Chapter 10

THUNDERSTORMS

Two characteristics of thunderstorms make them an important element in fire weather. The first is the fire-starting potential caused by lightning strikes from cloud-to-ground. The second is the thunderstorm downdraft which spreads out upon nearing the ground, producing strong, shifting, and gusty winds for a short time.

Wildland fires may be started by lightning most anywhere on the North American Continent where thunderstorms occur. But the problem is most serious where thunderstorms produce little or no precipitation that reaches the ground. These so-called “dry” thunderstorms occur mainly in the mountainous West. Several hundred wildfires can be started by lightning during one day on a single forest or district, overwhelming all possible fire control efforts. In dry periods, such fires have burned hundreds of thousands of acres in the Western United States and Canada during a few days.

On the beneficial side, heavy precipitation from “wet” thunderstorms moistens fuels, decreases the activity of going fires, and lessens the risk that lightning strikes will start fires. But let us not become overconfident! The few fires that do start may be hard to find and may “sleep” until the woods dry out, and then suddenly become major conflagrations.

THUNDERSTORMS

A thunderstorm is a violent local storm produced by a cumulonimbus cloud and accompanied by thunder and lightning. It represents extreme convective activity in the atmosphere, with both updrafts and downdrafts reaching high speeds. The thunderstorm depends upon the release of latent heat, by the condensation of water vapor, for most of its energy. We learned in chapter 1 that for each pound of liquid water condensed from vapor, more than 1,000 B.t.u.'s of heat energy is released.

Tremendous amounts of this energy are released in a single well-developed thunderstorm. The amount may well exceed 10 times the energy released in a World War II atomic bomb. And it is estimated that there are 45,000 thunderstorms occurring daily over the earth. Part of the heat energy is converted to kinetic energy of motion to cause the violent winds which usually accompany thunderstorms.

A thunderstorm, as we experience it, is composed of one or more individual convective cells or units. A cell may range from a few miles to 10 miles in diameter. A cluster of cells, each in a different stage of development, with interconnecting cloud masses may extend for 50 miles. Each convective cell has its individual identity and life cycle, even though cumulus cloud bases may join to form a solid overcast which obscures the multicellular structure.

Because thunderstorms seriously affect the inception and behavior of wildfire, we will consider them in some detail. We will first discuss the environmental conditions necessary for, and the process of, thunderstorm development. Then, we will look into the life cycle of an individual cell, the phenomenon of lightning, the type of thunderstorms, and finally consider briefly the most violent of all storms, the tornado, which on occasion occurs with thunderstorms.

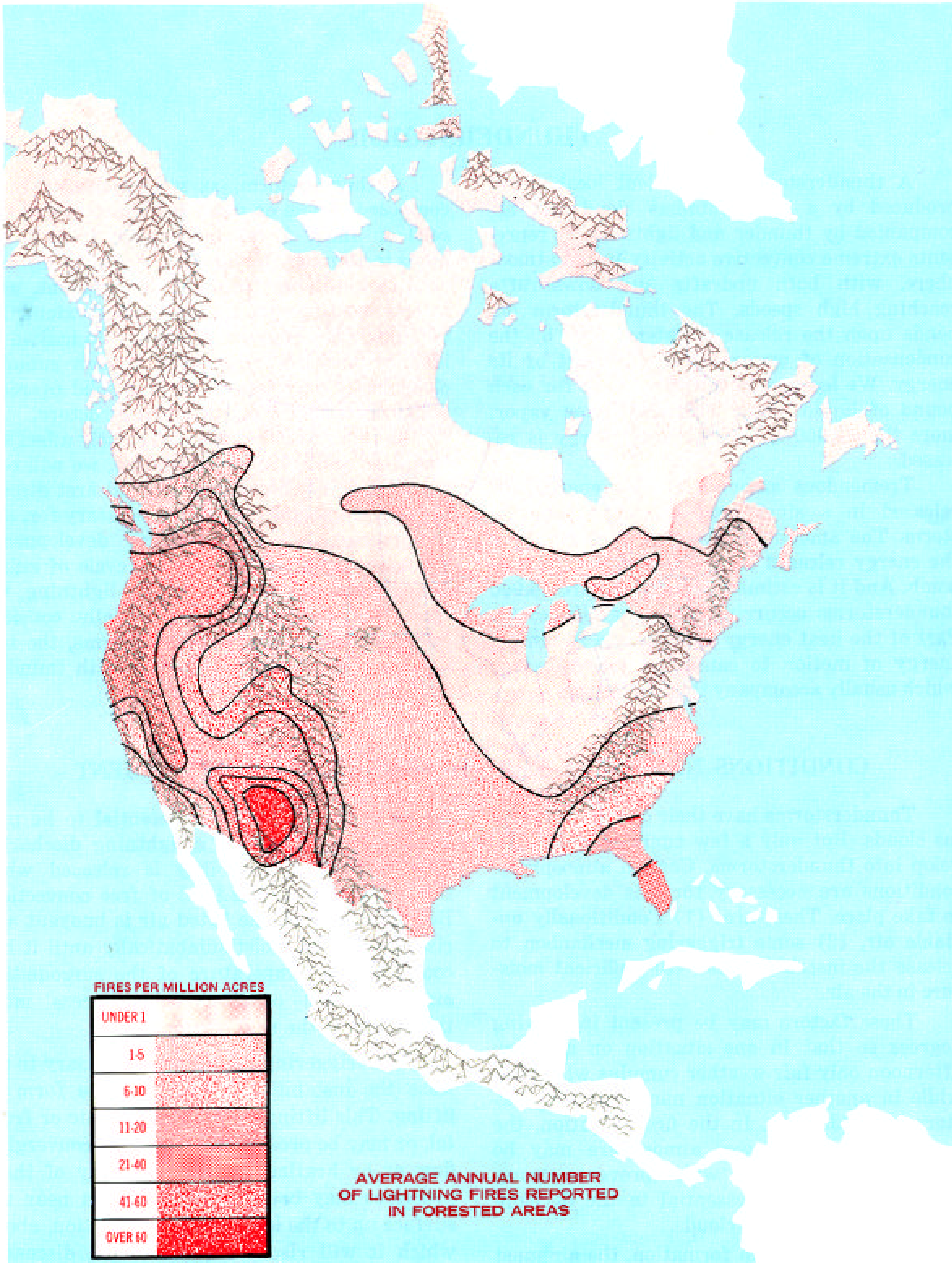
CONDITIONS NECESSARY FOR THUNDERSTORM DEVELOPMENT

Thunderstorms have their origins in cumulus clouds. But only a few cumulus clouds develop into thunderstorms. Certain atmospheric conditions are necessary for this development to take place. These are: (1) Conditionally unstable air, (2) some triggering mechanism to release the instability, and (3) sufficient moisture in the air.

