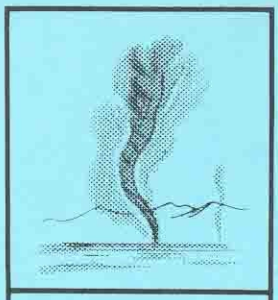
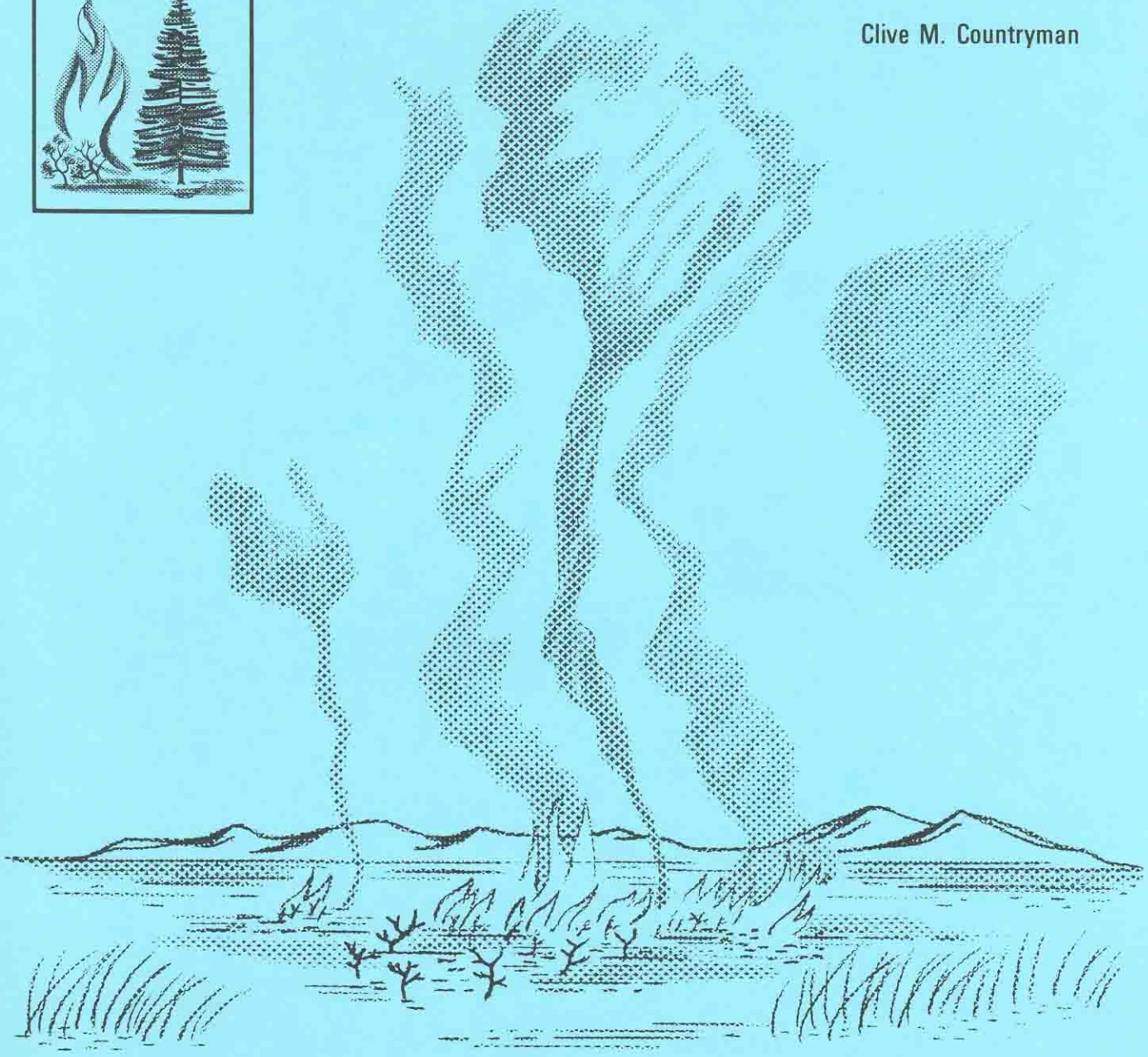


FIRE WHIRLS ...
why, when, and where

Clive M. Countryman



PACIFIC SOUTHWEST
Forest and Range
Experiment Station

FOREST SERVICE
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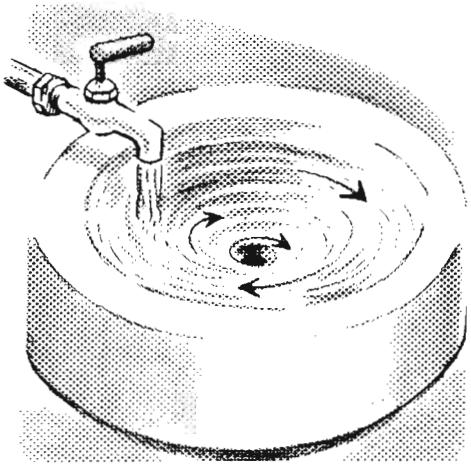
FIRE WHIRLS why, when, and where

"If it hadn't been for that damn fire whirl we would have caught it at 5 acres," yelled the fire boss to his assistant as they watched the fire crews mop up the final smoldering spots in a 250-acre brush fire. The fire had been contained at about 5 acres, and the crew had just started the mop-up work when a fire whirl developed in the heavy fuel near the bottom of a small ravine. Moving out of the fire area, the whirl scattered dozens of spot fires across the fireline. Unable to cope with them all, the fire crew had to abandon most of the fireline and start work anew on the top of the next ridge.

