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A Refinement of the Use of K-Values in Forecasting Thunderstorms in Washington and Oregon.

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Western Region

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U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

NOAA Technical Memorandum NWSTM WR-87

A REFINEMENT OF THE USE OF K-VALUES IN FORECASTING THUNDERSTORMS IN WASHINGTON AND OREGON

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WESTERN REGION
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TABLE OF CONTENTS

		Page
List of Figures and Tables		iii-iv
Abstract		1
I.	Introduction	1-2
II.	Thunderstorm-Day Frequency	2-4
III.	Results from Dependent Data	4
IV.	Modification of the Objective Probabilities	5-6
V.	Conclusion	6
VI.	Acknowledgments	6
VII.	References	6-7

LIST OF FIGURES AND TABLES

		Page
Figure 1.	Location of Areas A and B and Radiosonde Stations Bounding Each Area	8
Figure 2.	Scatter Diagram Relating Frequency of Thunderstorm Days in Area A to Average 850-mb Temperatures and Average K-Values Computed from Radiosonde Observations at Boise, Salem, Medford, and Winnemucca	9
Figure 3.	Relationship Between Computed Values of $\hat{Y}$ and Relative Frequency of Thunderstorm Days for Area A	10
Figure 4.	Same as Figure 2, Except Lines Have Been Adjusted to Reflect Parabolic Relationship Shown in Figure 3	11
Figure 5.	Scatter Diagram Relating Frequency of Thunderstorm Days in Area B to Average 850-mb Temperature and Average K-Value Computed from Radiosonde Observations at Boise, Salem, Quillayute, and Spokane	12
Figure 6.	Relationship Between Computed Values of $\hat{Y}$ and Relative Frequency of Thunderstrom Days for Area B	13
Figure 7.	Same as Figure 5, Except Lines Have Been Adjusted to Reflect Parabolic Relationship Shown in Figure 6	14
Figure 8.	Mean Number of Thunderstorm Days in U. S. National Forests in Washington and Oregon from 1 July to 15 September 1950-1966 and 1968	15
Figure 9.	Reliability Graph Relating "Forecast" Probabilities for Area A to Observed Relative Frequency of Occurrence of Thunderstorm Days	16
Figure 10.	Reliability Graph Relating "Forecast" Probabilities for Area B to Observed Relative Frequency of Occurrence of Thunderstorm Days	17
Table 1.	Percent Frequency of Occurrence of Thunderstorm Days in Area A in Categories of $\hat{Y}$	18
Table 2.	Percent Frequency of Occurrence of Thunderstorm Days in Area B in Categories of $\hat{Y}$	18

List of Figures and Tables (Continued)

		Page
Table 3.	Percent Frequency of Occurrence of Thunderstorm Days in Area A by Categories of P	19
Table 4.	Percent Frequency of Occurrence of Thunderstorm Days in Area B by Categories of P	19
Table 5.	List of Equations	20
Table 6.	Scores for Probability "Forecasts" from Dependent Data	21
Table 7.	Scores for Categorical "Forecasts" from Dependent Data P≥40% Used as Forecast of Thunderstorm Event	21

A REFINEMENT OF THE USE OF K-VALUES IN FORECASTING THUNDERSTORMS IN WASHINGTON AND OREGON

ABSTRACT

Average 1200 GMT K-values and 850-mb temperatures were used to develop an objective aid for making probability forecasts for afternoon and evening lightning occurrences in two target areas over Oregon and Washington. Thunderstorm and lightning reports from airway and Forest Service stations were used in this study.

The aid was developed on three summer seasons (1970-72 inclusive). Results on dependent data indicate that the objective forecasts can be expected to be better than climatological probabilities for the two target areas, and should be useful in preparing the short-range forecast of probability of thunderstorm occurrence issued during the early morning. Some qualitative synoptic features are discussed for modifying the objective forecast and to localize the concentration of thunderstorm occurrence in the target areas.

