RESEARCH PAPER No. 24

FREQUENCY of DRY EAST WINDS OVER NORTHWEST OREGON and SOUTHWEST WASHINGTON

by

Owen P. Cramer

PACIFIC NORTHWEST FOREST & RANGE EXPERIMENT STATION
R. W. COWLIN, DIRECTOR
U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

PORTLAND, OREGON SEPTEMBER, 1957

SUMMARY

There is a close relation between occurrences of severe easterly winds and large forest fires in northwest Oregon and southwest Washington. With the east winds comes the dreaded combination of low humidity and high wind that in the past has whipped small fires into conflagrations such as the Tillamook fire of 1933 and the fire that burned Bandon in 1936. These easterly winds are of the foehn type, typically dry because they are downslope winds.

East winds important to fire control arise from several weather-map situations. A high-pressure center east of the Cascades or a heat low along the coast account for most. Of lesser severity and duration are the east winds that flow toward an approaching low-pressure storm center and those occurring when a storm center moves inland to the south.

East-wind frequencies over northwest Oregon and southwest Washington vary by month, and the pattern of monthly variation differs with elevation. These frequencies have been obtained from winds aloft over Portland in the study years 1934-41 and 1948-54.

Coming at the end of the usually dry summer period and following the near minimum frequencies of August at all elevations, September bears the greatest impact of easterly winds as they affect forest fire control. This is the month of greatest frequency of major east winds at 3,500 to 6,000 feet elevation, of greatest increase in frequency from a previous month at all elevations, and second only to April in frequency of major east winds in exposed valleys below 500 feet elevation.

On an annual basis, east winds are more frequent in the middle elevations (800 to 3,000 feet) than at other levels. In the middle elevations they reach maximum frequency in the cooler months--October through January.

Minimum frequency of east winds occurs in June through August. In these months, they are more frequent in the 3,500- to 6,000-foot range than at other elevations.

Research Paper 24

FREQUENCY OF DRY EAST WINDS OVER NORTHWEST OREGON AND SOUTHWEST WASHINGTON

by

Owen P. Cramer

September 1957

PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
R. W. Cowlin, Director Portland, Oregon

FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

CONTENTS

INTRODUCTION

The weather that causes greatest consternation among fire-control agencies in western Washington and western Oregon is the parching east wind. The history of forest conflagrations in the Northwest is, for the most part, a history of the simultaneous occurrence of small fires and severe east winds. Recognition of this situation in the early days of forest protection in this region led to the organization of the U. S. Weather Bureau's Fire Weather Warning Service (1, 15). Although recognized for more than 40 years, east winds continue from time to time to tax fire-control agencies far beyond their usual capacities. It is therefore important that foresters be familiar with some of the characteristics of these winds. The purpose of this paper is to present a climatological basis for expectation of east winds in exposed areas west of the Cascade Range in northwest Oregon and southwest Washington. A brief resume of east-wind dynamics is included for better understanding.

Sometimes easterly winds occur when the air mass is relatively moist, as for example in connection with a storm bringing precipitation to the region. These, however, are not the east winds we are concerned with. East wind in fire control means an exceptionally dry wind from an easterly quadrant that may blow continuously for 24 to 48 hours or longer, sometimes at gale force, and often reaching maximum strength during night and early morning hours. It is accompanied by relative humidities that remain extremely low around the clock with relief only at night in some of the deeper ravines. Under these conditions fires run wild and fire-control men must be prepared for the worst. Consequently, the forecast of east winds stirs feverish preparation in any forested area where either intentional or accidental fires are burning.

Dry east winds are a heterogeneous group. They differ in depth, some extending from the surface to the stratosphere while others are confined to layers a few thousand feet thick. Position of east-wind layers varies, too. Some are at higher elevations while others may be restricted to the lower two or three thousand feet. Geographical extent of these winds also varies, sometimes including western parts of all three Pacific Coast States and at other times only the areas in and immediately west of major Cascade Range passes. During its existence, an east wind may itself vary in depth, position, and extent. Nevertheless, the east winds described here have in common other characteristics--low humidity, high speeds, and only slight variation between day and night.

The effects of easterly winds west of the Cascade Range have often been described in the literature. Dague (7) relates that many small fires in western Oregon and western Washington went out of control to become major fires when east winds hit in September 1929. Dague and Morris (8) describe how August east winds in 1933 drove the Tillamook fire to nearly 40,000 acres in several days and then to 244,000 acres in one additional day. Buck (2) recounts how, in the fall of 1936, many debris and clearing fires along the Oregon coast were fanned into conflagrations by the east wind. The town of Bandon was wiped out in one of these. Other east wind effects also have been described (3, 4, 10).

