The Nature of 
Lightning Fires

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The prevalence and behavior of lightning fires are of interest to those of us who study the mosaic of plants and animals and attempt to interpret the ecological conditions existing before changes made by man. We at Tall Timbers are particularly interested in those natural processes and principles that underlie the occurrence, abundance, and welfare of the plants and animals that surround us. We are vitally concerned with the ecology of man and his environment. Lightning, and lightning fires assumed a position of great impact on ecosystems before man came to this continent some 20,000 years ago, more or less. As I have discussed many phases of this “fire mosaic” in several previous papers (1962, 1963, 1964, 1965, 1966), let me simply state the obvious: Man did not invent fire or forest fires. They were a part of the natural environment long before the coming of man.

My personal interest as a fire ecologist is to develop an understanding of the many ramifications of fire in nature; its effects on the habitat and on the plants and animals themselves as well. At the same time, however, I wish to point out that as an ecologist I am all too aware that man himself is a creature of his environment —his fire environment if you will. Thus, if man is to be successful in this environment with its great potentiality for fires he must understand the processes that control such an environment. All too
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often we are concerned too much with the final effects instead of the underlying basic patterns of both the living, as well as the chemo-physical world in which we live. It is with these thoughts in mind that I present this paper.

Lightning as a cause of forest fires has long been recognized and a rather extensive literature has developed in the past half-century. Unfortunately, most of the more detailed studies have appeared in publications of specialized interest with limited distribution. Much of this material is not indexed and has found its way into all too few bibliographies. After some 10 years or more of constant interest in a study of this subject, I still continue to find excellent and thorough scientific studies made many years ago that, in a manner of speaking, have been lost in the literature. This study of the nature of lightning, and lightning fires, is based on 22 years accumulation of data on lightning fires by the U. S. National Forest Service as published in its Annual Fire Reports for the National Forests. In addition, I have reviewed the literature quite extensively in the Library of Congress, the National Agricultural Library, the Library of the American Institute of Electrical Engineers, as well as others. I will incorporate considerable data, particularly from earlier studies in publications that are not easily accessible.

First, however, I wish to thank both the U. S. Forest Service and its many workers both in the Washington office and on the forests for their readiness to furnish data. Much time as well as expense was necessary to furnish the information for which I asked. Likewise, members of the staffs of the Environmental Sciences Service Administration have been both kind and helpful in furnishing data ranging from thunderstorms to satellite meteorology.

LITERATURE REVIEW

The U. S. Forest Service has conducted many excellent studies on lightning fires. G. F. Plummer (1912) pointed out the prevalence of lightning and lightning fires in the forests and gave a diagram on “Lightning Zones in Mountain Country.” S. B. Show and E. I. Kotok (1923) recorded much valuable information on lightning fires and included a map showing “Lightning Fire Zones in the National Forests.
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of California.” J. A. Larsen and C. C. Delavan (1922) wrote on “Forest Fires in Montana and Northern Idaho, 1909 to 1919”, and included data on lightning-caused fires. H. T. Gisborne (1926) reported on four years of intensive study from 170 lookout stations in 1922 to 1925 inclusive. He pointed out that in a period of 18 years, 39% of the forest fires were caused by lightning in that region and that, “. . . for the seasons of 1924 and 1925 the figures are 51% and 80%, respectively.” George W. Alexander (1927) summarized data on thunderstorms and lightning fires in the state of Washington on the basis of Weather Bureau and other records for a 20-year period 1904-1923, in that area. H. T. Gisborne (1931-1932) discussed and presented sound evidence on the nature of lightning fires based on a study of 14,754 lightning fire reports in the forests of Idaho and Montana. He gives an annual average of 824 such fires for the 10-year period, 1919-1928, as against only 379 man-caused or unknown fires on 23,000,000 acres of land in that region. William G. Morris (1934) reported on a study “. . . based on more than 6,000 systematic reports describing lightning storms seen by United States Forest Service fire lookouts in Oregon and Washington during the summer months from 1925-1931, inclusive.” Richard E. McArdle and Donald N. Mathews (1934) point out differences in lightning starts in snags and green trees in different areas and stated that over the Pacific Northwest region 42% of the lightning fires started in needles and duff. In this same report William G. Morris reports on lightning fire altitude zones. J. S. Barrows (1954) points out that, “. . . during the 5-year period 1948-1952 over 17,000 lightning fires occurred in the ten Rocky Mountain states. The average annual load of 3,500 lightning fires amounts to 63% of the total number of fires occurring in the rugged mountain country ranging northward from Arizona and New Mexico through Idaho and Montana.” Arnold Court (1960) in two papers gives much data on “Lightning Fire Incidence in Northeastern California and on Thunderstorm Frequency in Northern California.” Donald M. Fuquay (1962) states in a Skyfire Progress Report 1958-1960:

