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Probability Forecasting in the Portland Fire-Weather District

H. S. AYER

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A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

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PROBABILITY FORECASTING - A PROBLEM ANALYSIS WITH REFERENCE TO THE PORTLAND FIRE-WEATHER DISTRICT

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Fire-Weather Office
Under WBAS, Portland, Oregon

WESTERN REGION
TECHNICAL MEMORANDUM NO. 32

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PREFACE

Mr. Ayer wrote this paper for local distribution to users of his fire-weather precipitation-probability forecasts. His purpose was to inform them regarding the meaning and use of such forecasts.

We are publishing this paper as a Western Region Technical Memorandum because Mr. Ayer's discussion is generally applicable to the type of precipitation-probability forecasts issued throughout the Region.

L. W. Snellman, Chief
Scientific Services Division

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PROBABILITY FORECASTING - A PROBLEM ANALYSIS WITH REFERENCE TO THE PORTLAND FIRE-WEATHER DISTRICT

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I. INTRODUCTION

There has been considerable discussion in the field of probability forecasting lately. Partly this is due to two or three technical papers dealing with theory and definitions. Partly it is due to some apparent disenchantment with probability statements on the part of the general public (Weather Bureau Western Region Staff Minutes, 4/1), with only about 15% of the general public seeming to understand them. In the case of special user groups the acceptance was stated as about 50%. In the case of Forestry and Fire Control groups we are sure the acceptance would be higher than 50%. Nearly all foresters whom we have talked to have expressed approval of the inclusion of a confidence factor by the forecaster.

We assume, therefore, that probability statements will continue to satisfy a need in the foresters' operations and should be refined and extended whenever possible. The ultimate objective, when considered as perfect forecasting, is to bring all probability statements toward 0% and 100%.

II. USER NEEDS

In arranging a forecasting service we always have to reach some compromise among three factors: (1) user needs, (2) forecasters' capabilities (the state of the art), and (3) basic physical differences in behavior of different weather types.

The physical difference in types is illustrated by the spatial patterns that occur in lightning storm situations vs. rain storms. As a rule, at least in the Northwest, lightning storms occur as scattered phenomena when considered in relation to areas as large as an average County or National Forest. On the other hand, rainstorms blanket such areas with rain. If we assume that lightning storms and rain storms are the only weather events which we might predict in terms of probability for the time being (these two have the most pronounced effect on fire danger, with the possible addition of wind), then we see that they might need different treatment from the standpoint of forecast statements, and especially probability forecasts. When we consider that the percentage of an area actually affected by lightning strokes, even in the most highly developed lightning storm situations, is almost infinitesimally small then the difference in the two kinds of weather situations becomes apparent. Of course there is sometimes a grey area overlapping the two, when in a situation of frequent lightning storms and many lightning strikes the pattern over a forecast period might resemble the pattern in a situation of widely scattered showers. Such occurrences are not typical, however. This example serves to illustrate a point that we were going to make later on, namely that no system of probabilities or verification is ever perfectly rigorous in practice in meteorology. This also relates to the compromise mentioned in the preceding paragraph.

In regard to rain patterns it has seemed to us that the forester wishes to know whether or not his administrative unit or a substantial portion thereof, such as a forecast reference weather zone, will receive general rain over the area. It cannot conceivably make a great difference to him to hear that some scattered showers will occur within the zone or unit, since the computation of burning index, etc., is for the zone or unit as a whole. Sullivan /1/ has also made this point recently, in addition to the same suggestion by Root /2/.

Scattered showers are of some interest, though, and have an effect on other operations; they should be stated in the headline forecast, but the estimated fractional areal coverage used as an additional factor in computation of the overall probability seems to us to thwart the applicability in rating fire-danger. Therefore we would state all rain probabilities as estimates of chance of general rain. It has also become well accepted in the Northwest that a rain of 1/10 inch or more is "significant" and a rain of 1/4 inch or more is a "wetting" rain. "Significant" can be taken to mean a modification of fuel moisture for a period of 24 hours or so and "wetting" to mean a modification for two days or more. The estimate of rain probability should be fixed upon one or both of these minima.

We have stated how the areal coverage patterns differ between rainstorms and lightning storms. The lightning probability cannot be stated in terms of a probability of blanket coverage as the rain can. The probability of lightning must be stated as an estimated chance of occurrence of a <u>situation</u> within a given area, and this is the meaning of most Fire-Weather forecasts in the West. As directed in instructions to Western Region Fire-Weather offices, the lightning storm probability is for the chance of occurrence of one or more lightning storms within a given area. The additional problem of specifying frequency or density has not been tackled as a routine procedure, although a good correlation between area probability and density does exist.

The prospect for distinguishing between cloud-to-cloud and cloud-to-ground lightning seems far away. In other words, the forecast capability at present is not such as to allow a great degree of pinpointing of lightning storms for 12 to 24 hours ahead within an area smaller than an average National Forest. Root /2/ has suggested an area of about 2500 sq. mi. as a practicable target. The increasing availability of radar reports of location and velocity of thundershowers allows a prediction of location and density of lightning storms for two or three hours ahead. The question of applying probability to these short-term warnings has not yet been raised.

