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AN IMPROVED THIESSEN GRID FOR EASTERN OREGON: AN INTERSTATION CORRELATION STUDY DETERMINING THE EFFECT OF DISTANCE, BEARING, AND ELEVATION BETWEEN STATIONS UPON THE PRECIPITATION CORRELATION COEFFICIENT *

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ABSTRACT

Sneva, F. A. and Calvin, L. D., 1978. An improved Thiessen grid for eastern Oregon: an interstation correlation study determining the effect of distance, bearing, and elevation between stations upon the precipitation correlation coefficient. Agric. Meteorol., 19: 471—483.

Multiple regression analysis of approximately 2,500 interstation correlation coefficients of crop-year precipitation (October—June, inclusively) from 74 stations in eastern Oregon yielded significant ($P < 0.01$) regression coefficients for bearing and horizontal distance and a non-significant regression coefficient was obtained for elevation difference between stations. Higher correlation coefficients were found for stations oriented in a SW—NE direction than for stations lying in a SE—NW direction. Correlation coefficients between stations decreased as horizontal distance between them increased; however, this decrease was influenced by the bearing between stations. Construction of an isohomeotrope (line of equal correlation) diagram utilizing the two primary determinants provides opportunity to (1) select for any given area in eastern Oregon that station having the most similar fluctuations in precipitation, (2) project for any given station the area it represents for predetermined levels of r, and (3) permit the construction for eastern Oregon of a Thiessen-like grid depicting bounded areas of equal crop-year precipitation similarity.

INTRODUCTION

It has been amply demonstrated that herbage production and thus the foundation of the ranching industry in the semiarid and arid regions of the western United States is dependent upon precipitation received during critical periods (Hutchings and Stewart, 1953; Smoliak, 1956; Blaisdell, 1958; Sneva and Hyder, 1962a; Dahl, 1963; Springfield, 1963). Unfortunately the extension, and therefore the practical use of these

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relationships has been hampered because (1) much of the data have been evaluated quantitatively; hence, their utility has been restricted to like areas of nearly equal production and precipitation, and (2) information is lacking regarding the spatial distribution of precipitation within the semiarid and arid regions where precipitation point estimate density is low. The first of these two factors can be made more useful by expressing the forage—precipitation relationship qualitatively as shown by Sneva and Hyder (1962a, b). This paper examines certain precipitation spatial characteristics in eastern Oregon and presents a method for defining areas of precipitation similarities.

The need for an estimate that was more reliable other than the arithmetic average for large areas motivated Thiessen (1911) to devise a weighting scheme. According to Richards and Strahl (1967), "This method (Thiessen's) assumes linear variation of precipitation between stations . . . It makes no allowance for orographic effects." It can be further said that the Thiessen method makes no allowances for the effects of storm pattern. Thiessen was not unaware of the shortcomings of his method; however, the lack of data and nonexistence of sophisticated computers limited his opportunity to examine other important factors.

Since Thiessen's contribution, a number of schemes for estimating areal or spatial distribution have been advanced. Hall (1972) reviewed 15 precipitation assessment papers, most of which have been completed since the advent of the high-speed computer. Pierrehumbert (1976) summarized 13 of the 15 methods presented by Hall and concluded that the most reliable method currently available is the Isohyetal Average Method but further noted that it was very time-consuming and was not practical in an operational environment.

The use of the correlation coefficient to describe the pattern of precipitation is, perhaps, best shown by the works of Stenhouse and Cornish in 1958. In that study, they described the mean monthly precipitation storm patterns derived from interstation correlations of 25 stations and considered the two factors of distance and bearing between stations. Unfortunately they did not extend the application of their results beyond that of defining the isohomeotropes for each month. McDonald (1956) utilized correlation and regression techniques to study spatial variation of Arizona's precipitation. He acknowledged the need for further analysis but stated that interstation correlation "shed some light on climatic gradients within the State".

Pierrehumbert, in summarizing Hall's review, lists a "Correlation Thiessen Polygon Average" and a "Correlation-Influence Function Analysis Average", with a brief description of each. The original papers dealing with those two methods were not obtainable; it is assumed that the data presented herein treats areal precipitation estimates in a similar manner.

STUDY AREA

Eastern Oregon is here defined as that portion of the state lying east of the Cascade Mountains (Fig.1). The total land area is approximately 155,400 km^2.