During the 20-year period 1939-1958, lightning caused more than 132,000 fires in the 13 western states including Alaska. About 7,500 lightning-caused fires occur annually in the United States.
In the western United States, lightning is the most frequent single cause of forest fires; in the Rocky Mountain states, 70 per cent of all forest fires are lightning caused. During one 10-day period in July 1940, the National Forests in western Montana and northern Idaho reported 1,488 lightning fires.

Keith Arnold (1964), at our Third Annual Fire Ecology Conference in Tallahassee, presented a paper, "Project Skyfire Lightning Research," and said,

What is the lightning fire problem? Consider this; at this very moment some 1,800 thunderstorms are in progress over the earth's surface. During the next 20 minutes these storms will produce 60,000 cloud-to-ground lightning discharges. Some of them will start fires. This sequence occurs 9,000 times each summer in America's forests and grasslands (including Alaska and Hawaii.) During the period 1946-1962, the United States experienced more than 140,000 lightning-caused fires.

These studies are all by Forest Service and Weather Bureau personnel. These are exceedingly well conducted scientific investigations and there are many others. There is a great amount of scientific data of the highest quality and of much value in these investigations by foresters and as an ecologist, I certainly feel greatly indebted to them. In contrast, studies by plant and animal ecologists on this vital force in nature are practically non-existent.

LIGHTNING FIRES: 1945 — 1966 INCLUSIVE

An analysis by myself of the Annual Fire Reports of the National Forests for the 22-year period, 1945-1966, shows that the number of lightning-caused fires continues to be high. In this paper I have only used data relative to fires on federally owned lands. I have presumed that these are the most accurate. In this respect this data is on the conservative side.

On the 186,497,010 acres of federally owned lands, 168,632 wildfires occurred, during the past 22 years (Fig. 1). This includes all 50 states and Puerto Rico. During this period 64% or 107,160 of these fires were caused by lightning and only 36%, or 61,472 were attributed to man or were from unknown causes. The number of lightning fires ranged from a high incidence of 9,344 in 1961 to a
low incidence of only 2,445 and an average annual figure of 4,871 per year (Fig. 2).

The relation of the number of lightning fires to the acres of land in these same national forests is also of interest. In this 22-year period, the relationship of number of lightning fires to acres of land ranged from a high of one fire per 19,958 acres to a low of one fire per 76,276 acres; and an average of one lightning-caused fire per each 38,287 acres, federally owned (Fig. 3). These figures are nearly unbelievable, particularly when it is realized that the 186,487,010 acres of land considered, included millions of acres that can be classified non-flammable such as roads, water areas, bare desert and certain kinds of deciduous forests where lightning is rarely encountered as a forest fire producing agent. Likewise, areas in buildings are not excluded. Were it not for the supporting data from the studies already referred to in the literature review and others, they would be unbelievable.

This data means that, if the fires were averaged out over this area, each acre would be subjected to at least one lightning fire in less than 50 years. When we consider that the incidence of lightning-caused fires does vary considerably from year to year, and from region to region, then there must have been lands that before the advent of man, burned over from lightning fires periodically during a very short period of time; a ratio in some areas of nearly every three or four years.