To summarize the situation with respect to probability of lightning: The nature of the phenomenon, considered along with forecast capability, requires that the probability be stated as an estimate of the chance of occurrence of such a situation or weather condition within an area of roughly 2500 sq. mi., with perhaps some added expression of density or frequency in space. This is the same as expressing a probability for a point but defining the point as a given area, e.g. a National Forest or other administrative unit, or a weather zone.

A problem comes up in connection with user applications or user operations. When a lightning storm probability is issued for a Forest or agency administrative unit of similar size, or for a reference weather zone, who is it that should take action or make operational decisions based on that probability? Obviously the staff of the Forest should act on the basis of a probability given for it. But what action should be taken by individual Ranger Districts or even smaller areas of field projects? The probability of one or more lightning storms in a Forest is normally greater than the probability for a Ranger District (there are usually six to twelve Districts in a Forest). The problem is compounded by giving probabilities for the newly adopted weather zones which overlap two or more Forests; in this case there are no personnel responsible for making decisions for a reference zone as a whole or a grouping of zones. The actual probability for that fraction of a reference zone that might lie within an administrative unit would again be smaller than the probability given in a forecast for the whole zone or group of zones.

In a tentative way the Forest Service has approached the problem of responsibility for action by specifying that certain actions should be taken by an administrative unit when the probability in the forecast reaches a certain value. This seems to be a good, practical, approach, and the guidelines should be refined so as to cover actions under all of the chance values (10%, 20%, 30%, etc.) and should be specified for the various administrative sub-units within each large unit.

The problem of reference zones that overlap administrative units is not so easily solved; the problem seems to demand that the lightning probabilities be expressed for administrative units.

III. APPLICABLE PROBABILITY THEORY

In meteorology and in most of statistics the term, probability, is synonymous with relative frequency. The word "relative" means that a given frequency of occurrence of some event or characteristic has been expressed as a percentage frequency. If we have a basket of 100 red balls, 100 white balls, and 100 blue balls (similar in all respects except color) the frequency of red balls is 100 and the relative frequency is 1/3 or 33%. The probability of drawing a red ball on a first trial is also 33%. Li /3/ states, "Any statement of probability originates from the relative frequency." One sometimes encounters the term "relative probability". This is the probability of an event whenever another specified event has already occurred or begun to occur. For example, the probability of rain at Salt Lake City might be 20% (climatological relative frequency). But the relative probability might be 80% in those cases when rain was observed at Provo. This kind of probability, where there is a correlation between events, is usually referred to in the U. S. as a "conditional probability".

Panofsky and Brier /4/ point out that in practice in meteorology any probability is only an estimate. We can never count the frequency of all the cases of synoptic situations and events that have ever occurred and will occur in the future, in order to obtain a mathematically true probability. Our probabilities are estimates based on samples that are often quite limited. It is well to remember this lack of definitional rigor in meteorology.

If two different types of event are statistically independent of one another and they have probabilities of p_1 and p_2 respectively, then the probability that both will occur jointly is the product, p_1p_2. In meteorology the assumption of independence is seldom valid. One should generally utilize a conditional probability, which is based on a relative frequency count of actual cases of the specified conditions and/or parameters. In most real situations, as Panofsky and Brier say, the precise answer can be determined only empirically.

If two different types of event cannot occur simultaneously (they are mutually exclusive), such as rainfall of 0.01-0.10 inch or rainfall of 0.11-0.20 inch, and they have probabilities of p_1 and p_2 respectively, then the probability of either one occurring (that is, a rainfall of amount 0.01-0.20 inch) is the sum: p_1 plus p_2.

These theories of probability are generally familiar to meteorologists. In application to real weather forecasts, however, we have to deal with the additional concept of area; here some confusion on the part of both the users and the meteorologists themselves has seemed to appear. Each rain or shower situation and each thunderstorm situation involves a dispersion of the particular event over an area; moreover the size of the area is increased as time is extended from an instant to a 12-hour forecast period or longer. In his basic thinking the forecaster is always considering the area to be covered by a synoptic event such as a traveling rainstorm.

The concepts of "point" and "area" probabilities have recently been re-opened for discussion by Epstein /5/ and Curtiss /6/. The choice of terminology is perhaps unfortunate. It may be helpful to keep in mind that an application of probability theory to an area can be simplified by considering all probabilities as point probabilities and then defining given areas as points.

In the context of his paper, Epstein defines a point probability as: "...the probability that measurable precipitation will be observed during the forecast period at one, or any, given point in the forecast area." The context was concerned only with precipitation forecasts of any measurable amount. Epstein defines the area probability as: "...the probability that measurable precipitation will be observed at some point in the forecast area during the forecast period." We might improve the phrasing in the definition of area probability by saying, "...some one or more points..." Note that if the area is considered as a point these definitions are identical.

