equilibrium with corresponding temperatures and relative humidities as measured under controlled conditions at the Forest Products Laboratory.

Duff.

Relative humidity.	Temperature.	Moisture content.
Per cent.	*Degrees.*	*Per cent.*
25	92	14
29	77	9
56	77	14
70	75	10

Wood.

Relative humidity.	Temperature.	Moisture content.
Per cent.	*Degrees.*	*Per cent.*
25	92	5
29	77	7
56	77	10
70	75	13

Thus it is seen that relative humidity one day may be 25 per cent and the moisture content of duff 14 per cent. The next day the relative humidity may be 29 per cent and the moisture content only 9 per cent. This sort of variation, when it occurs near the danger line of inflammability, as in this particular case, is a very important factor in predicting dangerous fire conditions.

At the Priest River Experiment Station, therefore, moisture content is used directly as an index of inflammability. As the top layer of duff is the material which carries fire through the forest, it is the one which is chiefly concerned in predicting dangerous fire conditions. This is true in the virgin forest with which the Forest Service in Idaho and Montana is mainly concerned in fire protection. In order to measure the moisture content of duff in place, a recently developed duff hygrometer is being used at the experiment station. The instrument consists of a hollow, perforated metal tube containing a strip of rattan which expands and contracts with changes in moisture content and so arranged as to register the changes on a dial attached to one end of the instrument.

Knowledge of the existing moisture content of the fuel, and therefore its existing condition of inflammability, is one of the requirements necessary for making a prediction of inflammable conditions in the forest. The other equally important requirement is a thorough weather forecast, in order to know whether the forthcoming weather will bring conditions making for greater or less moisture in the atmosphere and thus greater or less moisture in the fuel. The weather forecast, of course, should be of such a nature as to give this information—whether the changes in the moisture of the atmosphere are to be influenced by rain, temperature, cloudiness, or other elements.

Although relative humidity is the most important factor involved in the moisture content of the débris on the forest floor, it is not by any means the only factor which must be taken into consideration. Without going into the subject too deeply, some of the other factors may be mentioned. For instance, the duff moisture contents resulting from various amounts of rainfall must be determined. The rate of drying out of duff and other materials after receiving various amounts of rain must be known. The effect must also be known of a given quantity of rain occurring in one hour, for example, as compared with the same quantity occurring evenly distributed through a much longer period. What is the relative amount of rain reaching the duff through the forest canopy as compared with that falling freely to the ground in the open? What, under various conditions, is the effect of temperature, humidity, and wind velocity in the drying out of duff after a rain? What are the moisture contents of duff, twigs, branches, down logs, and such materials, under all the possible combinations of temperature and humidity commonly experienced during a fire season? And so on.

It is desired to point out, in closing, that the weather forecast and the existing condition of the fuel are both necessary in predicting dangerous forest fire conditions. Weather forecasts in themselves are not sufficient as fire warnings; nor are the records of measurable conditions on the ground alone sufficient. The Forest Service can determine the prevailing conditions of inflammability, but is dependent on the trained meteorologists of the Weather Bureau for accurate and complete forecasts of what the weather is to be. It is realized that it is exceedingly difficult to make the sort of detailed weather forecasts that are needed. In this connection, Mr. Beals stated in a recent article in the MONTHLY WEATHER REVIEW:

> The making of reliable fire weather warnings is even more difficult than the making of frost predictions; and in the latter case it has been proven that the most satisfactory method is to obtain all the information possible regarding the past weather, and then have a man on the ground capable of amplifying a general forecast to meet the conditions over a small area.

This suggests the possibility of having a meteorologist of the Weather Bureau on the ground to work side by side with the men of the Forest Service who are conducting the fundamental fire studies in several localities in the West. So far as the prediction of dangerous fire conditions is concerned, it is believed that this would be one of the most effective ways in which the Weather Bureau could help in the solution of the forest fire problem.