The northeastern corner of the area is occupied by several large irregular mountain masses generally referred to as the Blue Mountains, but there are many open valleys and considerable areas of rolling land. Two peaks of the Blue Mountains exceed 3,050 m elevation. The southern half of the area is dominated by a plateau ranging from 1,200 to 1,830 m above sea level. A few prominent ridges that extend in a north—south direction rise from the general level of the plateau. The most important of these is the Steen Mountain, which in its higher portion exceeds 2,745 m elevation. The plateau declines to the northwest corner of the area where, at The Dalles, the Deschutes River empties into the Columbia River at 46 m above sea level.

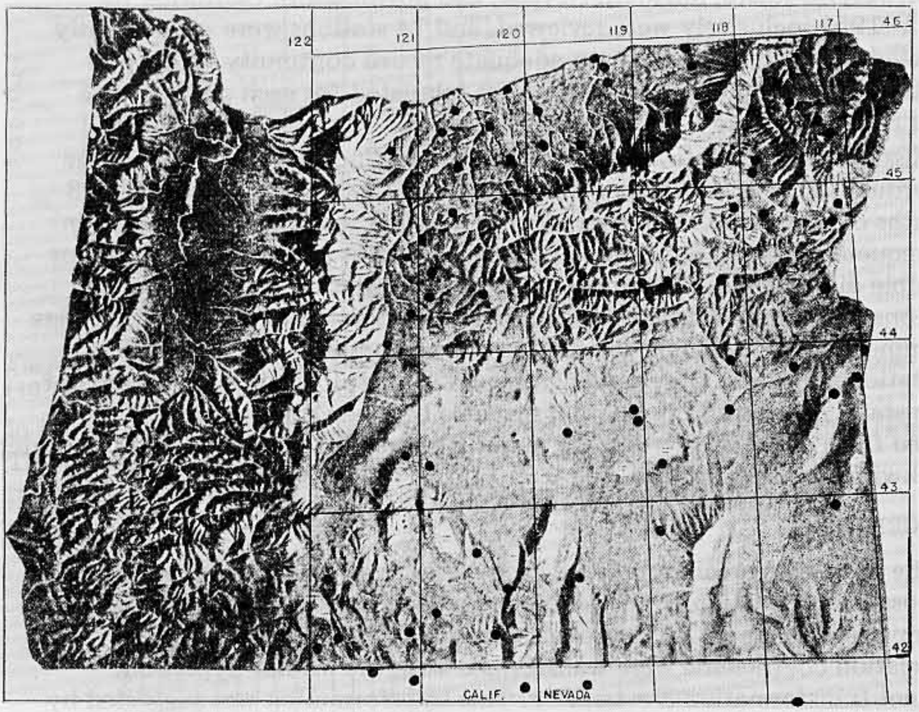

Fig.1. Physiographic map of Oregon showing station locations in eastern Oregon.

Westerly winds predominate, carrying the modifying effect of the Pacific Ocean over the state but to a lesser extent into eastern Oregon, a direct result of the towering Cascade Mountain range. The weather system is largely cyclonic, incident to low pressure systems moving eastward but distribution is greatly affected by topography. East of the Cascades, fall, winter and spring precipitation account for 88% of the total amount received. The greater portion of this precipitation is received as snow over much of the area but at lower elevations the snow dissipates rapidly.

DATA BASE

Precipitation records of over 100 weather stations in eastern Oregon, southwestern Idaho, northern Nevada, and northeastern California for 1932—1957 inclusively were reviewed, and 74 stations were subsequently selected for analysis based upon adequate record continuity. Crop-year (October—June, inclusively) totals were tabulated for each station from their respective state's "Climatological Data". *1

Missing monthly data were estimated by the "normal ratio" technique according to the U.S. Weather Bureau Manual III-C-0545. If more than 3 months of records were missing in any crop-year that year was ignored in subsequent analyses. Sub-station history of each station was examined for possible disturbances affecting its record. Precipitation records of stations suspected to have been affected by relocation or other factors were examined for deviation by the double mass technique (Merriam, 1937).

Station elevations were obtained from "Climatological Data" records of each state. Bearing and horizontal distance between stations were determined from U.S. Weather Bureau maps, with bearing being measured in degrees clockwise from the north.

