

Natural Phenomena Exhibited by Forest Fires

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ABSTRACT

Forest fire phenomena are presented through a series of motion pictures and 35 mm slides. These films have been taken by the staffs of the Southeastern, Pacific Southwest, and Intermountain Forest and Range Experiment Stations of the U. S. Forest Service and by Dr. Vincent J. Schaefer during the course of fire research activities. Both regular speed and time-lapse motion picture photographic techniques are employed. During parts of the presentation two motion picture projectors and two screens are used simultaneously to facilitate comparisons of fire behavior under various fuel and weather conditions. The films illustrate certain behavior features of wild fires as well as small-scale experimental fires in forest fuels.

Examination of the natural phenomena of forest fires is related to the International Symposium topic of Fire Models. Analysis of the behavior of large-scale forest fires and smaller scale experimental fires in forest fuels permits critical examination of combustion theory for free-burning fires. Introduction of the atmospheric, topographic, and heterogeneous fuel factors associated with forest fires indicates the complexity of the many variables to be considered in the development of fire scaling theory. Many of the characteristics of forest fires have not yet been measured or analyzed in relation to existing theory. The viewing of forest fire phenomena through the medium of various photographic techniques presents an opportunity to consider some of the courses for future fire research.

Introduction

Forest fires are free-burning fires. Unless restricted by suppression measures the rate of spread, size, intensity, and life cycle of forest fires is governed by natural phenomena in the forest and in the atmosphere above the forest. Complex interre-

relationships of physical, chemical, and atmospheric factors influence forest fire behavior. In particular, forest fire behavior is influenced by fuels, weather, and topography.

In some parts of the world the vegetative cover forms one of the most massive fuel bodies for fire. When extensive areas of certain brush and forest types become critically dry, violent fires may result from almost any ignition source. Wind velocities of 13 to 18 miles per hour or more are often present during fires of the type viewed here, although wind is not an essential prerequisite for violent fire. Such fires display massive flames, an advancing flame front, frequent small and sometimes large flame whirls, a pulsing motion to flames, and extremely rapid destruction of all finely divided fuel particles.

Large forest fires produce great volumes of smoke which vary in character and color in accordance with variations in fuels and rates of combustion. The Dudley Lake Fire shows many distinct phenomena that are typical when a massive wind driven fire develops in a dense coniferous forest. The smoke column is carried forward in a long relatively narrow band perpendicular with the wind. Vertical development of the convection column is restricted by the wind. Relatively small vertical smoke columns develop over the site of more intense combustion. Occasional black puffs of smoke usually come from rapid combustion of coniferous tree crowns and limbs. The main smoke column exhibits an almost continuous cork screw motion.

Massive flames extending 100 feet or more vertically from the fuel body or nearly equal distances horizontally when driven by wind are characteristic of violent forest fires. Flames from burning gases appear sporadically in the convection columns. Topography influences heat transfer by radiation and convection processes. Heat transfer is so intense that fires jump from one side of a canyon to another. As shown in the Topango Canyon Fire, barriers such as roads are of little consequence in stopping the fire spread. Fire brands are lifted in the convection columns and fall out to start new fires. The phenomenon of vegetative cover on an entire mountain being on fire and then moving rapidly to the next mountain indicates the great amounts of energy being released.

The foregoing serve as a brief introduction to forest fire phenomena. Because of the complexity of the many factors in-

volved, it is necessary to attempt to simplify forest fire behavior through separate examination of some of the major variables.

Fuel Factors

Forest fuels are heterogeneous in character. Part of the forest fuel body, commonly known as ground fuels, lies on the forest floor. This fuel complex includes duff, freshly fallen tree leaves, grass, low shrubs, dead tree branches, and down logs. Another part, known as aerial fuels, is suspended above the ground. This includes tree trunks, limbs, leaves, hanging moss, and dead standing snags. Such fuels involve a wide range of surface exposure to weight ratios.

The Dudley Lake Fire, Arizona, illustrates some of the features of rapid and large-scale combustion of heterogeneous fuels. In a 48 hour period some 20,000 acres of mature timber, fresh logging slash, and the normal fuels associated with this type were consumed. Estimates indicate that about 300,000 tons dry weight of forest fuels were consumed. During the peak burning periods fuels were being consumed at a rate of about 22,500 tons per hour.