These two kinds of probability statement can be further explained by reference to Figure 1. Figure 1(a) illustrates the point probability. The dots represent an almost infinite number of points throughout the area. These could be observation stations or rain gages. The heavy dot marked "S" could be a particular weather station for which forecasts of rain are made. The meaning of the point probability makes it entirely immaterial where within the area the S is located; the probability is the chance of rain at any point. Any point could be chosen to verify the forecast as long as there are no local topographical influences to affect the distribution of the occurrences of measurable rain over the area. In the absence of such influences each and every point has the same chance of rain. How to treat the case when there are local influences and a non-uniform spatial distribution of occurrences will be discussed further on.

Figure 1(b) illustrates the point probability when an area is considered as a point. An event, such as lightning or a shower, might occur at only one point, S. Or it might occur at T also and at several other points in the area. In either case the meaning of area probability would be the same: the estimated chance of occurrence of one or more of the events. In stating the area probability of lightning the forecaster is estimating the chance of development of the condition or situation which would lead to thunderstorm occurrence within the area. Any statement about density or coverage (to be interpreted as relative frequency in space for the forecast period) would be a different kind of probability.

One might be tempted to multiply this probability by the additional probability due to spatial frequency in order to obtain a point probability. However, we recall that the mathematical validity of such a procedure requires that the two different probabilities, such as lightning storm situation vs. areal coverage, be independent of each other. There should be no physical association. Yet studies have shown that there is indeed an association: the higher the probability of lightning conditions the greater the density in most cases. This conditional probability can be determined or estimated empirically from past records, as described above, but there would remain the question of the practical applicability of the very low percentage figures that would result.

The mathematical treatments presented by Epstein and Curtiss /5,6/ are mainly devoted to the problem of conditional probability in the area concept and in the framework of situations of scattered showers, and the treatments need not be taken up here. Someday the sciences of meteorology and forest practices may reach a stage where meaningful conditional probabilities can be applied and used in a thoroughly quantitative way. The analyses by Epstein and Curtiss show that the proper use of conditional probabilities in meteorology is much more complicated than the simple multiplication of two probabilities, however independent they might be.

IV. VERIFICATION AND OTHER FACTORS IN FORECASTING

There is one serious problem in connection with probability statements when areas are considered as points. This is the difficulty in verification. For the purpose of determining the reliability of the probability figures given in a series of forecasts and the degree of resolution in bringing the figures toward 0% and 100%, in each individual case of a forecast for a given area there should be reasonable surety about whether one or more lightning storms did or did not occur. Referring to Figure 1(b), one can see that if there is only one observer in the forecast area at S, say, he might be unaware of any thunderstorm occurringat T or beyond. One solution would be to saturate the area with observing stations. Another solution would be to go along this direction to a practicable extent and then to expand the definition or nature of an event so as to allow a greater range of audio-visual detectability. The official instructions for observers at fire-danger rating stations (WB Form 612-17) allow the recording of a lightning storm occurrence when either thunder is heard or lightning is observed. In cases of severe limitation of stations, one could allow verification of an occurrence on the basis of sighting of cumulonimbus clouds, if estimated to be within the forecast unit area. Another alternative is a sferics triangulation system, and this should be considered when automatic telemetering weather stations begin to replace observers. A daily roll call of field personnel on the radio network in the unit area might be made as a last resort!

The question of the number of observing stations is related to the size of the area. As a rule, we would say that for an area of the size of the average National Forest (about 2000 sq. mi.) any station arrangement of less than three well dispersed observing stations would make any verification program questionable with present definitions. As a result of attrition of fire-danger stations over the course of several years the network in the Portland Fire-Weather District has been approaching this minimum requirement and may soon fall below it in some cases. This is especially true of mountaintop lookouts, and these are the stations which give the best detection of thunderstorms and lightning.

It has been the practice to group several administrative units, such as National Forests, in one portion of the daily forecast and often to state a single probability of lightning storms which is applicable to each of the Forests. On other occasions separate probabilities or qualifying statements would be given. In the case of a single probability value it is necessary to bear in mind that the probability of occurrence depends on the size of the area, other things being equal. For the United States as a whole the area probability of thunderstorms in the warm season is likely to be near 100%. For an individual Ranger District, even with indications of a well-developed thunder situation, the probability would often be in the low range. The individual National Forests and other units vary considerably in size, making any common estimate of probability of doubtful utility. The specification of approximately a 2500-square-mile area as a unit for probabilities for lightning storms is designed to overcome this difficulty in a practical manner. It would be rare for thunderstorm occurrences or tracks during a 12-hour forecast period to be spaced more than 50 miles apart, although this does happen.

Our problem is to establish the forecast unit areas so as to approach the 2500-square-mile minimum. Most of the Forests have about 2000 sq. mi. or more, but one Indian Agency with separate administration and decision-making has only about 1500 sq. miles. Some of the State Forestry areas are even less. In any event, a probability statement for an area the size of a Forest should not be interpreted by the users as necessarily an equal probability for an area the size of a Ranger District. In well-developed thunderstorm situations each Ranger District and even smaller areas would receive lightning, but our probability statement calls for "one or more" and does not distinguish between degrees of density.