PROCEDURE

The crop-year precipitation for each station was computer processed and all possible correlation coefficients (r) between stations were obtained with the minimum number of year pairs set at 13.*2 The resulting 2,467 correlation coefficients were transformed with the inverse hyperbolic tangent transformation $Z = \tanh^{-1} r$. This transformation was suggested by Fisher (1970) and yields an approximately normal distribution. The data were then separated by 80 km and 45° bearing classes, but summation of that breakdown suggested smaller intervals and the addition of an elevation variable. Subsequently, the coefficients were separated into 16 km, 10°, and 15.2 m, distance, bearing and elevation classes, respectively.

Regression analyses were used to define the relationships of the variables upon the coefficient. The correlation coefficients are not presented in this paper, but may be obtained upon request to the authors.

RESULTS AND DISCUSSION

The frequency distributions of bearing, distance, and elevation difference between stations (with a total of 2,467 observations each) are presented in

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*1 Climatological Data. E.D.S., N.O.A.A., U.S. Department of Commerce.

*2 The authors gratefully acknowledge the financial assistance of the Bureau of Land Management, U.S. Department of Interior and use of the Western Regional Computer facility of the National Weather Service, U.S. Department of Commerce.

Figs.2, 3, and 4. A slightly greater concentration of stations lies in the 355° to 55° bearing classes (Fig.2), yet the bearing variable shows the greatest uniformity in distribution of the three variables. Few stations were recorded

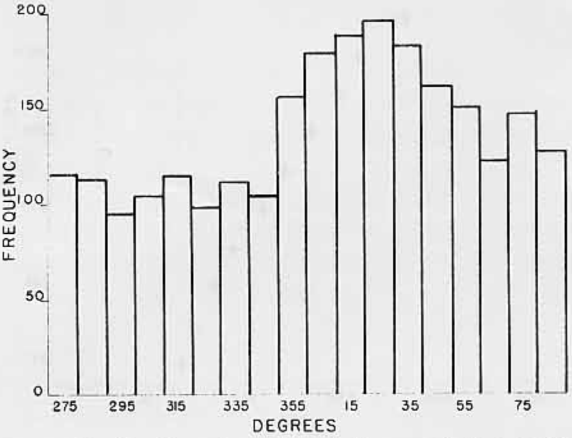

Fig.2. Distribution of weather stations as influenced by the bearing between stations (10° bearing classes).

in the distance classes less than 56 km and greater than 362 km apart (Fig.3). The lack of observations in the less-than-40-km-distance-classes is a reflection of U.S. Weather Bureau policy not to establish new stations

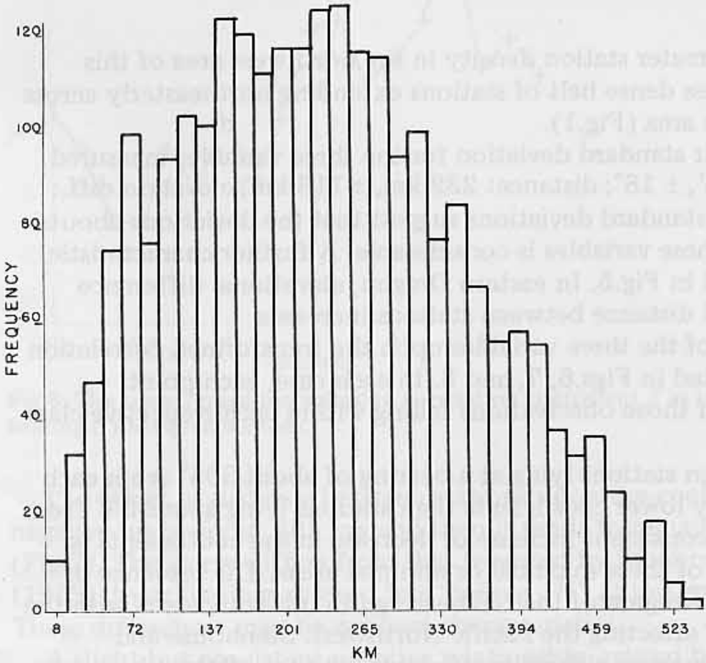

Fig.3. Distribution of weather stations as influenced by the horizontal distance between stations (16.1 km classes).

within close proximity to existing stations. Only a very few stations were noted in the elevation classes greater than 1,296 m (Fig.4). For the most part, the scarcity of observations or the skewness of the histograms shown can be attributed to greater station density in the northwest area of this region and a second less dense belt of stations extending northeasterly across the mid-section of the area (Fig.1).