Close-up views of the Dudley Lake Fire show some of the phenomena existing when both ground and aerial fuels are burning. The fire on the ground is intense and advances wherever fuels are continuous. Fuel concentrations cause heat to be transmitted vertically to ignite the tree crowns. Wind driven flames sporadically travel horizontally through the tree crowns. The flame front travels through the finer fuels. The heavier fuels continue to burn for many hours after the flame front has moved ahead.

The Topango Canyon Fire illustrates fire behavior when the fuel body is composed primarily of small size materials. In this case the fuel body is mainly brush. Green vegetation in brush fields may contain as little as 50 per cent moisture content. Dead vegetation will contain as little as 3 per cent moisture content and measurements of $\frac{1}{2}$ per cent have been recorded. The fuel body on this fire contains about 15 to 20 tons dry weight per acre. Such fuels are extremely flammable and are a major factor in a violent fire such as the Topango Canyon Fire. A nearly solid flame front moves rapidly through the area.

The Intermountain Lumber Fire illustrates fire behavior features when the fuel body is composed primarily of large-size material. The fire is in a log deck containing some 6½ million feet of timber. The log deck contains about 130,000 tons dry weight of fuel. A fire of this type travels slowly, but develops very intense heat. Relatively little smoke is produced in comparison to fires burning in green vegetation. Pulsing flames are shown by the time-lapse photography. Rising currents in the convection column carry some of the chemicals dropped by low flying aircraft upward and away from the fire. Chemicals dropped at the outer edge of the convection column fall to the fuel body at the fire front. Small whirls occur in the flames and in areas adjacent to the fire at infrequent intervals.

Experimental burning of logging slash plots at the Priest River Experimental Forest in Idaho illustrates fire behavior characteristics in fuels containing a large amount of finely divided particles. Each plot contains a measured amount of slash.

Time-lapse photography shows the behavior characteristics of different weight concentrations of logging slash. Light slash plots contain 7.5 tons of fuel, dry weight per acre; medium slash 20 tons; and, heavy slash 32.5 tons. Rate of spread, flame heights, and fire intensity increase as the amount of fuel increases.

Simultaneous projection of time-lapse motion pictures of fires in two different weight concentrations of logging slash permits comparison of fire behavior characteristics. One of these fires is burning in heavy white pine slash (32.5 tons per acre). This fire has an average linear rate of spread of 18.3 seconds per foot. The other fire is burning in light white pine slash (7.5 tons per acre). This fire has an average linear rate of spread of 84.1 seconds per foot. The fire in the greater weight concentration of slash exhibits a well developed convection column and much greater flame heights.

Weather Factors

Weather factors have a major effect on fire behavior. Part of these effects may be expressed in terms of fire spread according to the dryness of the fuels, the amount of moisture in the air,

and wind velocity. These three measurements of weather factors and their effects on fuels have been combined into a single numerical expression known as burning index. Great diurnal changes occur in burning index.

Time-lapse photography with an 84 degree sphere camera during three days of the Coal Creek Fire illustrates variations in fire behavior according to typical diurnal changes in weather factors and burning index. During the afternoon hours the fire produces a well developed convection column and fuel consumption reaches peak intensity. At night the fire dies down. In the early morning hours the valleys are filled with drift smoke and the combustion rate remains at a low level. As air temperature increases and air moisture decreases the fire increases in intensity. Drift smoke clears and the fire again develops a strong convection column. These diurnal changes illustrate the importance of fire environment and especially the importance of weather factors to combustion rates in forest fuels.

Wind is a vital element in fire behavior. The Dudley Lake Fire is a classic example of the violent combustion which takes place when high winds and low humidity occur in a fire area. Winds here range from 20 to 35 miles per hour. During the late afternoon the relative humidity fell to less than 5 per cent. As a result the fire was driven some ten miles and would have gone further had it not run out of the heavy fuels in the ponderosa pine type. The smoke column extends nearly 200 miles downwind from the fire. The smoke is so intense that the fire front is obscured. Measurements from an airplane showed that the maximum height of the smoke column was about 7000 feet above the fire. Without wind the smoke column would be much higher. Under these wind conditions a massive convection column becomes horizontal. Minor vertical convection columns appear for short periods over areas of intense combustion.

