

Chapter 2

TEMPERATURE

Temperature of forest fuels, and of the air around and above them, is one of the key factors in determining how wildland fires start and spread. Temperature directly affects the flammability of forest fuels, since the amount of heat required to raise the temperature of the fuels to the ignition point depends on their initial temperature and that of the surrounding air.

Temperature indirectly affects the ways fires burn, through, its influence on other factors that control fire spread and rate of combustion (e.g., wind, fuel moisture, and atmospheric stability). An understanding of local temperature variations is the first step toward a better understanding of almost every aspect of fire behavior.

TEMPERATURE

Temperature was defined in chapter 1 as the degree of hotness or coldness of a substance. We also learned there that the atmosphere is warmed only slightly by direct, mainly short-wave, solar radiation. Most of the warming takes place by conduction and convection from the heated surface of the earth and from long-wave radiation from the surface.

We will see later that temperature has far-reaching effects on general atmospheric circulation, the formation and movement of air masses, and regional weather patterns. These are all important to fire weather. But in fire weather, we are also concerned **with smaller scale patterns-those** that change from hour to hour, from one slope facet to another, from one forest type to another, from a closed canopy to a forest opening, etc. In these patterns, temperature variations also are often the

controlling factor.

Large-scale weather patterns are commonly identified by sampling the weather at regular weather observation stations. Small-scale patterns and their variations, however, cannot be defined from measurements made at the usually widely spaced fixed stations. Sometimes portable instruments permit satisfactory measurements, but more frequently local variations must be identified by judgment based on personal knowledge of the detailed ways in which heating and cooling of surface materials and the air around them takes place, and on how thermal energy is transferred between the earth's surface and the lower air.

In this chapter, we will consider variations in surface and air temperatures and why they occur.

MEASURING TEMPERATURE

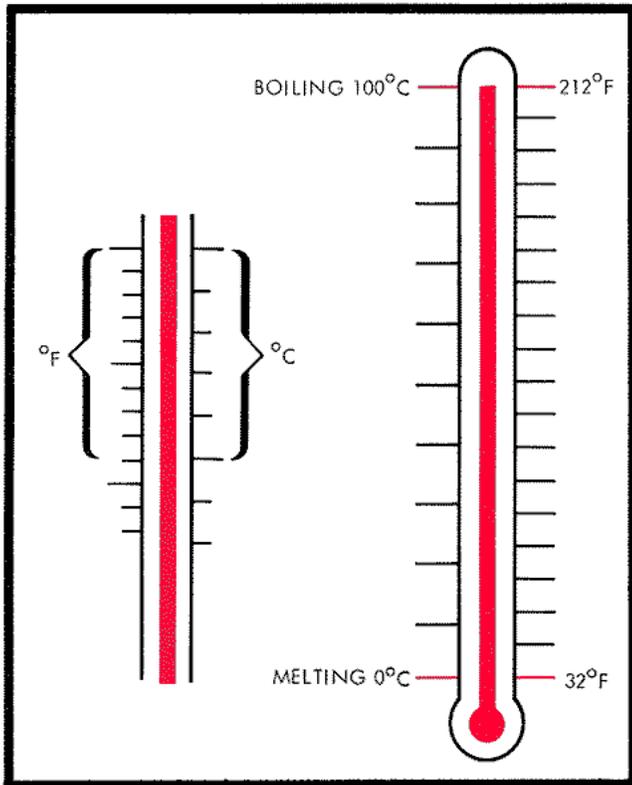
Fahrenheit, Celsius

We measure temperature in degrees on arbitrary scales based on fixed reference points. On the **Fahrenheit** scale, which is commonly used in the United States, the melting point of ice is 32°F. and the boiling point of water is 212°F. under standard sea-level pressure, a difference of 180 Fahrenheit degrees. Upper-air temperatures are commonly reported on the Celsius scale. This scale is also used in most scientific work around the world. On this scale the melting point of ice is 0°C. and the boiling point of water is 100°C., a difference of 100-Celsius degrees. Thus, 1 degree C. is equal to 1.8°F., a ratio of 5 to 9. °C. is converted to °F. by multiplying by 1.8 and adding 32.

The operation of common thermometers is based on the expansion and contraction of substances when heated or cooled. In the familiar mercury or alcohol thermometers, the liquid from a small reservoir expands into a long column with a very small inside diameter. Thus,

the expansion is sufficiently magnified so it can be accurately scaled in terms of actual temperature change.

A thermometer embedded in a solid or immersed in a liquid soon comes to a temperature equilibrium with the substance, and shows the actual temperature of the substance. Measuring the air temperature is a bit more difficult. During the day, for example, if sunlight strikes the bulb of the thermometer, the reading will be higher than the air temperature because of direct radiation. At night, if the bulb is exposed to the sky, the reading will be influenced by the outgoing radiation from the bulb, and will be lower than the air temperature. To avoid this difficulty, thermometers are usually shielded from radiation so that the exchange of heat between the thermometer and the air is restricted as much as possible to conduction. A standard instrument shelter provides this shielding at fixed locations while still permitting free flow of air past the thermometer in



The two common temperature scales in use are Fahrenheit and Celsius. Nine degrees Fahrenheit equals five degrees Celsius.

side. A hand-held thermometer should be kept shaded and should be swung rapidly for a few seconds to insure a comparable reading.

Representative Measurements

The measured air temperature at a fire-weather station, to be most useful in fire control, should be representative of the surrounding conditions. Many factors, as we will see, affect the air temperature; these include the type of ground surface, nearby buildings or trees, the local topography, and the height above the ground.

EARTH SURFACE TEMPERATURES

Effects of Factors Affecting Solar Radiation

The temperature of the surface of most materials comprising the surface of the earth, except water and ice, has a greater range than does that of air. The temperature of surface materials is important because the air is primarily

certain standards of thermometer exposure have been established so that temperature readings at one weather station may be compared to those at another. Measurements are made at a standard height of 4 1/2 feet above the ground. Locations near buildings or other obstructions are avoided, as are types of ground surfaces such as concrete or asphalt, which would obviously affect temperature readings. Purely local effects are avoided where possible.

The local variations in temperature that are avoided when readings are used for fire-weather forecasting or for area fire-danger rating become most important when judgments must be made concerning fire behavior at a particular time and place. Then it is necessary either to take closely spaced measurements to show the temperature variations, or to make judgments based on personal knowledge of where and how these variations might occur.