EAST WIND CONDITIONS

Topographic

Easterly winds west of the Cascade Range are a type in which the flow is down the lee side of a mountain barrier. Defant (9) describes them as follows:

"In almost all mountain areas, conspicuous local winds can be observed which blow from the ridges down into the leeward lowlands. At times these winds can assume gale intensity. Their chief characteristics, after reaching the plains, are abnormal temperature rise and dryness, which are of climatic significance over a more or less wide belt in the lee of the mountains. These local winds have become known under various names; however, today the general term, foehn, is used."

This wind is known as the Chinook east of the Rocky Mountains where it blows downslope from the west. Southern Californians are familiar with the Santa Ana, which blows from the east. The cold counterpart of the foehn is the fallwind, most common in winter, which also warms and dries with descent but still remains colder than the air it displaces. Foehn winds characteristically are further deflected downward by friction of the lower layers with the surface. The result is a violent and exceedingly turbulent wind that reaches into the lowest levels on the leeward side of the main barrier ridge (12).

Meteorological

The easterly foehn of western Oregon and western Washington is unusually warm and dry. It is frequently an outflow from an area of high air pressure east of the Cascades and is characteristically dry due to the basic circulation of a high-pressure area--outward and downward in a clockwise spiral. The downward motion (subsidence) in turn brings air from high altitudes to the surface. This air is warmed by compression due to the increasing atmospheric pressure as lower levels are reached. Further descent west of the Cascades results in additional warming. At its origin in the high altitudes, the air is cold and therefore contains very little moisture. Humidity decreases with the rise in temperature, resulting in very low humidities wherever these winds reach the surface.

Foehn winds cause decreasing pressure on the lee side of a mountain range and thereby tend to be self intensifying. This comes about partially as a result of the rise in temperature (13) described above and partly because descent tends to produce curvature in the wind flow so as to create a trough of low pressure on the lee side (11). This second process apparently operates only under certain conditions (14) and would therefore not be expected to apply to all east winds.

Briefly, east winds tabulated for this study result from several different weather situations. Most east winds result from either a high pressure center east of the Cascades or a low pressure trough along the coast. The most severe east winds occur when both trough and high are present. East winds of shorter duration sometimes occur with the approach of a low pressure storm center, and may last a day without being followed by precipitation if the center moves inland to the south of the area. Finally, there are the night and early morning east winds over higher ridges of the Coast and Cascade Ranges. These east wind types are described in greater detail in the appendix.

METHOD OF ANALYSIS

Ideally, wind frequencies over an area might be determined by counting the days during which winds of specified minimum force were generally observed. In this study it was necessary to approximate the frequency for two reasons. First, the year-round weather stations in northwest Oregon and southwest Washington do not give an adequate sample, as they are confined to the lower elevations. Past occurrences of easterly winds in the Coast and Cascade Ranges cannot, therefore, be counted directly. Second, dry easterly winds vary in altitudinal extent, sometimes hitting only the higher peaks and ridges, sometimes occuring only below 2,000 feet, and at other times affecting all elevations.

Except when confined to the lowest levels, these dry easterly winds usually extend over northwest Oregon and southwest Washington and sometimes much farther. Their approximate frequency at various levels might, therefore, be determined by counting occurrences at several levels over a station centrally located within the study area. Accordingly, in this study, approximate frequencies of dry easterly winds at three elevations were determined from surface and pilot balloon observations at two elevations above Portland. Tabulations were made for all months for the years 1934-41 and 1948-54.[1/]

The east wind frequencies derived represent winds of general extent and important intensity. This has been checked by comparing frequencies over Portland with those of major easterly surface winds at three widely spaced stations at lower elevations in southwest Washington during August through November of study years 1934-41 and 1948. Details of this comparison may be found in the appendix.

Classification

Certain restrictions were imposed to define degree of severity of dry east winds and to eliminate other winds. For simplification, east winds were defined and tallied by days on which the specified conditions were observed.

Upper-level east winds.--In the present study, frequencies were determined for two levels from pilot-balloon observations at the Portland International Airport. Since humidity aloft is not measured as part of such observations, moist east winds were

---

1/ Tabulations were purchased from the Weather Bureau's National Weather Records Center at Asheville, North Carolina. The period 1942-47 and years prior to 1934 were omitted because necessary observations for those periods had not yet been placed on punch cards.

eliminated on the basis of low clouds being present.[2] Pre-storm east winds, when rainfall is imminent, were eliminated by limiting permissible upper cloudiness. Under these limitations, rainless days with east winds[3] were classified as follows for both 1,640-foot and 4,920-foot levels:

1. Major-east-wind day.--Day with wind between northeast and southeast greater than 13.4 miles per hour (6 meters per second) observed on two of the four regular daily pilot balloon observations, when the sky was not overcast with middle clouds,[4] and no low clouds were present.