These factors may be present in varying degrees so that in one situation on a sultry afternoon only fair-weather cumulus will form, while in another situation numerous thunderstorms will develop. In the first situation, the instability in the lower atmosphere may be offset by stability aloft, which prevents strong convectional activity essential to the development of cumulonimbus clouds.

For thunderstorm formation, the air must be conditionally unstable through a deep layer. Convection must develop well beyond the freezing level for an electrical potential to be produced which will cause a lightning discharge. The conditional instability is released when the air is lifted to the level of free convection. Beyond this level, the lifted air is buoyant and rises freely and moist-adiabatically until it has cooled to the temperature of the surrounding air. (We will consider this process more thoroughly in the next section.)

The triggering mechanism necessary to release the instability is usually some form of lifting. This lifting may be orographic or frontal, or may be produced by low-level converging flow or by heating from below. Any of these processes may bring warm air from near the surface up to the level of free convection, above which it will rise freely. We have discussed these lifting actions in chapters 4 and 9 and need not dwell on them here.



Most lightning fires occur in the mountainous West and the Southwest. More thunderstorms occur in the Southeast but start fewer fires because of the accompanying rain.

Another triggering mechanism is the further steepening of the temperature lapse rate through advection of cold or warm air. Cold air moving in at high levels will steepen the lapse rate and make the atmosphere more unstable. Warm air moving in at low levels will have the same steepening effect.

Clouds will not form in air containing little moisture even though other factors present may be favorable for thunderstorm development. For cumulus clouds to develop, air must be lifted to the condensation level, and for significant cloud growth it must be further lifted to the level of free convection. The greater the air moisture, the lower the condensation level and the easier it is for the level of free conviction to be reached. Above the condensation level, the heat released in the condensation process tends to make the rising air more buoyant. For this reason, the air need be only conditionally unstable rather than absolutely unstable for thunderstorms to develop when other factors are favorable.

The building upward of cumulus clouds into cumulonimbus may be prevented by layers of air at intermediate levels which are initially very stable or dry. Thunderstorms are unlikely to develop under these conditions even though all other factors favor development.

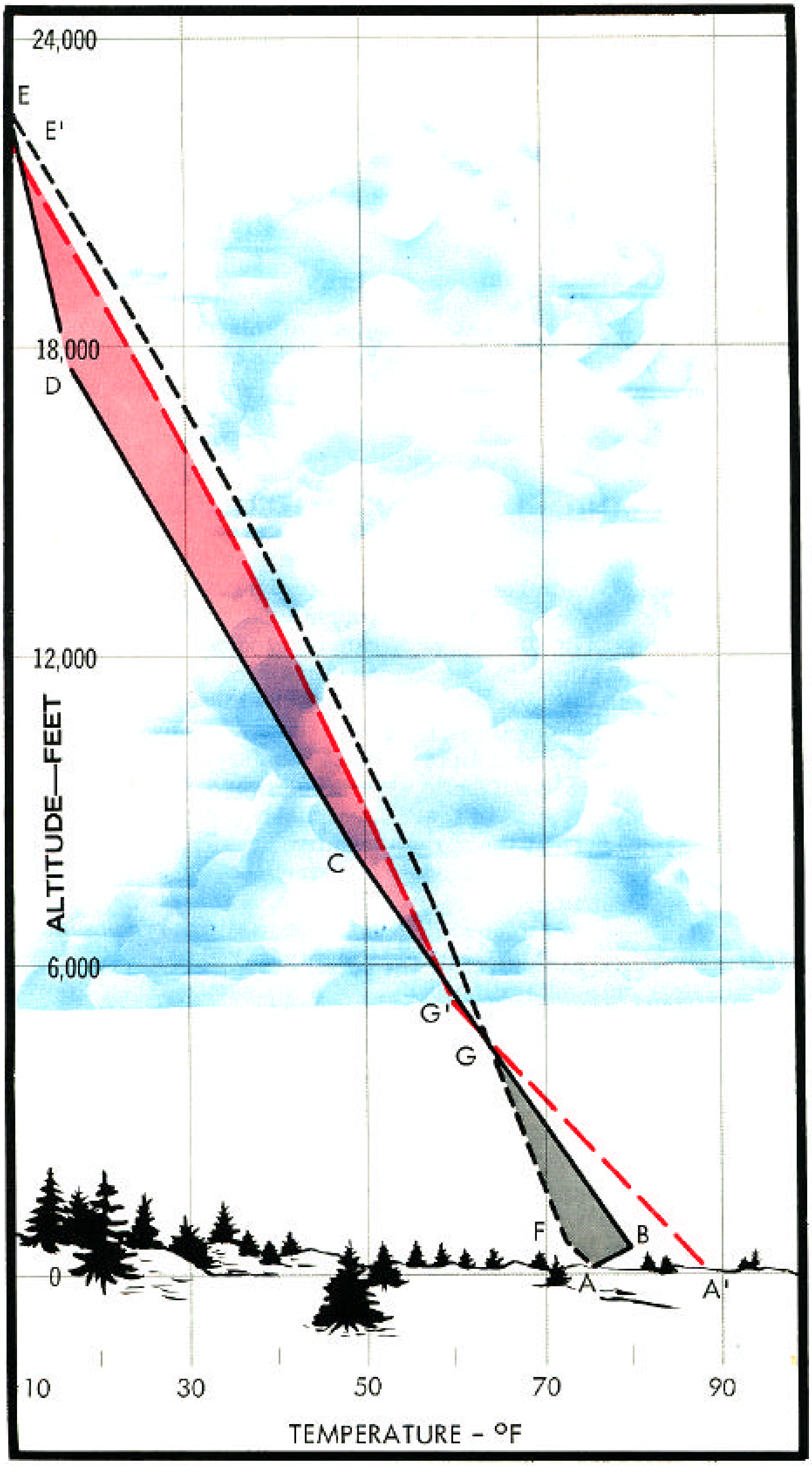
THERMODYNAMICS OF THUNDERSTORM DEVELOPMENT

The development of a thunderstorm in a moist, conditionally unstable atmosphere can best be illustrated on an adiabatic chart. On the accompanying graph the line ABCDE represents the early morning temperature structure of the lower atmosphere. The stable layer AB is the nighttime surface inversion. From B to D, the atmosphere is conditionally unstable since its lapse rate lies between the moist-adiabatic and dry-adiabatic lapse rates. An analysis of the graph will show that convection from the surface cannot take place unless energy is provided either in the form of heating or lifting.