The causes of these temperature changes are many and varied. However, three important processes underlie all causes: (1) Heating and cooling of the earth's surface by radiation, (2) exchanging of heat between the surface and the air above it, and (3) conversion of thermal energy in the atmosphere to other forms of energy, and vice versa. All three processes vary continuously.

In the process of warming and cooling, heat is exchanged between the earth's surface and the atmosphere. Some of the heat transferred to the atmosphere is transformed to potential and kinetic energy, and becomes the driving force of weather processes. To understand these processes, and the resulting temperature variations, let us first consider surface temperatures and then consider air temperatures.

heated and cooled by contact with heated or cooled surfaces.

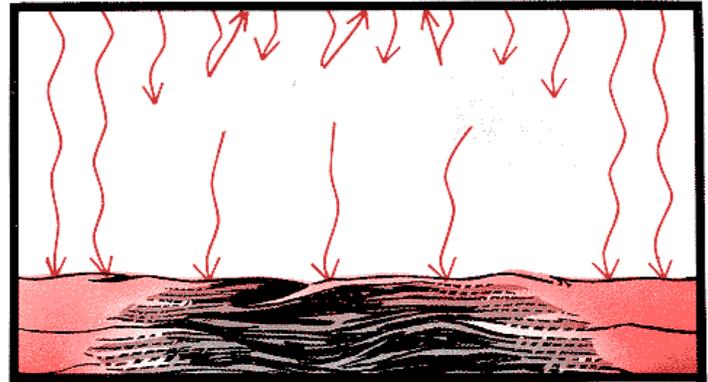
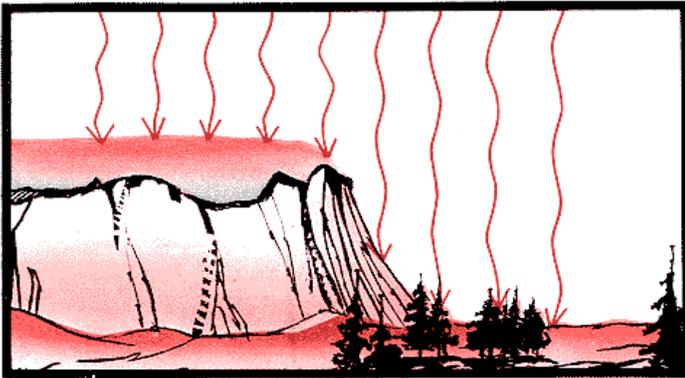
Some factors affect surface temperatures by influencing the amount of solar radiation that strikes the surface or by trapping the earth's radiation. We have considered some of these factors in chapter 1.

A lower sun angle results in the reception of less solar radiation per unit area and a lower surface temperature. More hours of daylight mean more heating and higher surface temperatures. Conversely, more hours of darkness result in more cooling and lower surface temperatures,

Topography plays an important role in local surface temperature variations. Differences in topography cause local variations in the angle at which the sun's radiation strikes the ground surface. Both the steepness and the aspect of a slope affect surface heating and cooling. Surfaces more nearly perpendicular to incoming radiation receive more heat per unit area than do those more nearly parallel to incoming radiation. As the sun moves across the sky, its rays are more nearly perpendicular to different slopes and aspects at various hours. South-facing slopes, which in the Northern Hemisphere receive more nearly direct rays from the sun during most of the day than do north-facing slopes, may have a surface temperature in midsummer as high as 175°F.

Level surfaces reach their maximum temperatures around noon, but the maximum temperature on a slope depends upon both the inclination and orientation of the slope and on the time of day. Accordingly, east-facing slopes reach their maximum temperature rather early in the day; west-facing slopes attain their maximum temperatures later in the afternoon. In general, the highest surface temperatures are found on slopes facing to the southwest.

Shading and scattering by any means, such as clouds, smoke or haze in the air, and objects such as trees, reduce the solar radiation reaching the ground surface. In hilly or mountainous regions, higher ridges shield lower elevation surfaces from incoming radiation, and actually reduce the hours of sunshine. All vegetation creates some shade, but the variations in type and density cause local differences in surface temperatures. In open stands of timber, shaded and unshaded areas change temperature throughout the day according to the position



Upper Left. – Surfaces more nearly perpendicular to incoming radiation receive more heat per unit area, and become warmer, than do those more nearly parallel to the incoming radiation. Lower Left. – As the sun arcs across the sky, its rays are more nearly perpendicular to different slopes and aspects at various

hours. South-facing slopes receive more nearly direct rays than do north-facing slopes. Upper Right. – In open stands of timber, surface temperatures vary considerably from shaded to sunlit areas. Lower Right. – Clouds both absorb and reflect incoming radiation and thereby reduce surface temperatures.

of the sun. Surface temperatures respond quickly to these changes. For example, a forest floor with a mottled sun and shade pattern may have temperature variations during the summer of as much as 50-60°F. within a few feet. In deciduous forests in the winter, there will be a fair degree of uniformity of ground temperature. In open pine forests, marked differences in ground temperature are noted both in summer and winter.

Both liquid water droplets in clouds and the water vapor in the atmosphere directly affect surface temperatures. They both absorb some incoming radiation, and clouds reflect much of the solar radiation. The thicker and lower the clouds, the less incoming radiation strikes the surface. The surface temperature may drop as much as 50°F. within 3 minutes as a thick cloud passes overhead in clear midsummer weather. Water droplets in clouds, and invisible water vapor in the air, also influence the cooling of the surface at night. Both absorb much of the outgoing thermal radiation, and some of this heat is reradiated back to the earth. Thus, surface temperatures normally are much lower on clear nights than on cloudy nights. The lack of water vapor in the air is one reason why surface temperatures in the desert become so low at night.

A blanket of smoke from forest fires, like clouds, causes significantly lower daytime surface temperatures, and higher nighttime temperatures, when skies are otherwise clear.

Effects of Surface Properties

However, even when a certain amount of radiation strikes a surface, there are several properties of the substance itself, which affect its resulting temperature.