I. INTRODUCTION

Hambidge [1] has indicated that George's [2] technique of forecasting thunderstorm probability occurrence is applicable to western United States. George's results were applicable to southeastern United States. George's technique requires a scalar analysis of three parameters: K-value, 850-mb and 700-mb height summation, and winds below 700 mb. For air-mass thunderstorms, George used the K-value distribution to classify the number of thunderstorms for an area, modified by confluence or diffluence, and wind speeds below 700 mb. Hambidge used K-values to forecast probability of thunderstorm occurrence over western United States, modified also by confluence or diffluence.

In Washington and Oregon, fire-weather forecasters are required to forecast lightning probability for a number of federal and state protected areas. The forecaster is required to forecast a numerical probability of lightning occurrence. It is felt that a distribution of K-values combined with other numerical parameters will produce a useful objective method for forecasting lightning probabilities.

Wadsworth [3] and George both stress that parameters used in an objective forecast method should incorporate both static and dynamic atmospheric processes. The K-value is indicative of static conditions relative to thunderstorm occurrence. The 850-mb temperature can be a good dynamic predictor for thunderstorm occurrence. Generally, summer thunderstorms over Washington and Oregon occur west of the axis of the 500-mb ridge and ahead of a short-wave trough or upper low with colder air aloft moving over warmer air at lower levels. Thus, after a hot spell in the Pacific Northwest and before the on-rush of low-level marine air, summer thunderstorms generally tend to occur in this transitional period.

Through a limited investigation with thunderstorm occurrences, it was discovered that the 850-mb temperature was a good parameter to screen the K-value array in deriving probabilities of thunderstorm occurrences. Using the relationship of the 850-mb temperature with the K-value produced a better probability distribution of lightning occurrence than the relationship of the K-value with the 850-mb dew point, the 700-mb dew-point depression, the 500-mb temperature or the Showalter stability index. Although the 850-mb temperature is used twice in this objective method, the K-value masks the absolute value of 850-mb temperature. Since the 850-mb temperature is considered as a good dynamic predictor and is related to the synoptic patterns, it was felt that the array of the 850-mb temperature had to be used as a predictor.

II. THUNDERSTORM-DAY FREQUENCY

Two forecast areas were selected and are shown in Figure 1. Area A includes about 30,000 square miles in Oregon and is bounded approximately by four upper-air sounding stations: Salem, Medford, Boise, and Winnemucca. Area B includes about 54,000 square miles in Oregon and Washington and is bounded approximately by Salem, Spokane, Boise, and Quillayute. Predictors from 1200 GMT soundings from these six upper-air stations and observed lightning or thunderstorm occurrences at airway and Forest Service stations in Oregon and Washington from June 1 to September 30, 1970, 1971 and 1972 were used to develop frequency distributions.

The following conditions were specified in deriving the objective forecast: 1) Thunderstorm and lightning occurrences are considered to be identical; 2) A thunderstorm day was defined as a day when one or more thunderstorms occurred in the given area between 1000 and 2200 Pacific Daylight Time; 3) Average K-values and average 850-mb temperatures were computed from four soundings surrounding the given area. The K-value equals the algebraic summation of the 850-mb temperature and dew point, minus the 700-mb dew-point depression, and minus the 500-mb temperature (degrees Celsius):

$$K = T_{850} - T_{500} - (DP.\ D.)_{700} + DP_{850}\ .$$

Figure 2 shows the joint relationship between average K-value, average 850-mb temperature and the occurrence of lightning in Area A. A linear least squares regression equation of the following form was computed for these data.

$$Y = A X_1 + b X_2 + C$$

where Y = 100 if one or more thunderstorms occurred in the area; 0 if no thunderstorms occurred