The preceding account is fictitious but many such incidents occur every fire season. Fire whirls—whirlwinds of fire—are spectacular and often frustrating phenomenon. In appearance and behavior, they resemble the dust devils that often develop over strongly heated land surfaces. Originally, the term "fire whirl" was applied only to whirls containing fire. Now it is often used for all whirls that appear in and around a fire, although many of these contain only smoke or other hot gases, ashes, and dust.

A frequent event in wildland fires, the whirls vary greatly in size, strength, and duration. Fire whirls usually originate at the ground surface, but sometimes one develops above the surface and then extends to the ground. Most whirls are small, but occasionally a large one of destructive size and force develops. Airspeed in fire whirls has not been accurately measured, but must be high—possibly exceeding 300 miles per hour in large and intense whirls. In the larger whirls, the damage done is similar to that of tornadoes. In the Polo Fire near Santa Barbara, California, in 1964, for example, a large whirl moved out of the fire, demolished two houses, damaged several other buildings, and slammed a piece of quarter-inch plywood 3 inches into an oak tree. Even in moderate-size whirls, limbs may be twisted from trees and shrubs uprooted. The following discussion explores the origins and characteristics of fire whirls.

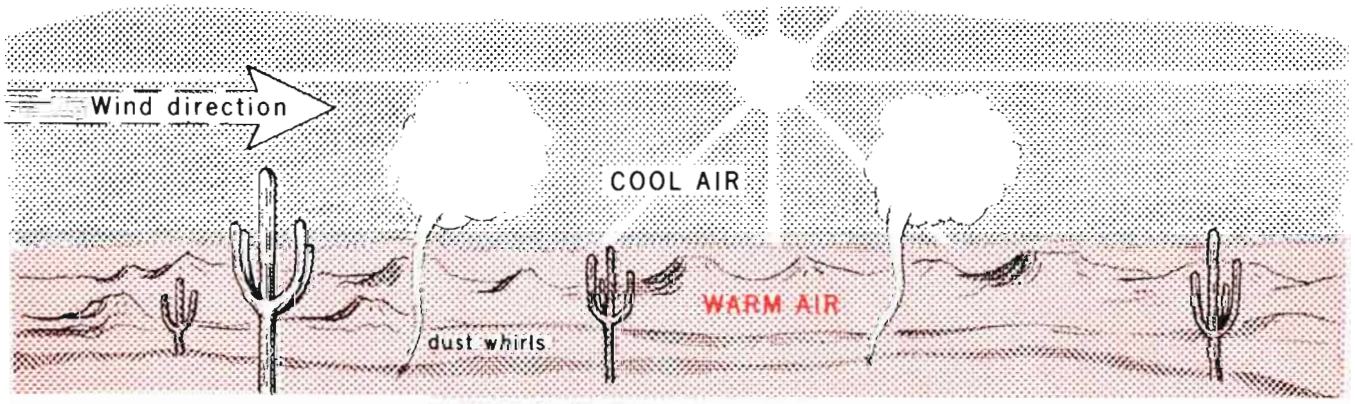
ORIGIN OF FIRE WHIRLS

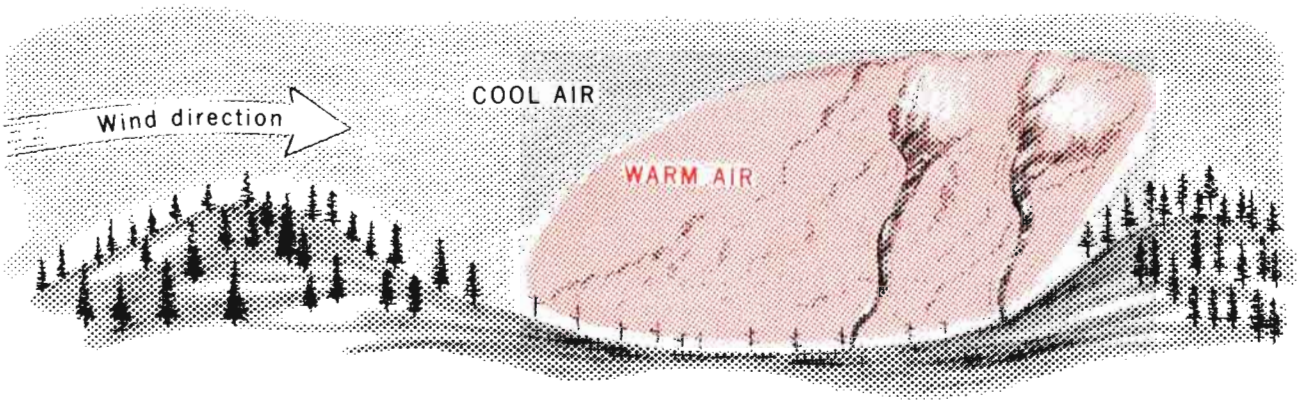


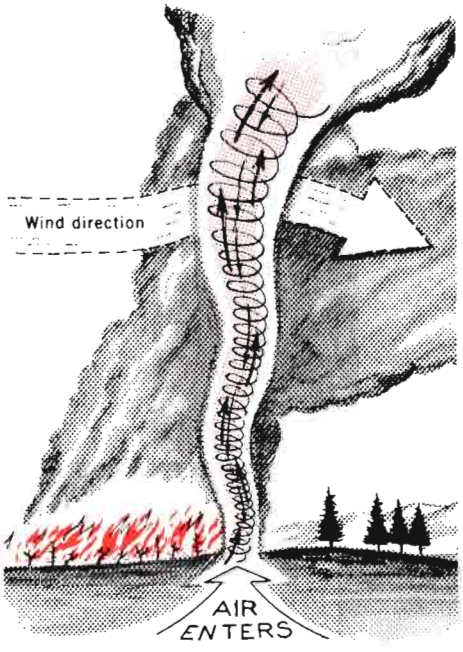
In meteorological terms, a fire whirl is a vortex—a fluid or gas mass with rotational motion. Vortexes are common in nature. Water flowing down the drain often develops a vortex. The familiar smoke ring is a vortex in air. A tropical hurricane is a vortex on a larger scale.

In general, a fire whirl is a stronger and more intense dust devil—in characteristics and mode of development the two are much alike. Both depend on a supply of heated, buoyant air. On hot days when the skies are clear and winds light, dry land surfaces can become strongly heated by the sun—surface temperatures of 165° F. are not uncommon. Under these conditions, a layer of superheated air is formed near the surface. This hot, buoyant surface air tends to rise in columns, which draw in more of the hot surface air as they move along with the wind. Some of the columns develop a strong rotational motion—these pick up dust and debris and become visible as a dust devil.