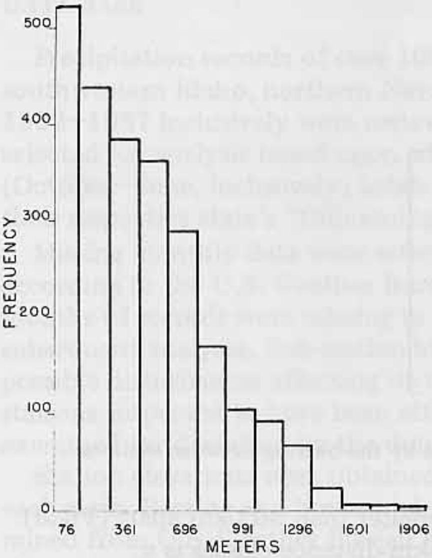

Fig.4. Distribution of weather stations as influenced by the elevation between stations (15.2 km classes).

The means and their standard deviation for the three variables measured were: bearing: 35° 35′, ± 18°; distance: 232 km, ± 116 km; elevation diff.: 474 m, ± 351 m. The standard deviations suggest that the deviations about the mean of each of these variables is considerable. A further characteristic of the area is provided in Fig.5. In eastern Oregon, elevational difference increases as horizontal distance between stations increases.

The simple effects of the three variables upon the transformed correlation coefficient are presented in Figs.6, 7, and 8. In each case, each point represents the mean of those observations falling within each respective class interval.

Coefficients between stations lying at a bearing of about 305° from each other had considerably lower coefficients than stations lying about 55° from each other (Fig.6). A consistent increase or decrease in the coefficients is evident on either side of these maximal or minimal areas. The presence of high correlations in the region of the NE bearing (45°) is coincident with the general "storm track" affecting the Pacific Northwest. Stenhouse and Cornish (1958) also reported highest coefficients between stations having an orientation approximating that of the direction of storm front movement.

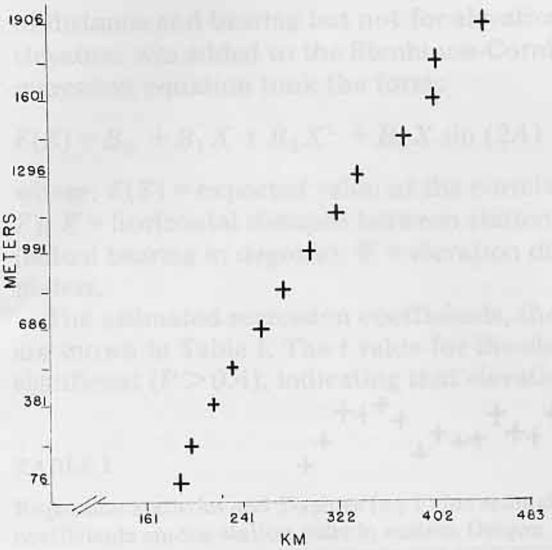

Fig.5. The elevation difference (m) between stations as related to horizontal distance (km) between stations in eastern Oregon.

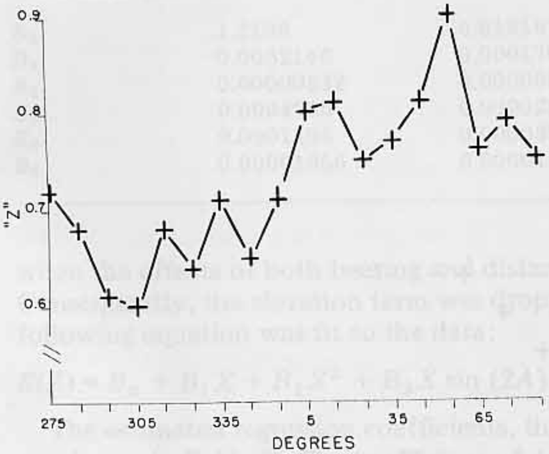

Fig.6. The transformed precipitation correlation coefficient *Z* as influenced by the bearing (°) between stations.

The effect of distance between stations upon the coefficient is strongly negative up to about 281 km and then it tends to remain reasonably constant (Fig.7). This curve differs from that reported by Stenhouse and Cornish (1958); their findings showed less "tailing off" at the greater distances. These differences may be regional characteristics.

A slight but consistent negative relationship existed between the correlation coefficient and the elevation difference between stations (Fig.8).

