3. The number of fires set per storm ranges from a few up to nearly 350.

4. Well-defined zones of lightning fires are found to exist in the national forests. Both the relative area of the lightning zone compared to total national forest area, and intensity of fires within that zone are found to decrease, though by no means regularly, from north to south.

5. In general, the regions affected by the three very heavy storms of the past decade correspond.

6. Lightning fires have certain characteristics differentiating them from man caused fires, chief of which are bunching, slow spread at start, and inaccessibility. These affect methods of forest-fire control.

7. An investigation of this important phenomenon is now under way, and further study is needed.

DISCUSSION OF THUNDERSTORMS AND FOREST FIRES IN CALIFORNIA.

By E. A. BEALS, District Forecaster.

[Weather Bureau Office, San Francisco, Calif., April 13, 1923.]

Unfortunately the Weather Bureau has no regular stations reporting by telegraph in the forested areas of California. There are a number of cooperative stations in these regions, but the data obtained from them are very meager. No continuous records of pressure, temperature, humidity, evaporation, wind direction and force have been kept in the forests of California, except possibly sporadically at a few places by the United States Forest Service. Also there are no records of cloud characteristics and their movements. It is quite necessary in order to predict weather phenomena that the forecasters should have available as much information as possible about the weather that is liable to occur in the region for which he makes predictions. This is all the more necessary when the prediction is for a limited area, and for a rather slight change in one or two elements. The foresters want forecasts of drying north winds, of high temperature, and of local or heat thunderstorms. Information regarding these phenomena are wanted as far in advance as possible so they can strengthen their fire-fighting forces, and place them in advantageous positions to combat the fires which they know at such times occur most frequently.

Forests are mostly in mountainous regions, and the surface winds do not always obey the barometric gradients in such localities. The winds blow up and down the canyons, in whatever direction they happen to lie, unless of extraordinary force, when they follow more closely the barometric gradients. To cause the spread of a forest fire the winds need not be very strong; an increase from light (8 to 13 miles an hour) to moderate (18 to 23 miles an hour) is ample to produce a great conflagration. After the fire once gets a good start, it causes inblowing winds that sometimes reach hurricane force without the barometer at outlying stations giving any indication that winds of such force are blowing in that neighborhood.

As to information regarding high temperatures, these phenomena in California generally are of slow growth. The temperature rises from 4° to 6° daily until the thermometer in the valleys reaches about 100°, when it fluctuates to the extent of two or three degrees up or down, until an offshoot from an Arizona LOW moves northeastward. This causes a sudden drop in temperature that lasts for two or three days, when the temperature again begins to slowly rise as before. It is not difficult to predict these hot spells; but we are not always certain as to their duration. One may start without going very far before the break occurs, and that is the great difficulty in predicting them, for, to meet the requirements, it really means a long-range prediction of several days.

Regarding local thunderstorms, weather maps are presented (fig. 1) showing the conditions the evenings before, and on the mornings of the dates when forest fires due to lightning were unusually numerous in California. It will be noticed that there is a great similarity in the weather maps for the different years. In each a trough-shaped low-pressure area extends from Arizona northwestward through California, and on July 16, 1917, and on August 4, 1920, there is a small high-pressure area over Nevada. All the charts show a HIGH impinging on the North Pacific coast.

This type of weather map is frequently in evidence during midsummer, and the difficulty in predicting thunderstorms is that so far as known they occur with this type in just about 50 per cent of cases.

Table 1 shows the temperature for seven days preceding the day when forest fires due to lightning were most troublesome, on that day, and for the two following days. These temperatures of course were taken at stations at the bottom of the valleys in California, and on the plateau on the east side of the Sierra Nevada Mountains. None is representative of the temperatures that actually occurred in the forested areas. They show in a general way a gradual increase in temperature up to the day when lightning fires were most numerous, with a change to cooler either on the days when the fires were most numerous or a day or two later.

TABLE 1.—*Maximum temperatures.*

[Dates of numerous fires due to lightning are inclosed between heavy rules.]

Stations.	July, 1917.									
	9	10	11	12	13	14	15	16	17	18
Red Bluff	98	102	110	110	106	98	110	100	102	100
Sacramento	92	102	106	100	98	94	98	92	96	96
Fresno	98	104	106	106	108	106	106	106	106	100
Reno	88	94	[1] 102	100	102	96	96	88	92	92
Tonopah	90	92	94	[1] 96	94	94	92	88	90	90
	June, 1918.									
	5	6	7	8	9	10	11	12	13	14
Red Bluff	94	96	100	100	102	104	110	92	96	96
Sacramento	92	90	90	98	100	102	108	96	90	88
Fresno	98	94	92	100	106	102	104	104	100	90
Reno	88	88	90	92	90	96	94	94	88	86
Tonopah	82	82	84	84	88	90	92	92	92	90
	July and August, 1920.									
	28	29	30	31	1	2	3	4	5	6
Red Bluff	96	96	96	102	100	100	100	96	96	104
Sacramento	88	92	94	100	98	94	94	90	92	100
Fresno	100	98	98	102	104	102	102	102	96	100
Reno	90	88	92	92	96	92	92	88	90	94
Tonopah	90	90	90	92	90	88	80	82	86	88

[1] Absolute highest.