**CALIFORNIA LIGHTNING-CAUSED FIRES**

When we study the figures for lightning-caused fires on California national forests we see a much higher incidence of such fires than the national figure. During the 22-year period, there were 25,055 wildfires on 19,370,383 acres of federally owned lands within the California national forests. Of these 69% or 17,056 were caused by lightning and only 31% or 7,999 by man or from unknown causes (Fig. 4). In 1948, the low year, 210 lightning fires occurred, and 1961 was a year of high incidence with 1,764 fires of lightning origin (Fig. 5).

There was an average of one lightning-caused fire for each 24,927
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WILDFIRES ON U.S. NATIONAL FORESTS

168,632 WILDFIRES ON 186,487,010 ACRES LAND

107,160 or 64% CAUSED BY LIGHTNING

61,472 or 36% CAUSED BY MAN OR UNKNOWN

22 YEAR PERIOD 1945 - 1966

Fig. 1. Percentage of lightning-set and man-caused fires on all U. S. National Forests for the 22-year period 1945-1966.

107,160 LIGHTNING FIRES ON U.S. NATIONAL FORESTS

LIGHTNING FIRES PER YEAR AVERAGE 4871

LOW INCIDENCE-1948 --- 2445
HIGH INCIDENCE-1966 -- 9344

186,487,010 acres - 50 states
22 year period -1945 - 1966

Fig. 2. Incidence of lightning-set fires on all U. S. National Forests for the 22-year period 1945-1966.
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107,160 LIGHTNING FIRES
ON
U.S. NATIONAL FORESTS

AVERAGE - ONE LIGHTNING FIRE
PER EACH 38,287 ACRES

LOW INCIDENCE - 1948
ONE LIGHTNING FIRE
PER EACH 76,276 ACRES

HIGH INCIDENCE - 1961
ONE LIGHTNING FIRE
PER EACH 19,958 ACRES

186,487,010 acres - 50 states - 22 year period 1945-1966

Fig. 3. Acreage burned by lightning-set fires on all U. S. National Forests for the 22-year period 1945-1966.

WILDFIRES
ON
CALIFORNIA NATIONAL FORESTS

25,055 wildfires on 19,370,383 acres

17,056 or 69% caused by LIGHTNING
ONLY

7,999 or 31% caused by man or unknown

22 year period 1945-1966

Fig. 4. Percentage of lightning-set and man-caused fires on all California National Forests for the 22-year period 1945-1966.
17,056 LIGHTNING FIRES on CALIFORNIA NATIONAL FORESTS

LIGHTNING FIRES PER YEAR AVERAGE 775

LOW INCIDENCE - 1948 -- 210
HIGH INCIDENCE - 1961 -- 1,764

19,370,383 acres in 17 National Forests
22 YEAR PERIOD - 1945 - 1966

Fig. 5. Incidence of lightning-set fires on all California National Forests for the 22-year period 1945-1966.

17,056 LIGHTNING FIRES on CALIFORNIA NATIONAL FORESTS

AVERAGE - ONE LIGHTNING FIRE PER EACH 24,927 ACRES PER YEAR

LOW INCIDENCE - 1948 ONE LIGHTNING FIRE PER EACH 92,239 ACRES
HIGH INCIDENCE - 1961 ONE LIGHTNING FIRE PER EACH 10,981 ACRES

19,370,383 Acres in 17 National Forests
22 YEAR PERIOD - 1945 - 1966

Fig. 6. Acreage burned by lightning-set fires on all California National Forests for the 22-year period 1945-1966.
acres; a low incidence in 1948 of one such fire to each 92,239 acres and a high ratio in 1961 of one lightning fire for each 10,981 acres (Fig. 6). Thus, it is evident that the incidence of lightning-caused fires in the California national forests is higher than that in the national average; and also that the average ratio of lightning fires per acres of land is larger in California, and that the extremes from low to high incidence lightning years is greater than the national average.