It is our understanding that some Fire-Weather offices outside the Western Region are issuing thunderstorm probability statements that are based upon, and to be interpreted by the user as, the areal percentage to be "affected" by thunderstorm cells or thunderstorm clouds. It can be seen that this is not the probability as defined above. Any stated percentage more than zero might be considered as tantamount to a categorical yes-forecast (100% probability of occurrence) multiplied by the estimated spatial relative frequency. This procedure would be difficult to rationalize. It is not an area probability, nor a valid conditional probability, nor a true point probability. But in practice, no doubt, the forecaster at such a location is aware of these problems and is making an estimate of the conditional probability, based either on experience or on objective aids. As a matter of fact, objective aids using the technique of the scatter diagram are climatological summaries of the relative frequencies of past joint events; therefore they are conditional probabilities IF the dependent variable in the objective aid is made to be the areal coverage or density. This would then be a refinement of the system of using area probabilities and would constitute an improvement in utility of the forecasts.

We have pointed out that there is some correlation between area probability and areal coverage. The acceptance and workability of the areal-coverage system of forecasting are no doubt due to this. We suggest that the use of this system, with a good climatological and objective backup, be considered for the future. We also suggest that some adaptation of the mathematical treatment by Curtiss be developed.

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It would appear that point probabilities of rain should be easy to verify. Since the definition states "chance of rain at <u>any</u> point in an area", then we should be able to choose any station to determine whether or not rain did occur in each case. Also, one observation station in the area would be sufficient; no more would be needed for this purpose. This would still be true even if we allowed situations of scattered showers to be included in the probability program. However, this argument is based upon the assumption of uniform distribution of rains throughout the forecast area. If there are local influences such as varying topography, then the rains will not be evenly distributed. Moreover, this would tend to recur at about the same stations time after time. The effect this has upon the probability program depends to some extent on the nature of the forecast item. If this is "0.01 inch or more of rain", we will see many cases when some stations get no rain at all while others do. We do not, then, have complete freedom in picking a verification point.

This argument is even more critical when we have specified that only general, blanketing, rains will be referred to in the probability program, for then we must be able to determine in each case whether or not rain did blanket the area. If one had several stations in an area and knew which one had the least frequency, then it could be used for a verifying point as a practical solution to the problem.

It can also be seen that, in the practice of specifying threshhold values such as 1/10 inch, we are in fact dealing again with conditional probabilities. The forecaster must make an estimate of the probability of a general rain situation in the forecast area and then estimate the probability that the least observed amount will reach or exceed the minimum value. It seems likely that there is some correlation between these two probabilities and hence we have a conditional probability. Some work on objective aids and climatology of relative frequencies of the joint events seems called for in the rain case, too. In the meantime the forecaster can no doubt make fairly reliable estimates of these conditional probabilities.

An idea of the problems we might encounter with respect to forecasting and verification can be obtained from Figures 2-5. These have been analyzed with consideration of the larger features of the terrain relief but are smoothed with respect to small features. The area within the heavy outline is approximately equivalent to one of the National Forests, one which extends from the Cascade Range crest westward to the foothills of the Cascades (a little over 2500 sq. mi.). The station values used for Figures 2-4 were obtained from published climatological data.

Over the State as a whole there are gradients both west to east and north to south. The pattern shown is fairly typical of each month in the warm half of the year. The largest variation in number of days tends to occur east of the crest of the Cascade Range, especially with the higher threshhold values. In Figure 2 the decrease from west of the crest to the minimum on the east is 9-10 days. Or, one could say that days with 0.01 inch or more occur about two to three times as often on the west side as on the east. This ratio becomes more pronounced with the higher threshhold values in Figures 3 and 4.

Figure 5 is a repetition of Figure 3, but the analysis is based on an unpublished set of data providing a denser network, in an attempt to refine the analysis.

The area within the outlined National Forest is one of the more uniform areas of a similar size, yet it still shows significant variation. In some of the other administrative units the variation is considerable. The point to be made is that a large percentage of days occurs when the specified amount of rain may be observed in one part of the forecast unit but not in other parts. This requires care in specifying the probabilities for general rain amounts in the forecasts.

The charts in Figures 2-5 were compared to average annual isohyetal charts (average rainfall amounts) based on sophisticated techniques for interpolation between stations and an analysis according to small features of topography (Schermerhorn /7/). A striking similarity was noted. One can thus say that plots of average rainfall amounts would serve the main purpose for which Figures 2-5 were prepared, namely to delineate the sub-areas and stations in any forecast unit area in which or at which the least number of days of rain of a specified amount would occur. These need to be known in order to forecast and verify general rains of specified minimum amounts. The demand on the forecaster for attention to climatology is greatest for the forecast areas east of the Cascade crest.

Post-season verification could perhaps be facilitated by use of daily station data from the ESSA climatological network, but these will be of little help in verifying 12-hour forecasts.

V. RECOMMENDED PROCEDURE FOR PORTLAND DISTRICT

Probabilities for lightning storms considering administrative units as points should continue to be used, taking advantage of the various techniques and objective aids as before. Forecasters should give increased consideration to the relative sizes of the various administrative units, especially in expected weak or marginal situations when a wide scattering of thunderstorms might occur. This will require an increased use of separate probability percentages for various units. A list of square miles must be posted for a while.