A layer of hot air overlain by cooler air is an unstable condition, and this in itself can start the updraft columns. More often, however, some sort of "push" is required to start the air moving upward. This may be created simply by wind flowing over some obstacle, such as a rock, small mound, or hill. In a fire area, the air is much more strongly heated than it can be over a surface heated by the sun—air temperatures exceeding 2,000° F. in some parts of the fire are quite possible. Because of the intense heating, updraft columns start almost immediately when the fire is ignited. Except for very small fires, the lower part of the fire convection column is not a homogeneous mass of rising gas, but actually is made up of many separately rising columns—similar to the columns over a sun-heated surface. Like them, also, some of the fire columns develop rotational motion, and a fire whirl is born. Why some of the columns develop rotational motion whereas most do not is not yet clearly understood. Probably some sort of mechanical action, such as friction with obstructions, is required to start the air rotating. Once started, the rotation







is intensified by the upward moving, buoyant air.

The airflow pattern in and around vortexes has some singular characteristics that give fire whirls their marked effect on fire behavior. In the central core of a well-developed whirl—the most visible part—the air movement is likely to be downward. Adjacent to the core, however, is a strong updraft. Speed of the rotating air outside the core is greatest close to the core, and decreases as the distance from the core becomes greater. It is the rapidly rotating air and the updraft that permit the fire whirl to pick up burning material and other debris.

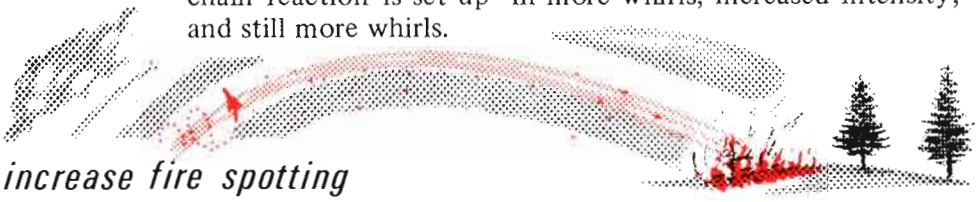
The rapidly moving air and effects of centrifugal force tend to prevent air from entering the vortex from the side. Most of the air must enter near the ground surface where the rotational flow is slowed by friction. Thus, a relatively thin layer of horizontally moving air flowing into the vortex from all sides is created. The size and strength of the fire whirl determines how far from the vortex the airflow—and hence the fire—will be affected. Moderately strong fire whirls about 50 feet in diameter have been observed to affect the horizontal flow up to 500 feet from the whirl itself.