2. Extreme-east-wind day.--Major-east-wind day with wind speed greater than 22.4 miles per hour (10 meters per second).

Surface east winds.--Although it is recognized that many east winds do not reach the surface at Portland International Airport, frequencies at that station might be considered indicative of seasonal variation of dry, surface east winds at lower levels in the Willamette Valley of Oregon and lower valleys of southwest Washington. The Portland surface east winds were classified into two intensities, corresponding fairly well to the intensity classes of the winds aloft where they come in contact with the terrain. Days with surface east winds between northeast and southeast were classified as follows:

1. Major-east-wind day.--Day during which easterly wind was greater than 9 miles per hour accompanied by relative humidity less than 36 percent on at least two regular hourly observations.

2. Extreme-east-wind day.--Major-east-wind day with wind speed greater than 19 miles per hour accompanied by relative humidity less than 26 percent on at least two regular hourly observations.

2/ The low cloud group is composed of specific types of clouds with bases generally less than 6,500 feet above the general level of the land.

3/ The terms major and extreme were used to designate these two arbitrarily selected intensities of dry winds in order to avoid use of common wind description terms that refer to speed alone.

4/ Middle cloud group is composed of specific types of clouds with bases generally between 6,500 and 20,000 feet above the general level of the land.

RESULTS

Interpretation

Although winds at only specific levels at Portland have been tabulated for this study, the elevations used were selected as indicative of rather broad elevation zones in the forest land of northwest Oregon and southwest Washington. These zones cannot, of course, be delineated precisely but may be thought of approximately as follows:

1. Frequency of surface east winds at Portland as representative of exposed valley stations below 500 feet elevation in interior southwest Washington and northwest Oregon.

2. Frequency of east winds at 1,640 feet above Portland as indicative of east wind frequencies at exposed places in northwest Oregon and southwest Washington at elevations between 800 and 3,000 feet.

3. Frequencies of east winds at 4920 feet above Portland as indicative of east wind frequencies at exposed places in northwest Oregon and southwest Washington at elevations between 3500 and 6000 feet.

These approximate zones are set forth solely as an aid to application of the average wind frequencies determined in this study. They do not necessarily apply in every case, since individual winds differ in vertical structure.

As with most weather phenomena, frequency of esterly winds in any given month is likely to vary considerably from the average. An average of 0.5 east-wind days in May, for examples, does not mean that half a day of east wind should be expected in May, nor one east-wind day every other year in May. Rather, it means that over a period of years no east winds occurred in most Mays, one occurred in a few Mays, and two or three occurred in others. The average occurrence in May over the entire data period was 0.5 east-wind days.

Frequencies

Dry easterly winds vary in likelihood of occurrence from month to month, and for different elevations (fig. 1). The impact of east