The user procedures for utilizing the lightning-storm probabilities should be refined, it would seem. Along with this the forecasters and user administrative staffs should educate field personnel on the meaning, interpretation, and application of the forecast percentages. Once the new reference weather zones become established in a quasi-permanent fashion it would be feasible to spell out the user guidelines in terms of the reference zones. The unit areas for use in the probability forecasting could then be re-oriented toward groupings of these zones.

Further development of objective aids and climatology should proceed with a view toward eventual use of conditional probabilities and estimates of areal coverage or density, when this can be coordinated throughout the Western Region of the Bureau.

A trial of rain probability forecasting should be made. It appears that this should be restricted to general, blanketing, rain situations for a given administrative unit and directed toward minimum values of 1/10 inch or more and 1/4 inch or more. No restriction on other customary and routine rain or shower descriptions is implied.

Greater study of QPF guidance will have to be made. The procedures will be considered as a trial because little in the way of climatological or objective data and aids is available. The forecaster should know that he is making a subjective estimate of conditional probabilities.

In each administrative unit area, the estimate of probability should be directed at the station or sub-area with least frequency of occurrence of the stated amount of rain. This is a necessary criterion in order to be reasonably sure that all of the given forecast unit or area receives the stated minimum as a verification statistic. It would be reasonable to incorporate some permissible limits of error in the verification data; there is nothing magical about the quantities of 1/10 and 1/4 inch.

Frequency maps like those in Figures 3 and 4 should be prepared for other calendar months for reference.

After a year's trial the program should be appraised. If considered unsatisfactory the source of difficulty should be pinpointed as either (1) general lack of any utility in such forecasts no matter how reliable, or (2) unreliability of the probability estimates alone, in which case the situation could be remedied by development of climatological relative frequencies and/or objective aids as time goes on.

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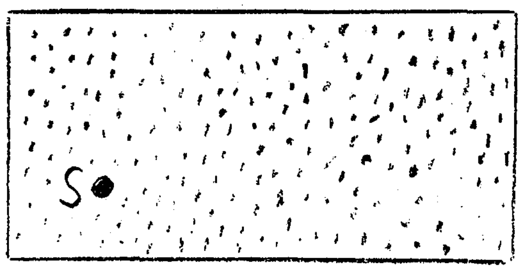
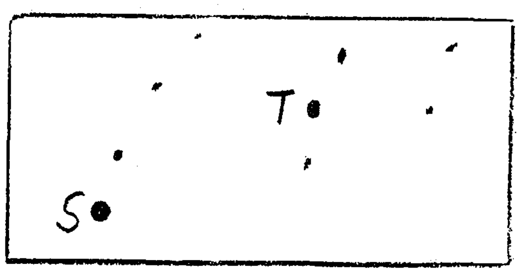


(a)



(b)

Fig. 1- Schematic illustration of definitions of (a) "point" probability and (b) "area" probability. Each rectangle is an area which could be a city and vicinity, a National Forest, or a large portion of a State. Also it could be an area marked out by 12-hour rainfall from a disturbance, or an area of thunderstorms. Discussion in text.