DANGER OF FIRE WHIRLS

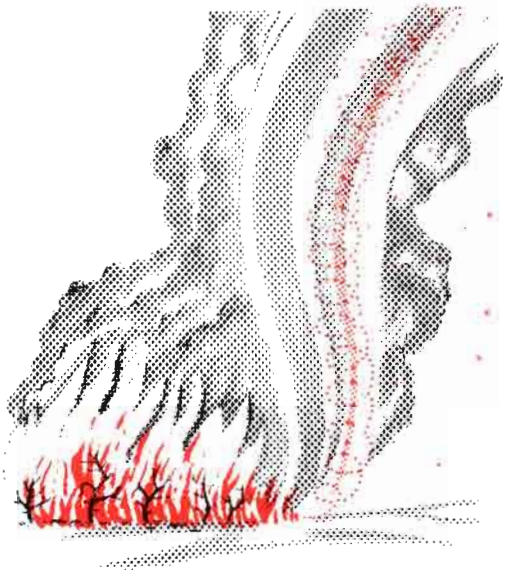
Burning rate is increased by fire whirls

In artificially created fire whirls in the laboratory, it was found that the rate of burning of liquid fuels increased to 5 or 6 times the rate in still air. Although there is little experimental data about the amount of increase for woody fuels, observation indicates it is probably substantial. For woody fuels the increased rate appears to be largely due to the higher windspeeds, both in the whirl itself and in the inflow into the whirl. Since faster burning rate means greater fire intensity, the fire can be expected to spread more rapidly and be more difficult to control when whirls are prevalent.

The increase in fire intensity also makes conditions more favorable for the development of additional fire whirls, so a chain reaction is set up—in more whirls, increased intensity, and still more whirls.



Fire whirls increase fire spotting



The rapidly moving air in a fire whirl, combined with its updraft, can tear loose and pick up burning material and inject it into the fire convection column. There it can be carried farther aloft and ahead of the fire. Thus, when whirls develop, there are more firebrands, and these tend to be larger and hence burn longer, so that they travel farther before they burn out. In southern California chaparral, fire whirls have been observed to uproot and carry aloft whole burning shrubs. In fires with fire whirls, there is likely to be more than usual long- and intermediate-distance spotting.

Fire whirls sometimes remain more or less stationary, but more often move in the direction of the prevailing wind or fire spread. When they move out of the fire area they usually lose their active fire, but scatter their firebrands into unburned fuel a short distance ahead of the fire or across the fireline. The many resulting spot fires can create an intense fire front very quickly.

In some fuels, spot fires start easily and build up rapidly; then the active fire in a whirl that moves out of the main fire is occasionally maintained as the whirl moves cross-country. When this happens, the fire is spread very rapidly on a narrow front, because the whirl can move with about the speed of the prevailing wind—ordinarily fire spread is much slower than the wind speed. This event is most likely to occur on relatively flat terrain, since individual whirls tend to dissipate rather quickly on moving out of a fire in rough country.

Whirls can be hazardous to fire crews

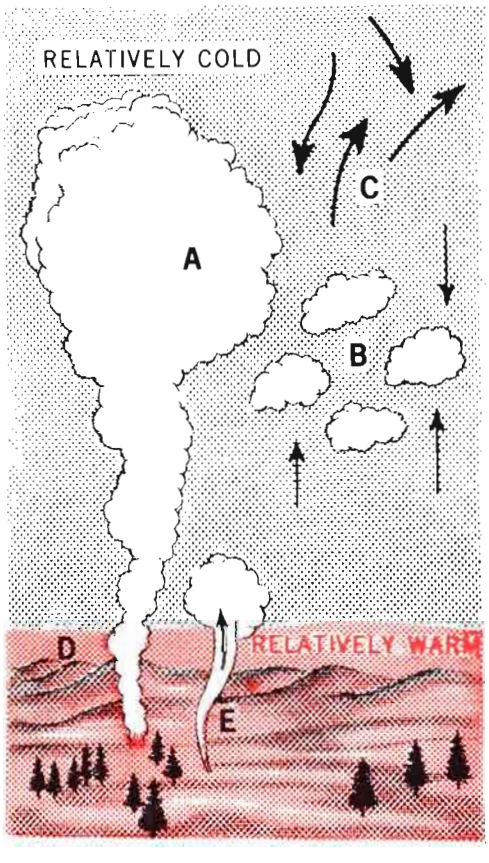
The ability of fire whirls to spread fire rapidly is a constant threat to fire crews. A single whirl can fan back to life even a fire that seems to be nearing control; it can scatter fire extensively across the fireline. When a whirl that moves out of the fire area contains fire, the hazard is obvious. But fire whirls no longer containing fire can also be dangerous. For a short time after moving out of the fire, they contain embers and hot gases, and dust and debris moving at high speed remain in the whirls through most of their life. The whirls may contain carbon monoxide and carbon dioxide, and may frequently be deficient in oxygen. Thus, fireline personnel should avoid whirls, even small ones.

CONDITIONS OF FIRE WHIRL DEVELOPMENT

Fire whirls cannot easily be prevented

Little can be done to prevent the occurrence of fire whirls in wildfires. They are a phenomenon we must learn to live with in fire control. We can, however, note the conditions under which whirls are likely to occur and the places where they develop most frequently. With this knowledge, we can take action to provide for the safety of fire crews and to minimize the effect of the whirls. Primarily by quick control and mop-up of fire areas where whirls can be expected. In prescribed burning, it is possible to minimize the number of whirls, as well as their effects, because the general weather conditions and the firing pattern are chosen by the fire boss.

