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TEST of WIND PREDICTIONS for PEAK FIRE-DANGER STATIONS in OREGON and WASHINGTON

by Owen P. Cramer

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SUMMARY

Relative accuracy of several wind-speed forecasting methods was tested during the forest fire seasons of 1950 and 1951.

For the study, three fire-weather forecast centers of the U. S. Weather Bureau prepared individual station forecasts for 11 peak stations within the national forests of Oregon and Washington. These spot forecasts were considered the best forecasts available. They were compared with routine area forecasts, with forecasting aids suggested for use by forest-protection agencies, and with some routine statistical forecasts often used in comparing accuracy of forecasting methods. Forecasts of 4:30 p.m. wind speed were prepared by each method morning and evening.

Forecasts were determined to be correct or incorrect according to limits of error that could be tolerated by a protection agency using the wind forecast to predict burning index. Performance of each method was checked for several important types of days: days on which speed changed from the previous day, days with nonnormal speeds, and days with unusually high burning index.

Results of the study include the following: Accuracy of methods tested varied significantly between stations and no one method was best for all stations. The area forecast gave significantly poorer results than other methods. Spot forecasts issued in the morning were no more accurate than those issued the previous evening. All methods showed least accuracy on the more important days; consequently, practicality of using forecasts as a basis for regulating protection-force activities must be determined locally. Wind forecasting must make considerable progress before complete reliance may be placed on wind-speed forecasts.

The report recommends that where wind is considered important, suggested forecasting aids be given a trial, since they did show some promise for certain stations. In the absence of completely reliable forecasts, however, it is recommended that fire-control agencies rely on good observation and quick reporting of important winds. In addition, careful consideration should always be given to the most recent forecast.

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CONTENTS

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INTRODUCTION

Behavior of forest fires is influenced more by wind speed than by any other factor. When a quiet fire in calm air is fanned by a sudden wind, it may become a raging inferno in a matter of seconds. Fires starting on windy days usually spread more rapidly, are more difficult to control, and reach greater size before control than fires starting on calm days.

To be fully effective, a forest-fire-control organization must therefore have ready access to accurate information on current and prospective wind conditions.

Most fire-protection agencies keep abreast of current fire-weather conditions through periodic reports from fire-danger stations located on representative exposures within their protection districts. These stations are usually equipped with instruments for measuring important fire-weather factors such as fuel moisture, relative humidity, wind speed, temperature, and rainfall. Observations are taken several times each day and reported to a headquarters office. When an appreciable change occurs in the level of fire danger over a district, the number, organization and disposition of men in the fire-fighting force are adjusted to meet the new fire-weather situation.

Before 1949, adjustments in protection forces on the national forests of Oregon and Washington were based primarily on current fire-danger conditions Use of fire-weather forecasts provided by the U. S. Weather Bureau for this purpose was left to the discretion of the field units because a standard procedure was not available for interpreting the area forecast in terms of a prediction of local fire danger. During periods of fairly stable weather, this reliance on current fire-danger reports kept the protection force reasonably in line with the protection need. When a sudden change occurred, however, the protection force was likely to be out of balance until adjustments could be made. If communication and transportation were slow, needed adjustments might require an entire day. Meanwhile, fire might gain the upper hand.

In 1949, formal instructions for determining the expected level of fire danger were revised by fire control administrators from national forests of Oregon and Washington, and predicted fire-danger became the basis for day-to-day adjustment of protection activities. At this time the experiment station was asked to prepare guidelines for applying the rather general forecasts to local exposures. Subsequently, the author suggested several field forecasting aids that could be prepared locally from past records. The Regional Office Division of Fire Control requested that these aids be field tested. A project to test procedures for predicting fire danger was therefore undertaken late in 1949 in cooperation with several national-forest district rangers and fire-weather forecasters from three local offices of the U. S. Weather Bureau.

Since wind speed is given greater weight than other factors in rating fire danger, this study was conducted during the fire seasons of 1950 and 1951 to determine the relative success of wind-speed forecasts then available for field use. The results are reported in this paper.[1/] No attempt was made to develop new techniques for wind forecasting.

PREDICTION METHODS

The following methods of forecasting wind speed were analyzed:

A. U. S. Weather Bureau forecasts

1. Routine area forecasts --actually not intended for application to individual stations

2. Spot forecasts--specifically prepared for individual stations.

1/ A forthcoming paper will report tests of methods for predicting fuel moisture and relative humidity.

B. Local forecasting aids

1. W-2 Aid--adapts the area forecast to the individual station

2. W-3 Aid--depends entirely on local observations

C. Statistical forecasting procedures

1. Persistency forecasts--predicts that tomorrow's wind will be the same as today's

2. Normalcy forecasts--predicts each day will have normal summer speed

3. The mean of normalcy and persistency forecasts

Weather Bureau forecasts, particularly the spot forecasts, received most attention as they represent the probable future source of most wind predictions. Area forecasts were analyzed only for comparison of overall accuracy with accuracy of individual station methods. The two aids, W-2 and W-3, were compared primarily with the spot forecasts. Persistency forecasting, formerly the official procedure, was analyzed for comparison with the other methods. Each of the three statistical procedures was considered both as a possible forecasting procedure and as a standard of comparison against which to compare accuracy of other methods.

All methods predict wind at 4:30 p.m., the regular observation time for which prevailing fire danger is usually rated.

Weather Bureau Forecasts

Both spot and area forecasts were furnished by three U. S. Weather Bureau offices. Forecasts prepared by the Seattle office were used in Washington. Pendleton forecasts were used for northeast Oregon and Portland forecasts for other parts of Oregon.

Spot forecasts.--For each of several test stations, a special afternoon or evening forecast of wind speed and wind direction at 4:30 p.m. on the following day was prepared. Similarly, spot forecasts were prepared in the morning for 4:30 p.m. winds on the same day. In making these predictions, fire-weather forecasters relied on the most recent surface-weather and upper-air maps (table 1).

Table 1.--Release times[1] of spot wind forecasts and approximate age of forecast data by sources, 1950-51

Originating office	Time of forecast release	Test station reports: Noon weather	Test station reports: 4:30 p.m. weather	Surface-weather map	Upper-air map	Pilot-balloon soundings
		Hours	Hours	Hours	Hours	Hours
P. M.						
Portland	3:30	3	23	5	8	2/ 2
Pendleton	4:25	4	24	6	9	2/ 3
Seattle	7:35	--	3	3	12	6
A. M.						
Portland	8:25	20	40	4	13	7
Pendleton	8:55	20	40	4	13	7
Seattle	7:35	--	15	3	12	6

1/ Pacific standard time.

2/ Local only.

They also received special reports of current wind speed and direction from the test fire-danger stations. Although no special techniques were developed for making these spot forecasts, participating forecasters studied past wind records at test stations and in some cases made special compilations of general wind characteristics at each station.

Fire-weather area forecasts.--The routine fire-weather area forecast, released each afternoon or evening by the Weather Bureau, was used directly as a prediction of 4:30 p.m. wind speed at a given station on the following afternoon. The area forecast usually provides a range of expected wind speeds within broad classes of elevation. In making a prediction for a given test station, the range of wind speeds appropriate to the elevation at that station was first selected. The high end of the range was then used if the station was exposed and the lower end if sheltered. For example, a forecast of "NW 15-20 over exposed ridges" would be interpreted as 20 for the higher stations with greatest exposure and 15 for high stations with less exposure.

Adjusted Area Forecasts (W-2 Aid)

The Weather Bureau fire-weather area forecast was adjusted to provide a wind-speed prediction for a given station. The adjustment at each station was based on the relation between area forecasts of wind and observed wind speed during the previous 5 years (1945-49). To simplify use, results were summarized in a table, which was designated the W-2 aid (fig. 1). Detailed instructions for preparing the W-2 aid have been published previously.[2]

Observed 8 a.m. Wind Speed Forecasts (W-3 Aid)

In this method, the 8 a.m. observed wind speed and wind direction at a given station are used to predict 4:30 p.m. wind speed on the same day at the same station. The method is based on two assumptions: first, that the pressure pattern or weather type controlling local weather in the morning will continue throughout the day; and second, that changes in weather during the day tend to follow certain fairly consistent patterns. For each test station the

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2/ Cramer, O. P. Methods for estimating future burning index from fire-weather forecasts and local weather observations. Pacific Northwest Forest and Range Experiment Station, 22 pp, May 1950.