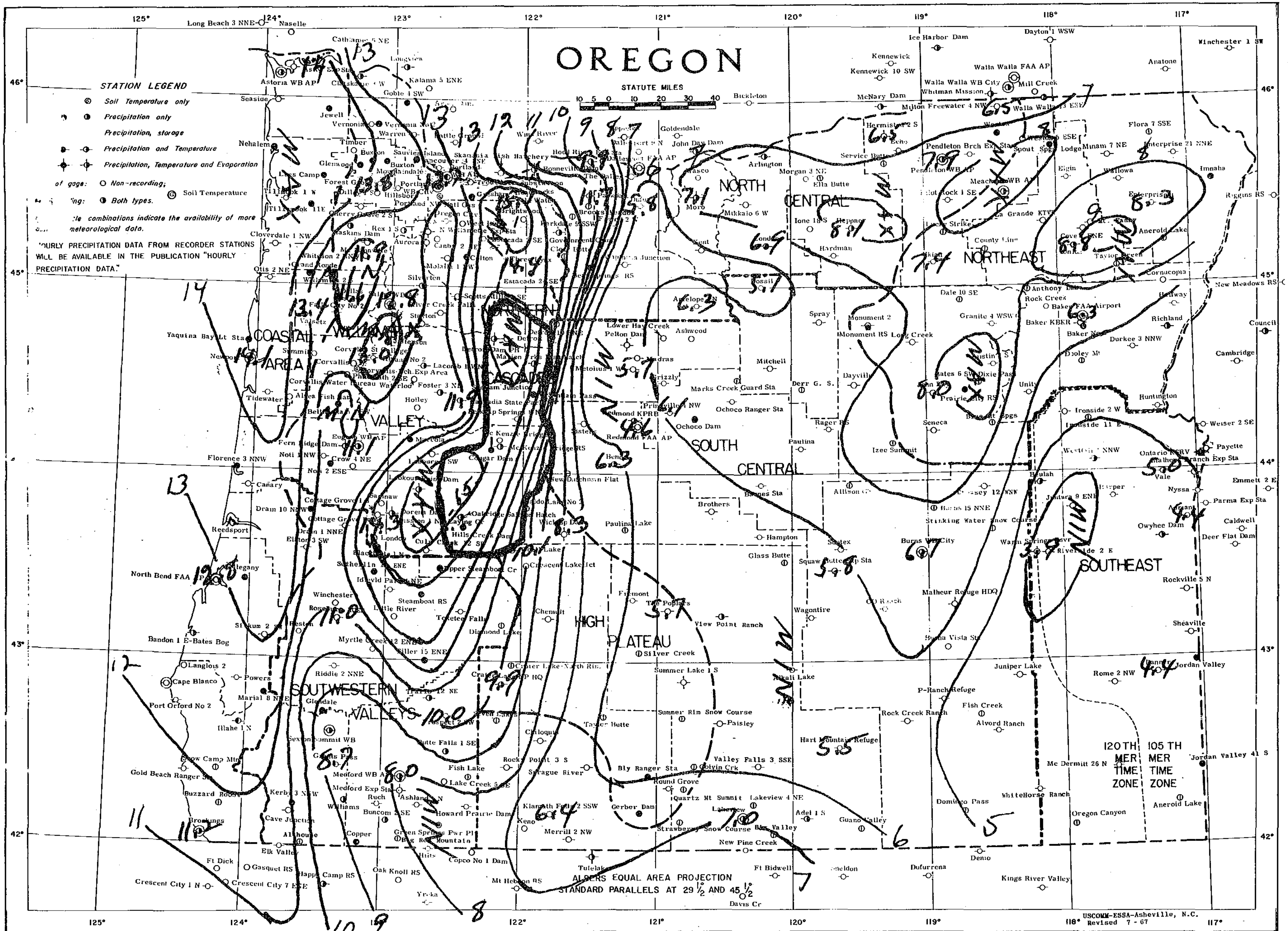


FIGURE 2 - Average number of days in October with rainfall of 0.01 inch or more. Based on data from 53 stations.