**METEOROLOGICAL BASIS FOR FIRE ECOLOGY**

Since I have presented a paper on "The Meteorological Basis for Fire Ecology" (Komarek, 1967), I shall give only a short review here. All too frequently, we take the weather more or less for granted and do not stop to consider the global patterns of weather that determine our local weather conditions. Thunderstorms, even those that seem rather local, are due to processes of meteorological phenomena, some of which take place far away. To have thunderstorms and consequently lightning, there must be air masses in which certain conditions of temperature and moisture are present. These masses of hot and cold and moist air must meet. Although there are still several theories in regard to the development of lightning, they all are concerned with the friction of rain drops or ice crystals within this electrical generator we call the thunderstorm. Now these conditions can be rather limited, in which event only small local thunderstorms will develop. Then again, if a large tongue of moist, warm unstable air flows up from the Gulf of Mexico or from off the Pacific Ocean, particularly the southern or more tropical part of it, and this meets cold air descending from mountain tops or a cold air mass traveling from the north, we have conditions for thunderstorms over a very large region. The length of one such large thunderstorm area has been reported (Climatological Summary 1966) to have extended for 800 miles in California along the Sierra Nevada. Morris (1934) reported,

Most of the lightning storms in Washington and Oregon have progressively built up ("moved") for a distance of from 11 to 40 miles. Only a few storms have exceeded 80 miles in length.

The lightning fires in western United States have been plotted
(Fig. 7) for the entire 22-year period. Note that the greatest frequency of such fires occurs in southern Arizona and then progresses northward through central California and on into Oregon, Washington, Idaho and Montana. The arrows show the way in which moist, unstable air can come into this region to "trigger" thunderstorms. In the previous mentioned paper I have shown several combined weather and lightning-caused fire maps that show this quite clearly. The same patterns as illustrated in 1965 occurred in 1966.

The topography of the western states with its mountain chains running largely north and south and with the intervening valleys, lowlands, basins, and plateaus usually "open" on the southern end, so that moist unstable air can easily flow northward, is admirably suited for such thunderstorm development. This to a great extent determines the lightning fire zones as portrayed by Plummer, by Show and Kotok and others.

**Direction of Travel of Thunderstorms:**—There is considerable agreement in all studies made in the West that thunderstorms travel from south and southwest to north and northeast about half of the time, and in some years as much as 67% of the time. The two maps by Morris (1934) for Washington and Oregon show this quite well. These are composite maps for all the lightning storms reported during the summer seasons of 1929 and 1930. My data assembled from the fire reports of the California national forests show this same direction of travel as shown in this diagram (Fig. 8).

**Types of Thunderstorms:**—There is agreement by all who have studied this subject that conditions for lightning-caused fires are created by three main types of thunderstorms.

1. The small "local storm"—only a few fires are caused by these.
2. The "general" type storm which occurs over a wide area and literally creates waves of lightning fires for three or more days.
3. The "intermediate" type storm that occurs over a smaller area and then for only a day or two.

Nearly all the "peak loads" of lightning fires occur on these waves of "general" type storms which seem to occur somewhat regularly two to four times a month. Furthermore, when these "pulsating" storms occur after a long drought or when they consist of "dry lightning thunderstorms", and if there is any great amount of
flammbale material in the forest or grassland, they create "fire storm" conditions. And the forest fire fighters cannot control such fires no matter how many men and how much equipment is available. Nature must intervene with a change in weather conditions, a large natural barrier or the fire enters a region of low fuel.
Other Thunderstorm Characteristics:—There is general agreement, as would be expected, that most of the lightning-caused fires occur in the summer months from June to October, but less frequently also earlier and later in the year. Gisborne's chart on the occurrence of thunderstorms appears to be typical of the far western region. He also has written that, at least in his studies, the so-called dry lightning storm did not produce an appreciably larger number of fires and that the condition of the forest as regards to moisture and fuel content was the most important factor.
Some studies have been made on the speed with which thunderstorms move. Gisborne showed that in Washington and Oregon most thunderstorms moved only about six to ten miles per hour. However, from a fire spread viewpoint the winds generated by the thunderstorm itself are most important. Downdrafts occurring as the thunderstorm moves by, can create winds of forty to fifty miles per hour. Also, as the thunderstorm moves on, a wind-shift usually occurs. Thus, winds from one direction during or after the strike may push the fire in one direction. When a wind-shift occurs, and this can be a 180° shift, the fire then moves on a broad front of many miles in width. This is one of the main reasons that fires started by “general” type thunderstorms are so difficult to control.