Wind Estimation Aid W-2

Station Mount Wilson   Forecast Zone or Area #8

Estimated wind speed at 4:30 p.m., based on area wind speed and direction forecast[1] (miles per hour)

Wind speed (from area forecast)	N	NE	E	SE	S	SW	W	NW	Variable
	Wind direction (from area forecast)								
0 - 3									8
4 - 6									
7 - 9									
10 - 12	14	13				11	12	14	
13 - 15	11	11				14	14	15	
16 - 18							12	14	
Over 18							12	17	

1/ From the area forecast use the upper limit of speeds predicted for higher elevations and the direction closest to west. Where estimate not specified in table, use average 4:30 wind speed 12 m.p.h.

Figure 1.--Wind estimation aid (W-2) prepared for the Mount Wilson fire-danger station.

relation between 8 a.m. wind speed and direction and 4:30 p.m. wind speed (on the same day) was determined[3] from an analysis of records taken at that station over the preceding 5 fire seasons (1945-49). Results were then summarized in a table called the W-3 aid (fig. 2).

Persistency Forecasts

This method assumes that wind speed at 4:30 p.m. will closely approximate the speed observed at 4:30 p.m. the previous day. This is based on the supposition that there will be no appreciable change in the general weather situation between days--a characteristic of much of the summer in Oregon and Washington. Among forecasters, persistency is known as a forecast that is difficult to beat. In this study, persistency takes on additional importance as the officially prescribed method, prior to 1949, of estimating the next day's fire danger in Region Six.

Normalcy Forecasts

During that portion of the year when the weather is dominated by a few similar weather situations, most winds may be expected to be within a limited range of speed. This is the usual summer condition in Region Six and the basis for the prediction that the next day's wind speed is more likely to be normal than any other value. A normal 4:30 p.m. summer wind speed was determined for each station by averaging the 4:30 p.m. wind speeds during the preceding five summers (1945-49).

Mean Normalcy - Persistency Forecasts

These tests brought out that a large proportion of 4:30 p.m. winds were normal and also that a large proportion were persistent. It followed that the mean of normal and persisting speeds might describe a greater proportion of winds than either separately. A forecast of the mean of normal and persisting speeds was therefore introduced. This method assumes that the most likely speed is the summer normal and that any nonnormal speeds will change the next day toward the normal speed. With this method, the predicted speed for the next day is the mean of the normal speed computed for the station and the current observed 4:30 p.m. speed.

3/ Cramer, ibid. See footnote 2, p. 5.

Wind Estimation Aid W-3

Station Mt. Wilson

Estimated wind speed at 4:30 p.m., based on observed 8 a.m. wind speed and direction[1] (miles per hour)

Observed 8 a.m. wind speed	Observed 8 a.m. wind direction								
	N	NE	E	SE	S	SW	W	NW	Calm
0 - 3									
4 - 6				9		11	11		
7 - 9		6	11			13	13		
10 -12		12				13	12	12	
13 -15						14	16		
16 -18		9				16	18		
Over 18		14				23	23		

1/ Where estimate not specified in table, use average 4:30 p.m. wind speed 12 m.p.h.

Figure 2.--Wind estimation aid (W-3) prepared for the Mount Wilson fire-danger station, Mount Hood National Forest.

DESIGN OF STUDY

The test of prediction methods consisted essentially of the following steps:

1. A number of peak fire-danger stations (fig. 3), widely scattered in various parts of Oregon and Washington, were designated as test stations.

2. During the July 1 to September 15 period in both 1950 and 1951, daily predictions for each test station were made by each method of prediction. Daily 4:30 p.m. observations were made at each of the test stations during the same period as a means of checking accuracy of the forecasts.

3. Verification analysis was then conducted to determine the relative success and characteristics of each method by comparison of predicted and observed wind speeds.

Selection of Test Stations

The study was limited to mountaintop fire-danger stations because it was thought that peak stations would be less affected by local and diurnal winds than valley stations and that peak stations would be better exposed to general air movement, and would therefore present a simpler relation to the general air-flow pattern described in area forecasts. Fourteen peak stations were originally selected, but three of these were subsequently eliminated because of insufficient wind to provide a test, or because previous records were invalidated by faulty anemometer or poor instrument exposure. Names, locations, and elevations of the 11 stations used throughout the study are shown in fig. 3.

Measurement of Wind Speed

Precautions were taken to insure, as far as possible, that anemometers used were accurate, that instruments were properly exposed, and that recorded wind speeds were based on an adequate sample. To obtain an adequate sample, each observer was asked to take three 4-minute observations spaced 15 minutes apart, with the first observation starting not earlier than 3:50 p.m. The average of these three observations was then recorded as the 4:30 p.m.

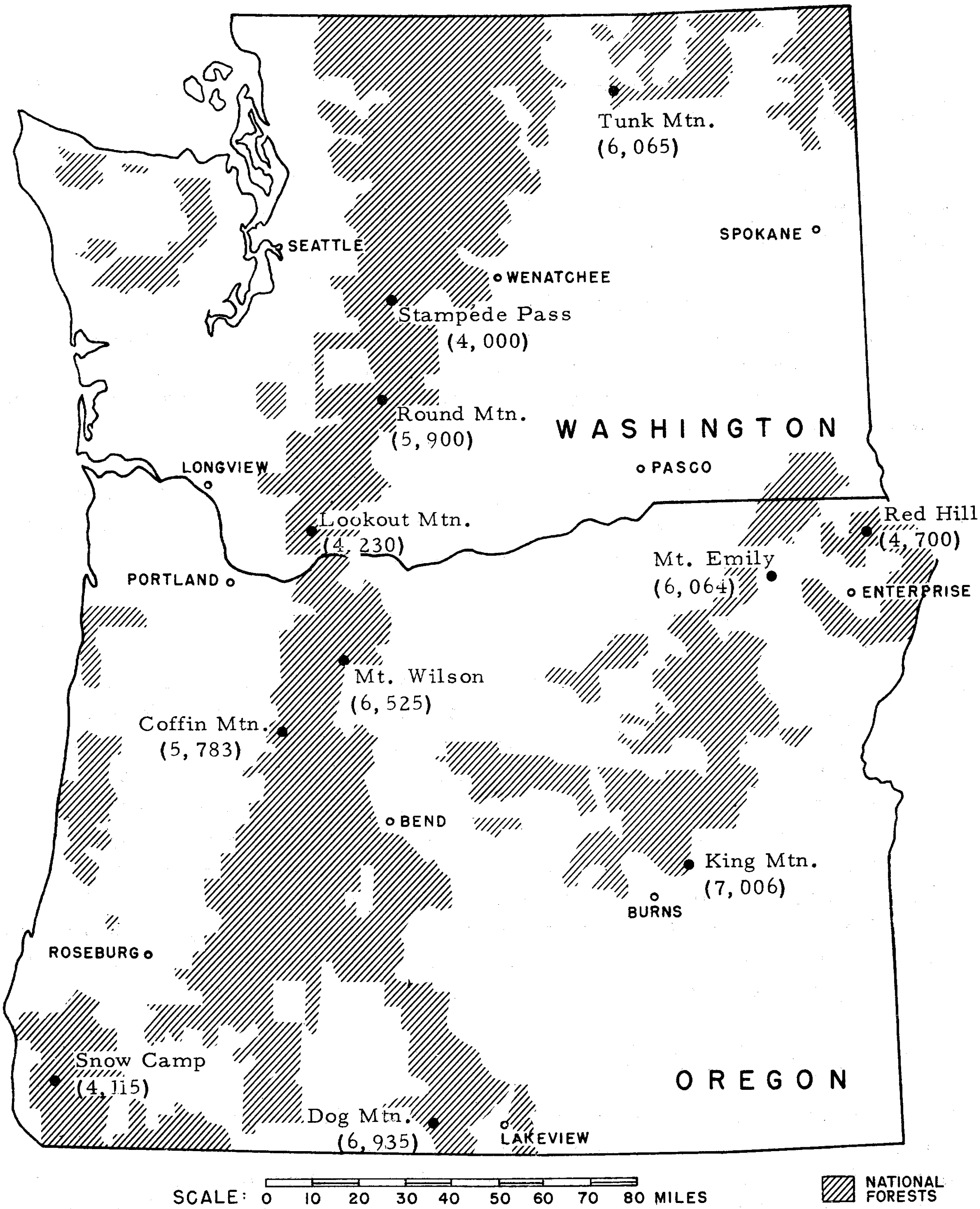


Figure 3.--Fire-danger stations used in testing wind prediction methods.

wind speed. A previous study[4] had shown that samples taken in this way provide an estimate within 3 miles per hour of the average true wind speed 95 percent of the time.