If a parcel at A were lifted, its temperature would decrease at the dry-adiabatic rate of 5.5°F. per thousand feet until saturation is reached, and above that level it would decrease at the lesser moist-adiabatic rate. If the moisture content of the parcel were such that condensation would be reached at level F, the temperature of the parcel would follow the dry adiabat from A to F, then the moist adiabat from F to G and up to E. During this lifting from A to F to G, the parcel would be colder than the surrounding air whose temperature is represented by ABG, and would have negative buoyancy. Without energy being supplied to the parcel to lift it, the parcel would tend to return to the surface. Above the level G, the parcel, with its temperature following the moist adiabat to E, would be warmer than the surrounding air, would have positive buoyancy, and would rise freely.

The area on the graph enclosed by AFGB is approximately proportional to the energy which must be supplied before free convection can take place. It is usually referred to as a negative area. The area enclosed by GCDE is a measure of the energy available to accelerate the parcel upward after it reaches level G. It is referred to as a positive area. In forecasting, thunderstorms are considered to be more likely if the positive area is large and the negative area is small. It must be remembered, however, that whatever the size of the negative area, it represents negative buoyancy that must be overcome before the conditional instability is released.

A common method by which the negative area is reduced is through daytime heating. Suppose that by afternoon on the day under consideration, the surface temperature has increased to A' and mixing and heating have produced a dry-adiabatic layer from the surface to level G'. The negative area would be completely eliminated, and convection of air from the surface to level G' would be possible. Let us suppose also that the moisture content of this layer is such that condensation would take place in rising air upon reaching level G'. Above level G', which in this case would be both the convective condensation level and the level of free convection, the temperature of rising air would follow the moist-adiabatic line G'E'. The air would rise freely, because it would be increasingly warmer than the surrounding air



Thunderstorms con be triggered in a conditionally unstable atmosphere by surface heating. Line *ABCDE* represents an early morning lapse rate, and *A'G'CDE* a corresponding afternoon lapse rate.

up to level D and would remain warmer until level E' is reached. It is in the region from G' to E' that energy is made available. Here, the upward motion is accelerated and highly turbulent.

If more moisture is present in the surface air layers, the rising air parcels reach saturation at a lower level. This has the effect of decreasing the negative area and increasing the positive area. As the atmosphere becomes more unstable, either through heating near the surface or cooling at upper levels, the lapse rate steepens and the line ABCDE tilts more to the left. Again the negative area decreases and the positive area increases. In either case—more low-level moisture or greater instability— thunderstorms become more likely.

The convection column that creates a thunderstorm does not exist as a completely isolated chimney. Friction at the outer surface of the column, between the rising air and the nonrising environment, causes small eddies. Air from outside the column which is slightly cooler, tends to mix somewhat with the rising air, and also to be carried upward. This is called entrainment. Entrainment of cooler air tends to weaken the updraft; nevertheless, the type of analysis given in our example is a good guide to thunderstorm probability.

The moisture content of the air surrounding the updraft also influences thunderstorm development. The entrainment of very dry air may cause the updraft to cease. Cumulus clouds sometimes build upward into a thick layer of very dry air aloft. The cloud particles evaporate, and the cloud disappears because of entrainment. Conversely, if the air aloft is moist, entrainment will help to maintain a supply of water vapor for condensation. Thus, moisture content of the air aloft is an important factor in thunderstorm probability.

Our discussion of the thermodynamics of thunderstorm development has been concerned with air-mass thunderstorms caused by heating. For this type of thunderstorm the parcel method of analysis of temperature soundings is very useful. But thunderstorms may also be produced by frontal or orographic lifting, in which deep layers of air instead of parcels are lifted. Temperature soundings can also be analyzed for thunderstorm probability which may result from the lifting of layers, but these procedures are much more complex, and we will consider them only briefly.

We should recall from chapter 4 that a layer with a lapse rate less than dry-adiabatic stretches and becomes more unstable as it is lifted, even if no condensation takes place. For thunderstorm development, condensation is required and the distribution of moisture through the layer must be considered. If moisture in a lifted layer is adequate and decreases sufficiently from the bottom to the top, the bottom of the layer will become saturated before the top of the layer. The temperature of the bottom of the layer will cool at the lesser moist-adiabatic rate, and the temperature of the top at the greater dry-adiabatic rate until the top of the layer also reaches saturation. This process rapidly produces instability and may result in thunderstorms if the layer is relatively deep. Orographic and frontal lifting of layers often produce thunderstorms protruding from the top of broad, solid cloud masses.

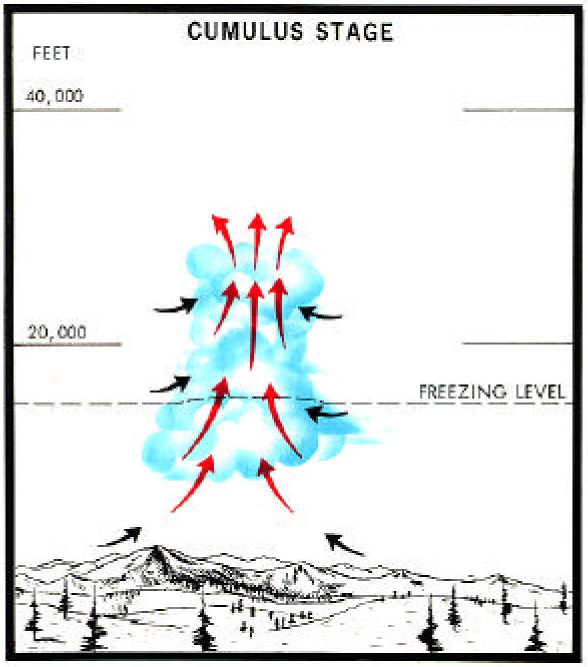
LIFE CYCLE OF A THUNDERSTORM CELL AND ASSOCIATED WEATHER

As mentioned above, the thunderstorms that we see are composed of one or more individual convection cells. A storm composed of a cluster of cells will contain cells in various stages of development and decay. Each cell goes through a definite life cycle which may last from 20 minutes to 1½ hours, although a cluster of cells, with new cells forming and old ones dissipating, may last for 6 hours or more.

Individual thunderstorm cells have many variations in growth and behavior, but typically go through three stages of development and decay. These are the cumulus, mature, and dis-sipating stages.

