is water stored in all three states of matter, but it can change from one state to another. In doing so, it is involved in the heat energy exchange of the earth system. The molecules of a gas move faster than do those of a liquid. Thus, during the process of **condensation** when water vapour changes to water, its molecules must slow down and some of their energy is released (590 calories per gram). The molecules of a solid move even more slowly than those of a liquid, so during the process of **freezing**, when water changes to ice, additional energy is released (80 calories per gram). When the process is reversed, heat must be added. Thus, **melting** requires the addition of 80 calories per gram, and evaporation requires the addition of 590 calories per gram. This added energy is stored as **latent** (or hidden) **heat**.

Some of these energy exchanges can be easily demonstrated. For example, if you hold an ice cube in your hand, your hand feels cold because it is giving off the heat needed to melt the ice. We are cooled by perspiration evaporating from our skin, since heat must be absorbed both from our skin and from the remaining perspiration, thereby lowering the temperature of both.

Scientists have become increasingly aware of the importance of the energy exchange because the atmosphere and the hydrosphere, especially at the ocean's surface. Three fourths of the earth's surface is covered by water. Because water heats up more slowly than land, it retains its heat longer. Thus, the oceans act as huge reservoirs of heat energy to power the atmosphere, which directly influences our weather and climate on land.

Effects of the Atmosphere on Solar Radiation

In addition to its involvement in these latent energy exchanges, the sun's energy, as it passes through the earth's atmosphere, loses over half its intensity through various processes. In fact, the amount of insolation actually received at a particular location depends not only on the latitude, the time of day, and the time of year (all of which are related to the angle at which the sun's rays strike the earth), but also on the transparency of the atmosphere (or the amount of cloud cover, moisture, carbon dioxide, and solid particles in the air).

When the sun's energy passes through the atmosphere, several things happen to it. The following figures represent approximate averages for the entire earth: at any location or time they may differ. (1) Twenty-six percent is directly *reflected* back to space by clouds and the ground; (2) 8 percent is *scattered* by minute atmospheric particles and returned to space as diffuse radiation; (3) 20 percent reaches the earth's surface as diffuse radiation after being scattered; (4) 27 percent reaches the earth's surface as direct radiation; and (5) 19 percent is *absorbed* by the ozone layer and by water vapour in the clouds of the atmosphere. In other words, on a worldwide average, 47 percent of the incoming solar radiation eventually reaches the surface, 19 percent is retained in the atmosphere, and 34 percent is returned to space. Since the earth's energy budget is in equilibrium, the 47 percent received at the surface is ultimately returned to the atmosphere by processes that we will examine.

HEATING OF THE ATMOSPHERE

Since the 19 percent of direct solar radiation that is retained by the atmosphere is 'locked up' in the clouds and the ozone layer and is thus not available to heat the troposphere, some other source must be found to explain the creation of atmospheric warmth. The explanation lies in the 47 percent of incoming solar energy reaching the earth's surface (i.e. both land and bodies of water) and in the transfer of heat energy from the earth back to the atmosphere through such physical processes as (1) radiation, (2) condensation, (3) convection (along with the related phenomena, advection), and (4) the latent heat of condensation.

Methods of Heat Energy Transfer

1. Radiation – The process by which electromagnet energy is transferred from the sun to the earth is called **radiation**. We should be aware, however, that all objects emit radiation energy.

The characteristics of that radiation depend on the temperature of the radiating body. In general we can state that the warmer the object, the more energy it will emit and that the warmer the object, the shorter the wavelength of peak emission. Since the sun's absolute temperature is 20 times that of the earth's, we can predict that the sun will emit more energy, and at shorter wavelengths, than the earth. This is borne out by the facts: The solar energy output per square meter is approximately 160,000 times that of the earth! Further, the majority of solar energy is emitted at wavelengths shorter than 4.0 microns whereas most of the earth's energy is radiated at wavelengths longer than 4.0 microns. Thus, short-wave radiation from the sun reaches the earth and heats its surface, which, being cooler than the sun, gives off energy in the form of long waves. These are then radiated back to the atmosphere. It is this **long-wave radiation** from the earth's surface that heats the lower layers of the atmosphere.

2. Conduction – The means by which heat is transferred from one part of a body to another or between two touching objects is called **conduction**. Heat flows from the warmer to the cooler (part of a) body in order to equalize temperature. Conduction actually occurs as heat is passed from one molecule to another in chainlike fashion. It is conduction that makes the bottom of your soup bowl too hot to carry. Conduction also occurs when a spoon left in your coffee gets hot.