Atmospheric instability is favorable for fire whirls



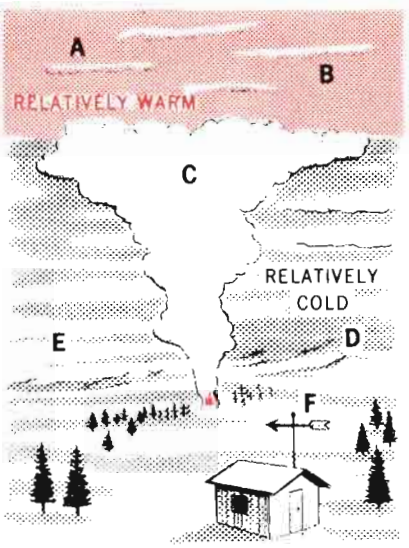
A Clouds grow vertically and smoke rises to great heights.
B Cumulus type clouds.
C Upward and downward
D Good visibility.
E Dust devils.

Atmospheric stability may be defined as the resistance of the air to vertical motion. In a stable atmosphere, a parcel of air displaced vertically tends to return to its original level. In an unstable atmosphere it will tend to keep moving. Atmospheric instability encourages the strong updrafts that start fire whirls. Heating by a fire always creates unstable conditions near the ground, but when the atmosphere in the fire area is already unstable to a considerable height, fire whirls are much more likely to appear than under stable conditions.

To determine atmospheric stability with precision requires special meteorological measurements and rather complex calculations. Usually the fire weather forecaster provides some evaluation of the stability conditions in his fire weather forecast, especially if unstable conditions are expected. But local fire weather forecasts are often not available, particularly in the early stages of a fire. Fortunately, however, there are some indicators of atmospheric stability –most of them visual–that anyone can use to get a general idea of the stability conditions.

In an unstable layer of air there is strong convective activity. Warm air rises rapidly in columns and cooler air sinks to the earth between them. The warm air columns often generate dust devils and thus become visible. Numerous and persistent dust devils hence are a good indicator of unstable air. Fair-weather cumulus clouds–the white, puffy clouds that frequently appear on summer days–are the product of condensation at the top of the warm air column. These clouds, when prevalent, give evidence of unstable air between the clouds and the ground. Towering cumulus clouds, such as those that sometimes build into thunderstorms, indicate greater instability and its extent through a deeper air layer.

The absence of clouds does not necessarily mean the



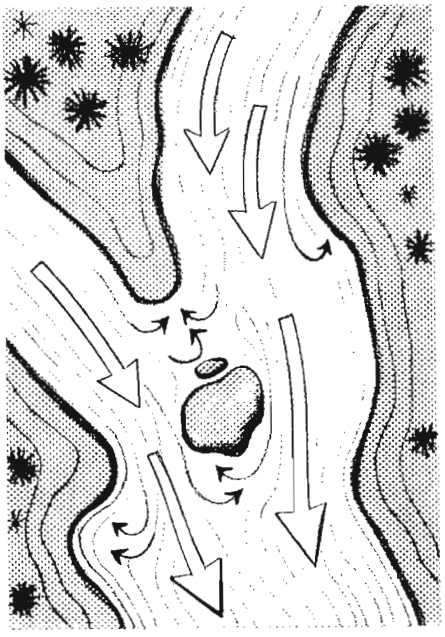
A Clouds in layers - no vertical motion.
B Stratus type clouds.
C Smoke column drifts apart after limited rise.
D Poor visibility in lower levels.
E Fog layers.
F Steady winds.

atmosphere is stable, since the air may be too dry for clouds to form at the top of the upward convective currents. In that event, other indicators must be relied upon. One of these is the effect of the convective columns on the air flow pattern. The inward flow of air into the base of the convection column tends to reinforce and speed up the prevailing wind on the upwind edge, and oppose and slow the prevailing wind on the downwind edge. On the sides of the column the wind may be turned in toward the column. Thus, with unstable atmospheric conditions, the wind is likely to be gusty and wind direction often erratic.

Another indicator is the behavior of the smoke column from the fire. In unstable air, the hot air and combustion products from the fire can move upward more easily, and hence the smoke column rises rapidly to considerable height before spreading out, and remains coherent during its rise. In general, visibility is better in unstable air, because the convective activity spreads dust, smoke, and haze through a deeper layer. Visibility is not as reliable an indicator as some others, however, particularly in the vicinity of a fire.

In stable air, dust devils are few and short lived, or absent entirely. Clouds or fog form in flat layers. Wind speed and direction are generally steady. The smoke column from the fire tends to break up and spread out at low levels. Visibility is often poor.