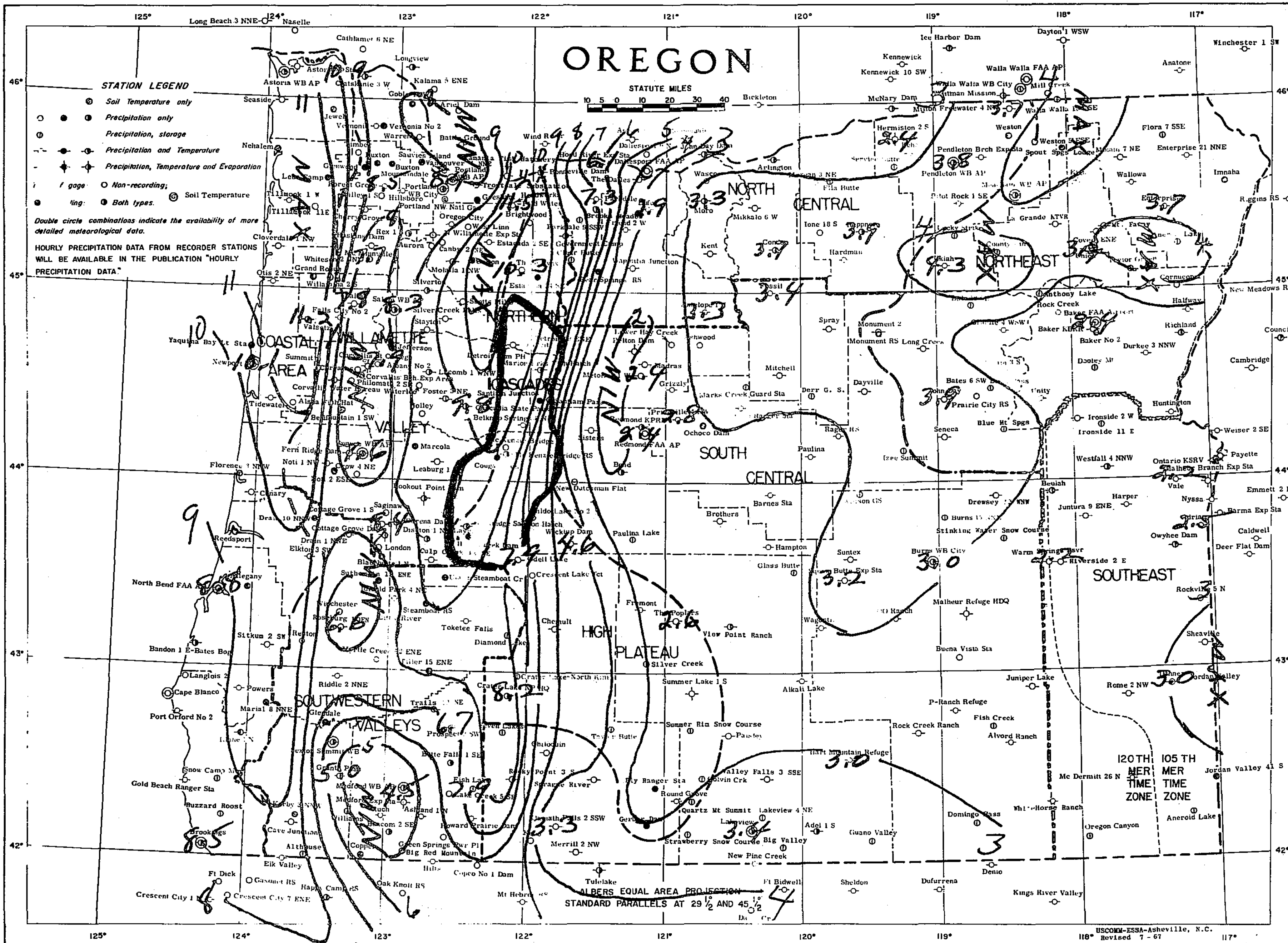


FIGURE 3 - Average number of days in October with rainfall of 0.10 inch or more. Based on data from 53 stations.

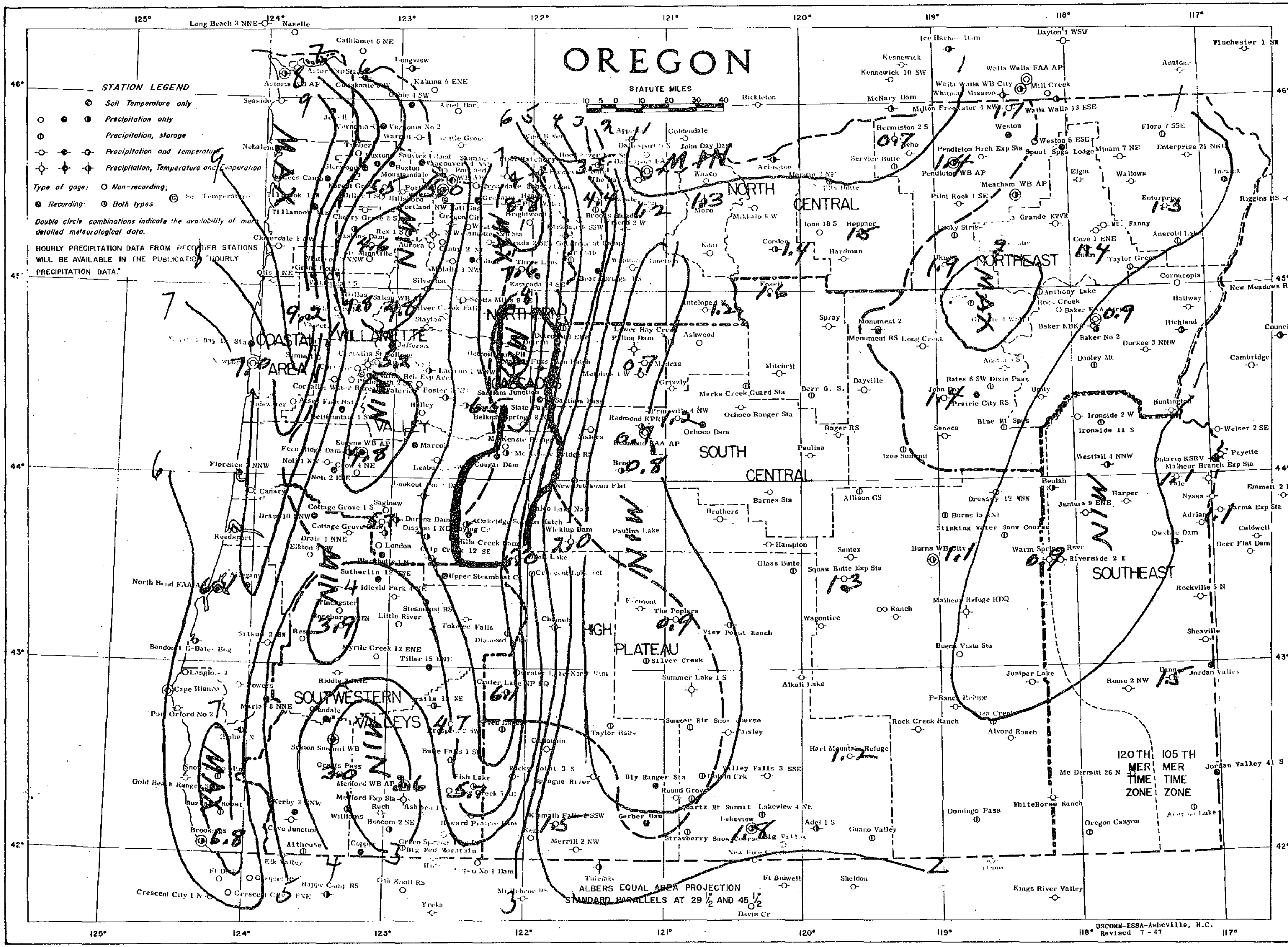


FIGURE 4 - Average number of days in October with rainfall of 0.25 inch or more. Based on data from 53 stations.