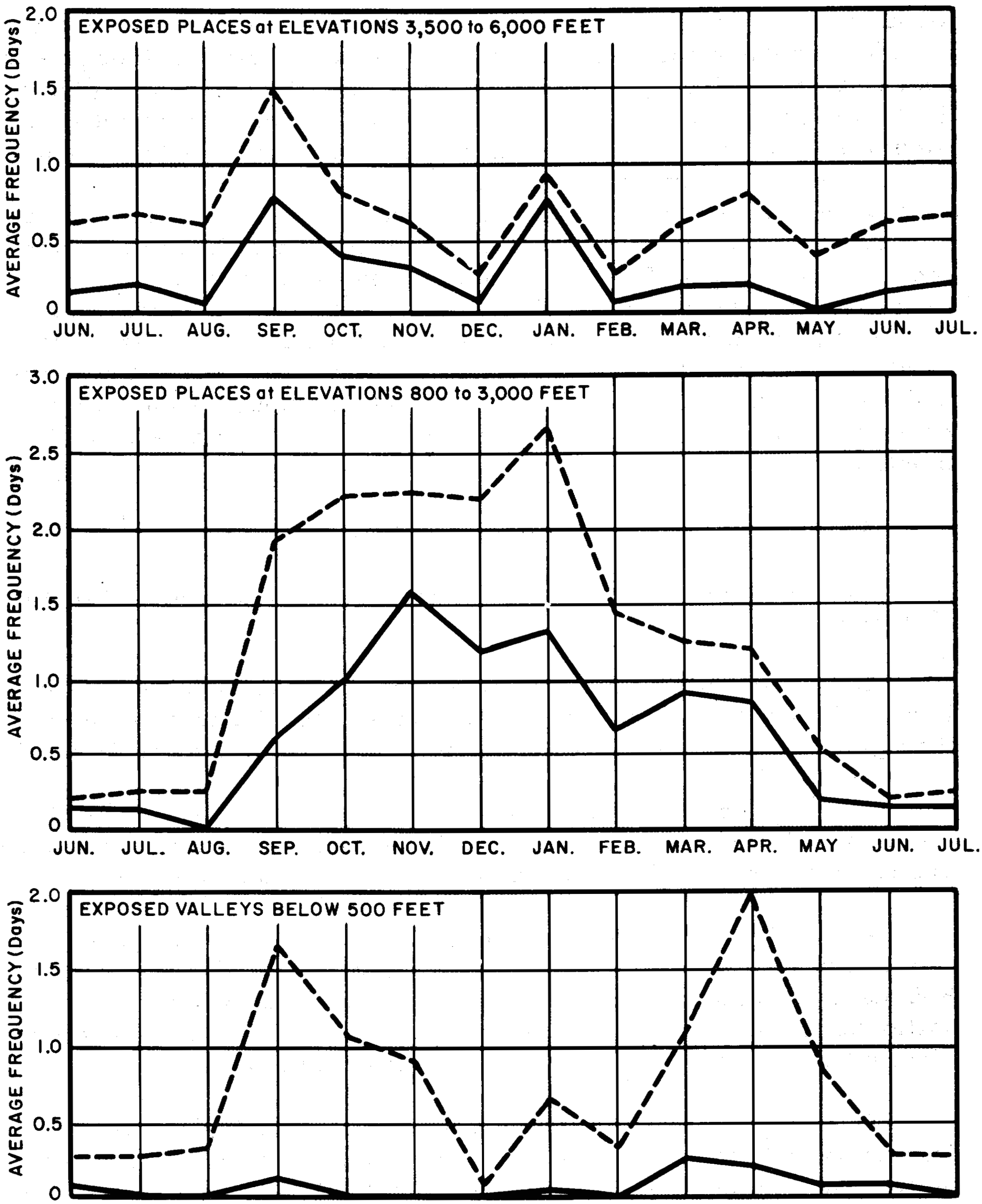

Figure 1.--Average number of days per month with major (dashed line) and extreme (solid line) east winds at exposed places within three elevation zones in northwest Oregon and southwest Washington. Based on surface observations and pilot balloon observations at 1,640 feet and 4,920 feet (mean sea level) at Portland International Airport during 1934-41 and 1948-54.

winds on fire occurrence is likely to be greatest in September, the month of greatest increase in frequency at all levels. Although even more easterly winds are to be expected at middle elevations (800 to 3,000 feet) in October, they are less frequent than in September at higher and lower levels. The maximum frequency of extreme east winds at middle elevations is in the colder and wettest months (November through January), and therefore does not greatly affect fire occurrence except in those rare seasons when the normal summer drought extends far into the fall. Maximum frequencies of extreme winds occur in March and April in the low elevations and are of importance to fire control as these months are occasionally predominantly rainless. East winds are at a minimum in the middle and low elevations in June, July, and August, though even extreme east winds have been known to occur in these driest and warmest months.

Other results of this study are as follows:

1. Frequency of dry easterly winds is greatest in the middle elevations.

2. Frequency of extreme east winds at the middle elevations is a minimum during August, but increases steadily to November, then gradually decreases to less than two in May, June and July.

3. Although major east winds in middle elevations are less frequent in March and April than in September, extreme east winds are more frequent in both March and April than in September.

4. In the valley bottoms, frequency of major east winds shows two maxima--in September and April. Minima occur in December, February, and June through August. Extreme east winds in the valley bottoms are most frequent in March and April and next most frequent in September. They are rare in other months.

5. The high elevations experience major easterly winds most frequently in September with a secondary maximum in January and tertiary maximum in April. Extreme easterly winds have equal maxima in September and January.

6. Major winds during June, July, and August occur at the high elevations with about twice the frequency found at middle elevations and in valley bottoms.

7. Graphs of maximum occurrence by months during the years studied (fig. 2) show approximately the same trends as those of average monthly occurrence. During the 15 years of the study, minimum monthly occurrence of major easterly winds in the middle elevations was in May through August, with a maximum in January and secondary maxima in September and March. March had the greatest number of extreme easterly winds for any one month. September again showed up as a triple-threat month, with maximum number of major winds observed for any single month at high levels, an abrupt increase over August in the middle elevations, and second greatest single-month occurrence at low levels. Extreme east winds in September occurred as often as in any month at both high and low levels.

8. In the middle elevations, June and July are most likely to have no major east winds, with chances of none only slightly less in August (table 1). January, on the other hand, is least likely to pass without major easterly winds.

Now shown in the figures or tables, are the following observations of frequencies of major easterly winds at 1,640 feet over Portland. They apply to middle elevations (800 - 3,000 feet).

1. During the 15-year period of record, each of the 12 months of the year went without any major east wind at least once. However, no entire year was free from major east winds. The years 1950 and 1953, with 9 days of major easterly winds each, are years of minimum occurrence.

2. The year of maximum occurrence of major winds was 1949, with 29 days. This was followed by 1951 with 26 days. The 1951 fire season (April through October) showed east-wind influence in reaching the highest burning index[5/] of record in both western Oregon and western Washington. The 1949 fire season burning index was third highest of record in western Oregon and fourth highest in western Washington (5). The period of record of these indexes goes back to 1932 in Oregon and 1939 in western Washington.