First is the **capacity of the substance to absorb or reflect radiation**. Dark materials generally absorb most of the radiation in the visible wavelengths, whereas light materials reflect most of this radiation back to space. Since dark soils and forest litter are rather good absorbers and poor reflectors of radiation, they will become hotter than light-colored soils. Dark pavements will become quite hot on sunny days. The temperature of the tree crown in a forest will rise also, but not as much. Some of the incoming radiation is used in processes other than heating, such as in the production of food and in the vaporization of the moisture released by transpiration. Substances

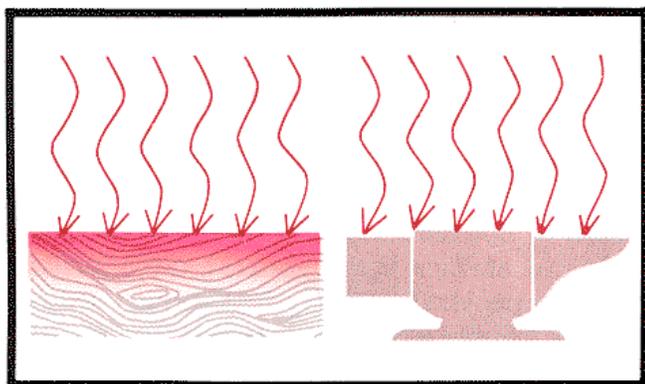
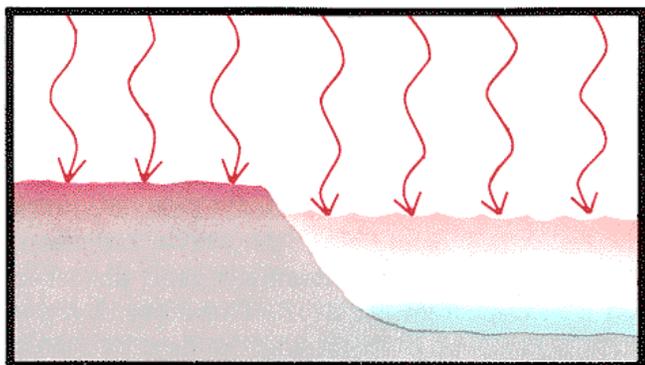
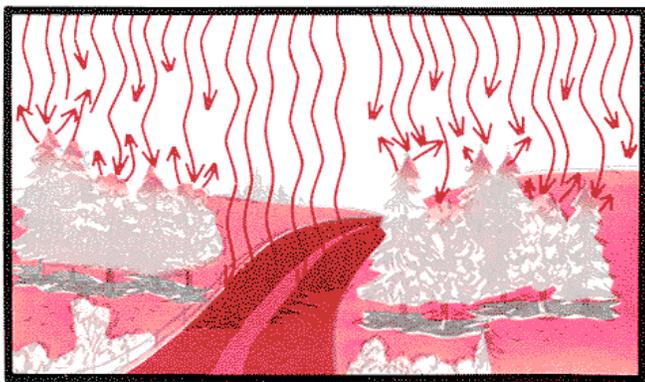
that are good radiators of long-wave radiation emit heat rapidly from their surfaces at night when exposed to a clear sky. If they are not supplied with heat from within, these surfaces become quite cold at night. Tree crowns, grass, plowed land, and sand are all good radiators.

The **absorptivity** and **emissivity** of a surface both vary with the wavelength of the radiation and the temperature. But under identical wavelengths and temperature, absorptivity and emissivity are assumed to be the same.

Snow is an interesting substance in that its properties are very different at different wavelengths. In the visible portion of the spectrum, snow will reflect 80 to 85 percent of the incoming short-wave radiation. This accounts for its white color. For long-wave radiation, however, snow is an extremely good absorber and a near perfect radiator. Therefore, a snow surface heats up little during the day, but cools by radiation extremely well at night. We will see later that these characteristics make snow ideal for the formation of cold, dry air masses.

A second property of surface materials affecting temperature is **transparency**. Water is fairly transparent to incoming radiation, while opaque materials are not. The heat absorbed by opaque substances is concentrated in a shallow surface layer, at least initially. But radiation penetrates deeply into water, heating a larger volume. This is one reason why opaque substances such as land become warmer during the day than water does. However, it is not the most important reason. The downward mixing of warmed surface water by turbulent motion is more important in distributing the incoming heat through a large volume.

A third property is the **conductivity** of the substance. Incoming radiant energy striking a good conductor, such as metal, is rapidly transmitted as heat through the material, raising the temperature of the metal to a uniform level. The same radiant energy applied to a poor conductor tends to concentrate heat near the surface, raising the surface temperature higher than that in the interior. Wood, for example, is a poor conductor, and heat applied to it concentrates at the surface and only slowly penetrates to warm the interior. Leaf litter is an



Top – Surface materials differ in their absorptive and reflective properties. Dark pavements become quite hot in sunlight; dark soils become warmer than light soils. The temperature of tree crowns will rise also, but not as much. Center – Heat absorbed by opaque substances, such as land, is concentrated in a shallow layer. Radiation penetrates deeply into water and warms a larger volume. Bottom – Radiant energy absorbed by a good conductor, such as metal, is rapidly transmitted through the material, while that absorbed by a poor conductor, such as wood, tends to concentrate near the surface, and the surface becomes quite hot.

other poor conductor. Common rocks, damp soil, and water, although not as efficient conductors of heat as metals, are much better conductors than wood, other organic fuels, or dry soils.

Air is a very poor conductor, so porous substances such as duff or litter with many air-spaces will bar the passage of surface heat to the soil below. At night, as surfaces cool by radiation, the surfaces of good conductors do not cool as fast as those of poor conductors so long as there is heat below to replenish that lost at the surface by radiation. A weathered board, for example, lying on bare ground in the open may have frost on it, whereas none has formed on the nearby ground.

To summarize, the surfaces of poor conductors get hotter during the day and cooler at night than the surfaces of good conductors.

We learned in chapter 1 that different substances have different heat capacities, and that the specific heat of a substance is the ratio of its heat capacity to that of water. The specific heat, then, is another reason why the surface temperature of substances vary under similar conditions of incoming and outgoing radiation. A substance with a low specific heat will warm up rapidly as heat is added to it, simply because it takes less heat to change its temperature. Water has a high specific heat, and its temperature changes 1°F. when 1 B.t.u. of heat energy per pound is gained or lost. Wood, which has about half the specific heat of water, changes about 2°F. with a change of 1 B.t.u. per pound. Materials like charcoal, ashes, sand, clay, and stone change about 5°F. Litter surfaces composed of dry leaves, needles, and grass have low heat capacities, and, as mentioned above, are also poor heat conductors. For these two reasons, direct solar radiation often heats litter surfaces to temperatures far above the temperature of the overlying air without heating the soil below,