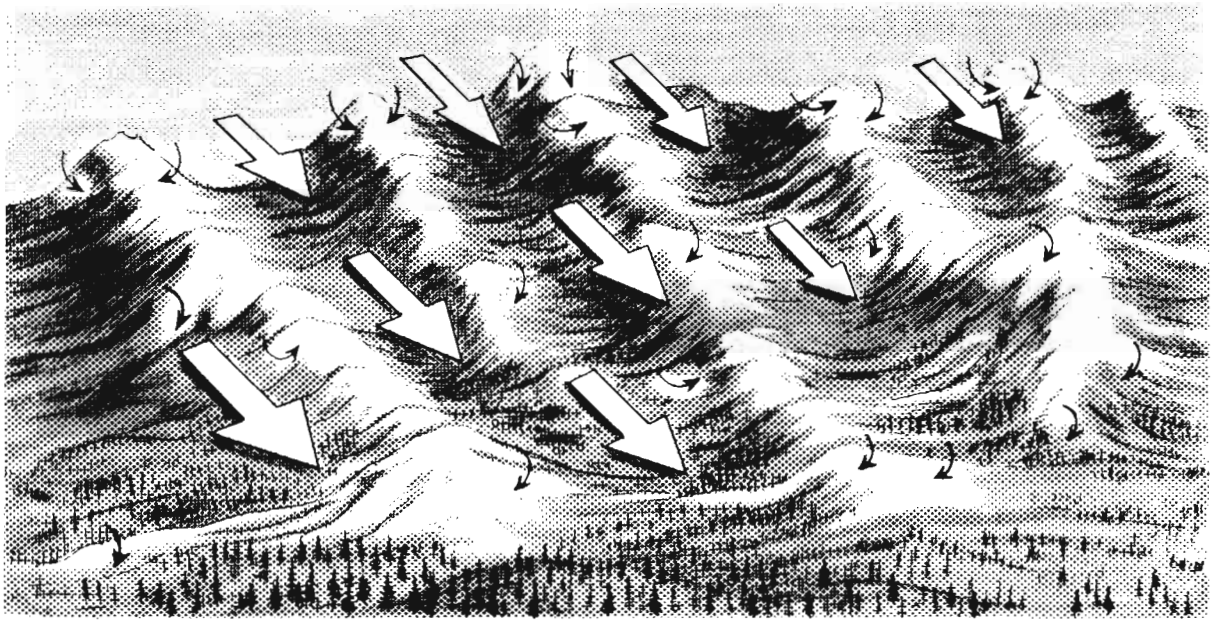
Fire whirls develop in wind eddies



Fire whirls frequently appear in places where eddies in the normal windflow can be expected to develop. The heat produced by the fire appears to concentrate and intensify the whirling motion of the eddy, triggering the start of the whirl and providing energy for its continuance. Thus, wherever an eddy is likely to appear, a fire whirl is possible when the area burns.

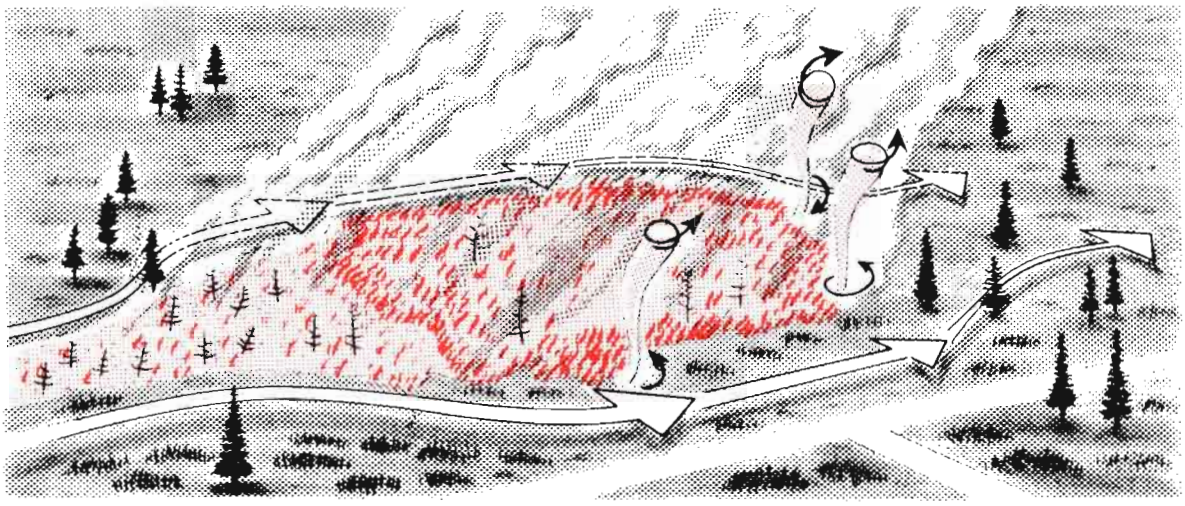
Airflow over the earth's surface is not unlike the flow of water in a stream. Just as obstacles in the streambed or along its banks create visible eddies in the water downstream from the obstacle, so do obstacles create invisible eddies in the air. Thus, we can expect eddies to form on the lee side of obstructions such as ridges, hills, large rocks, clumps of trees or shrubs—anything that hinders the free flow of the wind and changes the speed or direction of part of the air mass with respect to the rest. If the prevailing wind flow is either up-canyon or down-canyon, eddies are likely to be found behind spur ridges, at sharp bends in the canyon, and particularly where two or more canyons come together.