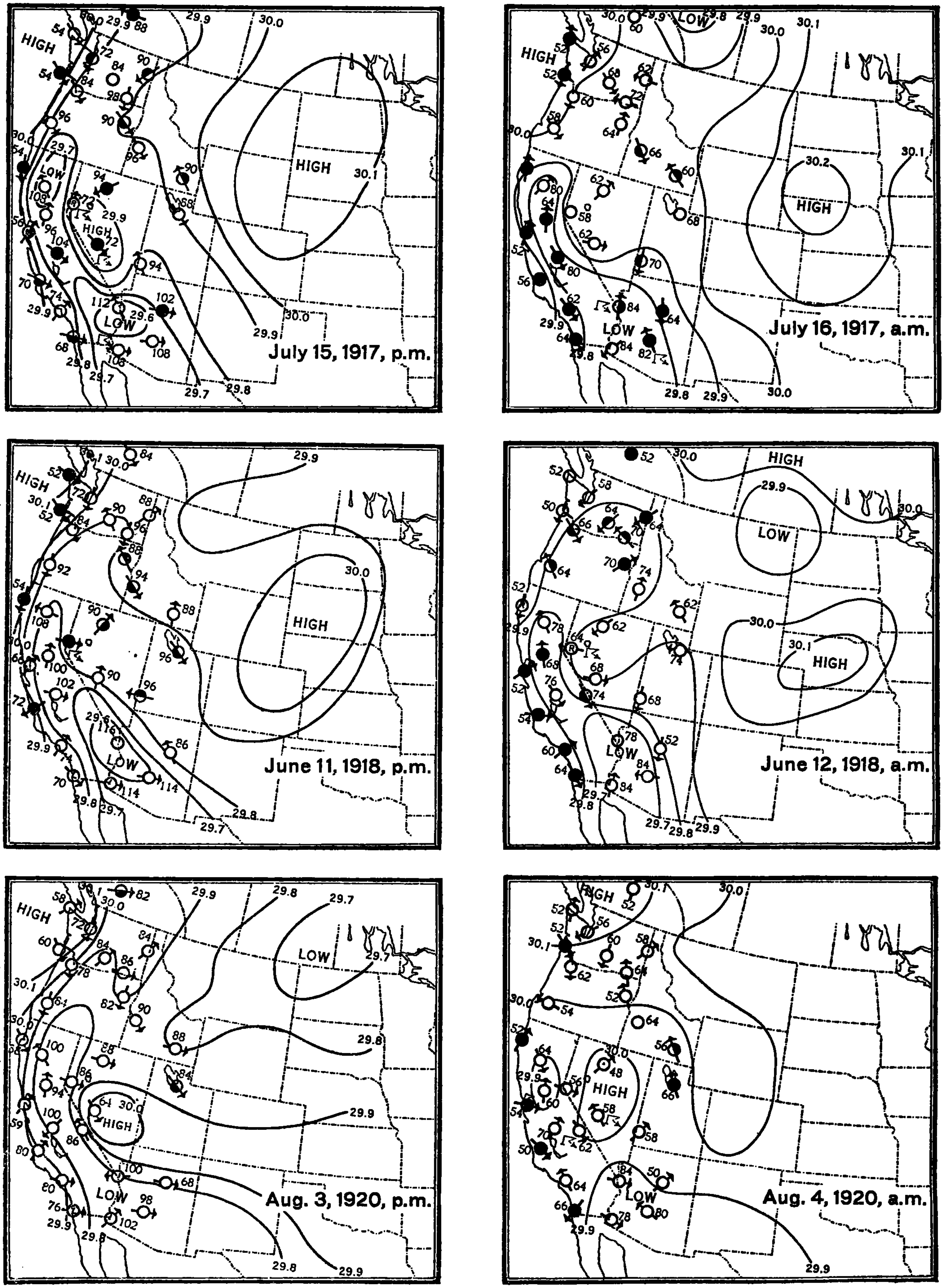

FIG. 1.—Weather conditions on the evening before and the morning of three dates when lightning-caused fires were numerous in California.