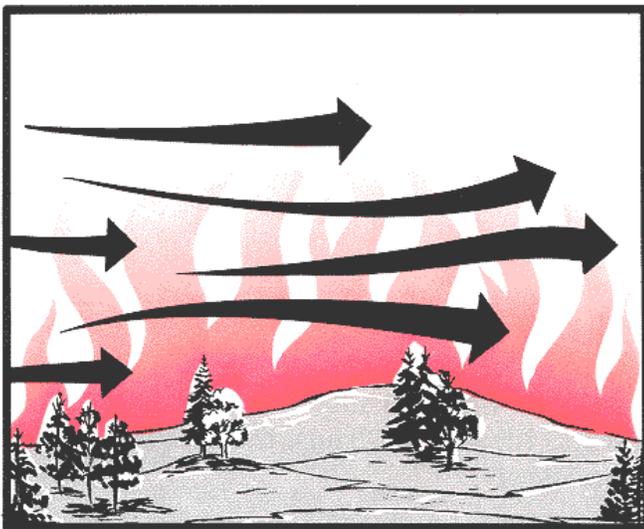
Since water has a high specific heat and is a fairly good conductor, the surface temperatures of substances are greatly influenced by the presence of moisture. Moist surfaces, when compared with dry surfaces, will not reach as high temperatures in the day or as low temperatures at night. This is another reason why and semiarid areas, when compared with moist regions, have both higher daytime surface temperatures and lower nighttime surface temperatures.

The presence of moisture is also important because of the heat used in evaporation and re-

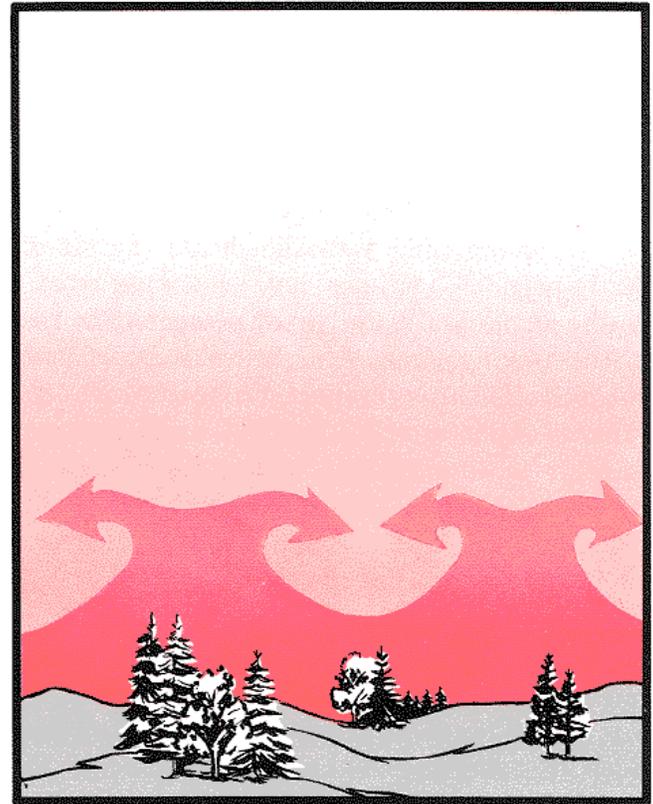
leased in condensation. We have seen that while 1 B.t.u. will raise the temperature of 1 pound of water 1°F., nearly 1,000 are required to evaporate 1 pound of water under normal conditions of pressure and temperature. Thus when water is evaporated from a surface, cooling takes place at the surface with a corresponding reduction in the surface temperature. This, then, is another reason why surfaces of moist substances have lower daytime temperatures than dry substances. At night, if vapor condenses, an equally large amount of heat is liberated to warm the surface.

Effect of Wind

Strong daytime winds near the surface tend to prevent high surface temperatures. Transfer of heat between the surface and the air is improved by mixing, which carries heat away from the heated surfaces. This air movement also transports moisture, increasing evaporation from moist surfaces and thus restricting the temperature rise. At night the effect of strong winds is to prevent low surface temperatures by mixing warmer air downward and bringing it into contact with the surface, where some of the heat can be transferred to the ground by conduction. Thus, windiness has a moderating influence on surface temperatures.



Strong daytime winds cause turbulent, mixing, which carries heat away from warmed surfaces and lowers surface temperatures.



In a stable air mass, the daytime heating and mixing are confined to a shallow layer, and the temperature of this air will increase rapidly.

AIR TEMPERATURES

The exchange of heat between the air and the surfaces over which it flows is the master controller of air temperatures. This exchange is a continuous process, taking place everywhere at all times. When a large body of air comes to rest or moves very slowly over a land or sea area having uniform temperature and moisture properties, such as the oceans or the polar regions, it gradually takes on the temperature and moisture characteristics of the underlying surface. Then, when the body of air, called an air mass, moves away from this region, it tends to retain these characteristics, although slow modification takes place during its travel.

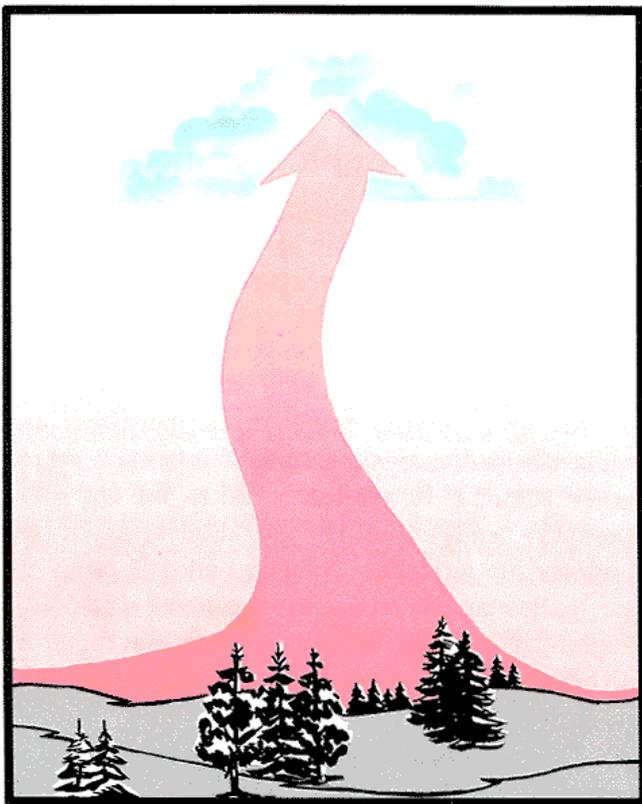
The **air-mass temperatures** impose some restraint on the daily heating and cooling that the air mass encounters. For example, under the same conditions of daytime heating, a cold air mass will not reach as high a temperature

as a warm air mass. We will now consider how local changes in air temperatures are produced within the limitations of the air-mass temperature.