Atmospheric conduction occurs at the interface of (zone of contract between) the atmosphere and the earth's surface. However, it is actually a minor method of heat transfer in terms of warming the atmosphere because it affects only the layers of air closest to the earth' surface. This is because air is a very poor conductor of heat (unlike certain metals). In fact, air is just the opposite of a good conductor; it is a good insulator. This property of air is why a layer of air is sometimes put between two panes of glass to help keep heat inside. The same principle is used in a thermos bottle. The air sandwiched between layers of glass keeps the contents warm or cold, as the case may be. Air is also used as a layer of insulation in sleeping bags and ski parkas. In fact, if air were a good conductor of heat, our kitchens would become unbearable every time we turned on the stove or oven.

3. Convection – In the atmosphere, as pockets of air near the surface are heated, they expand in volume, become less dense than the surrounding air, and therefore rise. This vertical transfer of heat through the atmosphere is called **convection**, and it is the same type of process by which heated water circulates in a pan on the stove. The water in the center near the bottom is heated first, becoming lighter and less dense as it is heated. As this water tends to rise, colder, denser water flows down to replace it. As this new water is warmed, it too flows up, while additional colder water moves downward.

The currents set into motion by the heating of a fluid (liquid or gas) make up a convectional system. Such systems account for much of the vertical transfer of heat within the atmosphere and the oceans and are a major cause of clouds and precipitation.

Advection – **Advection** is the term applied to horizontal heat transfer within the atmosphere. Wind is the transfer agent of advection. Wind brings about the horizontal movement of large portions of the lower atmosphere. This advection transports warmer or colder air to new locations and accounts for a major proportion of the lateral heat transfer that takes place within the atmospheric system.

4. Latent Heat of Condensation – As we have seen, when water evaporates a significant amount of energy is stored in the water vapour as latent or potential heat. This water vapour is then transported by advection or convection to new locations, where condensation takes place and the stored energy is released. This process plays a major role in the transfer of energy within the earth system: The heat required for evaporation helps cool the atmosphere while the **latent heat of condensation** helps warm the atmosphere and, in addition, is a source of energy for storms.

The Heat Energy Budget

Budget at the Earth's surface – Now that we know the various means of heat transfer, we are in a position to examine what happens to the 47 percent of solar energy that reaches the earth's surface. Approximately 14 percent of this energy is returned in the form of long-wave radiation. This 14 percent includes a net loss of 6 percent (of the total originally received by the atmosphere) directly to outer space and 8 percent to the atmosphere. In addition, there is a net transfer back to the atmosphere by conduction and convection of 10 of the 47 percent that reached the earth. The remaining 23 percent returns to the atmosphere through the release of latent heat of condensation. Thus, the 47 percent of the sun's original insolation that reached the earth's surface is all returned to other segments of the system. There has been no long-term gain or loss. Therefore, at the earth's surface the heat energy budget is in balance.

Examination of the heat energy budget of the earth's surface helps us to understand the *open energy system* that is involved in the heating of the atmosphere. The *input* in the system is that of the incoming short-wave solar radiation that reaches the earth's surface, and this is balanced by the *output* of long-wave terrestrial radiation back to the atmosphere and to space. Since these are in balance, we may say that the overall temperature of the earth's surface is in a state of *dynamic equilibrium*.

Of course it should be noted that the percentages mentioned earlier represent an oversimplification in that they represent net losses that occur over a long period of time. In the shorter term, heat may be passed from the earth to the atmosphere and then back to the earth in a chain of cycles before it is finally released into space. In fact, it is the transfer of heat and energy back and forth between earth and atmosphere that produces usually high atmospheric temperatures over short periods.

We are all familiar with what happens to the inside of a car on a sunny day if all the windows are left closed. Short-wave radiation from the sun is able to penetrate the glass windows. When the insolation strikes the interior of the car and heats up the exposed surfaces, energy, emitted from them as long-wave radiation, cannot escape through the glass as freely. The result is that the interior of the vehicle gets hotter and hotter throughout the day. In extreme cases, windows in some cars have cracked due to differential expansion, or, what is more serious, temperatures have become so great in automobiles that pets or babies inside that were unable to open a door or window have died.

A similar phenomenon also occurs in the atmosphere. Like glass, carbon dioxide, water vapour, and dust can block the escape of long-wave radiation by absorbing it and then radiating it back to the earth. This is termed the **atmospheric effect** and is the primary reason for the moderate temperatures observed on earth.