Changes in wind direction are of major importance in fire behavior. Upslope winds occurring in the afternoon hours because of thermal activity may become downslope winds in the evening when surface heating is reduced. These downslope winds are especially pronounced when the gradient wind corresponds to the slope direction. Flames which climb upward on steep slopes are bent back down the slope. Under these conditions flames assume erratic behavior. Upslope convection cur-

rents collide with the downslope winds. Pockets of unburned gases periodically burst into flame in the smoke column. The bases of the flames creep into the wind. Firebrands are carried from the upper to the lower slopes.

Dryness of the atmosphere has a significant effect on combustion rates. Simultaneous viewing of two fires burning in identical fuels, but under different conditions of air temperature and relative humidity illustrate the differences in combustion rates. Each of these fires is burning in western hemlock slash, 32.5 tons per acre dry weight. One is burning when dew point temperature is 43, relative humidity, 26 per cent. The average linear rate of spread of this fire is 16.7 seconds per foot. The other fire is burning when dew point temperature is 48, relative humidity, 61 per cent. The average linear rate of spread of this fire is 55 seconds per foot.

Topographic Factors

Steepness of slope, altitude, aspect, position of fire on slope, and the shapes of mountains and canyons are all factors of topography which have an influence on fire behavior. Nearly all of these topographic factors are present in the Coal Creek Fire burning in the rugged mountain country of Glacier National Park, Montana. Wind direction changes at various points because of the shape of the mountains and the direction of canyons. The smoke column changes in both its vertical and horizontal configuration. A fire running up a steep slope changes to parallel the slope as it reaches a point where adjacent topography permits the gradient wind to have effect.

Fires on steep slopes burning during periods when upslope winds prevail have great capability to transfer heat up the slope. As displayed in the Refugio Fire in California, the result may be a massive fire which spreads rapidly and violently. As such fires near the ridgetops, the interplay of thermal and gradient winds causes erratic behavior.

Convection Columns

The convection columns of forest fires display many distinct phenomena. The strong vertical column indicates intense com-

bustion and will extend to great heights (5 miles or more) unless altered by gradient winds. The nature of atmospheric lapse rates may either favor or retard convection column development. Other features of convection columns include whirling motions, rhythmic pulsing, and sudden vertical accelerations.

Time-lapse photography of the Merten Creek fire in Idaho shows strong vertical motion above the fire. The smoke column continues upward until winds aloft break the ascent. Cloud motion indicates the direction of the gradient wind aloft.

Time-lapse photography of the Pungo Fire in North Carolina shows a convection column strongly altered by wind at the surface. However, convective activity is strong enough to permit the smoke to continue vertically as it moves with the wind. Rapid bursts of smoke are visible as new fuel areas burn. A rolling motion continues in the smoke column for several thousand feet beyond the site of initial convective activity.

Photography of a Priest River slash fire shows some of the features of a convection column throughout its life cycle. As the fire grows in intensity a single, well developed convection column forms. While the fire is at its peak intensity, rhythmic, pulsing motion characterizes the flame action. This pulsing continues until the fire passes its period of peak intensity. At this point the main convection column subsides and several small columns appear at the edges of the fire. This sequence of events was observed repeatedly on fires in heavy slash, but was not evident in lighter amounts of fuel.

Occasionally large and violent whirls occur in convection columns. One of the largest whirls viewed to date was seen in the Poleline Fire in Southern California. Estimates indicate a whirling velocity in excess of 200 miles per hour. Both horizontal and vertical motions are evident. The flames extend more than 500 feet into the whirling convection column.

Conclusion

This review has presented a few of the phenomena exhibited by forest fires. Analyses of these phenomena indicate the need for specific measurements of many forest fire factors and for continued study of them in relation to fire theory. Experience with

these fires suggests the need to carry forward some of the research outlined by the NAS-NRC Fire Research Committee. In particular the viewing of forest fire phenomena suggests the need to carry out three specific fire research projects: (1) analyses of existing forest fire data in relation to atmospheric variables, (2) measurements on forest fires, and (3) study of model fires in forest fuels in laboratories where some of the key atmospheric variables may be varied and controlled.