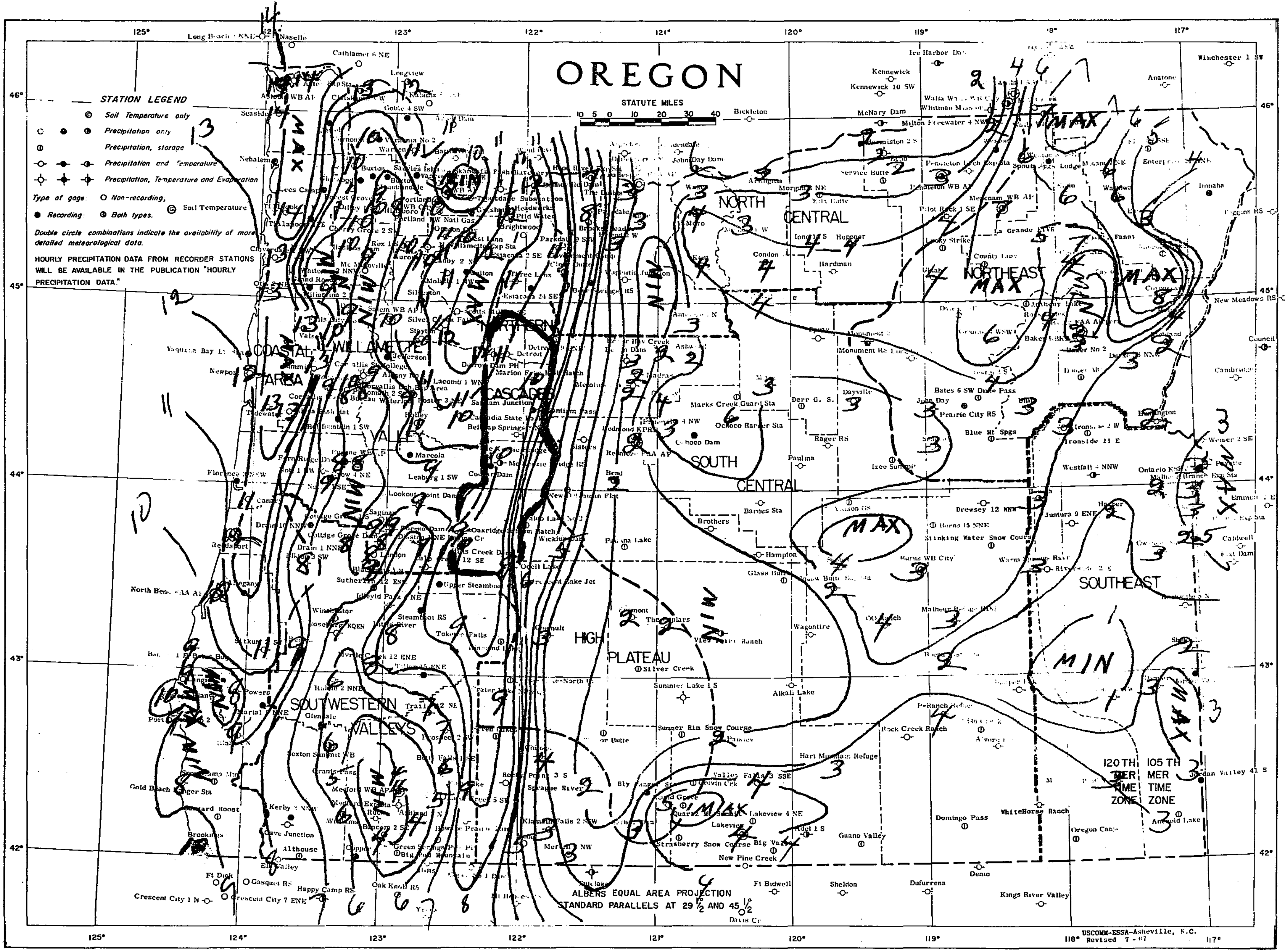


FIGURE 5 - Average number of days in October with rainfall of 0.10 inch or more. Similar to Figure 3 except based on data from 96 stations.

Western Region Technical Memoranda (Continued):

No. 24 Historical and Climatological Study of Grinnell Glacier, Montana. Richard A. Dightman. July 1967.

No. 25 Verification of Operational Probability of Precipitation Forecasts, April 1966 - March 1967. W. W. Dickey. October 1967.

No. 26 A Study of Winds in the Lake Mead Recreation Area. R. P. Augulis. January 1968.

No. 27 Objective Minimum Temperature Forecasting for Helena, Montana. D. E. Olsen. February 1968.

No. 28** Weather Extremes. R. J. Schmidli. April 1968.

No. 29 Small-Scale Analysis and Prediction. Philip Williams, Jr. May 1968.

No. 30 Numerical Weather Prediction and Synoptic Meteorology. Capt. Thomas D. Murphy, USAF. May 1968.

No. 31 Precipitation Detection Probabilities by Salt Lake ARTC Radars. R. K. Belesky. July 1968.

**Revised.