X_1 = Average 850-mb temperature

X_2 = Average K-value

The resulting equation was:

$$\hat{Y} = 2.59 X_1 + 1.99 X_2 - 30.90. \qquad (1)$$

The lines shown on Figure 2 are the graphical representation of equation 1. A value of $\hat{Y}$ was computed for each case and the relative frequency of thunderstorm days determined for categories of $\hat{Y}$, as shown in Table 1, and plotted as crosses connected by dashed lines in Figure 3. The relationship of $\hat{Y}$ to the frequency of occurrences of thunderstorm days obviously is not linear, and strongly suggest a parabolic relationship. Therefore, a parabola of the form:

$$P = A + B Y + C Y^2$$

was fitted to the points, resulting in:

$$P = 3.204 + .2647Y + .0124Y^2 \qquad (2)$$

$$P = 0 \text{ for all values of } Y \leq -15$$

$$P = 100 \text{ for all values of } Y \geq 79.$$

The plot of the parabola is shown as the dotted curve on Figure 3. Making use of this relationship the lines on Figure 2 were adjusted to reflect the parabolic relationship between the 850-mb temperature, K-value and percent frequency (probability) of occurrences of a thunderstorm day. These adjusted lines are shown in Figure 4.

Thus, by merely entering Figure 4 with values of average 850-mb temperature and K-value, the probability (to the nearest percent) of a thunderstorm day in Area A is obtained by interpolation between the lines on Figure 4. Alternatively, of course, it is a simple matter to program the solution of equations 1 and 2 for a desk programmable calculator or for a minicomputer. An unbiased categorical forecast of thunderstorms is obtained by forecasting thunderstorms if $P \geq 40$, no thunderstorm if $P < 40\%$.

A similar analysis was performed for Area B as shown in Figure 5, 6 and 7 and Table 2. The linear regression equation relating average 850-mb temperatures and average K-values to occurrence of thunderstorm is:

$$Y = 2.36 X_1 + 2.04 X_2 - 19.91 \quad (3)$$

and the parabolic equation relating Y to the percent frequency of occurrence of thunderstorm days is:

$$P = 5.2123 + .4181Y + .0084Y^2$$

$$(P = 0 \text{ for all values of } Y \leq -10)$$

$$(P = 100 \text{ for all values of } Y \geq 84).$$

III. RESULTS FROM DEPENDENT DATA

Listed in Table 5 are a number of formulas for scores used to assess the "goodness" of probability and categorical forecasts. Applying these formulas to "forecasts" made from the dependent data resulted in the scores listed in Tables 6 and 7. Climatological probabilities for the given area were computed from the highest average thunderstorm days based on 18 years of record from the Forest Service shown in Figure 8.

Results are somewhat better for Area A than for Area B. This could possibly be due to the much larger size of Area B, and perhaps due to the inclusion of the Quillayute (UIL) sounding which is rather far removed from the eastern portion of Area B which has by far the greater frequency of thunderstorm days. Based on these scores, independent operational forecasts using this objective aid alone could be expected to show an improvement over a climatological probability forecast of about 30% in Area A and near 25% in Area B.

An indication of the resolution of the probability forecasts can be obtained by noting the average forecast probability of near 50% on thunderstorm days and an average forecast probability of 20 - 25% on no-thunderstorm days. Certainly, greater resolution than this is desirable, and perhaps the forecaster can improve upon this resolution subjectively following the ideas discussed in the follow section.

The reliability of probability forecasts based on this aid can be expected to be good (on a reasonably large sample of independent data). Note the close agreement of the "forecast" probabilities and the observed percent frequency of occurrence of thunderstorms in Figures 9 and 10, with an average deviation of 4% for both areas.

A summary of categorical "forecasts" is presented in Table 7. The least biased categorical forecast is obtained for both areas from the probability forecasts by using P = 40% as the discriminant value. The prefigurance, postagreement and threat scores are very similar for both areas, and are quite respectable.

IV. MODIFICATION OF THE OBJECTIVE PROBABILITIES

By means of Figures 4 and 7 and daily 1200Z soundings which surround the given area, a forecaster has a means of deriving objectively a first approximation of lightning probabilities for afternoon and evening thunderstorms. The average lead time for the forecast of lightning occurrence is about seven hours. This is based on the idea that from 0600 to 0700 PDT the forecaster has ample time and information to use the frequency distribution and that thunderstorms tend to begin on the average about 1400 PDT. The maximum lead time is about 11 hours, assuming that the majority of thunderstorms begin after 1800 PDT.