FORECAST VERIFICATION

As defined by Brier and Allen,[5] "Verification is usually understood to mean the entire process of comparing the predicted weather with the actual weather, utilizing the data so obtained to produce one or more indices or scores and then interpreting these scores by comparing them with some standard depending upon the purpose to be served by the verification."

In this study, the verification analysis has been patterned primarily to show the relative success of the various forecast methods in predicting the most important wind situations, and to show some characteristics of the forecasting methods tested.

Basis for Judging Forecast Success

In the final analysis, success of fire-weather forecasts must be measured in terms of the extent to which they are useful to the forest protection organization. Usefulness, or utility, is a relative quality. If, for example, use of forecasts results in an economy in protection cost or in reduction in area burned, the forecasts have some utility. Degree of utility may be thought of as the improvement in results over those obtained when no forecasts are used. In this study we should also like to know which method produces the greatest improvement over, not only no forecasts, but over the forecast methods previously in use.

4/ Morris, W. G. Comparison of 1-, 2-, 4-, 6-, and 8-minute wind velocity measurements. Pacific Northwest Forest and Range Experiment Station. 4 pp. (Processed.) July 1941.

5/ Brier, Glenn W., and Allen, Roger A. Verification of weather forecasts. Compendium of Meteorology. American Meteorological Society. 1951.

Forecast utility, according to Thompson,[6/] is measured not by forecast accuracy alone but by accuracy in combination with probability of occurrence, cost of taking protective measures, and contingent loss likely to occur if protective measures are not taken. Since effe cts of differences in wind speed on cost and loss are not known for each ranger district, attention has been given to the wind conditions that would logically be expected to affect cost of protection and loss from fire.

In this region, where the normal fire season corresponds to the usual period of summer drought, some preparedness against the possibility of fire is the rule from the first of July to mid-September. As long as weather conditions remain near normal, the regular protection force can control the majority of fires with little additional cost at acceptably low area burned or loss. From the standpoint of wind speed we can define three conditions that could be expected to affect the cost of protection or the acreage burned. These are (1) changes in wind speed between days, (2) other than normal wind speeds, and (3) unusually high fire danger. Success of each forecast method has been rated primarily on ability to predict wind speed for these three conditions.

Verification Limits

To provide a basis for judging when a forecast is correct, when the wind speed has changed, and when speeds are nonnormal, tolerances known as verification limits have been established. In this study these limits represent the error fire-control organizations believed they could tolerate in adjusting their forces to meet a given fire-danger prediction. The limits selected vary with the speed of the observed wind as follows:

Observed wind speed (Miles per hour)	Verification limits[7/] (Miles per hour)
0 - 9	-2 to +3
10 - 15	-3 to +4
16 - 22	-4 to +5
23 - 30	-5 to +6
Above 30	-7 to +7

6/ Thompson, J. C. On the operational deficiencies in categorical weather forecasts. Bulletin of the American Meteorological Society. 33:6, June 1952.

7/ Allowable deviation of predicted from observed wind speed.

This one set of verification limits was used for all prediction methods at all stations. In order to verify, the forecast speed must be within the verification limits of the observed speed. For example, an observed wind of 9 miles per hour would verify any forecast between 7 and 12 m.p.h. If an 11 m.p.h. wind had been forecast, it would be considered correct or verified. Likewise, an observed wind speed of 24 m.p.h. would verify any forecast from 19 to 30 m.p.h.

These same limits were used in classifying nonnormal and "change" days, but in a different manner:

A day was normal if the 4:30 p.m. wind verified a normalcy forecast, i.e., if the 5-year normal for the station was within the verification limits of the observed wind. For example, if the normal wind speed for a station were 14 miles per hour, the lowest observed speed that includes 14 within the verifying range is 10 miles per hour; the highest, 18 miles per hour. Days with speeds of 10 to 18 miles per hour would therefore be considered normal for this station.

A change was said to occur if the 4:30 p.m. wind did not verify a persistency forecast, i.e., if the previous day's 4:30 p.m. speed were outside the verification limits of the observed wind. For example, if the previous day's speed was 21 miles per hour, the lowest observed speed that includes 21 within the verifying range is 16 miles per hour; the highest, 26 miles per hour. If the current day's observed speed were outside the limits of 16 and 26, then a change would have occurred from the previous day's speed of 21 miles per hour.

Other Characteristics of Forecast Performance

Other aspects of forecast performance are also important. Percentage of all forecasts correct in comparison with standards and correlation of predicted with observed winds were among the characteristics determined. Because spot forecasts represent the most intensive wind forecasts available for protection-agency use, their accuracy was more thoroughly analysed to determine just how clearly the forecasters actually foresaw wind conditions at the test stations.

Standards of comparison.--Percentage of all forecasts correct for any forecast method is of particular interest when it is compared with the percentage correct attained by other forecasting methods. In this study statistical forecasts--the persistency forecast, the normalcy forecast, and the mean of these two--are used as standards of comparison with the other forecast methods. These standards of comparison produce comparatively high accuracy and therefore permit a comparative measure of accomplishment. For example, where a method scores 80 percent correct, apparently good forecasting appears mediocre if one or more of the standards of comparison scores even higher.

Correlation.--Percentage of forecasts correct cannot alone provide a complete measure of forecast verification because the accuracy indicated depends as much on the verification limits selected as on the sensitivity of forecasts to a change in weather conditions. Where the forecast method truly predicted wind speed, we could expect a strong statistical relation between predicted and observed values. A limited number of correlation analyses were therefore made to determine for some of the methods how closely the two were related at some of the stations during the two test years.

Additional attention to spot forecasts.--Besides correlation, other checks were made on the spot forecasts in an attempt to determine the degree to which the forecaster comprehends the actual wind conditions he predicts. Wind direction forecasts were verified on the theory that accuracy of direction forecasts indicates correctness of the forecaster's prediction of the general wind pattern.

Two spot forecasts, p.m. and a.m., were prepared for each 4:30 p.m. observed wind. The morning forecaster frequently revises the evening forecaster's prediction. These revisions were analyzed to determine how clearly the morning forecaster visualizes the true situation.

RESULTS

Verification results are presented separately for each forecasting method. The adjective "significant" is used to describe results that are statistically significant at the 95% level of confidence. Other results are also mentioned but must be considered less certain. They have not been disproved but are less likely to be repeated in a similar test or in practice than are the significant results.

Spot forecasts are analyzed first and in more complete detail than the other methods since they are assumed to represent the product of regular weather-forecasting procedures used by qualified meteorologists. The estimation aids are considered second since they represent incomplete, stopgap forecasting procedures. Finally the statistical forecasts--normalcy and persistency--are taken up and their use as forecasting procedures is considered.

Verification of Spot Forecasts

As may be seen from table 2, the overall level of accuracy of spot forecasts is highly variable between stations, with verification scores ranging from 35 to 80 percent correct. Variation in accuracy level between years at any station may be as great as 20 percent. Table 2 also shows that the spot forecast has greater accuracy than the area forecast applied directly to individual stations. This difference, which is due more to manner of use than to quality of product, was found to be statistically significant.