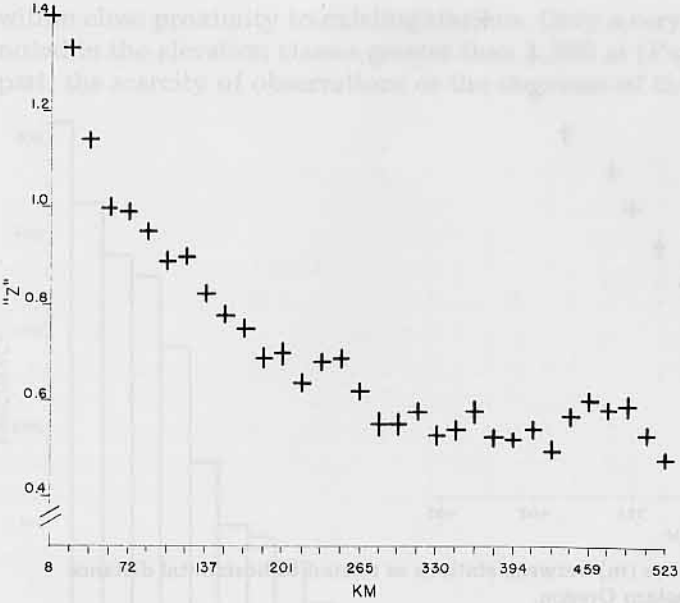

Fig.7. The transformed precipitation correlation coefficient Z as influenced by horizontal distance (km) between stations.

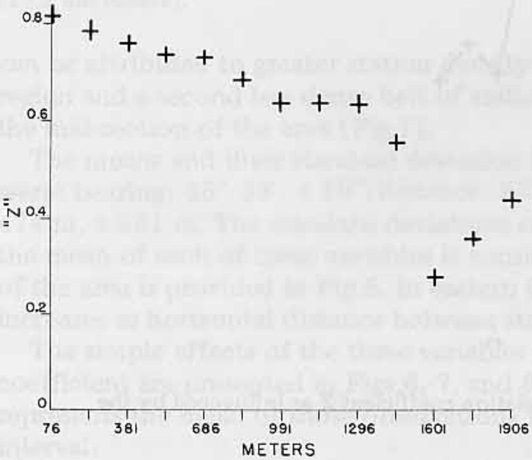

Fig.8. The transformed precipitation correlation coefficient Z as influenced by elevation difference (m) between stations.

Coefficients for elevation classes greater than 1,449 m were estimated by a very few observations.

Multiple regression techniques were used to describe the joint effects of the three variables upon Z. The regression model used was similar to the model developed by Stenhouse and Cornish, which accounted for the effects of distance and bearing but not for elevation differences. A linear term in elevation was added to the Stenhouse-Cornish model, and the resulting regression equation took the form:

$$E(Z) = B_0 + B_1 X + B_2 X^2 + B_3 X \sin(2A) + B_4 X \cos(2A) + B_5 W \qquad (1)$$

where: $E(Z)$ = expected value of the correlation coefficient (transformed to Z); X = horizontal distance between stations in kilometers; A = azimuth (actual bearing in degrees); W = elevation difference between stations in meters.

The estimated regression coefficients, their standard errors, and t values are shown in Table I. The t value for the elevation effect (B_5) was not significant ($P > 0.4$), indicating that elevation was not an important variable when the effects of both bearing and distance were taken into account. Consequently, the elevation term was dropped from the model, and the following equation was fit to the data:

TABLE I

Regression statistics and T-values (eq.1) for estimating crop-year precipitation correlation coefficients among station pairs in eastern Oregon

Coefficient	Estimate	St. error	t
B_0	1.2198	0.019157	63.67
B_1	−0.0032146	0.0001703	−18.88
B_2	0.00000322	0.000000342	9.42
B_3	0.0004755	0.0000299	15.90
B_4	0.0001495	0.0000323	4.63
B_5	0.00001355	0.0000166	0.82

$$E(Z) = B_0 + B_1 X + B_2 X^2 + B_3 X \sin(2A) + B_4 X \cos(2A) \qquad (2)$$

The estimated regression coefficients, their standard errors, and t values are shown in Table II. The coefficient of determination was 0.368, indicating that approximately 36.8% of the variation in Z was explained by the regression equation. A graphical representation of eq.2 is shown in Fig.9. The axis of maximal correlation (35.6°) was determined with a discriminate function analysis.