How Air is Heated

Incoming solar radiation heats the air directly only 0.5-1°F. per day, depending mostly on the amount of water vapor present. The rest of the heating comes from below, most of it by conduction, through direct contact with the warmed surface of the earth. The heated surface air becomes buoyant and is forced upward by cooler, more dense air. This convection may distribute the heat through a depth of several thousand feet during the day.

The final depth through which heat from the surface is distributed through the atmosphere will be affected by the **lapse rate** of the air. If the lapse rate is stable through a deep layer, the daytime mixing and heating of the atmosphere will be confined to a fairly shallow



In a relatively unstable air mass, heating and mixing will take place throughout a deep layer, and the air temperature near the ground will rise slowly and to a smaller extent.

layer of perhaps 1,000 to 2,000 feet, and the temperature of this layer will increase rapidly. If, through a layer of air several thousand feet deep, the temperature lapse rate approaches the dry-adiabatic rate, heated air parcels will be carried to much greater heights. Then the heating and mixing take place throughout a deep layer, and the rise in air temperature near the ground will be less and slower. Thus, we can see that the characteristic air-mass temperature at several thousand feet above the surface is important in estimating the maximum temperature of air near the surface.

The effect of wind on heating of the air is similar to that of stability. Strong winds cause more turbulence and mixing so that heat is distributed through a deeper layer and the temperature rise of air near the surface is less. The greatest temperature rises resulting from surface heating occur with light winds.

Another factor in the heating of the air near the surface that we should not overlook is the absorption of the earth's long-wave radiation by water vapor. Since most of the water vapor is concentrated in the lower layers of the atmosphere, these lower layers are heated by absorption of earth radiation as well as by conduction and convection.

How Air is Cooled

Air-cools at night by the same heat transfer processes-conduction, radiation, and convection-as it heats during the day. The surface begins to cool first by radiation, cooling the air in contact with it. On clear, calm nights this is the primary method of cooling. It is primarily the surface air layer, which is cooled while the air aloft may remain near day temperatures.

Water vapor and clouds also lose heat to the sky by their own radiation, but at a slower rate than the heat lost near the surface through clear, dry air. When clouds or significant water vapor is present, much of the outgoing radiation from below is intercepted and reradiated back to the surface. Thus, the surface is cooled more slowly.

Winds at night also reduce the cooling of surface air by bringing down and mixing warmer air from above. This process does not

slow the surface radioactive cooling, but it does spread its effects on air temperature through a deeper layer. On the average, however, the dif-

ference between day and night air temperatures is much greater near the surface than it is aloft.

VERTICAL VARIATION OF AIR TEMPERATURE

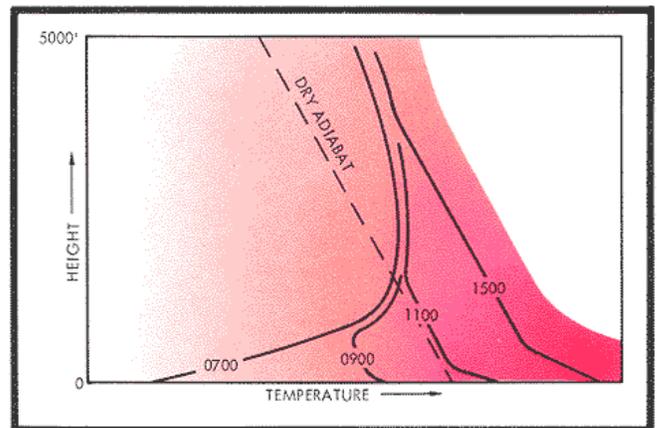
We have seen that the atmosphere is heated from below by conduction and convection. We also know that the gases and substances with good heat-absorbing properties, such as water vapor, liquid water, smoke, and dust, are more concentrated in the lower levels of the atmosphere. At higher levels in the atmosphere, heat is lost to space by radiation. We should expect, therefore, that the temperature of the atmosphere decreases with height. We generally find this situation when we measure air temperatures aloft. Such measurements are made by instruments, attached to balloons, that transmit signals electrically to receivers on the ground. Another reason for the decrease of temperature with height is that air expands and becomes cooler as it is moved up, and as air is moved down it is compressed and becomes warmer.

The year-round average rate of temperature decrease with height in the troposphere at 45° N. latitude, as determined from many hundreds of measurements or soundings, is 3.5°F. per 1,000 feet. In any altitudinal range in the troposphere at any time, however, the lapse rate may deviate significantly from this average. The atmosphere is often stratified as a result of horizontal motion aloft. Each stratum may have its individual temperature structure. Inversions aloft, though less common than at the surface, are caused by the inflow of warm air above, or by subsidence in large high-pressure systems.

In the lowest layers of the atmosphere, the change of temperature with height varies considerably from day to night. Early in the morning, heating begins at the surface, warming air in a very shallow layer. The warm air is forced upward, but only to the level where its temperature is equal to that of the surrounding air. The warmed layer becomes gradually deeper with additional heating, eliminates the night inversion, and reaches its maximum temperature about mid-afternoon.

On days with strong surface heating, air next to the ground can become quite hot. At the surface the temperature may be 150°F, while at the shelter height (4 1/2 feet) it may be only 90°F. Such changes in temperature with height far exceed the dry-adiabatic lapse rate. A lapse rate that exceeds the dry-adiabatic is called a **superadiabatic**, lapse rate. Under extreme conditions such a lapse rate may extend to 1,000 feet, but normally it is confined to the first few hundred feet. Superadiabatic lapse rates are conducive to convection and vertical mixing. Local winds may be quite gusty. As mixing continues, the superadiabatic lapse rate tends to change toward the dry-adiabatic. Therefore, strong superadiabatic conditions persist during times when excessive heat is continually supplied to the surface. They develop most readily with clear skies and light winds, and over surfaces with the highest temperatures, such as dark soils and surface materials, particularly burned-out and blackened areas.

Often under calm conditions, and especially over flat terrain, heated air parcels do not rise



Successive plots of temperature against height on a clear day show that early in the morning a shallow layer of air is heated, and gradually the warmed layer becomes deeper and deeper, reaching its maximum depth about mid-afternoon.