Ignoring for the moment variations between stations, we find that although spot forecasts average about 60 percent correct for all days, accuracy falls off for the wind situations of greatest importance to fire control (table 3). Spot forecasts show their greatest strength in predicting normal and no-change winds, though even for these groups some 25-30 percent of the forecasts indicate change or nonnormal winds that do not occur. On the important days of changed or nonnormal speeds, error predominates. The correct prediction of nearly half of the winds on days of high burning index becomes a less outstanding accomplishment when we learn that speeds are normal on 42 percent of these days and represent no change from the previous day on 48 percent of the high B.I. days.

Morning accuracy no greater.--Forecast users and forecasters alike are usually of the opinion that forecasts for shorter periods are more accurate than those for longer periods. It was therefore somewhat of a surprise to find that for all days the morning spot forecasts averaged only 1 percent greater accuracy than evening spot forecasts. The only group of winds that appeared to be benefited by the later forecast was the other-than-normal winds, which averaged an 8-percent improvement in accuracy in the morning forecast.

Standards of comparison high.--In comparison with the accuracy of normalcy and persistency forecasts, the spot forecasts are disappointing. In terms of overall accuracy for all stations, normalcy excels the average of morning spot forecasts by 4 percent. Persistency predicted 2 percent more of the other-than-normal winds than the morning spot forecast. Normalcy predicted 4 percent more of the speed changes than did the morning forecast. And the

Table 2.--Accuracy of spot forecasts and area forecasts of wind speed, for all days

(Percent correct)

Area and station	Forecast and year: 1950 Spot forecast p.m.	1950 Spot forecast a.m.	1950 Area forecast p.m.	1951 Spot forecast p.m.	1951 Spot forecast a.m.	1951 Area forecast p.m.
Washington:						
Stampede Pass	57	51	49	70	70	55
Round Mountain	58	60	57	79	79	28
Lookout Mountain	35	45	46	60	54	42
Tunk	62	47	54	62	63	44
Northeast Oregon:						
King Mountain	74	80	64	57	60	62
Mt. Emily	64	60	35	47	51	46
Red Hill	74	79	58	78	78	40
Western Oregon:						
Snow Camp	40	48	39	57	65	54
Coffin Mountain	62	74	24	71	64	14
Mt. Wilson	55	54	55	63	66	75
Dog Mountain	36	32	28	45	56	42
Average	56	58	45	63	64	46

Table 3.--Accuracy of spot forecasts compared with normalcy and persistency for different types of days

Type of day	Percentage of all days	Spot Forecasts: Evening	Spot Forecasts: Morning	Standards of comparison: Normalcy	Standards of comparison: Persistency
		-----Percent correct-----			
All days	100	59	60	64	55
Days with:					
Normal wind speed	64	72	70	100	63
Other-than-normal wind speed	36	34	42	0	44
No change in wind speed from previous day	55	70	73	72	100
Wind speed changed from previous day	45	42	46	50	0
High B. I.	21	49	50	42	48

morning forecasts were only 2 percent better than persistency in predicting wind speed for the days of high B. I. These small percentage differences are not significant.

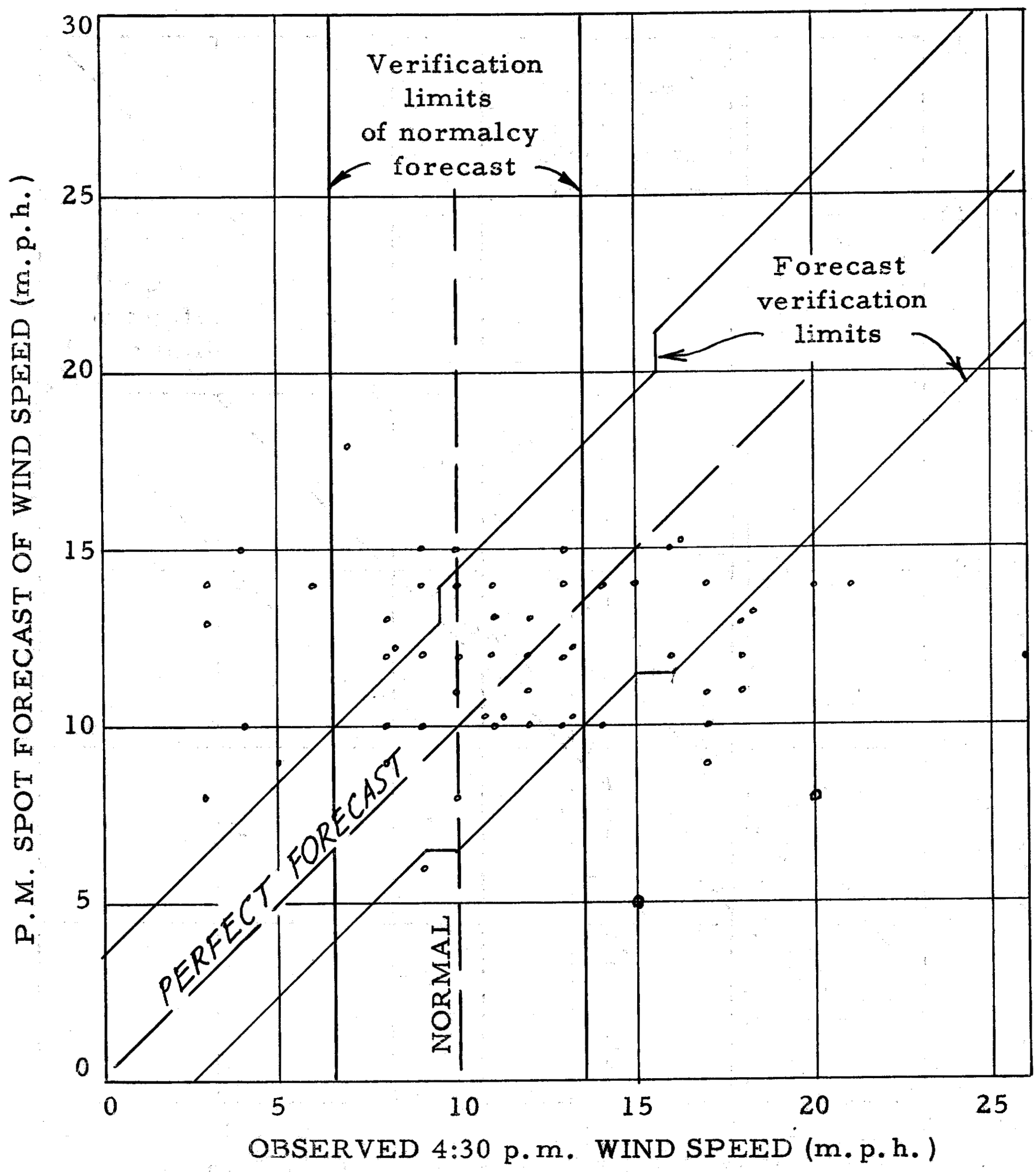
Advantage of the forecasts over the standards of comparison lies in the fact that the spot forecasts are able to predict successfully a portion of both change and nonnormal days, whereas the normalcy forecast predicts no nonnormal winds and persistency, no changes in wind. In other words, the spot forecasts are better able to predict all important winds.

Comparative value of these methods must be decided for each station as there are many exceptions to the average results.

Some correlations significant.--Correlation coefficients between spot-wind predictions and observed wind were determined for a few stations where there appeared to be the greatest likelihood of a significant correlation. Highly significant correlations were found for some stations and none for others. There appeared to be no relation between verification score for all days and degree of correlation. This was not due to forecasts that were either consistently high or consistently low.