We have much to learn about the development, movement, lightning behavior, and many other characteristics of thunderstorms. The very rapid development of satellite meteorology by the U. S. Weather Bureau and other agencies offers hope that someday we can, not only understand climatic developments such as thunderstorms, but may be then able to predict when and how they occur on a large scale. By photographing from satellites the development and movement of cloud cover, man for the first time can see such patterns in their entirety. Three of these photographs show three different types of weather development. Figure 9 shows a small tropical disturbance off the coast of Baja, California, of the type that can and does pump moist, unstable air into California and this combined with the hot temperatures of the valleys and the cold temperatures of the mountain ranges produce ideal conditions for thunderstorm development. Figure 10 shows the pattern of development and movement of “mountain waves” traveling down off the Rockies onto the Great Plains. These are not only hazardous to air travel but can push fires rapidly over large areas. Figure 11 shows thunderstorm development over a large section of the mountain ranges of western South America, the Andes, etc. Note the development of the thunderstorms right over the mountains (A), then the maturing of these (B) and (C) where the line of thunderstorms is dying and is characterized by the long line of eastward streamers. Pictures such as these and eventually some with even more resolution, taken 60 nautical miles above the surface of the earth every 23 minutes,
Fig. 9. Small tropical disturbance off Baja California coast, September 20, 1967. (Photo by ESSA National Environmental Satellite—Environmental Sciences Service Administration)

Fig. 10. Mountain wave east of the Rockies, September 12, 1967. (Photo by ESSA National Environmental Satellite—Environmental Sciences Service Administration)
allow meteorologists to study weather conditions on a vast scale. As satellites become even more sophisticated with various kinds of remote sensing devices for wind direction, temperature, barometric pressure, etc., they will certainly reorganize all our thinking on the atmosphere of the earth. The putting of these patterns on movie film with a lapse camera shows the actual movements shortened in time such as the motion pictures we commonly see of flower buds slowly opening and turning into flowers. In fact, satellite meteorology even now is gathering far more data than can be communicated or interpreted and an entire new “breed” of meteorologists will have to develop for its understanding.

AREA OF IGNITION—California National Forests, 1966

**Topography:** The upper third of the mountain slope apparently receives more lightning ignition strikes as shown in Figure 12 and the
remaining areas receive the rest rather evenly. In a recent study in Canada, Kourtz (1967) has reported that,

Sixty percent of the strikes were within the top third of the hills, 19 percent were within the middle third, and 21 percent were within the lower third.

**Fig. 12.** Ignition point by lightning in relation to topography. California National Forests 1966.

**Specific Fuel, Point of Origin:** Most of the time ignition from a lightning strike occurs in the litter, rotten-wood and duff; less frequently in snags or spiketop trees, and occasionally in green trees. This may vary considerably from one area to another, (this was reflected in my figures from forest to forest) and is indicated by Morris (1934).

Needles and duff on the ground formed the most important kindling material. Live trees were second in importance and dead trees third. In several national forests on the west slope of the Cascades, however, dead trees kindled more fires than any other material. Grass was important only in northeastern Washington.
Kourtz (1967) writes that,

Further analysis revealed that 31.1 percent of all the trees that were ignited by lightning were dry snags, and probably only about 5 percent of the trees in the forests of Canada are dry snags. This suggests either that snags attract more lightning or that, when struck, they were more easily ignited than green trees.