Budget in the Atmosphere – At one time or another, about 60 percent of the solar energy intercepted by the earth system is temporarily retained by the atmosphere. This includes 19 percent of *direct solar radiation* absorbed by the clouds and the ozone layer, 8 percent that is emitted by *long-wave radiation* from the earth's surface, 10 percent that is transferred from the surface by *conduction* and *convection*, and 23 percent released by the *latent heat of condensation*. As in the atmospheric effect, some of this energy is recycled back to the surface for short periods of time, but eventually all of it is lost into outer space after being replaced by other solar energy. Hence, just as was the case at the earth's surface, the heat energy budget in the atmosphere is in balance over long periods of time – a dynamically stable system.

Many scientists believe that an imbalance with possible negative effects is developing. Since the Industrial Revolution, human beings have been adding more and more carbon dioxide to the atmosphere through their burning of fossil (carbon) fuels. Since carbon dioxide absorbs the long-wave radiation from the earth's surface, restricting its escape to space, heat retention could increase in the earth's atmosphere, thus increasing the atmospheric effect. Such rising temperatures would have significant effects on other earth features such as the extent of polar ice caps and world sea level.

Variations in the Heat Energy Budget

Remember that the figures for heat energy budget that we have seen are averages for the whole earth over many years. For any particular location, the heat energy budget is most likely not balanced. Some places have a surplus of incoming solar energy over outgoing energy loss in their budget, while others have a deficit. The main causes of these variations (a) differences in latitude and (2) seasonal fluctuation.

As we have previously noted, the amount of insolation received is directly related to latitude. In the tropical zones where insolation is high throughout the year, more solar energy is received at the earth's surface and in the atmosphere than can be emitted back into space. In the Arctic and Antarctic zones, on the other hand, there is so little insolation during the winter, when the earth is still emitting long-wave radiation, that there is a large deficit for the year. Places in the midlatitude zones have lower deficits or surpluses, but only at about latitude 38° is the budget balanced. If it were not for the heat transfers within the atmosphere and the oceans, the tropical zones would get hotter and hotter, and the polar zones would get colder and colder.

At any location, the heat energy budget varies throughout the year according to the seasons, with a tendency toward a surplus in the summer, or high-sun season, and a tendency toward a deficit 6 months later. Seasonal differences may be small near the equator, but they are great in the midlatitude and polar zones.

AIR TEMPERATURE

Temperature and Heat

The amount of heat in an object or system is related to the energy within it. Some heat energy can be measured, but some cannot. **Temperature** is the measurement of available or sensible heat energy in a system. Your body has stored within it a lot of heat energy, much in the form of fats, yet this energy is not reflected in body temperature. Body temperature is an indication of the level of energy that is being used to support body functions and therefore is in a measureable form.

In the same way, the temperature of the earth system does not account for all the heat within the system, such as that stored as latent heat energy in green plants after the process of photosynthesis or in water vapour that has resulted from evaporation. Temperature does, however, record the decrease in available energy when, for example, heat has been used to evaporate water from a bowl, a lake, or the ocean. Therefore, since temperature can be used to measure changes in heat energy level, it is a useful indicator of changes in the heat energy budget of a system.

Scales

Three different scales are used in measuring temperature. The one with which Americans are most familiar is the **Fahrenheit** scale, devised in 1714 and included in the English system of measurements. By this scale, the temperature at which water boils at sea level is 212° F, while the temperature at which water freezes is 32° F.

The **Celsius** scale (also called the **centigrade** scale) was devised in 1742 by Anders Celsius, a Swedish astronomer. It is part of the metric system. The temperature at which water freezes at sea level by this scale was arbitrarily set at 0° C, while the temperature at which water boils was identified as 100° C.