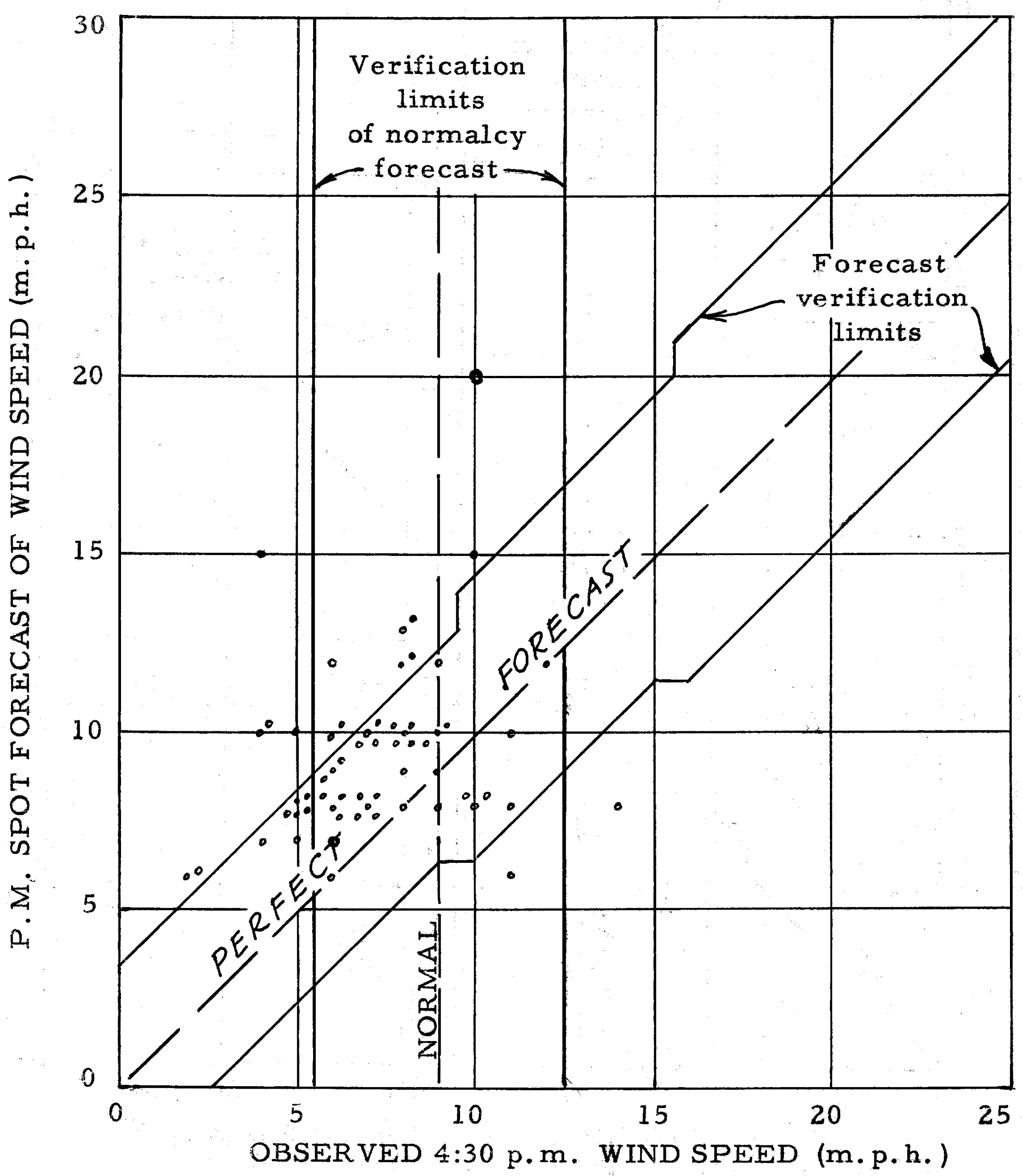
The weak relation between correlation and verification scores is illustrated in figures 4 and 5. King Mountain and Coffin Mountain were selected because verification scores of p.m. spot forecasts for these stations in 1951 differed by 14 percent while their average 4:30 p.m. wind speeds were nearly equal. Had the correlation been strong, the plotted points would have fallen in a sloping band. The lack of correlation illustrated in both diagrams is typical of many of the test stations. In spite of this weak relationship, verification scores were comparatively high because of: (1) broad verification limits, (2) predominance of near-normal observed speeds, and (3) preference of forecasters for near-normal predicted speeds. The last point is illustrated by the forecasters' tendency to predict speeds of 8, 10, and 12 m.p.h. at all levels of observed speed.

Do the forecasts foretell wind changes?--One might suspect that the forecasters have better insight into wind changes than the mediocre verification scores indicate--that because of the stringency of verification rules some wind changes might be predicted correctly in sense (increase or decrease) and still not verify in amount. Accuracy of predictions of sense of wind speed change is pertinent since ability to foresee change is prerequisite to ability to forecast.



Verification scores:
Spot forecasts 57% Normalcy 55% Correlation 0.025

Figure 4.--Comparison of p.m. spot forecast and observed 4:30 p.m. wind speeds at King Mt. (1951)



Verification scores:

Spot forecasts 71% Normalcy 79% Correlation 0.233

Figure 5.--Comparison of p.m. spot forecast and observed 4:30 p.m. wind speeds at Coffin Mt. (1951)

Changes in wind speed were observed on 45 percent of all days (table 3) and p.m. forecasts for these days were only 42 percent correct. For these days of observed change we find that the sense of the change, i.e., increase or decrease, was correctly predicted for 43 percent.[8/] A change opposite to that which occurred was predicted on only 6 percent of the days, and no change was predicted for the remaining 51 percent of the changes that occurred. It is likely that on at least a quarter of the days for which no change was predicted, the forecast correctly indicated the sense by small increases or decreases less than a change, i.e., within verification limits of predicted speed. We can then assume that change was foreseen by the forecaster for about 56 percent of the change cases. Accuracy at this level is low for effective forecast use in most situations.

A similar conclusion was reached when change was analyzed from a different standpoint. All days on which wind change might have affected the forest fire control organization--either observed wind change or predicted wind change--were considered together. For these days, sense of change was correctly predicted 50 percent of the time and oppositely predicted 20 percent. On another 20 percent of these days, a change occurred when no change was predicted. In the remaining 10 percent, change was predicted but none occurred. Apparently the forecaster has limited insight into the occurrence of change, i.e., he predicts change more frequently for change days than for days when no change occurs.

Accuracy not increased by morning revision of forecast.--An increase in accuracy had been expected between evening forecasts and those prepared the following morning. Since improvement was lacking, an analysis was made of changes made by the morning forecaster in the previous evening's wind predictions. Although there was some variation between years and between districts, the 1951 data illustrate the general condition:

In this analysis, a distinction was made between substantial changes and only minor forecast revisions. The table of verification limits was used to define "change": A "change in forecast" was said to have been made when the evening prediction was found to be outside verification limits of the value predicted in the morning. By this definition, 20 percent of all evening forecasts were changed in

8/ Analysis of forecasts for change days for 1950 season only.

the morning. An additional 41 percent of all morning forecasts slightly revised (less than a change) those of the previous evening.

Morning revision of the previous evening's forecast did not result in consistent improvement. Correction of incorrect evening forecasts was offset by correct evening forecasts made incorrect. Minor revision in the morning produced only a 2-percent increase in accuracy. Although 65 percent of the incorrect evening forecasts were revised, so also were 58 percent of the correct evening forecasts revised. It is apparently impossible to distinguish clearly the need for forecast revision.

Wind-direction forecasts analyzed.--Although wind direction is not considered in rating fire-danger, it was predicted in each spot forecast. Accuracy of direction forecasts is important as an indicator of the forecaster's ability to visualize the pressure pattern that will produce the winds he attempts to predict. If he is unable to foresee even the general orientation of flow, as would be indicated by low accuracy for direction forecasts, it is unlikely that he can accurately foretell the strength of the wind flow.

Direction was predicted to the nearest point of an 8-point compass, i.e., N., N.W., W., S.W., etc. The observed wind had to be within 45° of the predicted wind to verify the forecast.

The results indicate a close relation between accuracy of speed and direction forecasts. The average accuracy of direction forecasts for 11 stations for 2 seasons was 74 percent for evening forecasts and 78 per cent for morning forecasts (table 4). For all stations, there was a 7 percent difference between years, though this varied by fire-weather districts.[9/] The district with the greatest increase in accuracy of direction forecasts (1950-51) also showed the greatest increase in accuracy of wind-speed forecasts. That district showing the smallest increase in accuracy showed a decrease in accuracy of speed forecasts. The forecaster's ability to foresee wind speed is apparently closely associated with his ability to predict direction.

Accuracy of direction forecasts, like that of speed forecasts, is greater at stations where the variation from day to day is a minimum. Average persistency and normalcy verification scores for

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9/ Western and south-central Oregon, northeast Oregon, and Washington.