3. Spring (March-May) frequency of major easterly winds varied from none in 1936 to 10 days in 1941.

5/ Combination of low humidity and strong winds.

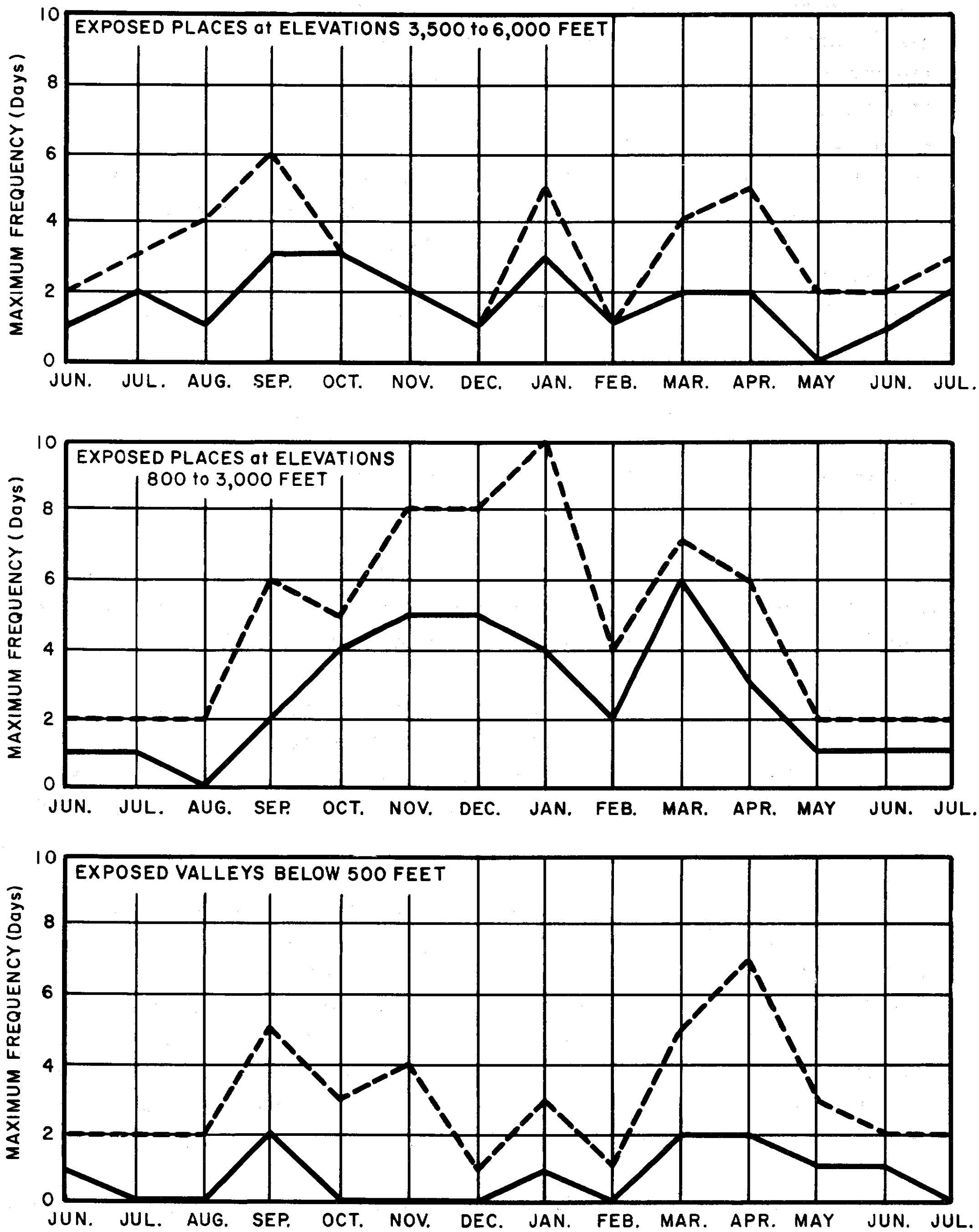

Figure 2.--Maximum number of days per month with major (dashed line) and extreme (solid line) east winds at exposed places within three elevation zones in northwest Oregon and southwest Washington. Based on surface observations and pilot balloon observations at 1,640 feet and 4,920 feet (mean sea level) at Portland International Airport during 1934-41 and 1948-54.