Moving airmasses that differ in temperature, speed, or direction do not mix readily. Where they come in contact, a tearing or shearing action may be set up that can cause segments of the air in the boundary area to rotate and form



eddies. This circumstance is one of the major causes of fire whirls in active fires. The air and combustion products in the convection column are much warmer than the surrounding air, and move in a different direction (upward) and often at a different speed than the horizontal general wind. Because of these differences, the fire may act as a block to the windstream, forcing it to split and flow around the fire, and then come together again on the lee side of the fire. Wind shear, and hence eddies, develop in the boundary area between the windstream and the fire, and some of the eddies become fire whirls.

Whereas some fire whirls develop as a result of the wind shear along the flanks of a fire, they are likely to appear more frequently and be more intense on the lee side of the fire. Here the fire is usually more active and the convection column hotter and stronger. Partly because the fire pulls in air for combustion and partly because a low pressure area generally exists behind an obstruction to airflow, the wind direction on the lee side of the fire is into the fire and opposite to the prevailing wind direction. Speed of the inflow increases toward the fire and reaches a maximum near the fire edge or a short distance inside. Where the inflow is in contact with the general windstream, wind shear develops and eddies are created. The strongest effect is usually near the outside edges of the fire front, and there fire whirls frequently appear. Sometimes fire whirls rotating in opposite directions will develop at both ends of the fire front at the same time. Often the whirls will move out of the fire and downstream with the wind. The development and behavior of these whirls is similar to the eddies that appear near the edges



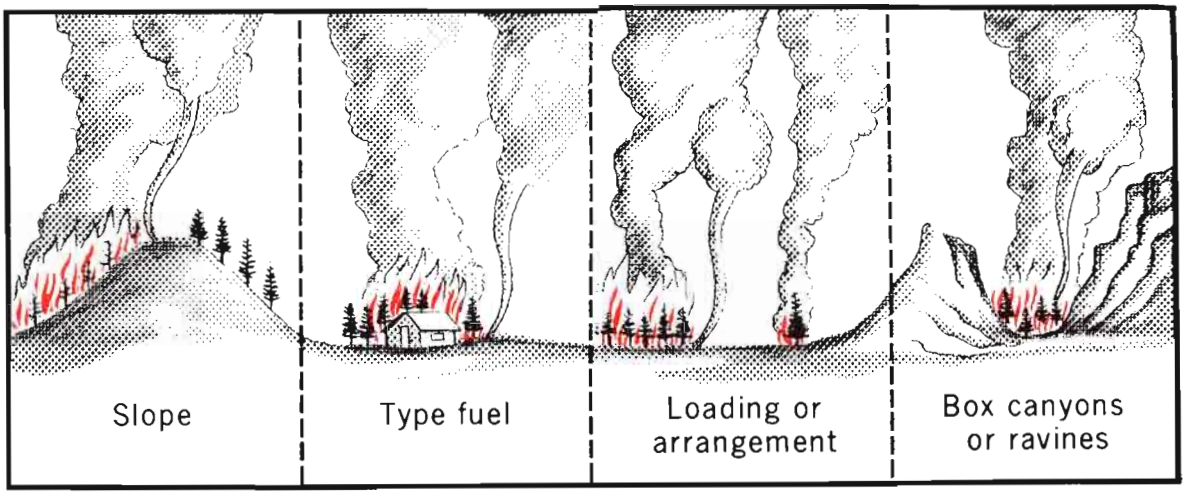
of an obstruction in a stream of water, or the wake eddies of a boat moving through water.

These wake-type fire whirls are most likely to appear in hot burning fires where the active front is deep enough to provide an effective block to the windflow. This can happen in heavy fuels or in rapidly moving fires in lighter fuels. Prescribed burns that are fired so that relatively large areas are on fire at one time can create conditions favorable for wake fire whirls.

Hotspots can trigger fire whirls

Convection in gases or fluids depends on temperature differences. If the temperature of a mass of air is uniform, there can be no convective activity within it. A fire in wildland fuel seldom burns uniformly—some areas are burning intensely while the fire in adjacent areas is dying out. Although all of the air and combustion products in the fire may be hot, the gases in and around the more intensely burning areas will be hotter than the rest, providing the temperature differences needed for convection. The strong upsurge of gases over these hot areas can create fire whirls—much like the upsurge of hot air that starts a dust devil. Once the whirl is started, the hot gases of the fire provide a source of energy for its continuance. Thus, within a fire area, fire whirls are most likely in or near the places where the fire is producing the most heat.

These "hotspots" in a fire area have a variety of causes. Differences in slope, fuel type, fuel loading, or fuel arrangement can cause one area to burn more rapidly than another. Terrain configurations that concentrate heat, such as ravines or box canyons, are often hotter than areas more exposed to



the general wind. Under favorable conditions, even a clump of brush or a single tree crowning out can generate enough extra heat to trigger a fire whirl.

Fire whirls within a hot burning front, although often numerous, are usually short lived. The extreme turbulence in such a fire destroys the whirls soon after they are formed. But after the main fire has died away, the remaining hotspots can continue to be a source of whirls—the kind that often scatter new fire across the fireline.