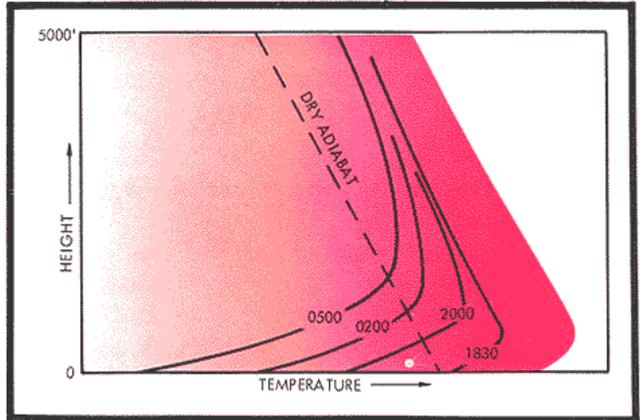
immediately. They have inertia and remain on the surface until some disturbance permits cooler surrounding air to flow in beneath and provide the needed buoyancy. This disturbance might be a sudden gust of wind or some other mechanical force. Dust devils and small whirlwinds are common indicators of this buildup and escape of hot surface air.

Marine Inversion

A common type of warm-season inversion, found particularly along the west coast, is the **coastal or marine inversion**. Here cool, moist air from the ocean spreads over low-lying land. The layer of cool, moist air may vary in depth from a few hundred to several thousand feet. This layer is topped by a much warmer, drier, and relatively unstable air mass. Marine inversions, although they may persist in some areas during the day, are strongest and most noticeable at night. Fog and stratus clouds often form in the cool marine air at night and move inland into coastal basins and valleys. If the cold air is quite shallow, fog usually forms. If the layer is deep, stratus clouds are likely to form.

Night Inversions

Air cooled at night, primarily by contact with cold, radiating surfaces, gradually deepens



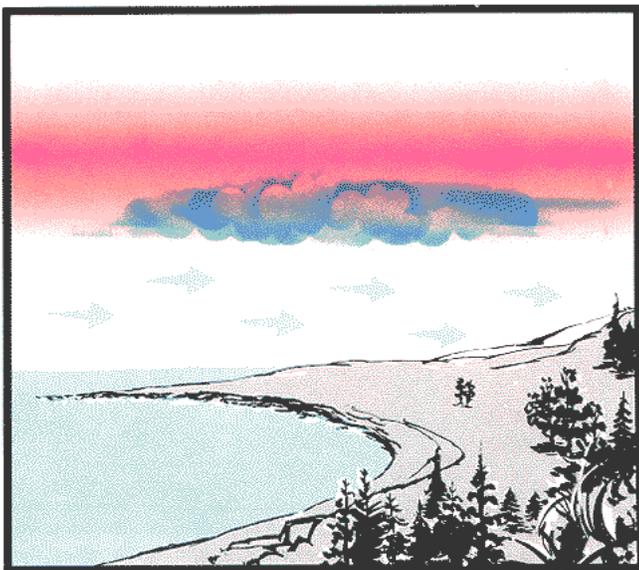
Plots of temperature against height during the night hours show that the air is first cooled next to the ground, forming a weak surface inversion. Then, as cooling continues during the night, the layer of cooled air gradually deepens, causing the inversion to become deeper and stronger.

as the night progresses and forms a **surface inversion**. This is a surface layer in which the temperature increases with height. Such an inversion may involve a temperature change of as much as 25°F. in 250 vertical feet. The cold air is dense and readily flows down slopes and gathers in pockets and valleys. Surface inversions forming at night are commonly referred to as **night inversions**. Night inversions are so important in fire behavior that we should consider them in some detail.

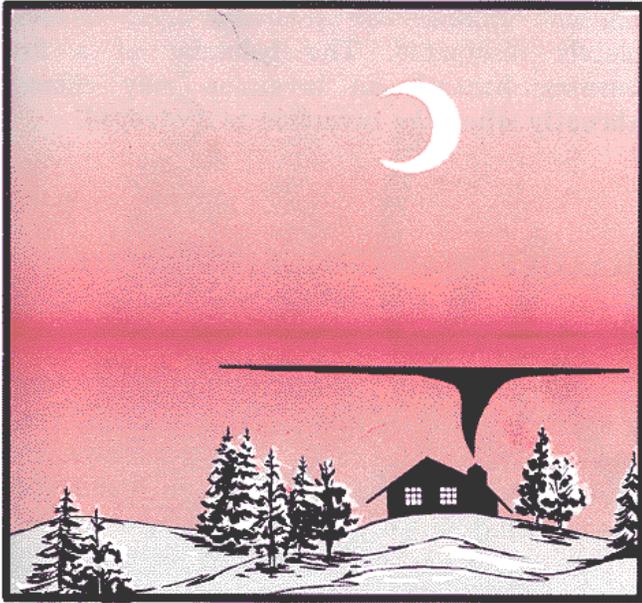
Night inversions are common during clear, calm, settled weather. They are usually easy to identify. Inversions trap impurities, smoke, and factory and traffic fumes, resulting in poor visibility. Smoke from chimneys rises until its temperature matches that of the surrounding air. Then it flattens out and spreads horizontally. If fog forms in the cold air, it is generally shallow ground fog, its depth generally less than that of the inversion. Ground fog in patches in surface depressions along highways is formed in small-scale inversions.

Cloudiness and water vapor in the atmosphere limit the formation and strength of night inversions by reducing the rate of outgoing radiation from the earth.

On windy nights, compared with calm nights, turbulence and mixing distribute the cooling through a deeper layer, and the temperature decrease is less. Winds may reduce and sometimes prevent the formation of a night inversion. The drop in temperature near the



Coal, moist air from the ocean spreads over nearby low-lying land areas beneath the marine inversion.



Smoke released into an inversion layer will rise only until its temperature equals that of the surrounding air; then the smoke flattens out and spreads horizontally.

ground at night is thereby often abruptly stopped or even reversed when the wind picks up.

Night inversions are shallow but more intense when the overall temperature structure of the atmosphere is stable. Under unstable conditions, convection distributes available heat. Inversions are therefore less likely, and those occurring will not be as intense. However, if a night inversion is able to form, mixing is reduced in the lower layers.