Table 1.--Occurrence of major east-wind days at exposed places within the 800 to 3,000-foot elevation zone of northwest Oregon and southwest Washington,[1] by months

Month	Average frequency	Maximum frequency	Year of maximum frequency	Proportion of months with one or more	Average number for months with one or more
	Days	Days	Year	Percent	Days
January	2.7	10	1949	80	3.3
February	1.5	4	1954	67	2.2
March	1.3	7	1941	53	2.4
April	1.2	6	1951	67	1.8
May	.5	2	1934 1941	40	1.3
June	.2	2	1937	13	1.5
July	.3	2	1951 1952	13	2.0
August	.3	2	1939	20	1.3
September	1.9	6	1951	73	2.6
October	2.3	5	1948	73	3.1
November	2.3	8	1949	60	3.9
December	2.2	8	1935	73	3.0

1/ Based on pilot balloon observations at 1,640 feet over Portland International Airport during 1934-41 and 1948-54.

4. Fall (September-November) frequency has varied from one day each in 1934, 1935, and 1941 to 12 days in 1936 and 1951, and 13 days in 1949.

5. July is usually without major easterly winds. However, two days with major or greater winds in 1951 accounted for a number of bad fires in both western Oregon and western Washington.

Other data show that:

1. Although August is usually without major easterly winds at middle elevations, three such days were recorded in 1933.[6/] Winds on these days were largely responsible for the phenomenal spread of the first Tillamook fire. There were two days with major easterly winds in August 1939, month of the second disastrous Tillamook fire.

2. Low-humidity easterly winds reaching the coast are at a maximum in September and minimum July through August, as shown in a study of frequencies of low humidities at North Head, Wash. (6).

DISCUSSION

Variations

Greater extremes in frequency of easterly winds are possible than those indicated by this survey over a limited number of years. It is believed, however, that the relations of frequencies between months and elevation ranges are basically representative of northwest Oregon and southwest Washington.

Frequencies reported here will probably differ slightly from those determined by other methods, or for any other group of years. Frequencies at surface stations will also differ somewhat from one locality to another, owing to local effects of terrain.

Causes

At the middle elevations, easterly winds are least frequent in June, July, and August. This corresponds to the period of maximum

---

6/ Based on surface observations at Crown Point, Oregon and North Head, Wash., and on the evening pilot balloon winds at 1640 feet over Portland.

heating of the continent, a condition which creates relatively low pressure over the land and relatively high pressure over the sea. On-shore flow from the northeast Pacific high is the usual condition. With the polar front far to the north, the general weather pattern is stable and changes slowly and infrequently.

As fall approaches, the stable weather regime dominated by cool ocean areas and warm continents begins to change, and the belt of westerlies with its alternating storms and highs gradually moves south, bringing greater variation in upper air wind patterns. East winds from high-pressure centers east of the Cascades appear more frequently as the land mass cools. As the weather patterns change from summer into winter types, many combinations of east wind types can occur. These are described in detail in the appendix.

Frequency of major, dry easterly winds at the 1,640-foot level at Portland remains high through November, December, and January. This is not true for surface winds because during cool weather the valleys are frequently filled with cold moist air, over which the warmer east winds may pass. Under these conditions, which are most common in the fall, slash on upper slopes may burn more briskly than desired while in the valleys, it remains too moist to ignite. During these months surface east winds occur more frequently than indicated in figure 1, but are not counted because of humidities higher than allowed by definition.

Actual frequencies of major east winds at the high level during the colder months may be slightly greater than indicated by the Portland tabulations. Under the conditions described above, a persisting blanket of fog or low clouds may form in the cold valley air below 3,000 feet. In the warmer air above there may be major easterly winds. However, no upper-level east winds could be counted if low clouds were present. Should these upper easterly winds increase in intensity to the extreme classification, they would likely penetrate the lower layers sufficiently to dissipate the low clouds.

Reason for the low number of east winds at all levels in December and February, as compared with the high number in January, is not known. Neither is the reason known for the pronounced maximum in April that occurs only at the surface. These apparent peculiarities may be exaggerated in this particular sample of years.

APPENDIX

A. Classification of East Wind Types

It is desirable for various purposes to differentiate between the several weather situations that produce east winds. There are many possible ways of classifying these situations. One classification is presented here.

Two weather situations cause most of the dry easterly winds west of the Cascades, and three other situations are occasional contributors.

Most east winds result when a center of high air pressure builds up or moves in east of the Cascades while pressure remains relatively lower west of the Cascades and along the coast. This is known as a high-pressure center east of the Cascades. It occurs most frequently in fall, winter, and early spring when continental highs form readily in the northern hemisphere as a result of cooling of the large land areas. Easterly winds originating from this situation may be warm or cold. East winds from a cold high may be confined to layers below 4,000 feet, whereas warm highs may cause a much deeper flow. East winds from the continental high abate when the high moves to the east or southeast.

A second weather situation that causes dry easterly winds usually occurs during the warmer months. Called the offshore thermal trough, it occurs when shifting of the upper-air wind streams places the warmest air aloft over the coast instead of its usual position far out over the Pacific high or well to the east over the continent. This results in a strip or trough of low pressure at sea level beneath the warmest air aloft. The trough normally develops slightly offshore, parallel to the coast. Easterly winds, which may further intensify the trough, then blow from the resulting higher pressure over the land to the offshore low. These winds are usually unseasonably warm and are likely to involve all layers of air from the surface to at least 10,000 feet. East winds cease when the low, which also corresponds to the area of highest surface temperature, moves east of the Cascades. In the spring and fall, this situation usually combines with the high east of the Cascades to create the most severe easterly winds.