The Celsius scale is used nearly everywhere except in the United States. Even in the United States, the Celsius scale is the one used by the majority of the scientific community. By this time, you have undoubtedly noted that comparable figures in both the Celsius (centigrade) and Fahrenheit scales are given side by side for all important temperatures. Similarly, whenever important figures for distance, area, weight, or speed are given, we use the metric system followed by the English system. Our interest in the Celsius and metric systems is more than just an educational exercise. The United States is slowly moving toward an acceptance of both in an attempt to increase uniformity of statistical information throughout the world. The following formulas can be used for conversion from Fahrenheit to Celsius or vice versa:

$$C = 5/9\ (F-32) \qquad \text{or} \qquad F = 9/C + 32$$

The third temperature scale, used primarily by scientists, is the **Kelvin** scale. It is based upon the fact that the temperature of a gas is related to the molecular movement within the gas. As the temperature of a gas is reduced, the molecular motion within the gas is reduced. There is a temperature at which all molecular motion stops and no further cooling is possible. This temperature is approximately -273° C and is termed absolute zero. The Kelvin scale uses absolute zero as its starting point. Thus 0 K equals – 273° C. conversion of Celsius to Kelvin is expressed by the following formula:

$$K = C + 273$$

Short-Term Variations in Temperature

Local changes in atmospheric temperature can have a number of causes. These are related to the mechanics of the receipt and dissipation of energy from the sun and to various properties of the earth's surface and the atmosphere.

The Daily Effects of Insolation – As we noted earlier, at any particular location, the amount of insolation varies both throughout the year (annually) and throughout the day (diurnally). Annual fluctuations are associated with the sun's changing declination, and hence with the seasons. Diurnal changes are related to the rotation of the earth about its axis. Each day insolation receipt begins at sunrise, reaches its maximum at noon (local solar time), and returns to zero at sunset.

Although insolation is greatest at noon, you may have noticed that temperatures usually do not reach their maximum until two or three o'clock in the afternoon. This is because, from shortly after sunrise until the afternoon hours, the insolation received by the earth exceeds the energy being lost through earth radiation. Hence, during that period, as the earth and atmosphere continue to gain energy, temperatures normally show a gradual increase. Sometime around three o'clock, when outgoing earth radiation begins to exceed insolation, temperatures start to fall. The daily lag of earth radiation and temperature behind insolation is accounted for by the time it takes for the earth's surface to be heated to its maximum and for this energy to be radiated to the atmosphere.

Insolation receipt ends with sunset, but on into the night energy that has been stored in the earth's surface layer during the day continues to be lost and there is a decreasing ability to heat the atmosphere. The lowest temperature occur just after dawn, when the maximum amount of energy has been emitted and before replenishment from the sun can occur. Thus, if we disregard other factors for the moment, we can see that there is a predictable hourly change in temperature called the **daily march of temperature**. There is a gentle decline from mid-afternoon until dawn, but temperature increases rapidly in the 8 hours or so from dawn until the next maximum is reached.

Cloud Cover – The extent of cloud cover is another factor that affects the temperature of the earth's surface and the atmosphere. Weather satellites have shown that any time about 50 percent of the earth is covered by clouds. This cover is important because a heavy cloud cover can reduce the amount of insolation a place receives, thereby causing daytime temperatures to be lower than if the sky were clear. On the other hand, we have already noted the atmospheric effect, in which clouds, which are composed in large part of water droplets, are capable of absorbing heat energy radiating from the earth, thereby keeping temperatures near the earth's surface warmer than they would otherwise be, especially at night. The general effect of cloud cover, then, is to moderate temperature by lowering the potential maximum and raising the potential minimum temperatures.

Differential Heating of Land and Water – Earlier we saw that bodies of water heat and cool more slowly than the land. The air above the earth's surface is heated or cooled in part by what is beneath it. Therefore, temperatures over bodies of water or on land subjected to ocean winds tend to be more moderate than those of land bound places at the same latitude. Thus, the greater the **continentality** of a location (the distance removed from a large body of water), the less its temperature pattern will be modified.

Reflection – The capacity of a surface to reflect the sun's energy is called its **albedo**. The more solar energy reflected back into space by an earth surface, the less will be available for heating the atmosphere. Temperature will be higher at a given location if its surface has a low albedo rather than a high albedo.

As you may know from experience, snow and ice are good reflectors: They have an albedo of 90 to 95 percent. This is one reason why glaciers on high mountains do not melt away in the summer or why there may still be snow on the ground on a warm day in the spring: Solar energy is reflected away. A forest, on the other hand, has an albedo of only 10 to 12 percent, which is good for the trees because they need solar energy for photosynthesis. The albedo of cloud cover varies according to the thickness of the clouds, and it can vary from 40 percent to 80 percent. The high albedo of many clouds is why much solar radiation is reflected directly back into space by the atmosphere. Cities have an albedo of only about 10 percent. This is one reason why hot summer days can be so miserable in the city, yet the surrounding countryside may be several degrees cooler. The albedo of water varies greatly, depending on the depth of the water body and the angle of the sun's rays. If the angle of the sun's rays is high, smooth water will reflect little: In fact, if the sun is vertical over a calm ocean, the albedo will be about 2 percent. Yet a low-angle sun, such as just before sunset, causes an albedo over 90 percent from the same ocean surface. Likewise, a snow surface in winter, when solar angles are lower, can reflect upto 95 percent of the energy striking it, and skiers must constantly be aware of the danger of severe burns from reflected solar radiation.