There seems to be general agreement that most lightning-caused fires are ignited in the litter and duff on the surface of the forest floor, but dead snags, spike-top trees, or even living trees can also be the point of ignition in considerable numbers in some areas. It should be obvious that heavy litter or duff provides an ideal “set” for lightning-caused fires.

**Fuel Type:** In California national forests, by far most of the lightning-caused fires occur in mature forest: A forest in which trees of saleable value occur. Figure 13, however, also shows that fires can be caused in brush, young forest, grass, slash from lumber operations, chaparral, etc.

**Cover Type:** Figure 13 showing the “cover type” in which lightning fires occur is quite interesting. Note that a large percentage of fires occurred in mixed conifer forests while lesser percentages occurred in pine and fir forests. It makes me wonder how much of this mixed conifer forest is natural and how much of it has been created by fire exclusion in a fire type forest, such as the original park-like ponderosa forests. Here in the West in many of the forests, as contrasted to the Southeast, fire exclusion allows a more highly flammable forest to develop than the original fire type forest. Examples of this might be ponderosa-fir; another, sequoia-white fir and in both instances the fir addition creates more flammable conditions than the original pure sequoia or ponderosa pine. In the southeastern pine forests, fire exclusion permits a build up of hardwood understories that in time become less flammable than the original pine forest. But in both the West and Southeast, the fire excluded forest changes to a forest of decidedly less value.

**Elevation:** In regard to the elevations at which lightning-caused fires occur, Morris (1934) writes,

It has been a common belief that zones of great lightning fire risk exist at high altitudes more frequently than at low altitudes,
because the highest mountains seem more exposed to lightning flashes; but analysis of the altitudinal distribution of lightning fires in the mountains of Oregon and Washington shows that on a given national forest the number of lightning fires per acre at low altitudes is as great as the number at high altitudes if approximately the same number of lightning storms occur over the two areas and if there is sufficient kindling material. The greater number of lightning fires simply occur at the level containing the greater part of the land surface. To determine this relationship precisely, the area of forest land between 0 and 2,000 feet altitude, 2,000 and 4,000, etc., was planimetered from United States Geological Survey topographic maps of three national forests in different parts of Oregon and Washington. In each case, the number of lightning fires which have occurred at each altitude during the 6-year period was directly proportional to the area of forest land at each altitude.

However, apparently lightning fires do occur most frequently on the upper third or top of ridges, small mountain slopes, etc., as shown
by Figure 12. I would like to emphasize here, however, that there can very well be climatic zones where certain atmospheric elements meet that would produce more lightning storms, but not necessarily more lightning fires because of heavier precipitation and different fuel characteristics of the forest.

**Lightning Fire Zones:** Several writers have described the possibility of lightning fire zones and Show and Kotok (1923) illustrate this by a map of the lightning fire zones in the national forests of California. However, Morris (1934) writes:

An attempt was made to construct a map showing comparative horizontal zones of lightning fire frequency. The starting points for 5,500 lightning fires which occurred on the national forests of Oregon and Washington were plotted on a single map. At first there appeared to be a few fairly well-defined groupings of these fires, but further analysis showed that there are not zones of consistently repeated fire occurrence. Detailed study of lightning fire maps for individual days indicates why there is little or no consistent zonation of lightning fire occurrence. Usually, the fires set on any one day are widely scattered throughout the area covered by the storms, which is often 7,500 square miles; but occasionally the storms of a single day set many fires within a small area, giving to that area the appearance of a dangerous fire zone. Several years often elapse before another fire is set in the same locality, even though storms occur over it.