Usually of less importance are easterly winds that occur when a low-pressure storm center approaches the coast. This situation may be called the approaching low. Although in some instances resulting east winds may be very important, they are (1) usually of short duration, (2) closely followed by precipitation, (3) confined to a comparatively shallow layer, and (4) do not involve extremely dry air. Furthermore, heating at the ground is usually reduced by the cloud system associated with the approaching low.

If the low pressure storm center moves inland across southern Oregon or northern California, southwest Washington and northwest Oregon come under the influence of the easterly winds normally found to the north of a low-pressure storm center in the northern hemisphere. East winds in this situation, which may be called the cyclonic storm, occur most frequently during the cooler months. They usually last no more than a day. Resulting easterly winds may involve a deep layer, but are generally not so dry as those resulting from the other situations.

To complete the picture, we must mention the night and early morning easterly winds frequently found at higher elevations of the Cascade and Coast Ranges. These occur in summer fair weather, when the wind flow pattern is either very weak or from a northerly direction. Though locally severe, these winds are not general in extent and usually disappear, shifting to northwesterly by early afternoon. Frequency of these easterlies is not indicated by this study.

B. Frequencies of Autumn East Winds at the Surface in Southwest Washington and at 1,640 feet over Portland

Frequencies of east wind determined in this study were compared with those of a preliminary study in 1950 based on observations at three widely spaced stations during August through November. Only those east winds were tallied that satisfied the following requirements:

1. Rainless, mostly clear weather.

2. Wind speed at least 35 miles per hour at Crown Point or Stevenson in the Columbia Gorge, and at least 30 miles per hour at Stampede Pass (elevation 3,958 feet) in the the Cascades 110 miles north of the Columbia Gorge. These wind speeds had to be reported on at least two of the regular hourly observations.