Cumulus Stage

The cumulus stage starts with a rising column of moist air to and above the condensation level. The lifting process is most commonly that of cellular convection characterized by strong updraft. This may originate near the surface or at some higher level. The growing cumulus cloud is visible evidence of this convective activity, which is continuous from well



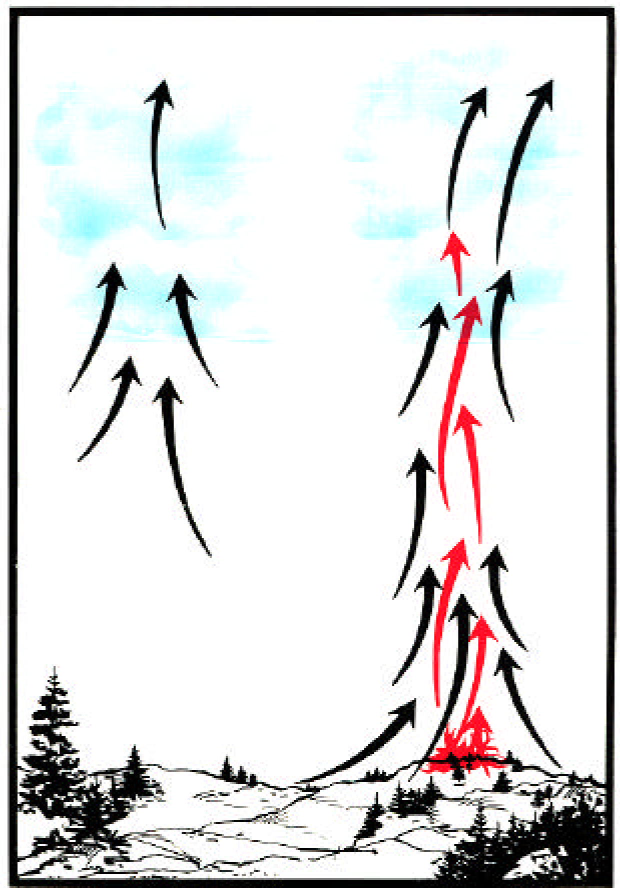
The cumulus stage of a thunderstorm cell is characterized by a strong updraft, which is fed by converging air at all levels up to the updraft maximum, Rain does not occur in this stage.

below the cloud base up to the visible cloud top. The primary energy responsible for initiating the convective circulation is derived from converging air below. As the updraft pushes skyward, some of the cooler and generally drier surrounding air is entrained into it. Often one of the visible features of this entrainment is the evaporation and disappearance of external cloud features.

The updraft speed varies in strength from point-to-point and minute-to-minute. It increases from the edges to the center of the cell, and increases also with altitude and with time through this stage. The updraft is strongest near the top of the cell, increasing in strength toward the end of the cumulus stage. Cellular convection implies downward motion as well as updraft. In the cumulus stage this takes the form of slow settling of the surrounding air over a much larger area than that occupied by the stronger updraft. During this stage the cumulus cloud grows into a cumulo-nimbus.

Cloud droplets are at first very small, but they grow to raindrop size during the cumulus stage. They are carried upward by the updraft beyond the freezing level where they remain liquid at subfreezing temperatures. At higher levels, liquid drops are mixed with ice crystals, and at the highest levels only ice crystals or ice particles are found. During this stage, the raindrops and ice crystals do not fall, but instead are suspended or carried upward by the updraft. Air temperature within the rapidly growing cell in this stage is higher than the temperature of the air surrounding the cell.

Surface weather during the cumulus stage is affected very little. Surface pressure falls slightly. Shade provided by the cloud during the daytime allows the ground to cool, and fuel temperatures approach that of the surface air. Except for cells which develop above a frontal surface, the surface wind field shows a gentle

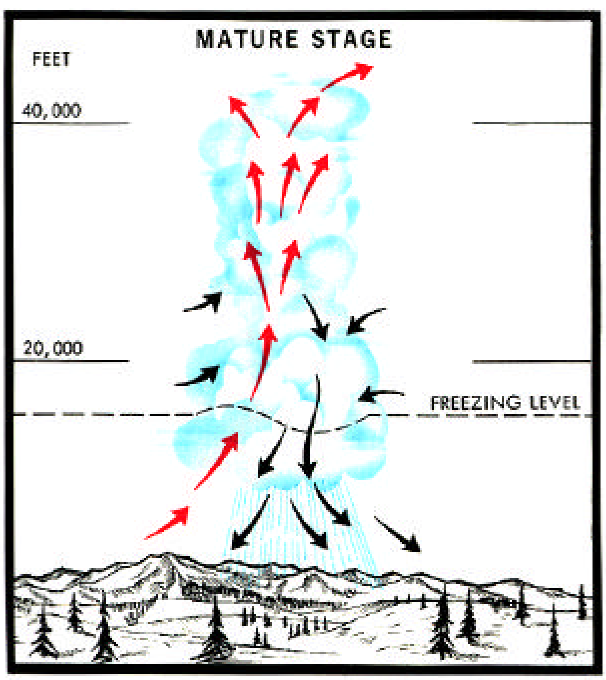


In the cumulus stage, the principal effect of a thunderstorm on a going fire is produced by the updraft. As a cumulus cloud drifts over a fire, the updraft into the cloud and the convection column over the fire reinforce each other. The indraft is strengthened, and spotting potential is increased.

inturning of winds forming the area of convergence under the updraft. The updraft at the center feeds into the growing cloud above. If such a cloud with its updraft passes over a going fire, the convection from the fire may join with the updraft and they may reinforce each other. This joining may strengthen the inflow at the surface and cause the fire to become active.

Mature Stage

The start of rain from the base of the cloud marks the beginning of the mature stage. Except under arid conditions or with high-level thunderstorms, this rain reaches the ground. Raindrops and ice particles have grown to such an extent that they can no longer be supported by the updraft. This occurs roughly 10 to 15 minutes after the cell has built upward beyond the freezing level. The convection cell reaches its maximum height in the mature stage, usually rising to 25,000 or 35,000 feet and occasionally breaking through the tropopause and reaching to 50,000 or 60,000 feet or higher. The visible cloud top flattens and spreads laterally into the familiar "anvil" top. A marked change in the circulation within the cell takes place.



The mature stage, the most active portion of the thunderstorm cycle, begins when rain starts falling out of the base of the cloud. The frictional drag exerted by the rain or other precipitation initiates a downdraft. There is a downdraft in part of the cell and an updraft in the remainder. The updraft is wormer, and the downdraft is colder, than the air surrounding the cell.