FOREST FIRE WEATHER IN WESTERN WASHINGTON.

GEORGE C. JOY, Chief Fire Warden.

[Washington Forest Fire Association, Seattle, Wash., September 15, 1923.]

In discussing the subject of forest fire weather in western Washington, I will take up only that phase of the weather which is the cause of crown fires in the Douglas fir region of our State.

The localities which are susceptible to such fires are the Douglas fir and white pine regions of North America. The Douglas fir region is located between the forty-third and fifty-third degree of North latitude; the summit of the Cascade Mountains on the east and the Pacific Ocean on the west. The center of this zone north and south is near latitude 47° north. The zone comprises an area approximately 650 miles long by 150 miles wide.

In the white pine region the conflagration zone is central along latitude 47° north from the foothills of the west slope of the Rocky Mountains to the Gulf of St. Lawrence.

During the past 100 years 15 great fires, of which we have more or less record, have occurred in these two regions. Six of the 15 fires referred to have occurred in the Douglas fir belt during the past 50 years. One who is

familiar with the lore of the fir region can find chronicled therein other great fires dating back beyond the discovery of America.

Our fir forests grow and thrive under the normal climatic conditions peculiar to the North Pacific coast region west of the Cascade Mountains. The whole region is wet; the prevailing westerly winds carrying the moisture in from the ocean, where it is condensed by the chain of high mountains and falls on their western slope.

As long as normal weather conditions prevail, the summer season is marked only by fires that are local in their character; their spread being due to diurnal convectional disturbances of the atmosphere, to local winds, or to a rough topography. Such fires are usually confined to small areas, and, as a rule, they are not difficult to control. I do not wish to minimize the danger from such fires, for occasionally they do considerable damage before being brought under control and they form the nucleus for larger fires.

It is when the *normal weather* conditions are jostled out of their equilibrium and the Douglas fir region is flooded with the hot dry air from the arid regions of the western part of the United States and Canada that the forest fire peril becomes imminent and fires are immediately fanned out of control, sweeping irresistibly over vast areas without regard to the topographic nature of the country. When this occurs, man is powerless and only a change in the wind will avail to stop them.

The fact that not more than six great fires have occurred in the fir belt during the past 50 years will give one an idea of the irregularity and infrequency with which they occur. Our fir forests are here because of this fact. No doubt such periods of fire weather have occurred more often than the foregoing record would indicate, but they have passed unnoticed for the reason that at the time of their occurrence no fires were started where they would sweep over and destroy large bodies of timber. *It should always be kept in mind that it takes two things to cause great forest fires, viz, the right condition of the weather and a fire in the right location.* Such a combination has not often occurred in the past, but the prospects are that it may occur more often in the future. Weather conditions will continue as they always have, but the chances of fire being started have increased a thousandfold. The potential danger is increasing and the possibilities are that some day the Douglas fir region will be devastated by a conflagration far surpassing any such disaster of the past. The stage was set for such a climax on August 1, 1922, but it did not occur as the right kind of weather did not materialize.

What element is it that causes such a disturbance in our normal weather conditions; that changes an easy fire situation into an alarming dangerous one overnight? For that is what does occur.

In the MONTHLY WEATHER REVIEW of February, 1914, Mr. E. A. Beals, then in charge of the Weather Bureau office at Portland, Oreg., discussed the value of weather forecasts in the problem of protecting forests from fire. Since that article was written we have had time and opportunity to study and observe the effect of weather conditions as affecting fires. The result of these observations and of our experiences have been such as to convince us that Mr. Beals's statements and conclusions were correct in every particular.

All of our trouble comes to pass when a high and a low pressure area are in such relation to each other as to cause the wind to blow across western Washington from off the high arid regions of eastern British Columbia, eastern Washington and Oregon, southern Idaho and Utah.

A glance at the charts of the normal relative humidity of the United States for the summer months shows the lowest humidity to be in the great basin situated between the Cascades and Rocky Mountains, and extending from Arizona to central Idaho. The altitude of this region is from 2,000 to 4,000 feet.