Despite what seem to be differences in regard both to elevation and lightning fire zones by various authors, Figure 14 shows that there are relationships between lightning fires and elevation on a broad scale. The differences by writers may be in part due to local observations. This graph, on only a one-year record of fires, does apparently show that lightning fires are at higher elevations in the southern Sierras and at lower elevations in the northern Sierras and northern California. Checks on other years apparently bear out this assumption. I might point out that this graph, in a way, is quite similar to the zonation of various plant communities and forest types as they range from south to north in accord with well established climatic zones. As an example, the ponderosa pine forest is definitely at lower altitude zones in the southern part of its range as contrasted to its northern range. This is in agreement with other climatic factors.
Fig. 14. Elevation of lightning-set fires in the California National Forests by Forest for one-year period 1966.
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such as temperature. As temperatures are an important part of thunderstorm development it would appear that at least through the summer months thunderstorms probably develop more frequently at certain altitudes depending in mountainous country on latitude, as well as elevation.

Daily Time of Lightning Fires: All studies apparently show that although thunderstorms and lightning fires occur at all hours of the day and night they predominately occur in the afternoon hours. This is quite evident in Figure 15 showing time of lightning fires on California national forests for 1966.

Fig. 15. Time of ignition of lightning-set fires in California National Forests for 1966.
FREQUENCY OF LIGHTNING FIRES

The global aspect of weather patterns responsible for lightning fires is discussed in my previous mentioned paper. I have since graphed the data on all the lightning fires and man-caused fires on a continental basis; on a regional basis; on only those fires that occurred in California, and finally on the basis of what appear to be different lightning fire regions in that state. The six graphs show in varying degree four basic trends (Figs. 16-21).

![Graph showing lightning and man-caused fires on U.S. National Forests from 1945-1966](image)

Fig. 16. Lightning-set and man-caused fires on all U. S. National Forests annually for the 22-year period 1945-1966.

Trend No. 1

I have already mentioned the fact that the summer months are obviously the months of highest lightning fire frequency. However, when the monthly records are analyzed not only for California but on a national basis, such fires do not occur randomly scattered
FIG. 17. Lightning-set fires for the 22-year period 1945-1966 by general regions. Eastern region includes the Southeast.
throughout the summer months. In fact, they occur in what one may call waves or clusters of fires. That is, these fires are ignited on only a few days, relatively speaking, and then only during short periods of from two to five or six days and these periods will occur only two or three times a month. As pointed out in my paper on the meteorological basis for fire ecology, I believe this is part of global weather patterns, not just purely local events.

The fluctuation of such fire activity here in California is shown in Figs. 18-21. This periodicity of lightning fires has been well discussed in a number of papers and all investigators are agreed that they occur in this manner. It is also a well-known fact among those who fight such fires.
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Trend No. 2

The number of lightning fires per year have increased or decreased from year to year in a rather periodic or rhythmic manner in two or three year periods. They have not occurred in a randomized pattern. Now is this periodicity due purely to chance, to a periodic waning of lightning activity, or is it related to some other phenomena of the atmosphere?

Alexander (1927) pointed out a similar "see-saw effect" in precipitation with a periodicity of about three years. Gisborne (1922) had previously suggested such a possibility. Larsen and Delavan (1922) reported that this three-year fluctuation was in possible accord with the cycles of sun activity and weather and with sunspot cycles. In this connection I should like to point out that nearly all summer
precipitation, in particular, is caused by thunderstorms as are lightning fires. Because thunderstorms are gigantic electric mechanisms and as sunspots are electrical phenomena, we may also have a rather rhythmic variation in actual electrical activity, and thus in lightning fires.

**Trend No. 3**

The largest number of lightning-caused fires during this all too short 22-year period occurred in two “peaks” of fire activity; 1950-51 and 1960-61. This period, in length of time, is comparable with the 11-year sunspot cycle, which, however, does vary a year or two from year to year. There is a further hint in older fragmentary records of high fire activity that this same periodicity, varying somewhat from 9 to 11 years, may also be in keeping with present day ideas on sunspot cycles. In fact, the terrific fire period of the 1910's
would appear to fit into this category. I am trying to get together such early records as are available on possible lightning fire periods of the past. It would appear to me from this study that the fires of this past summer in Idaho, etc., are but the beginning of a new cycle of intense lightning fire activity which may reach its peak in the next two years. The next sunspot maxima is predicted for 1969.