Subjective attempts to stratify or zone eastern Oregon on the basis of the calculated correlation coefficients were of little success. This was primarily due to that portion of the variation in the coefficients caused by differing network density in the various areas of the region. This can be done more successfully now that a mechanism is available (eq.2) to reduce those differences existing among the correlation coefficients.

TABLE II

Regression statistics and T-values (eq.2) for estimating crop-year precipitation correlation coefficients among station pairs in eastern Oregon

Coefficient	Estimate	St. error	t
B_0	1.2223	0.01891	64.64
B_1	−0.0031947	0.0001685	−18.96
B_2	0.0000032	0.000000341	9.38
B_3	0.0004717	0.0000296	15.94
B_4	0.0001599	0.0000297	5.38

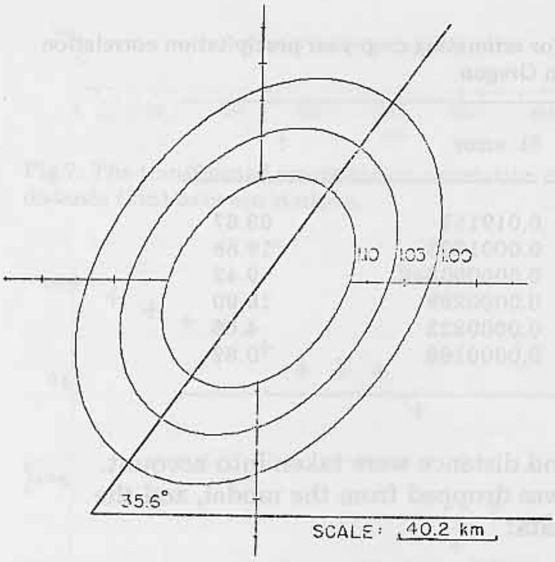

Fig.9. Isohomeotropes (Z) in eastern Oregon (crop-year precipitation).

The impact of mountain masses uplifting storm systems, the subsequent release of moisture at the high elevations and the corresponding rain shadow effect on the lee side are common knowledge. Separation of the transformed coefficients between stations after correcting for distance only by 1° longitude and 1° latitude classes was used to examine the correlation gradients east of the Cascade range. The mean of Z for each class follows:

Long.:	122°−121°	121°−120°	120°−119°	119°−118°	118°−117°
Z:	0.99	0.98	0.78	0.70	0.69

Lat.:	46°−45°	45°−44°	44°−43°	43°−42°
Z:	0.93	0.91	0.78	0.91

The mean Z decreases as the station pairs become more distant from the Cascade range. It is not possible to attribute this decrease entirely to the effect of the Cascade range as some portion may also be caused by the storm systems, *per se;* nevertheless, the similarity of precipitation fluctuations between stations in eastern Oregon decreases as station pairs become more removed from the Cascade Mountain range. Separation of the Z by latitude classes resulted in no distinguishable gradients.

APPLICATION

Eq.2 which accounts for two variables influencing the spatial distribution of precipitation in eastern Oregon provides the best means for estimating precipitation fluctuations at points remote from the recording point. However, in the practical sense, its use is restricted to those situations where sophisticated machines are available.

On the more practical level, the isohomeotrope diagram (Fig.9) can be used to locate the most representative recording station for any given location simply by centering the diagram on the given location and selecting that or those stations within the highest Z isopleth. Reversing the procedure, i.e., centering the diagram on a recording station, permits extraction of differing areas of representation for that station dependent upon the level of representation (Z) desired.

A Thiessen-like grid which divides the area into units of precipitation similarities can be constructed using the isohomeotrope diagram. Fig.10 is such a grid for eastern Oregon using stations in operation in 1977. Within the boundaries drawn for each station the crop-year precipitation is more highly related to points within the boundary lines. The boundary lines represent points of equal correlation of precipitation between pairs of stations.

The construction of the grid is straightforward in that boundary lines are located by the intersection of isopleths radiating from adjacent stations. The construction differs from that of Thiessen's grid only in that here the intersections result from oriented elliptical isopleths rather than nondirectional circular isopleths.

The use of the isohomeotrope diagram for grid construction carries the same drawback as does the construction of a Thiessen grid. Any deletion or addition to the station density of an area requires reconstruction of the grid in that locale surrounding the addition or deletion.