Since this method does not have a true dynamic parameter, the forecaster can subjectively modify the first approximation of thunderstorm probability by using 500-mb types and sea-level pressure patterns. From examining the 1200 GMT 500-mb patterns for ten thunderstorm days in the summer of 1971, two types of 500-mb patterns were noted. It is realized that ten days are a small sample but the patterns correlate well with the general features of thunderstorm occurrences in the Pacific Northwest, based on long experience of forecasters in this area.

The first pattern involves a slow eastward progression of both a deep trough and a large ridge, oriented north to south. And the second involves a steady, extensive, southerly current. In the first situation, the trough-axis is located near 130 to 140 degrees west longitude, while the ridge-axis is located near 110 to 120 degrees west longitude. Under this first situation, one can subjectively increase the lightning probability. In the second situation, areas of confluence and speed convergence are embedded in the southerly current, and are associated with a minor perturbation or a weak cut-off low. Under the second situation, one can increase the objectively obtained first estimation of lightning probability under and ahead of areas of confluence and speed convergence.

In reference to the sea-level pressure pattern, position and eastward movement of the thermal trough are significant in the climatological probability for the occurrence of thunderstorms. Surface winds on either side of the surface thermal trough indicate a convergence region and a line of discontinuity. It is suspected that often the thermal trough is a low-level trigger mechanism for thunderstorms. Ward [4] has indicated that 67% of 625 days of thunderstorm occurrence over Oregon and Washington National Forests occurred when the thermal trough was along or east of the Cascade Range at 0100 GMT. Ward used a 10-year period from May to September 1925-1934. With an approaching upper trough or weakening cold front, and the eastward movement of the surface thermal trough, one should increase the objectively determined probability along and ahead of the expected thermal trough position during the afternoon and evening.

A forecaster can also subjectively modify the objective lightning probability by noticing the thunderstorms occurring upstream under steady flow that is expected to persist over the given area, and by anticipating kinematic convergence or divergence on the 700-mb map.

In localizing thunderstorm occurrences and probabilities to areas smaller than Areas A and B, one can use the surface thermal trough position at 1200 GMT. Sullivan's [5] localization of thunderstorm occurrence in Alaska with respect to the thermal trough applies in this area. Instead of an east-to-west thermal trough as in Alaska, there is a tendency for thermal troughs to be aligned north to south in Oregon and Washington, probably due to the Cascade Range's orientation. Sullivan indicated that nearly all thunderstorm occurrences were within 150 miles of the thermal trough-axis. In this analysis of the ten thunderstorm days in the summer of 1971, the elongated areas of thunderstorms tended to be parallel to the 1200 GMT thermal trough-axis and concentrated in a band from 30 miles west of the axis to 130 miles east, under a slow eastward progression of a deep trough and large ridge. When there is a perturbation embedded in a southerly flow, the concentration of thunderstorms is within 50 to 70 miles east and west of the 1200 GMT surface thermal trough-axis, with a secondary concentration at 100 to 120 miles east of the thermal trough-axis.

V. CONCLUSION

The use of the mean K-value and the mean 850-mb temperature can produce a useful objective thunderstorm probability of occurrence as a first approximation in making a short-range forecast. However, other considerations such as present and future dynamic conditions of the atmosphere for the given area should be used to subjectively modify the first approximation to arrive at the final thunderstorm probability for the short-range forecast.

VI. ACKNOWLEDGMENTS

Appreciation is expressed to Mr. Harold S. Ayer, Fire Weather Supervising Forecaster, Portland, Oregon, and to Scientific Services Division, Western Region Headquarters, for their reviews and suggestions. Special thanks are due Mr. Woodrow W. Dickey for his suggestions and aid in analysis of the data.