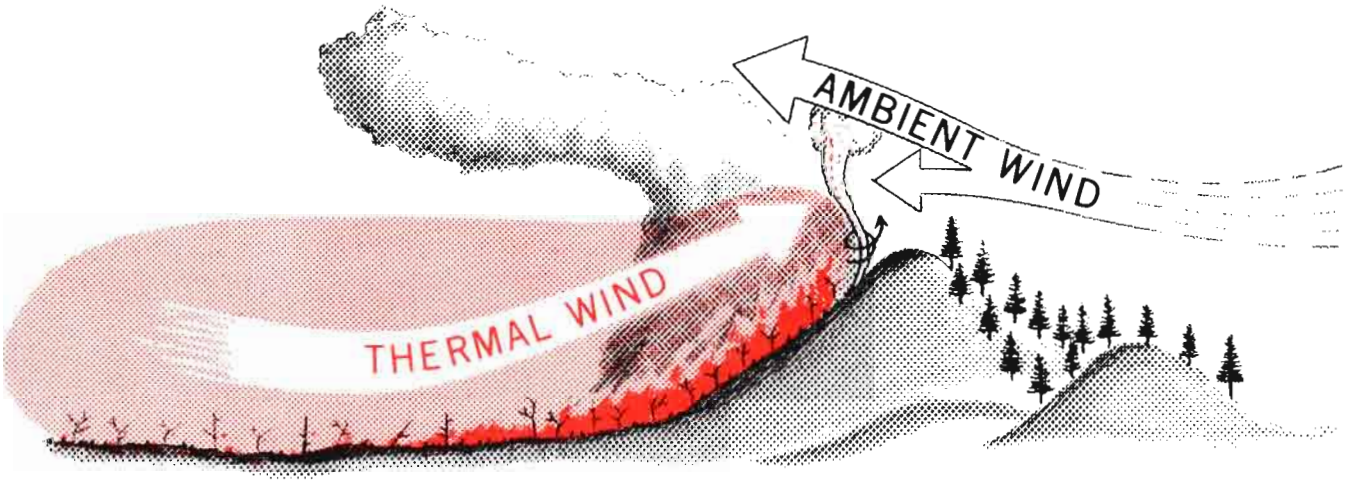
Lee sides of ridges are a likely place for fire whirls

The most favorable situation for fire whirls is a fire burning on the slopes or in the canyons on the lee side of a ridge. Several conditions, any one of which may give rise to whirls, are frequently combined on the lee side of a ridge. The mechanical obstruction of the ridge to airflow causes eddies to form naturally on the lee side. The flow of hot gases from the fire will be upslope, creating wind shear where it meets the cool opposing wind, and intensifying the eddying action. The combined blocking effect of the ridge and the fire causes part of the cool wind to flow over the hot air and gases of the fire area, setting up the unstable atmospheric condition that is conducive to fire whirl formation.

Most of the whirls develop where the hot gases from the fire and the cooler wind meet. Occasionally, several whirls are in motion at the same time along the boundary between the two air masses. Often the whirls remain more or less stationary where they are formed, but sometimes they move laterally along the slope or diagonally downslope, contributing to the spread of the fire along the ridge. The fire whirls are more likely to move when the wind approaches the ridge at an angle rather than straight on.

Lee-side whirls in a wildfire are no more preventable than

those that develop from other causes. About all we can do is recognize their probability and their effect on fire behavior, and adjust fire control operations and safety precautions accordingly. Because lee side whirls occur so frequently, and under conditions when whirls are unlikely elsewhere, their possible effects should be a major concern in prescribed burning. If fire whirls are a threat to containing the fire, the burning operation should be delayed until the wind direction has changed.



SUMMARY

Fire whirls appear frequently in and around wildland fires. Most of the whirls are small and short lived, but occasionally one becomes large and strong enough to do tornadolike damage to forests and structures. Many of the whirls—even small ones—can cause problems in fire control operations. The high windspeeds in the whirl increase the fire intensity and also permit it to pick up burning debris, increasing the amount and extent of fire spotting. Fire whirls pose other hazards to fireline personnel. Through part of their life, the whirls are filled with hot and sometimes noxious gases. Often they contain debris moving at high speed that can cause serious injury to anyone caught in the whirl. Although little can be done to prevent or break up fire whirls in wildfires, we know the conditions under which they are likely to develop and the places they appear most frequently. Armed with this knowledge, fireline supervisors can take action to provide for the safety of their crews and to minimize the effect of the whirls on fire control operations.

An unstable atmosphere is often favorable for the development of fire whirls. Easily recognizable signs of instability include numerous dust devils in the general fire area, fair-weather cumulus clouds, gusty and erratic winds, a tall and coherent smoke plume over the fire, and generally good visibility.

Fire whirls frequently appear where eddies in the airflow can be expected—either the natural airflow or that generated by the fire. Thus, whirls can be expected on the lee side of obstructions, at sharp bends in canyons, and at the confluence of two or more canyons. Since the fire itself may sometimes serve as a block to airflow, fire whirls often develop on the lee side of a fire, particularly near the outside "corners" of the fire front. Fire whirls are often associated with strong convective activity, so within a fire area, whirls are most likely in or near hotspots, such as those created by fuel concentrations or terrain configurations that concentrate the heat from the fire.

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