Eq.2, its resultant isohomeotropes (Fig.9) and the modified Thiessen grid (Fig.10) are derived from data peculiar to eastern Oregon. Because the frontal storms that dominate are a part of the weather system influencing much of the Pacific Northwest, eq.2 may be also describing precipitation fluctuation across adjacent areas as well. If so, the bearing of the major axis is the more likely factor to differ as the relation of the coefficients about the bearing approximated that reported by Stenhouse and Cornish (1958) in

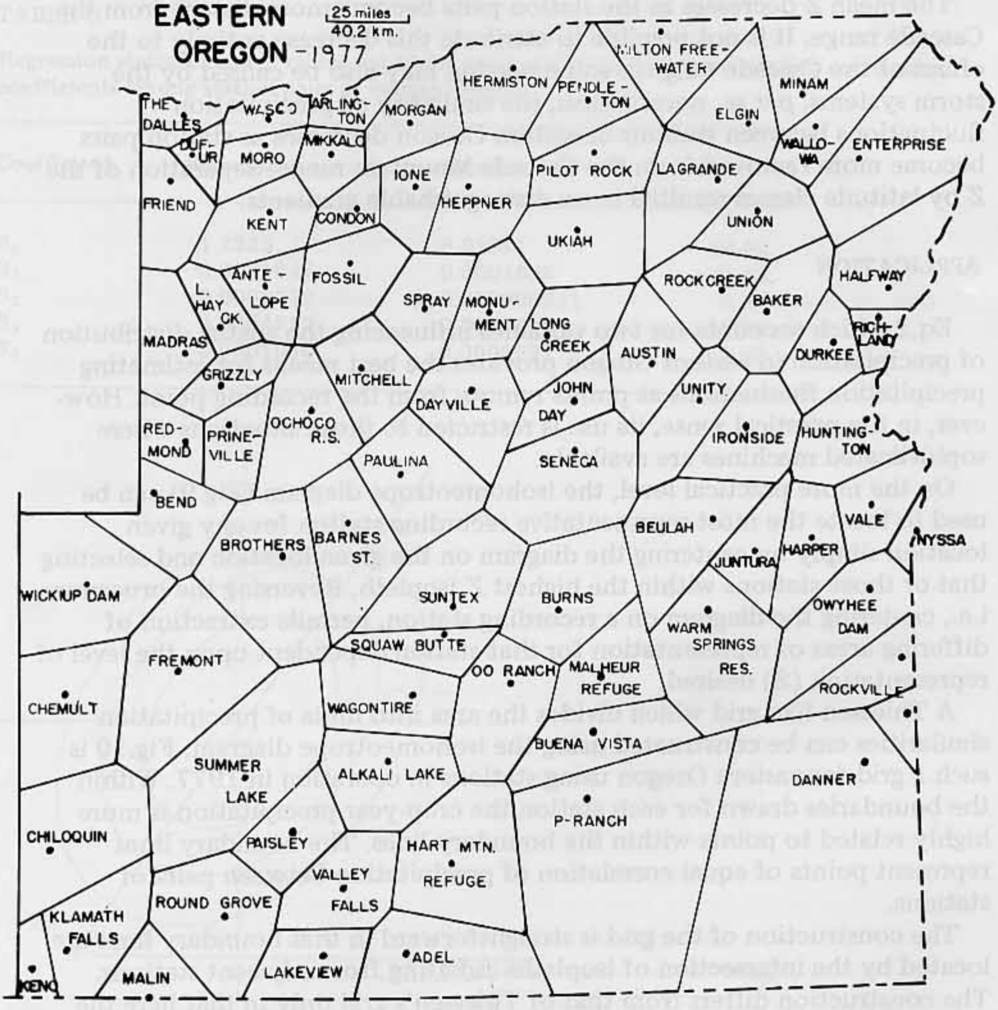

Fig.10. Precipitation-correlation grid for eastern Oregon.

Western Australia. The application of the isohomeotrope to areas eastward of Oregon is doubtful because of the decreasing correlation coefficients obtained when stratified by longitude. Thus, in those areas a new eq.2 developed from interstation correlation coefficients would be required.

SUMMARY

Horizontal distance, bearing, and elevation difference between stations were factors contributing to the variation of correlation coefficients of crop-year precipitation between stations. Horizontal distance contributed the greatest effect, but this effect was influenced by changes in bearing. As elevation difference between stations increased, the correlation coefficients decreased; however, the effect was negligible when horizontal distance and bearing were taken into account. Coefficients were highest for stations lying about SW or NE of each other, and this approximates the general storm track movement of precipitation-bearing frontal systems affecting the area.

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