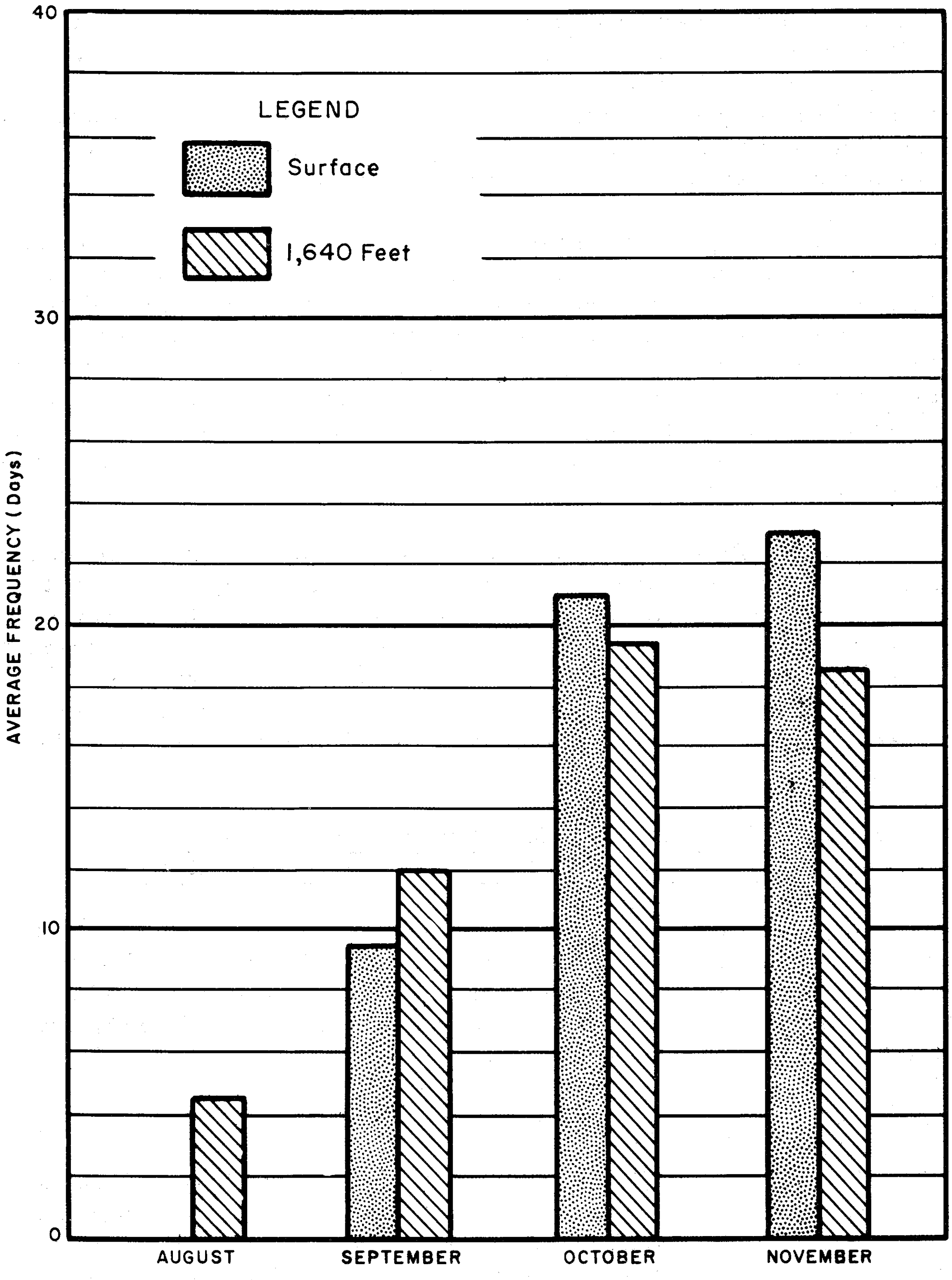

Figure 3.--Comparison of frequencies of major easterly winds at 1,640 feet over Portland with major surface winds in northwest Oregon and southwest Washington during 1934-41 and 1948.

3. East-wind effects in the form of above-normal temperatures, low humidities, or easterly wind direction at North Head, Wash. (at the mouth of the Columbia River some 110 miles west-northwest of Stevenson).

Although humidities were not measured directly, it was observed that high-humidity east winds were effectively eliminated by the above requirements.

In the nine seasons (1934-41 and 1948) in which comparable data were available from both studies, the frequency of major easterly winds at an elevation of 1,640 feet (500 meters) over Portland compared closely with frequency of major easterly surface winds (fig. 3). The similarity lends weight to the basic assumption of this study--that frequency of important dry easterly winds covering lower levels of northwest Oregon and southwest Washington can be estimated from the frequency of easterly winds at 1,640 feet over Portland.

No direct comparison could be made between the frequencies of east winds at 4,920 feet (1,500 meters) over Portland and winds hitting upper parts of the Cascade and Coast Ranges. It is reasonable to assume, however, that a close relationship exists and that the relation demonstrated for the months August through November holds true for the remainder of the year.

C. Literature Cited

(1) Beals, E. A.
1916. Droughts and hot weather. U. S. Weather Bur. Monthly Weather Review. 44 (3): 135-138.

(2) Buck, C. J.
1936. What happens when the dreaded east wind finds clearing fires burning in Oregon? U. S. Forest Serv. Fire Control Notes 1(1):17-18.

(3) Cameron, Donald C.
1931. Easterly gales in the Columbia River Gorge during the winter of 1930-31--some of their causes and effects. U. S. Weather Bur. Monthly Weather Review 59 (11): 411-13.

(4) Cameron, Donald C.
1931. Great dust storms in Washington-Oregon April 21-24, 1931. U. S. Weather Bur. Monthly Weather Review 59 (5): 195-97.

(5) Cramer, Owen P.
1955. 1955 forest fire weather in western Oregon and Washington. U. S. Forest Serv. Pacific Northwest Forest and Range Expt. Sta. Res. Note 123, 8 pp.

(6) Dague, Charles I.
1929. Low relative humidity in Oregon. U. S. Weather Bur. Monthly Weather Review 57 (4): 146-53.

(7) ________.
1930. Disastrous fire weather of September, 1929. U. S. Weather Bur. Monthly Weather Review 58 (9): 368-370.

(8) ________ and Morris, W. G.
1934. Weather of the great Tillamook Fire. U. S. Weather Bur. Monthly Weather Review 62 (7): 227-31.

(9) Defant, Friedrich
1951. Local winds. Compendium of Meteorology. 655-72. Amer. Met. Soc. Boston.

(10) Graham, Howard E.
1953. The Columbia Gorge wind funnel. Weatherwise 6 (4): 104-7.

(11) Holmboe, Jorgen.
1942. Meteorology basic principles of dynamics. Univ. of Calif. at Los Angeles. 366 pp., illus.

(12) Humphreys, W. J.
1940. Physics of the air. 676 pp., illus. New York and London.

(13) Little, Delbert M.
1931. Some effects of California mountain barriers on upper air winds and sea-level isobars. U. S. Weather Bur. Monthly Weather Review 59 (10): 376-80.

(14) Queney, Paul
1948. The problem of airflow over mountains: A summary of theoretical studies. Bul. of the Amer. Met. Soc. 28 (1): 16-26.

(15) Williams, H. E.
1916. Fire-weather warnings. U. S. Weather Bur. Monthly Weather Review 44 (3): 133-35.