As raindrops and ice particles fall, they drag air with them and begin changing part of the circulation from updraft to downdraft. The mature stage is characterized by a downdraft developing in part of the cell while the updraft continues in the remainder. The air being dragged downward by the falling rain becomes cooler and heavier than the surrounding air, thus accelerating its downward fall. Melting of ice and evaporation of raindrops cool the descending air. The change from updraft to downdraft is progressive. The downdraft appears to start first near the freezing level and spreads both horizontally and vertically. The updraft continues in its decreasing portion of the cloud and often reaches its greatest strength early in the mature stage. The speed of the downdraft within the cell varies, but may reach 30 m.p.h. Usually it is not so strong as the updraft, which may exceed 50 m.p.h. The downdraft becomes most pronounced near the bottom of the cell cloud where the cold air appears to cascade downward.

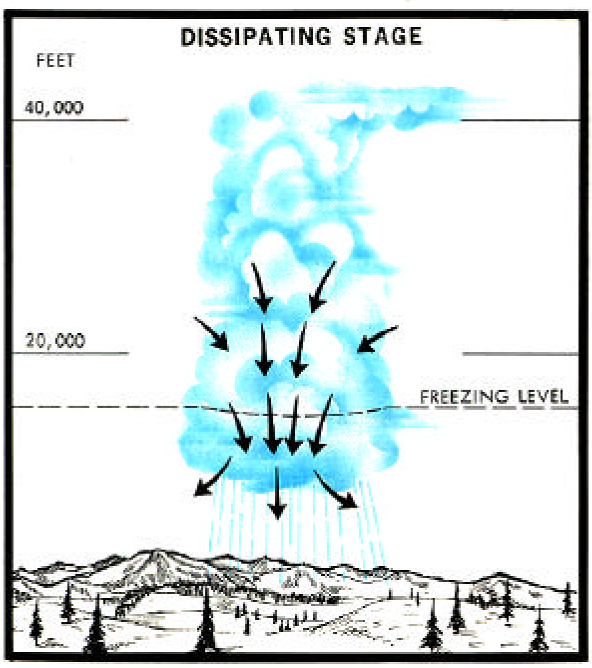
Below the cloud, in the lower 5,000 feet or so above the ground, the downward rush of cool air decreases somewhat. The effect of a fiat ground surface is to force the downdraft to pile up and spread out horizontally as a small, but intense, cold front. This horizontal outflow of air produces a strong and highly turbulent surge, frequently referred to as the "first gust." As this initial surge strikes an area it causes a sharp change in wind direction and an increase in speed. This wind discontinuity is most pronounced on the forward side of the thunderstorm. Here, the storm's movement is added to the speed of the outflow. To the rear, the storm's movement opposes the outflow and makes it much less pronounced.

Because the outflowing air is cold and heavy, the first gust is accompanied by a sudden temperature drop, sometimes as much as 25°F., and a sharp rise in surface pressure. The pressure remains high as long as the dome of cold air is over an area.

The mature stage is the most intense period of the thunderstorm. There is extreme turbulence in and below the cloud, with intense gusts superimposed on the updraft and downdraft. Lightning frequency is at its maximum. Heavy rain and strong gusty winds at ground level are typical of most thunderstorms, though precipitation at the ground may be absent in high-level thunderstorms, which we will discuss later. The heaviest rain usually occurs under the center of the cell, shortly after rain first hits the ground, and gradually decreases with time.

Dissipating Stage

As the downdrafts continue to develop and spread vertically and horizontally, the updrafts continue to weaken. Finally, the entire thunder-storm cell becomes an area of downdrafts, and the cell enters the dissipating stage. As the updrafts end, the source of moisture and energy for continued cell growth and activity is cutoff. The amount of falling liquid water and ice particles available to accelerate the descending air is diminished. The downdraft then weakens, and rainfall becomes lighter and eventually ceases. As long as downdrafts and rain continue, temperatures within the cell are lower than in the surrounding air. As the downdrafts cease, air in the cell is gradually mixed with, and becomes indistinguishable from, the surrounding air. Then, either complete dissipation occurs or only stratiform clouds at lower levels and the separated anvil top remain.



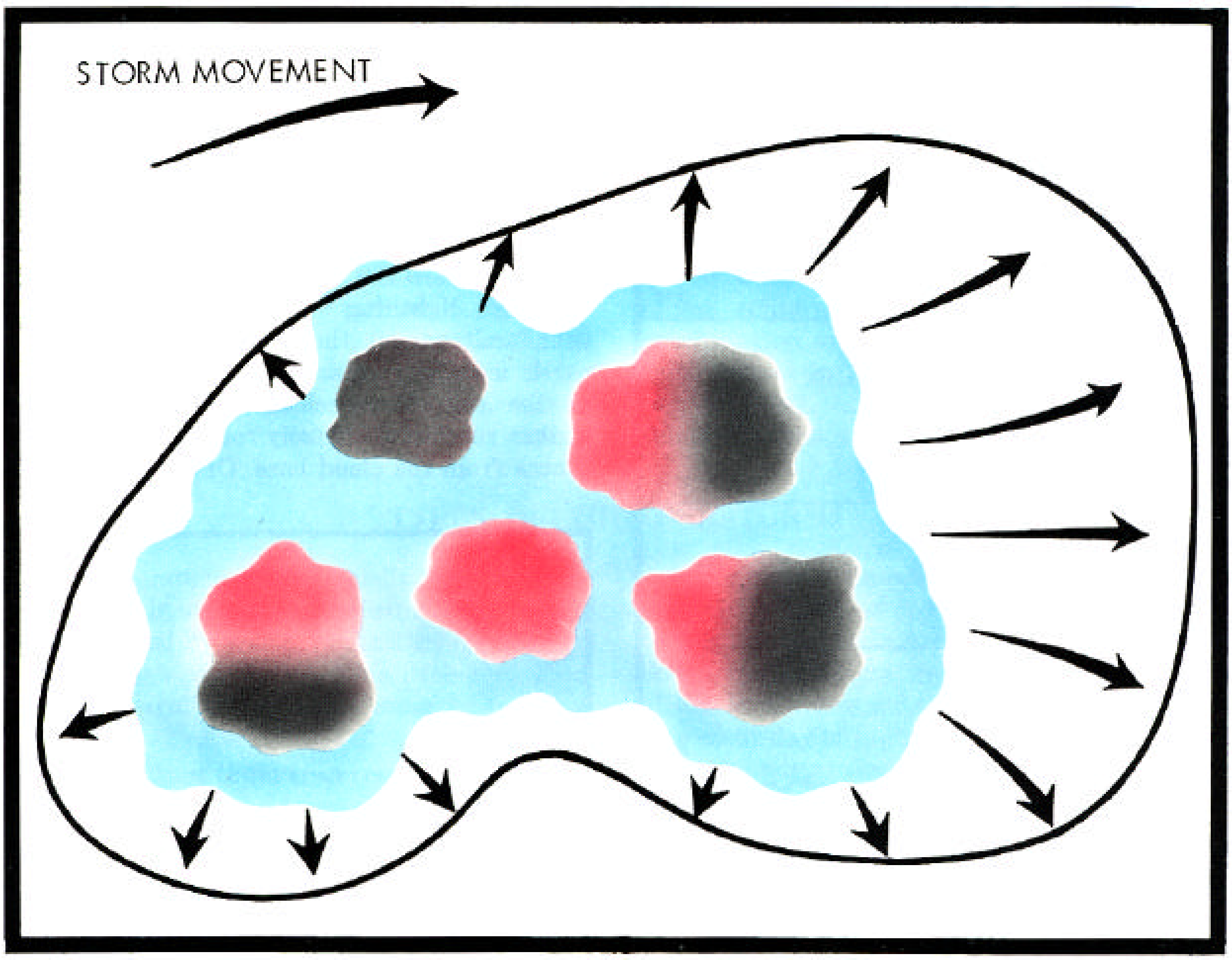
The downdraft spreads over the entire cell, and the updraft disappears in the dissipating stage. Light rain falls from the cloud. Gradually the downdraft weakens, rain ends, and the cloud begins to evaporate.