Table 4.--Accuracy of spot forecasts of wind direction[1/]

for all stations

(Percent correct)

Type of Prediction	1952 Direction	1952 Direction and speed	1951 Direction	1951 Direction and speed	Average of both years Direction
Spot forecasts:					
p.m.	70	42	77	49	74
a.m.	75	44	81	53	78
Normalcy[2/]	77	51	78	51	78
Persistency[3/]	71	38	75	48	73

1/ 1,291 station-forecast days.

2/ Percent of all days on which direction was within 45° of the direction predominating at 4:30 p.m. during the previous five years.

3/ Percent of all days on which the direction is within 45° of the direction observed at 4:30 p.m. the previous day. Not computed for direction and speed together.

all days at all stations actually equaled those of spot forecasts of wind direction. Direction forecast scores at individual stations ranged from 51 percent to 98 percent accurate. As with wind speed, where the wind direction is most variable and therefore where an accurate direction forecast might be most useful, the forecaster has the greatest difficulty.

A completely correct wind forecast should be accurate in both speed and direction. Such forecasts in the morning were made on only 44 percent of the days in 1950 and 53 percent of the days in 1951.

Verification of Forecasting Aids

W-2 estimates as accurate as spot forecasts.--The 2-year test of W-2 wind-estimation aids, based on more than 1,300 estimates (11 stations), shows an accuracy score for all days equal to that of spot forecasts. For some stations it was superior and for others not as accurate as spot forecasts. In 1951, W-2 performance ranged from a 16-percent advantage over spot forecasts at one station to a 16-percent disadvantage at another.

Highest score for all stations was for days with normal winds (table 5). On the days with other-than-normal winds, W-2 aid scored lower than the spot forecasts. When the wind changed from the preceding day, the W-2 aid scored higher. This is probably due to the inherent trait of the aid to estimate near normal in most cases. Since about 50 percent of the changes may be assumed to be toward normal, this result is not unreasonable. For the higher burning index cases, W-2 verification score was slightly under the spot forecast score for the 2-year test.

The W-2 aid was designed to adapt area forecasts, which are not intended for direct application to individual stations, to individual-station use. The extent to which this purpose was accomplished is indicated by the verification scores. The area forecast used directly resulted in an average verification score of only 46 percent, which was raised significantly to 61 percent by the W-2. Improvement of 20 percent or more was achieved at 5 of the 11 stations, with no improvement at only 2.

In addition to being dependent upon the accuracy of current forecasts for the area in which it is used, the W-2 aid has another basic weakness. It expresses the relation that existed in the past between wind predicted for an area and wind observed at an individual

Table 5.--Accuracy of W-2 forecasts for different types of days for all stations

Type of day	Percent correct	Comparison with p.m. spot forecast[1]
All days	[2] 61	+2
Days with:		
Normal wind speed	85	+13
Other-than-normal wind speed	20	-14
No change in wind speed from previous day	68	-2
Wind speed changed from previous day	50	+7
High B. I.	43	-6

1/ Positive or negative percentage values indicate greater or lesser accuracy of W-2 forecasts.

2/ Compares with 47 percent for area forecasts for all days.

station within the area. Therefore all errors in the forecasts from which the aid was constructed are incorporated into the aid. If forecast accuracy was poor, an extensive range of observed speeds may have been recorded for each predicted wind class. The less the accuracy of predictions in the base period, the more closely will the predominating observed speed for each class of predicted wind approach the 5-year average 4:30 p.m. speed. It is this weakness which causes the W-2 to adjust predicted speed toward normal. Despite this limitation, significant correlations were found between W-2 predicted and observed wind speeds at some stations in 1950. None was found in 1951.

Accuracy of W-3 estimates good.--Accuracy of W-3 varies with type of day (table 6). Only in the group of other-than-normal days is the W-3 markedly superior to the W-2. In comparison with spot forecasts, advantage of the W-3 for one type of day is offset by a poorer score in another. Its overall accuracy is slightly, but not significantly, better than that of the spot forecast and the W-2.

For the W-3 aid there was a great difference in accuracy for different stations. At Mount Wilson the accuracy of the W-3 was 21 percent greater than for the morning spot forecasts. At Coffin Mountain it was 8 percent higher. At Dog Mountain, W-3 accuracy was 6 percent higher than for the morning spot forecast and was significantly superior to both the W-2 and the evening spot forecasts. At a few stations the W-3 estimate was particularly reliable in indicating increases in speed from the previous day. At other stations, it was more reliable in indicating speed decreases. Significant correlations were found between W-3 predicted and observed wind speed at several test stations. As in other prediction methods, there appeared to be no relation between degree of correlation and total percentage of forecasts correct.

Verification of Statistical Forecasts

Normalcy forecasts score high.--Surprisingly, normal 4:30 p.m. wind speed as a continuous forecast achieved as high a score as any of the methods tested. The score for all days was approximately equal to that of the W-3 and of the mean normalcy-persistency forecasts. Prediction of normal speed obviously misses other-than-normal days, which constitute 36 percent of all days. For no-change days, the accuracy was average. The score of 50 percent for days with a change in speed was 8 percent higher than that of the p.m. spot forecasts (table 7) though not as high as the 54 percent achieved

Table 6.--Accuracy of W-3 forecasts for different types of days for all stations

Type of day	Percent correct	Comparison with[1/] a.m. spot forecast	W-2 Aid
All days	63	+3	+2
Days with:			
Normal winds	81	+11	-4
Other-than-normal winds	32	-10	+12
No change in wind speed from previous day	71	-2	+3
Wind speed changed from previous day	54	+8	+4
High B. I.	43	-7	0

1/ Positive or negative percentage values indicate greater or lesser accuracy of W-3 forecasts.

Table 7.--Accuracy of normalcy forecasts for different types of days, for all stations

Type of day	Percent correct	Comparison with p.m. spot forecast 1/
All days	64	+5
Days with:		
Normal wind speed	100	+28
Other-than-normal wind speed	0	-34
No change in wind speed from previous day	72	+2
Wind speed changed from previous day	50	+8
High B. I.	42	-7

1/ Positive or negative percentage values indicate greater or lesser accuracy of normalcy forecasts.

by W-3 estimates. For days of high-burning index, the normalcy forecast scored the lowest of all methods. Verification limits for normalcy forecasts are shown in figures 4, 5, and 6 for two of the test stations.

Persistency forecasts least accurate.--Persistency forecasts were the least accurate of all individual-station methods tested. There was considerable variation by year, district, and station. For example, in 1951 the persistency forecast gave the highest score of any method for Washington stations. For the difficult other-than-normal days, it surprisingly gave the best score of any method for the two years, exceeding p.m. spot forecasts by 10 percent (table 8). For the high-burning index days, it was not significantly worse than the spot forecasts, which were best. Accuracy for days with normal winds was the lowest scored by any of the estimation methods.

Table 8.--Accuracy of persistency forecasts for different types of days, for all stations

Type of day	Percent correct	Comparison with p.m. spot forecast[1/]
All days	56	-4
Days with:		
Normal wind speed	63	-9
Other-than-normal wind speed	44	+10
No change in wind speed from previous day	100	+30
Wind speed changed from previous day	0	-42
High B. I.	48	-1

1/ Positive or negative percentage values indicate greater or lesser accuracy of persistency forecasts.

Characteristics of the persistency forecast are shown for a representative station in figure 6. As was true of spot forecasts, the scatter of points indicates a lack of correlation between predicted and observed values. Significant correlation between persistency-forecast and observed speeds was found, however, at some stations in some years. Most obvious characteristic is the greater scatter than for spot forecasts, due to the fact that all observed speeds are automatically predicted as frequently as they occur. Another characteristic is that more of the higher speeds, which a forecaster might be hesitant to predict, are found within the verifying zone. Finally, no preference for certain speeds is evident, in contrast to the few values frequently used in the spot forecasts. A few points representing speed changes from one extreme to the other appear in the upper left and lower right hand corners.