Horizontal Air Movement – We have already seen the advection is the major mode of horizontal transfer of heat and energy over the earth's surface. Any movement of air due to the wind, whether on a large or small scale, can have a significant short-term effect on the temperatures of a given location. Thus, wind blowing from an ocean to land will generally bring cooler temperatures in summer and warmer temperatures in winter. Large quantities of air moving from polar regions into the midlatitudes can cause sharp drops in temperature, while air moving poleward will usually bring warmer temperatures.

Vertical Distribution of Temperature

Normal Lapse Rates – We have learned that the earth's atmosphere is primarily heated from the ground up as a result of long-wave terrestrial radiation, conduction, and convection. Thus, temperatures in the troposphere are usually highest at ground level and decrease with increasing altitude. For every 1000 meters of altitude, the temperature decreases an average of 6° C (3.6° F/1000 feet). This rate, in the free air, is known as the **normal** or **environmental lapse rate**.

The lapse rate at a particular place can vary for a variety of reasons. Low lapse rates can exist if denser and colder air is drained into a valley from a higher elevation or if advectional winds bring air in from a cooler region at the same altitude. In each case, the surface is cooled so that its temperature is closer to that at higher elevations directly above it. On the other hand, if the surface is heated strongly by the sun's rays on a hot summer afternoon, the air near the earth will be disproportionately warm, and the lapse rate will be steep. Fluctuations in lapse rates due to abnormal temperature conditions at various altitudes can play an important role in the weather a place may have on a given day.

Inversions – Under certain circumstances, the normal observed *decrease* of temperature with increased altitude may be reversed; temperature may actually *increase* for several hundred meters. This is called a **temperature inversion**.

Some inversions take place 1000 or 2000 meters above the surface of the earth where a layer of warmer air interrupts the normal decrease in temperature with altitude. Such inversions tend to stabilize the air, causing less turbulence and discouraging both precipitation and the development of storms. Above-surface inversions may occur when air settles slowly from the upper atmosphere. Such air is compressed as it sinks and rises in temperature, becoming more stable and less buoyant. Inversions caused by descending air are common at about 30° to 35° N and S latitudes.

The most noticeable temperature inversions are those that occur near the surface when the earth cools off the lowest layer of air through conduction and radiation. In this situation, the coldest air is nearest the surface and the temperature rises with altitude. Inversions near the surface most often occur on clear nights in midlatitudes and are encouraged by snow cover and the recent advection of cool, dry air into an area. Such conditions produce extremely rapid cooling of the earth's surface at night as it loses the day's insolation through radiation. Then the layers of the atmosphere that are closest to the earth are cooled by radiation and conduction more than those at higher altitudes. Calm air conditions near the surface both help produce and partially result from these temperature inversions.

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Another type of surface inversion is common in the coastal area of California. Cool marine air blowing in from the Pacific Ocean moves under stable, warmer, and lighter air aloft created by subsidence and compression. Such an inversion layer tends to maintain itself. That is, the cold, underlying air is heavier and cannot rise through the warmer air above. Not only does the cold air resist rising or moving, but pollutants, such as smoke, dust particles, and automobile exhaust, which are created at the earth's surface, also fail to rise and spread out. They therefore accumulate, filling the lower atmosphere with pollutants. This situation is particularly acute in the Los Angeles area, which is a basin surrounded by higher mountainous areas. Cooler air blows into the basin from the ocean and then cannot escape either horizontally, because of the landform barriers, or vertically, because of the inversion.

Surface Inversions and Frost – Frost often occurs as the result of a surface inversion. Especially where the earth's surface is hilly, dense cold surface air will tend to flow down the sides of the hills and accumulate in the lower valleys. This air drainage causes colder air to build up in the valleys. Temperatures will decrease there, sometimes resulting in a killing frost, while temperatures on the hillsides remain above freezing.

Farmers use a variety of methods to prevent such frosts from destroying their crops. For example, fruit trees in California that can be destroyed by a frost during the growing season are often planted on the warmer hillsides instead of in the valleys. Farmers may also put blankets of straw, cloth, or some other poor conductor over their plants. These take the place of the missing water vapor in the clear atmosphere, preventing the escape of the earth's radiation to outer space and thereby keeping the plants warmer.