As the thunderstorm cell dissipates, the surface signs also disappear unless new cells develop. Wind, temperature, and pressure gradually return to the conditions outside the thunderstorm area.

New Cell Development

Although each thunderstorm cell goes through a life cycle, different cells within a cluster at any time may be in various stages of development. As old cells die out, new ones are formed. The downdraft and outflowing cold air appear to be an important factor in the development of new cells. The preferred place for new cell development is the area between two cells where their outflowing cold air collides and causes upward motion in the overlying warm air. The forward edge of the cold dome may also act as a small cold front and cause lifting of warm air and the development of new cells. Local topographic features may also in-fluence the initiation of new cells. A cell may form over a mountain peak and drift off downwind as another cell develops over the peak.

The interaction of cells in a cluster can cause false impressions of the behavior of thunderstorms. Thunderstorm cells usually move in the direction of the airflow in the layer in which they develop but at a speed somewhat less than this airflow. Cell growth, decay and replacement of old cells, and the extension of the storm area by new cell formations may make the storm system appear to split, back into the wind, turn at right angles to the wind, or move faster than the general wind itself. The true movement is difficult to discern from the ground, particularly in mountain topography.



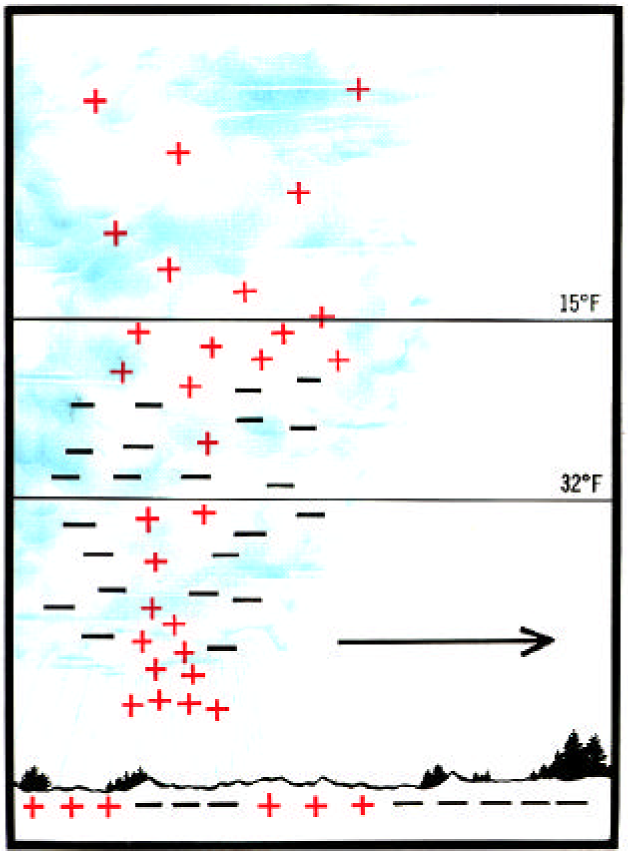
Thunderstorms are often made up of clusters of convective cells, in various stages of development. embedded in a cloud mass. Developing cells have only an updraft (red), mature cells have both an updraft and a downdraft (gray), and dissipating cells have only a downdraft. The downdrafts from different cells often merge into an outflow from the thunderstorm mass.

LIGHTNING

Lightning occurs in a thunderstorm when an electrical potential builds up that is strong enough to exceed the resistance of the atmosphere to a flow of electrons beteeen the centers of opposite charge. Most cloud-to-ground discharges originate in the cloud and progress to the ground. They take place in two stages. First, a leader stroke works its way downward to the ground in a series of probing steps. Then a number of return strokes flash upward to the cloud so rapidly that they appear as a flickering discharge. The average number of return strokes in a lightning flash is four. Lightning discharges taking place within a cloud usually do not show return strokes.

The processes that generate the electrical potential are not fully understood, and a number of theories have been advanced. Regardless of the method or methods by which electrical potentials are generated, measurements with specialized electronic equipment have established where, in the thunderstorm, opposite charges tend to accumulate and how charges vary during storm development.

In fair weather, the atmosphere has a positive electrical charge with respect to the earth. This fair weather potential gradient has an average value of about 30 volts per foot. When a cumulus cloud grows into a cumulonimbus, the electric fields in and near the cloud are altered