When a high pressure area is in the right position, it causes the wind to blow off this region toward western Washington. This wind is hot and dry when it begins its journey and in its ascent to the east slope of the Cascade Mountains decreases in temperature at the well-known rate of 1.6° for every 300 feet of elevation. In its descent of the west slope it increases in temperature at the same rate, but it descends so much lower than it ascends that its temperature at tidewater is considerably greater than it was when it began its journey westward. As a result its capacity to absorb moisture has increased at an increasing rate, and this is why a fire which to-day is docile and easy to control, breaks all bounds on the morrow and sweeps irresistibly onward over valleys and hills, leaving death and destruction in its path. Such a situation is brought about by the desiccating effect of these winds. If this condition of weather prevailed over western Washington for only the summer months, there would be no Douglas fir region.

The abnormal condition is brought about by the development of a high pressure area in Alaska, British Columbia, or the North Pacific Ocean. Trouble begins immediately when this HIGH starts on its journey southeasterly across the States of Idaho, western Montana, Utah, Wyoming, and Colorado. Coincident with this movement, a LOW develops in southwestern Arizona and usually advances northward through central California, up to Sacramento Valley, and breaks over the barrier of mountains at the California-Oregon line, flooding western Oregon and Washington, and often extending into British Columbia.

The first effect of the HIGH is felt when it appears north of the Canadian border. Northerly and northeasterly winds are prevalent. As these are descending air currents from over a hot, dry land surface their desiccating effects are soon felt. As the HIGH advances to the southeast, these descending air currents, which flow spirally outward clockwise, cause the wind to veer and come from a more easterly direction. It keeps on changing its direction until a southeasterly course is reached, when a HIGH usually disappears and the atmosphere begins a new formation of its forces.

The severity of such a spell of weather is dependent upon the relative position the HIGH bears to the LOW; the difference in the extremes of pressure, and the length of time the HIGH takes in passing.

It will be observed that the winds are first northerly, veering to the east, and then coming from a southeasterly direction. A glance at the temperature and humidity charts of the western part of the United States will serve to demonstrate why, when the wind is from a southeasterly direction, our fire hazard is greatest. All of our large crown fires—real conflagrations—have spread in a northwesterly direction.

Humidity of the air is determined by the temperature, distance from the ocean, the inclosure of mountains, and the altitude. All of these factors are present in the direction from which our southeasterly winds blow.

One of these spells of weather occurred from May 26 to June 4, 1922. On May 26 and 27 a large HIGH appeared in southern British Columbia. At the same time a LOW developed in southern New Mexico and southeastern Arizona. On May 29 the southern end of the HIGH was

central in northern Montana, and the LOW had advanced to southwestern Arizona.

On the 31st the HIGH was central over southeastern Montana, and the north end of the LOW had advanced up the coast to Vancouver Island, and seemed to be central in the Pacific Ocean just off the entrance to Grays Harbor. The isotherms on the weather map for that date show that the highest temperature in the western part of the United States was a spot about 70 miles in diameter on Grays Harbor. At Seattle the temperature jumped to 89°, and at Aberdeen to 93°; both abnormally high for western Washington. The prevailing winds were southeasterly, and in some localities were very strong. The relative humidity went to 21 per cent.

The fires which had been fanned into life during the preceding six days now became uncontrollable. One fire covered 25,000 acres, and destroyed more than half a million dollars' worth of property in an afternoon. This happened six days after a heavy rain had fallen, with all forest material soaked through and through. But these six days had been hot, windy, and dry. The moisture evaporated from the moss on the trees, the leaves and scaly bark; the feathery rotten wood on dead trees; the resinuous spills on the branches; the dead ferns and fireweed; all these became as tinder.