Mean normalcy-persistency forecasts most accurate.--Combining normalcy and persistency forecasts in effect rotates the verification area in figure 6 halfway to the normalcy zone, thereby verifying a few more near-normal winds and a few less of the other-than-normal winds. Normalcy-persistency forecasts were tested and found to give accuracy as high as any other method for all days (table 9). This high accuracy is predominantly among the near-normal observed speeds at the expense of a loss in accuracy in other-than-normal speeds. Since it is these other-than-normal speeds, particularly those above normal, that are considered most important, the method was not given an exhaustive test. Significant correlation was found between predicted and observed wind at some stations in one or the other of the test years.

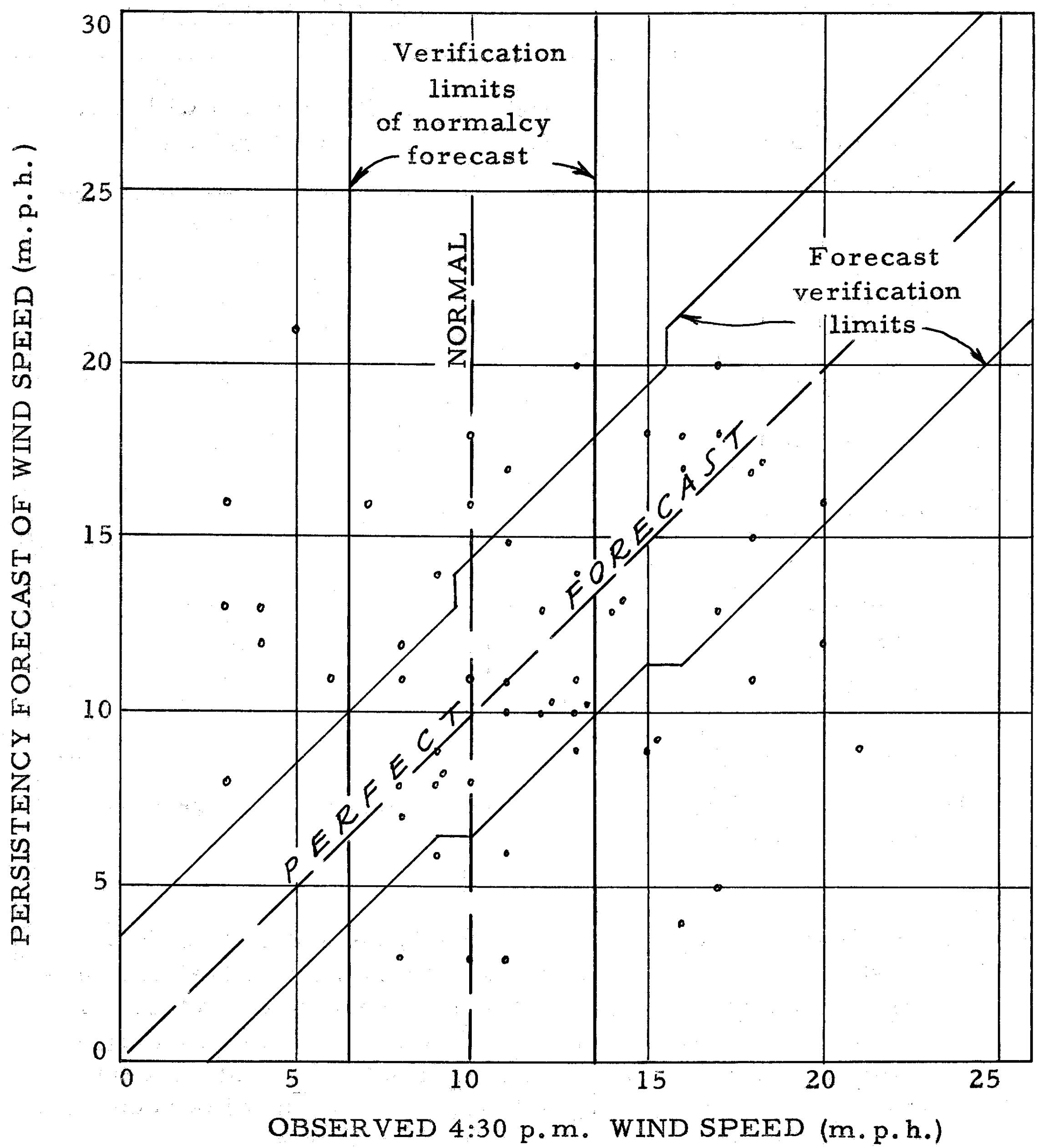
DISCUSSION

Factors Affecting Winds at Peak Stations

At each station, wind observed is the product of the existing weather type, or general weather condition, and the local terrain. Stratification and stability of the air mass, as determined by weather type, greatly influence the terrain effect. Exposure of the anemometer is a further complicating factor.

Weather Variation and Forecast Results

Since the relation of station wind to general wind varies by weather type, forecasting methods that disregard day-to-day changes in weather type will have limited accuracy. Normalcy and



Verification scores:
Normalcy (N) 55%   Persistency (P) 52%   (N+P)÷2 63%
Correlation 0.103

Figure 6.--Comparison of persistency forecast and observed 4:30 p.m. wind speeds at King Mt. (1951)

Table 9.--Accuracy of mean normalcy-persistency forecasts for different types of days, for all stations

Type of day	Percent correct	Comparison with p.m. spot forecast[1/]
All days	63	+4
Days with:		
Normal wind speed	82	+10
Other-than-normal wind speed	32	-2
No change in wind speed from previous day	88	+18
Wind speed changes from previous day	31	-11
High B. I.	50	+1

1/ Positive or negative percentage values indicate greater or lesser accuracy than p.m. spot forecast.

persistency forecasts both ignore day-to-day changes. The W-2 and W-3 forecasting aids reflect only the weather types that predominated during the period from which the aids were constructed. In making spot forecasts, the forecaster considers day-to-day variations. However, complexity of the relation between weather types and wind-flow characteristics at each station may limit his accuracy.

Accuracy of Forecasts

Variation by year.--Accuracy of the forecasting methods tested varied between the two test years. Conditions that resulted in decreases in persistency or normalcy also resulted in decreases in accuracy of other forecast methods. In other words, forecast accuracy falls off as forecast difficulty--proportion of change and nonnormal winds--increases. This relation was more evident at individual stations than for the eleven stations as a group. For a given station, any apparent differences between methods in one year could not be counted on to occur the following year. However, for all stations combined there was no significant difference between years in relative accuracy of the various methods.

Variation by forecast method. --During both years of the test, the two wind forecasts most commonly used in the field--area and persistency--gave distinctly poorer results, on the average for all days, than any other method tested (table 10). Poorest average showing was made by direct application of the area forecast, which was significantly less accurate than all other methods tested. Accuracy of the W-2 aid (adapted area forecast) was 15 percent greater than that of the area forecast used directly, and for all days was equivalent to accuracy of the spot forecasts. Persistency, though as accurate as any method on certain important types of days, was still 4 to 5 percent less accurate than the spot forecasts and 9 percent less accurate than a normalcy forecast for all days. Mean of normalcy and persistency used as a forecast was significantly more accurate than either area forecasts or persistency forecasts. All new forecast methods tested, though still far from the desired accuracy, showed improvement over methods used previously.

Variation by station. --Forecast accuracy figures based on means of several stations are likely to be misleading if their limitations are not realized. Usually a forecast procedure is tested for a single station. Whether or not it works satisfactorily at that station has no bearing on its effectiveness at any other station. When the forecast methods tested here were listed in order of their accuracy, order of listing was found to differ significantly between stations. Although the mean of verification scores for a forecast method at all stations obscures both excellent and unsatisfactory performance at the individual station, the higher means probably indicate methods that show the greatest promise at most stations.