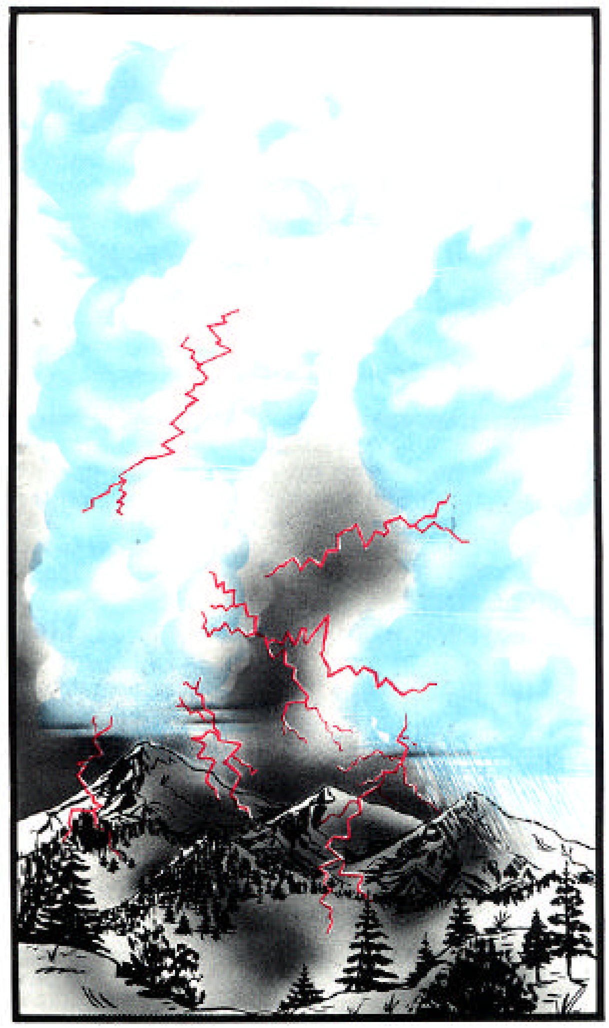


As a thunderstorm cloud becomes electrified, positive charges tend to accumulate in the top of the cloud and negative charges in the lower portion. Smaller positive and negative charge areas also develop. Rapidly falling rain carries positive charges downward and creates a positive charge center in the precipitation core.

and intensified. The upper portion of the cloud becomes positively charged and the lower portion negatively charged, although other smaller positive and negative charges develop. The negative charge near the cloud base induces a positive charge on the ground—a reversal of the fair-weather pattern.

Cloud-to-ground lightning is usually a discharge between the negative lower portion of the cloud and the induced positive charge on the ground and accounts for about one-third of all discharges. Most lightning discharges, however, are within a cloud or cloud-to-cloud. Many of the within-cloud discharges take place between the negative charge in the lower portion of the cloud and a positive charge center carried downward from the upper portion of the cloud by the falling rain in the precipitation core. This positive charge center disappears when the heavy rain stops.

Lightning sometimes occurs in the cumulus stage, but reaches its greatest frequency at the time the cell reaches maturity and its greatest height. The start of rain beneath the cloud base at the beginning of the mature stage marks the onset of the greatest lightning danger. The most extensive horizontal flashes occur at altitudes extending from the freezing level upward to where the temperature is about 15°F. Although lightning may occur throughout a thunderstorm cell, the strongest flashes to the earth usually originate in the lower portion of the cell. Many cloud-to-ground lightning strikes reach out laterally for considerable distances from the cloud base. Once lightning has



Lightning discharges take place within a cloud, from cloud-to-cloud, or from cloud-to-ground. Most discharges are within a cloud or from cloud-to-cloud, but the cloud-to-ground discharges are stronger. Lightning frequency is at a maximum in the mature stage.

started, it may continue well into the dissipating stage of the cell. Apparently, less cloud height is needed to maintain continuing discharges than to initiate the first. But as the height of the cell decreases after reaching maturity, the frequency of lightning flashes decreases. However, individual flashes may remain strong.

The noise of thunder is due to compression waves resulting from the sudden heating and expansion of the air along the path of the lightning discharge. These compression waves are reflected from inversion layers, mountainsides, and the ground surface so that a rumbling sound is heard, instead of a sharp explosive clap, except when the discharge is very near. Since light travels so very much faster than sound, it is possible to estimate the distance of a lightning flash using the elapsed time between seeing the flash and hearing the thunder. The distance to a flash is about 1 mile for each 5 seconds of elapsed time.

Weather radar, in which portions of transmitted radio signals are reflected back from precipitation areas in clouds and displayed as radar echoes on an indicator, is helpful in locating, tracking, and revealing the intensity of thunderstorms and their associated lightning.

TYPES OF THUNDERSTORMS

Thunderstorms are usually classified as frontal or air-mass thunderstorms. The frontal type is caused by warm, moist air being forced over a wedge of cold air. This lifting may occur with warm fronts, cold fronts, or occluded fronts.

Warm-front thunderstorms are usually embedded in large stratiform cloud masses. They are likely to be the least severe of frontal thunderstorms because of the shallow slope of the warm-front surface. Surface wind conditions, in the cold air wedge beneath the warm front, may be unaffected by the thunderstorms above.

Cold-front thunderstorms are generally more severe and occur in a more-or-less continuous line. Their bases are normally lower than those of other frontal thunderstorms.

Thunderstorms occurring along a squall line are similar to those along a cold front, but may be even more severe. Heavy hail, destructive winds, and tornadoes are usually associated with **squall-line thunderstorms.**

Thunderstorms are often associated with a warm-front type occlusion. In this case, they occur along the upper cold front and are set off by the lifting of the warm, moist air. They are usually more severe than warm-front thunderstorms and less severe than the cold-front type.

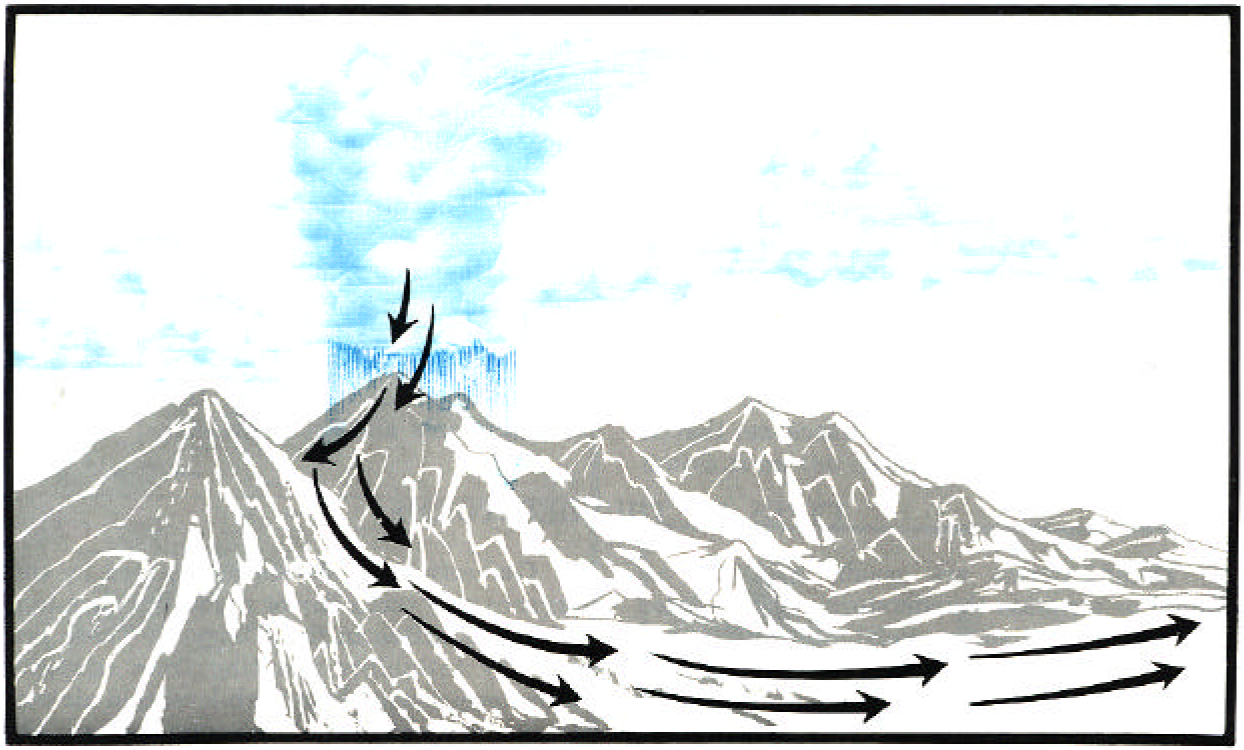
Air-mass thunderstorms are unaffected by frontal activity. They are usually scattered or isolated. Air-mass thunderstorms may be further classified as **convective** or **orographic**, although these lifting processes often act together.