It is worth while to note that this HIGH rotated clockwise; that its nose first pointed southeast on the 27th, on the 29th it was a little to the southwest, on the 31st the elongation was southeast and northwest, on June 1 it had rolled northeasterly, and on June 5 had completely disappeared. It had occupied 10 days in passing—an unusually long time. Its strongest effects were felt when it was central over southeastern Montana and northeastern Wyoming.

At the time of the great Columbia fire, on September 12, 1902, the HIGH and the LOW occupied the same relative position to each other.

As soon as this HIGH disappeared, the weather conditions in western Washington immediately became normal; fires died down, were easy to control, and ceased to run.

Right here I want to emphasize the statement that the danger of a conflagration is just as great—and it as frequently occurs—in the spring of the year, when all forest material is damp and wet, as in the autumn following a dry summer. The rapid heating of the atmosphere in the spring as the sun advances north gives the air a greater capacity to absorb moisture than in the fall when it is cooling off

All of the large fires in the Douglas fir region are caused by descending winds blowing outward from a HIGH.

In his discussion of the subject, Mr. Beals states "that in the case of the Michigan fires, and the Hinckley fire in Minnesota, the air currents were ascending and blowing inward toward a LOW."

I have not given this phase of the subject sufficient study to warrant me in making a statement as to why such a condition should cause great fires in one locality and not in another, but in passing I want to venture a guess on the matter, and that is, that it does not make any difference whether the wind is blowing from a HIGH or backing into a LOW—the effect is the same if it continues any length of time to come off a hot, arid land surface.

It would seem to me that the study of fire weather forecasts should include a close observation of what is taking place in Alaska and British Columbia, as there is where our trouble seems to develop. I will have to leave the question as to why the HIGH develops up there to the technician who understands that phase of meteorology. I am more concerned about where they go when they start wandering away from home.

From my own observation it would appear that an intensive study of the actions of these HIGHS by the United States Weather Bureau, supplemented and correlated with similar work done by our Canadian brothers, who are as vitally affected and interested in the subject as we are, would lead to a knowledge of the atmospheric disturbances which is the cause of all our trouble.

We need men versed in the technique of meteorology, who can give all of their time and attention to a study of the relationship of changes of weather as affecting forest fires. In order to render a maximum of help, they must, during critical periods of weather, be on the job night and day—Sundays and holidays included. They should be stationed in the danger zone where they can get first-hand knowledge of what occurs and the causes leading to it. Congress could not do anything more to assist reforestation and conserve the timber resources of the Douglas fir and white pine regions than to make the small appropriation asked for, which will enable the Weather Bureau to undertake this work.

The Weather Bureau has already done much to assist forest protective agencies. We fully appreciate what they are doing.

The fire hazard on the Pacific coast is growing worse; the potentialities of a catastrophic combination of weather and fire conditions which can bring disaster and ruin unprecedented are here. We are powerless to prevent the atmospheric forces from assembling and venting themselves in all their might, but we may gain a knowledge of their secrets and of the effect of their movements which will enable us to thwart their fury.

LIGHTNING AND FOREST FIRES IN CALIFORNIA.[1]

By S. B. SHOW.

[United States Forest Service, September 17, 1923.]

Thunderstorms with accompanying lightning as a cause of forest fires have become of great importance during, roughly, the past 15 years, or since the national forests in California were put under administration. Foresters therefore are of necessity keenly interested in any contribution to our rather meager knowledge of this subject.

I propose to outline the nature of the problem as it affects the national forests, to point out what we are doing in an effort to solve it, and what seem to be worthwhile lines for future study.

Lightning fires since 1911 have averaged about 440 per year, contributing over 41 per cent of the total fires from all causes. They are by long odds the most important single cause of fires. An analysis of 4,363 fires shows that they occur in extremely concentrated form: 89 per cent of all lightning fires are in June, July, and August; 77 per cent in July and August; and 44 per cent

[1] Presented at meeting of the American Meteorological Society at Los Angeles, Calif., Sept. 19, 1923.