Variation between stations in the relative performance of forecasting methods may be seen in table 10. The danger of overly simple categorical statements describing the advantage of one method over another is illustrated by the following comparisons:

1. Although morning spot forecasts averaged 60 percent correct and area forecasts for the individual station averaged 46 percent, morning spot forecasts were no more accurate (less than

Table 10.--Accuracy of forecast methods, by test station, for all days

(Percent correct)

Station	Evening area forecast	Spot forecasts a.m.	Spot forecasts p.m.	Estimation aids W-2	Estimation aids W-3	Statistical forecasts Persistency	Statistical forecasts Normalcy	Statistical forecasts 1/ (N+P)/2
Washington:								
Stampede Pass	52	63	60	2/ 72	72	51	69	59
Round Mountain	42	67	69	64	66	68	84	74
Lookout Mountain	44	48	50	48	48	46	48	56
Tunk	50	62	54	73	73	54	70	63
Northeast Oregon:								
King Mountain	63	66	70	59	54	53	63	62
Mt. Emily	41	55	56	52	48	50	44	47
Red Hill	51	76	82	75	81	68	85	80
Western Oregon:								
Snow Camp	47	48	57	44	46	51	51	57
Coffin Mountain	19	66	68	80	76	70	75	82
Mt. Wilson	65	58	58	67	79	60	66	66
Dog Mountain	34	40	44	40	52	47	43	56
Mean for all stations	46	59	60	61	63	56	64	63

1/ Mean of normal speed and persisting speed.

2/ Underlining indicates most accurate methods.

5 percent improvement) than the area forecast at 2 stations and were considerably more accurate (15 percent improvement or greater) at 4 stations.

2. Although the W-2 forecasts averaged 61 percent correct and the area forecast 46 percent, the W-2 showed no improvement over the area forecast at 4 stations and considerable improvement at 5 stations.

3. Although the W-3 forecasts averaged 63 percent correct and the morning spot forecasts 60 percent, the W-3 was considerably less accurate (lower accuracy by 15 percent or more) than the morning spot forecast at 1 station and showed considerable improvement over the morning spot forecast at 2 stations.

4. Used as a forecast, normalcy gave a lower accuracy than the morning spot forecast at 3 stations and considerably greater accuracy at 2 stations.

Intensive analysis of the winds at fire-danger stations on each district would be expected to disclose some stations for which certain estimate methods may provide improved wind-speed forecasts. Several such stations were among those listed in table 10. Unfortunately, such stations cannot be identified without thorough testing.

Accuracy for Important Winds

Although level of accuracy was similar between several of the forecasting methods for all days, there were distinct differences in accuracy for the important days. All forecast methods showed considerably less accuracy in predicting wind changes, nonnormal winds, and high B.I. winds. These are the important wind events about which the protection agency most needs reliable advance information. Accuracy differences for these days define the important advantages and disadvantages of the methods tested.

No forecast method was consistently accurate. For example, the highest average verification score for days when the speed changed from the previous day was only 54 percent (table 11). Even a continuous forecast of normal speed correctly predicted 50 percent of the changes, and a normalcy forecast is certainly not an indicator of change.

All methods tested were even less reliable for predicting other-than-normal winds. No method scored 50 percent for these days, and the highest score was made by persistency forecasting--a method that should be used only in the absence of a reliable forecast.

For the 20 percent of the days with highest B.I., several forecast methods, including persistency, resulted in accuracies near 50 percent. As B.I. increases, so also does the proportion of days on which high wind speed is the primary causative factor. High wind speeds were the primary cause of all B.I. class ratings of seven and above. The higher the wind speed, the less likely it is to be predicted by any method and the greater the comparative advantage of the persistency forecast.

Table 11.--Summary of verification scores for methods of predicting wind speed for all stations for different types of days

Type of days	Number of days	Percent of total days	Percent correct forecasts						
			p.m. spot	a.m. spot	W-2	W-3	Normalcy	Persistency	$\frac{N+P}{2}$ [1]
All days	1,364	100	[2] 59	60	61	[3] **63**	**64**	55	**63**
Normal	860	64	72	70	85	81	**100**	63	82
Other-than-normal	490	36	34	**42**	20	32	0	**44**	32
No change	736	55	70	73	68	71	72	**100**	88
Change	571	45	42	46	50	**54**	50	0	31
High B.I.	235	21	**49**	**50**	43	43	42	**48**	**50**

1/ Mean of normal speed and persisting speed.

2/ Compares with 47 percent verification from direct use of area forecasts.

3/ Underlining indicates most accurate methods.

Economic considerations.--Average scores achieved by the various methods for the most important types of days have been combined in several ways in table 12 to show comparative accuracy. Selection of the most valuable method in the final analysis depends on local economics of protection cost and fire loss for the different types of days. Under any combination of types of days, the morning spot forecast has an average score at least as high as any other method. No method even approaches desirable accuracy for all test stations, however, since for the important types of days, accuracy is below 50 percent. Whether or not the forecasts are useful at this low accuracy depends on comparisons between costs of protection with forecasts and costs without.

Importance of Current Observations

Although several of the methods tested were slightly more accurate than both area and persistency forecasts, there was no consistent source of accurate wind forecasts for all peak fire-danger stations among the methods tested. The tests show that we do have some guideposts available, but that the protection force at all times must be prepared to adjust quickly to observed changes in fire danger caused by changes in wind. Most of the really important days, i.e., those with greatest changes or highest burning indexes, are not likely to be predicted and will first become evident from current fire-danger observations at the fire-danger station. Direct observation appears to be the only consistently reliable source of information on the most important winds.

Usefulness of Persistency and Normalcy

Besides giving a basis upon which accomplishment of the forecast method can be judged, the normalcy and persistency scores give a measure of the variability of the wind at each station. In this study, it was found that forecast difficulty, as indicated by the verification scores, is also closely related to normalcy and persistency. Where persistency and normalcy were low, forecast difficulty was found to be great as evidenced by low verification scores for spot forecasts. Variability of wind and the consequent difficulty of wind prediction was found to vary between stations and from year to year.

Possible independent variables in a forecasting formula.--There is some basis for use of mean persistency-normalcy forecasting as a foundation upon which to develop a bonafide forecasting procedure for predicting wind speed. Such a procedure would be more likely to be

Table 12.--Relative accuracy of wind-speed forecasting methods, by average scores for type of days

(Percent correct)

Type of day	Spot forecast: p.m.	Spot forecast: a.m.	W-2	W-3	Normalcy	Persistency	$\frac{N+P}{2}$ 1/
All days	59	60	61	2/ 63	64	55	63
Days with:							
1. Other-than-normal wind speed	34	42	20	32	0	44	32
2. Wind speed changed from previous day	42	46	50	54	50	0	31
3. High B. I.	49	50	43	43	42	48	50
Average all days, 1, 2 and 3	46	49	43	48	39	37	44
Average, 1 and 3	41	46	31	37	21	46	41
Average, 2 and 3	45	48	46	48	46	24	40
Average, 1 and 2	38	44	34	43	25	22	32

1/ Mean of normal speed and persisting speed.

2/ Underlining indicates highest scoring methods.

used by a forecaster than by any fire control personnel in the field. That there is a high degree of persistency and normalcy in winds at peak stations during the fire season in Oregon and Washington is demonstrated by the high percentages of days on which the wind does not change and of days with normal wind speeds.

It has also been shown that high verification scores from other forecasting procedures occur when there are comparatively high percents of normalcy and persistency during the period checked. A change in level of forecast verification scores between years is usually accompanied by a corresponding change in persistency or normalcy scores or both. This leads to the possibility that persistency and normalcy might be considered dominating independent variables in the wind forecasting methods tested. The mean persistency-normalcy forecast appears to provide a highly useful base to which other variables indicative of expected weather may be added as identified.

NEEDED STUDY

Although this study found no single accurate method of forecasting wind for all mountaintop stations, the results are nonetheless important as stepping stones toward additional research which may improve accuracy of wind forecasts. The study has shown need for investigation to answer the following questions:

1. Is it possible to predict station wind speeds accurately? Wherever a high level of verification was obtained for spot forecasts, persistency and normalcy scores were correspondingly high. This indicated that the important events, that is, changes and unusual speeds, were not being predicted.

2. Are there stations at which wind should be considered a nonvariable? Any station with a normalcy score near 85 percent might be considered so sheltered that it does not experience true wind. It is possibly subject only to turbulence controlled by nearby obstacles, local terrain, and temperature relations. Many fire-danger station anemometers may be in this category.

3. Are there large areas where the wind does not vary even for exposed anemometers and where the usual air motion is local air turbulence? If there are not, then a station reporting non-varying wind may need relocating or increased exposure of the anemometer.