Before going on to the next trend, the fourth, in this discussion I would like to digress to discuss the possible harmonic analysis of lightning fire frequencies for if this is possible it might lead to the prediction of such periods. The possibility of the periodicity of such fires being subject to such a harmonic analysis should be investigated by qualified investigators. May I point out that our present ocean
tide tables of low and high tides are the result of such a harmonic
analysis. Schureman (1941) in the Manual of Harmonic Analysis and
Prediction of Tides, points out that,

Sir William Thomson (Lord Kelvin) devised the method of
reduction of tides by harmonic analysis about the year 1867. The
principle upon which the system is based—which is that any
periodic motion or oscillation can always be resolved into a sum
of a series of simple harmonic motions—is said to have been dis­
covered by Eudoxas as early as 356 B.C. when he explained the
apparently irregular motions of the planets by combinations
of uniform circular motions.

Horin (1960) discusses in detail such wave-like patterns in rainfall.
Sabbagh and Bryson (1962) in An Objective Precipitation Clima­
tology of Canada wrote,

Climatologist, in their effort to arrive at the genesis of climate and
to relate climate to associated phenomena, must contend with the
problem of establishing the nature of the climate in a precise, ob­
jective manner. This is particularly difficult when both regional and
seasonal variations of climatic elements are involved. A method of
objectively describing and mapping such variations of space and
time is that of harmonic analysis.

They then go on to say,

The depiction of the annual march of precipitation over Canada
by the harmonic charts reveals the existence of regions having
distinct seasonal characteristics of precipitation. It is possible
therefore, to identify precipitation regimes.

Similar studies and analysis of lightning fires may perhaps show
characteristic behavior of thunderstorms, lightning activity, and iden­
tify lightning fire “regimes.”

Trend No. 4

There appears to be a trend upward in numbers of lightning fires
over the entire 22-year period. The same sort of trend has also
occurred in man-caused fires. In regard to all fires from whatever
cause, Raymond (1961) presented graphs that showed a steady trend
upwards in the number of all fires in California, a downward trend in the acreage burned, and a very decided trend upward in both manpower and equipment costs. Maclean and Lockman (1967) in “Forest Fire Losses in Canada 1965” pointed out that from 1945 to 1965 fire occurrence increased by about 30 to 35% and that “about 25 percent of this increase occurred between 1955 and 1965.” My graphs also show a rather consistent trend in increased number of man-caused fires, as well as lightning fires, for the 22-year period, not only on a national scale, but particularly so for the California national forests.

The increase in numbers of man-caused fires has been attributed to the expanding recreational use of forest land. However, in my opinion, this is not the entire answer for lightning fires have also shown an upward trend.

The increased number of both lightning fires and those caused by man appears to be largely due to increased combustibility of the forest. Man appears to always work towards greater uniformity over vast areas, greater conformity within these areas, and then hopes that time will stand still. Unfortunately, these are human attributes for in nature uniformity and conformity are not the rule and certainly time does not stand still. These dynamic processes such as plant succession, variations in climatic conditions, soils, topography are opposed to man’s efforts. Lightning fire is one such dynamic process and man must learn to live with this fire environment.

SUMMARY

Lightning fires are an integral part of our environment and though they may vary in number in both time and space they are rhythmically in tune with global weather patterns. This periodicity of such fires, monthly, seasonally, yearly, and perhaps even in much longer periods, appears to be subject to a harmonic analysis and if so, then subject to prediction.

The original fire mosaic of plants and animals created by the varying frequency and intensity of lightning fires, in both time and space, has been disturbed by man. However, the causative agent, lightning and lightning-fires still remains with us and our environ-
ment can properly be called a "fire environment." That both the number of lightning and man-caused fires are increasing is evident and so the reason must lie in the condition or man's use of those lands. Man, I fear, has been the unknowing agent of our catastrophic fires for both the forest and the lightning long preceded him.

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