Fans are sometimes used to stir up the air in an effort to mix the layers and disturb the inversion. Another device used to prevent frost is huge orchard heaters that heat the air, disturbing the temperature layers. Smudge pots, an older method of preventing frost, have declined in favour because they are major air polluters. The smoke they pour into the air provides an insulation blanket much like the straw or blankets just mentioned, preventing the escape of terrestrial radiation.

Temperature Distribution at the earth's Surface

Isotherms (from Greek: *isos*, equal; *therm*, heat) are defined as lines that connect places of equal temperature. When constructing isothermal maps showing temperature distribution over the earth's surface, elevation has to be accounted for by reducing temperature readings to sea level. This adjustment means adding 6° C for every 1000 meters of elevation (the normal lapse rate). The rate of temperature change on an isothermal map is called the **temperature gradient**. Closely spaced isotherms indicate a steep temperature gradient (or rapid temperature change over distance), and widely spaced lines indicate a weak one (or slight temperature change over distance).

A more detailed study of the figures and a comparison between the two maps reveal some additional important features. The highest temperatures in January are in the Southern Hemisphere; in July they are in the Northern Hemisphere. Look up the latitudes of Lisbon, Portugal, and Melbourne, Australia, in an atlas. Now note on the July map that Lisbon in the Northern Hemisphere is nearly on the 70° isotherm while at Melbourne in the Southern Hemisphere the average July temperature is less than 50° F, even though the two cities are approximately the same distance from the equator. The temperature differences between the two hemispheres are again a product of insolation, this time changing insolation as the sun shifts north and south across the equator between its positions at the two solstices.

Note the greatest deviation from the east-west trend of isotherms occurs where the isotherms leave large landmasses to cross the oceans. As the isotherms leave the land, they usually bend rather sharply toward the pole in the hemisphere experiencing winter and toward the equator in the summer hemisphere. This behaviour of the isotherms is a direct reaction to the differential heating and cooling of land and water. The continents are hotter in the summer and colder in the winter than the oceans.

Other interesting features on the January and July maps can be mentioned briefly. Note that the isotherms poleward of 40° latitude are much more regular in their east-west orientation in the Southern than in the Northern Hemisphere. This is because in the Southern Hemisphere (often called the 'water hemisphere') there is little land south of 40° latitude to produce land and water contrasts. Note also that the temperature gradients are much steeper in winter than in summer in both hemispheres. The reason for this can be understood when you recall that the tropical zones have high temperatures throughout the year, whereas the polar zones have large seasonal differences. Hence, the difference in temperature between tropical and polar zones is much greater in winter than in summer. As a final point, observe the especially sharp swing of the isotherms off the coasts of eastern North America, southwestern South America, and southwestern Africa in January, and southern California in July. In these locations, the normal bending of the isotherms due to land-water differences is augmented by the presence of warm or cool ocean currents.

Annual March of Temperature

Isothermal maps are commonly plotted for January and July because there is a lag of about 30 to 40 days from the solstices when the amount of insolation is at a minimum or maximum (depending on the hemisphere) to the time of minimum or maximum temperature. This **annual lag of temperature** behind insolation is similar to the daily lag of temperature explained previously. It is a result of the changing relationship between incoming insolation and outgoing earth radiation. Temperatures continue to rise for a month or more after the summer solstice because insolation continues to exceed radiation. Temperatures continue to fall after the winter solstice until the increase in insolation finally matches earth radiation. In short, the lag exists because it takes time for the earth to heat or cool and for those temperature changes to be transferred to the atmosphere.

The mean temperature for each month at a place like Peoria, Illinois, is recorded and a line drawn connecting the 12 temperatures. The mean monthly temperature is the average of the daily mean temperature recorded at a weather station during a month. The daily mean temperature is the average of the maximum and minimum temperatures for a 24-hour period.

Such a temperature graph, depicting the annual march of temperature, is able to show the decrease in solar radiation, as reflected by a decrease in temperature, from midsummer to midwinter and then the increase in temperature from midwinter to midsummer caused by the increase in solar radiation.

It is these seasonal fluctuations that impose annual rhythms on our agricultural activities, our recreational pursuits, our clothing styles, and our heating bills. Human activities are constantly influenced by temperature changes, which reflect the input-output patterns of the earth's energy systems.