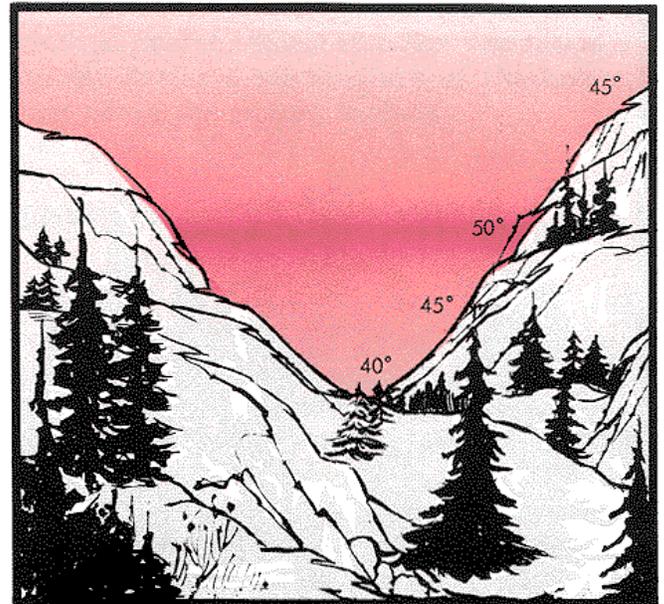
Topography plays a decided role in both the formation and intensity of night inversions. Cold air layers are quite shallow on slopes and in open canyons or ravines where the cold, dense air can drain away as it is formed. This descent of cold air results in the formation of deep, cold layers and inversions in valleys. Inversion layers are both more common and intense in lower mountain valleys or in basins with poor air drainage, than in flat areas.

In mountainous areas, the height of the top of night inversions, although it varies from night to night, is usually below the main ridges. The height of the warmest air temperature at the inversion top can be found by measuring temperatures along the slope. From this level, the temperatures decrease as one goes farther up or down the slope. At this level are both the highest minimum temperatures and the least

daily temperature variation of any level along the slope. Here also are the lowest nighttime relative humidity and the lowest nighttime fuel moisture. Because of these characteristics of the average level of the inversion top, it is known as the **thermal belt**. Within the thermal belt, wildfires can remain quite active during the night. Below the thermal belt, fires are in cool, humid, and stable air, often with down slope winds. Above the thermal belt, temperatures decrease with height. The effect of the lower temperatures, however, may be offset by stronger winds and less stable air as fires penetrate the region above the thermal belt.

Night inversions in mountainous country increase in depth during the night. They form early in the evening at the canyon bottom or valley floor and at first are quite shallow. Then the cold layer gradually deepens, the top reaching farther up the slope with the continued cooling from the surface and the flow of cold air from adjoining slopes. A maximum depth is reached during the middle of the night, and the depth may then remain constant or decrease slightly just before sunrise. If the air is sufficiently cold and moist, fog may form.

After sunrise, surface heating begins to warm the cold air, and the inversion top may actually rise slightly from this expansion. As heating destroys the inversion along the slopes,



The zone of warm nighttime temperatures near the top of the inversion is known as the thermal belt.

upslope winds begin. The transport of air from the valley bottom up the slopes may actually cause the inversion top to lower over the middle of the valley. Finally, with continued

heating and mixing, the inversion layer is completely dissipated. **The behavior of a fire burning beneath an inversion may change abruptly when the inversion is destroyed.**

EFFECTS OF FORESTS ON TEMPERATURE NEAR THE GROUND

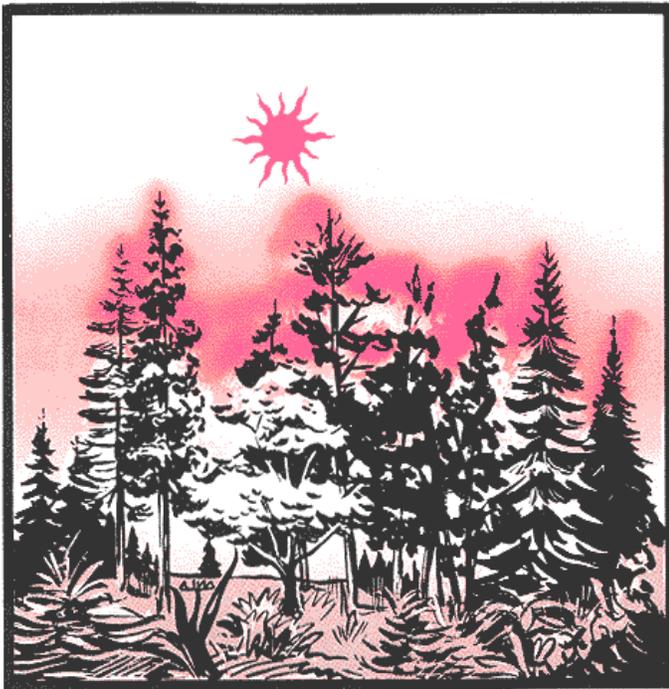
In all situations, vegetation moderates air temperatures within the vegetative layer for several reasons. **First**, it intercepts both incoming and outgoing radiation and therefore has a marked effect on ground temperature; second, green foliage does not warm up as much as ground or dry litter; and **third**, leaf surfaces exchange heat with air through a deeper, less restricted boundary layer. These effects result in less pronounced temperature changes with height above the ground.

In all vegetative cover, the temperature distribution depends upon the nature and density of the vegetation. With plants, such as low brush, the leaves form a nearly continuous upper surface, and this surface acts as the effective ground surface. The maximum daytime temperatures and minimum nighttime temperatures are near the top of the brush or dense plant cover, although temperatures near

the ground are not greatly different.

The crowns of trees in a heavy forest form a nearly continuous cover and the canopy thus becomes, in effect, the air contact surface. The highest daytime temperatures are found near the crown top, and the temperature will decrease gradually between this level and the ground. Maximum air temperatures near the crowns may be 180 to 200 warmer than air temperature near the ground. Above the tree crowns the temperature decreases fairly rapidly with height, although never as rapidly as over bare ground. This is because the temperatures of the tree crown surfaces in contact with the air are lower than bare ground, and because the air circulation around these surfaces is better.