The conclusions to be drawn from the facts outlined are that, in order to issue fire-weather warnings applicable for local areas, we should be supplied with more specific information regarding the actual weather taking place in these restricted areas. In the meanwhile all that can be done is to make a general forecast for a large area that probably in places would need considerable amplification to fit local conditions.

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. The areas for fire-weather warnings could be much larger than for localized frost warnings. The question of slope of mountains and canyons, as affecting the direction and velocity of the wind needs very careful study before much improvement can be expected with fire-weather warnings. From a study of wind movements, we would be better able to predict the local thunderstorms, as they seldom move any great distance, and rarely produce any large amount of rain. There must be certain localities where they form most frequently with one direction of the wind and other localities where they form most frequently with other winds.

FOREST FIRE WEATHER IN THE SOUTHERN APPALACHIANS.

By E. F. McCarthy, Silviculturist.

[Appalachian Forest Experiment Station, U. S. Forest Service, May 9, 1923.]

This paper is intended to promote the use of information, collected daily by the United States Weather Bureau, in predicting the occurrence of forest-fire hazard. Forest fires, while started mainly through human agencies, can occur only when forest conditions are favorable to them, and this is directly related to weather. The autumn fall of hardwood leaves, followed by dry days, creates the fall fire season of the Southern Appalachian forest region. The spring fire season is the direct result of dryness of the forest floor following winds and warm dry days of spring. As the season advances the starting of foliage and ground cover reduces and eventually terminates the danger of fire for the summer season.

Although this study has been made with reference to the forest and weather conditions of western North Carolina, the results may be applied to the entire Southern Appalachian region with only minor modifications. While the interpretation of weather data must take into account the local conditions, the storm path through the eastern United States, by its comparative definiteness, is favorable to such prediction. The general easterly movement of storms makes possible the recording of their approach and intensity with considerable certainty because they are usually under observation for two days or more before they reach the eastern mountain region.

The records studied for western North Carolina indicate the necessity for a careful weighing of the influences of each storm as it approaches, to determine its effect, both upon precipitation and upon the moisture content of the air. At each of the established weather stations, conducted by a paid observer of the United States Weather Bureau, the data needed for prediction of fire hazard are available. While there is but a superficial knowledge of forest inflammability resulting from variations in the moisture content of the air, and the field is a suitable one for more exact studies, an empirical knowledge has been acquired through the frequent recurrence of fires.

Promptness of attack upon forest fires is a first principle of fire fighting in all regions, but the urgency is especially great in the Southern Appalachian forest, where fire may spread from a single blaze to a flaming mountainside in an incredibly short period of time, if conditions of slope, wind, and forest floor favor it. The fuel, which is largely leaves, responds quickly to atmospheric conditions both in drying out and in absorbing moisture. It is a region in which each member of the fire organization must be extremely alert in times of greatest fire hazard. Short periods in each fire season call for added expense for patrol and the employment of supplementary fire guards. The need for such variation in the strength of the organization has brought a demand for a more accurate definition of the danger periods and prediction of the approach of conditions which increase the fire hazard.

This problem is one which yields most readily to graphic methods of study, since the factors which determine the character of the weather and the inflammability of the forest are too many and varying to permit mental mastery of their relations without resort to graphs.

The results presented here are the outcome of graphic comparison of weather records with the occurrence of fires. While it does not follow that the creation of fire hazard is bound to produce fires, the pronounced occurrence of fires in any short period is a reaction to the natural hazard, and is evidence of increase in inflammability, especially where the number of fires considered is large enough to offset the chance of variations caused by outside factors.

The fire record of the Pisgah National Forest was first examined over a period of five years from 1916 to 1920, inclusive, and comparison was made with the vapor pressure record for the Asheville station, covering this period. An examination of this chart showed that the forests of western North Carolina are practically free from fire during the growing season, but that the fall of any considerable part of the leaf crop in October ushers in the fire season, by furnishing the fuel. The subsequent fire hazard is dependent upon the moisture condition of the forest floor and of the air from its beginning until a green crown cover is again established. The relatively short period required to dry out the forest floor and the light snowfall of western North Carolina create an extended fire season, which is most severe immediately after the fall of the leaves, and again in the spring before the vegetation becomes established. Observation of this chart further showed a general relation between depressions in the vapor pressure curve and fire occurrence, but this relation was found to be sufficiently inconsistent to require consideration of other factors affecting moisture content of the forest litter. The vapor pressure curve has been used throughout the study, because it is the best medium for expressing absolute humidity from a single reading and because it is independent of diurnal changes of temperature. Moreover, Munns [1] has found in California a

[1] Munns, E. N.: Evaporation and forest fires. Mo. Weather Rev. March, 1921, 49: 149-152.