Convective thunderstorms formed by convergence may occur day or night, but they tend to be most active in the afternoon. Those produced by instability resulting from advection of low-level warm air or high-level cold air may also occur day or night. The nocturnal, or nighttime, thunderstorm, which is common in the Midwest during spring and summer, is usually due to low-level warm-air advection and convergence. These storms are among the most severe found anywhere.

Orographic thunderstorms develop when moist, unstable air is forced up mountain slopes. They tend to be more frequent during the afternoon and early evening because heating from below aids in the lifting process. Storm activity is usually scattered along the individual peaks of mountain ranges, but occasionally there will be a long unbroken line of thunderstorms.

One type of air-mass thunderstorm, the **high-level** or **dry thunderstorm**, deserves special consideration because of its importance in starting wildfires. The lifting process may be orographic, convergence, cold-air advection aloft, or a combination of these, often aided by surface heating over mountain ranges. High-level thunderstorms occur most frequently in the mountainous West during the summer months.

Their distinctive feature is that their cloud bases are so high, often above 15,000 feet, that precipitation is totally or mostly evaporated before it reaches the ground. As a result, lightning strikes reaching the ground frequently start fires in the dry fuels. The downdraft and



The downdraft and outflow from a high-level thunderstorm is likely to reach the ground even though the precipitation evaporates before reaching the ground. The cold, heavy air is usually guided by the topography into downslope and downcanyon flow, although flow in any direction is possible.

outflow usually reach the ground even though the precipitation does not. The cold, heavy air is generally guided by the topography into downslope and downcanyon patterns, but cross-slope flow may also occur.

There **are two principal weather patterns which produce high-level storms. One is the inflow of moist air,** usually from over the Gulf of Mexico but occasionally from over the eastern subtropical Pacific, at levels of 10,000 to 18,000 feet. Thunderstorms are set off by lifting over mountains, and by heating and upslope thermal winds at higher levels in the mountains, as the moist air spreads northward from New Mexico, Arizona, and southern California. These storms usually develop in the afternoon and may extend into the evening hours.

The second important weather pattern in high-level storms is the cold Low aloft. With this pattern a closed low-pressure system aloft becomes cut off from the main belt of westerlies. The cold air within this closed Low produces instability and causes convective currents to develop. If sufficient moisture is present, thunderstorms will form. They can develop at any time of the day or night, but are most active in the afternoon when they are assisted by daytime heating. The movement of a closed upper Low is erratic and very difficult to predict. The Low may move in virtually any direction, may deepen or fill, or may be picked up by a trough moving eastward at a higher latitude.

The Far West is a favorite place for closed Lows to develop. They may meander around for several days or a week before finally dissipating or moving on.

TORNADOES

Tornadoes are violent whirling storms which may occur with severe thunderstorms. They take the form of a funnel or tube building downward from a cumulonimbus cloud. These violently rotating columns of air range in size from a hundred feet to a half mile in

A tornado is a violently whirling vortex which occurs with a severe thunderstorm. The rotating tube builds downward from the cumulonimbus cloud. Destruction results from extremely strong wind and low pressure.

diameter. Technically, they are not tornadoes unless they touch the ground, but are referred to as "funnel clouds." When they do reach the ground, they are the **most destructive of all atmospheric phenomena on the local scale.** They travel with a speed of 25 to 50 m.p.h., usually from southwest to northeast, and often skip along. The length of the path of a single tornado is usually just a few miles, but some tornadoes have remained active for more than a hundred miles—striking the ground for a few miles, skipping an area, then striking the ground again, and so on.

The great destructiveness of tornadoes is caused by the very strong wind and **extremely** low **pressure.** Winds in the rapidly spinning vortex have never been measured, but from the destruction it is estimated that winds may exceed 500 m.p.h. The low pressure causes houses and structures to virtually explode when a tornado passes over them. There is a sudden decrease in pressure around the house, while on the inside the pressure changes little. The resulting difference in pressure between the outside and the inside is sufficient to blow the house apart.

Tornadoes have been reported in all of the 48 contiguous States and Southern Canada, but **they are rare west of the Rocky Mountains.** Maximum occurrence is in the central Midwest, and there is a secondary maximum in the Southeast. In Southern United States tornadoes may occur in any month of the year, but farther north the maximum occurrence is in late spring and early summer. They generally occur with prefrontal squall lines, but they may develop with other violent thunderstorms, including those in hurricanes. Tornadoes usually occur in the late afternoon or evening. Their main effect on the wildland fire problem is the resulting blowndown timber in forested areas that often creates high fire hazard.

SUM MARY

Thunderstorms are important in fire control because they start fires by lightning, blow them out of control with the downdraft and outflow, or put them out with rain. In this chapter, to increase our understanding of these severe storms, we have discussed various aspects of thunderstorm development. We have seen that a conditionally unstable atmosphere, sufficient moisture, and some lifting or triggering mechanism are necessary for their develop.ment. Once initiated, thunderstorm cells go through a life cycle consisting of cumulus, mature, and dissipating stages. The most active stage is the mature stage when lightning discharges, the thunderstorm downdraft, and precipitation are all at their maximum.