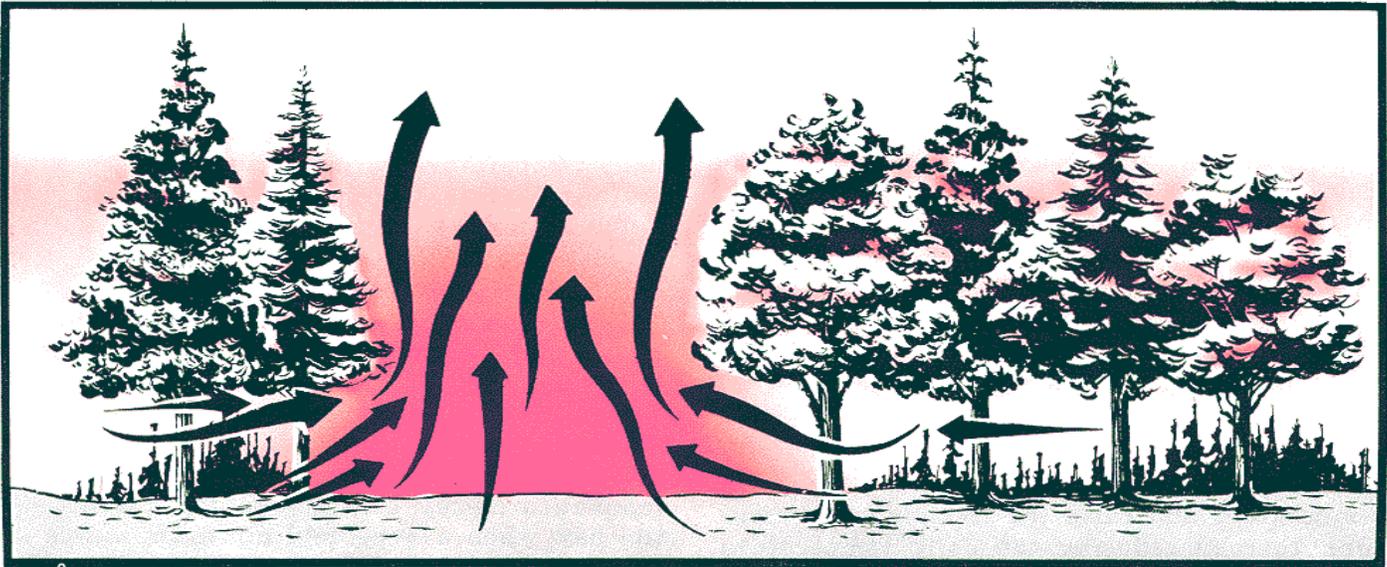
Less dense vegetation will permit more solar radiation to penetrate to the ground than will a dense cover. The degree of partial ground



Crowns of trees in a heavy forest become the effective air contact surface. Air in the crown region had higher daytime temperatures than air beneath the crowns.



Nighttime temperatures in a dense timber stand tend to be lowest near the tops of the crowns, where the principal radiation takes place.



Openings in a timber stand tend to act as chimneys under conditions of strong daytime heating and light winds.

shading provided by less dense vegetation determines; the air temperature distribution between the ground surface and the canopy top. It will range between that found over bare ground and that under a closed canopy.

Air temperatures at the standard 4 1/2-foot height within the forest in the afternoon are likely to be 5° to 8° cooler than the temperatures in nearby cleared areas. Openings in a moderate to dense timber stand may become warm air pockets during the day. These openings often act as natural chimneys and may

accelerate the rate of burning of surface fires, which are close enough to be influenced by these "chimneys."

Night temperatures in dense timber stands tend to be lowest near the top of the crown where the principal radiation takes place. Some cool air from the crowns sinks down to the ground surface, and there is some additional cooling at the surface by radiation to the cooling crowns. Sparse timber or other vegetation will merely decrease the strength of the inversion just above the ground surface.

SEASONAL AND DIURNAL VARIATIONS IN AIR TEMPERATURE

Seasonal temperature patterns are affected principally by **latitude**, **large water bodies**, and the general **circulation patterns**. The latitude effect is, as we have seen, due to the angle at which the sun's rays strike the earth. In general, the seasonal variation of temperatures near the surface is least in equatorial regions, where there is little difference in solar heating through the year. This seasonal variation increases with latitude to both polar regions, where summer days have a maximum of 24 hours of sunshine and winter days a maximum

of 24 hours of darkness. Large water bodies moderate the seasonal temperature cycle because of their great heat capacity. In one area, the general circulation pattern may produce cloudy weather with successive influxes of cold air, and thus a reduction in the monthly or seasonal temperature. In another area, the same pattern may produce opposite effects.

The diurnal temperature variation depends upon all of the factors we have discussed so far. The normal daily pattern at an inland location with level terrain consists of a daily temperature

range of 20-30°F. near the surface, with the highest temperature in mid afternoon and the lowest temperature just after sunrise. The reason for this lag in maximum and minimum temperature was discussed in chapter 1. This diurnal temperature range decreases with altitude above the surface. Various factors alter this pattern.

A primary factor is the character of the surface. In general, those surfaces that become warmest during the day also become coldest at night, and the air temperature above them also has a high daily range. Snow surfaces are an important exception.

Clouds, strong winds, high humidity, and atmospheric instability lower the maximum temperature and raise the minimum temperature, thereby reducing the daily temperature range.

In mountainous terrain, one finds a greater diurnal variation in temperature in the valleys, and less along the slopes (in the thermal belt) and at higher elevations. Aspect affects the solar radiation and therefore the diurnal temperature range and the time of maxima and minima. Maxima will occur earlier, for example,

on east slopes than on west slopes. Even minor shape characteristics of topography have their effects. Concave areas will have a larger daily range than convex areas.

Large water bodies tend to moderate the daily temperature variation just as they moderate the seasonal variation. Coastal areas have a marine, rather than continental, climate.

Diurnal changes in temperature take place within the limitations of air-mass temperature. The passage of a front, evidence that another air mass has moved into the area, is reflected in the temperature pattern. Temperatures drop when a cold air mass moves in, and rise when a warm air mass moves in. In some cases the diurnal pattern is completely obscured. The temperature may continue to fall throughout the day when a very cold air mass moves in rapidly, or may continue to rise throughout the night when a warm air mass moves in. Along the west coast during the summer, a cool, marine air mass is usually found at low levels, and a warm, dry air mass is usually found above. A change in the vertical height of the boundary layer between these two air masses will appear in the temperature patterns along the slopes.

SUMMARY

In this chapter we have seen that temperature varies considerably in both time and space and for various reasons, most of which are related to the heating or cooling of the earth's surface. Temperature is a basic weather element that influences other weather elements. Differences in temperature create differences in air density and atmospheric pressure and therefore cause vertical and horizontal air movement. Through air movement, temperature differences influence the transport of heat, moisture, and atmospheric

pollutants such as smoke, haze, and industrial contaminants. The influence of temperature on atmospheric moisture is fundamental, not only in moisture transport, but in changes of state, particularly evaporation and condensation.

With the understanding of temperature variations that we now have, we are ready to consider atmospheric moisture-humidity in some detail.