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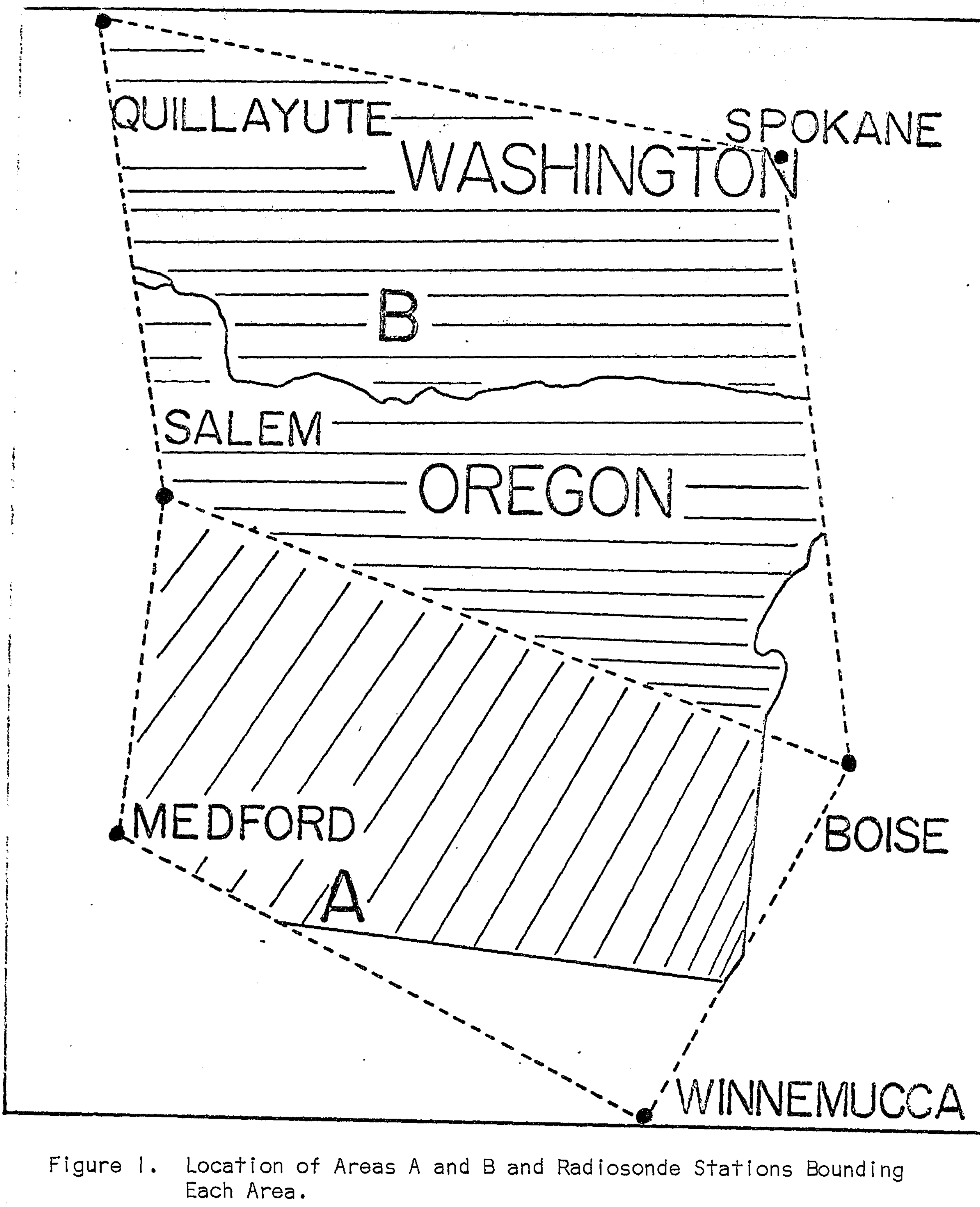

Figure 1. Location of Areas A and B and Radiosonde Stations Bounding Each Area.

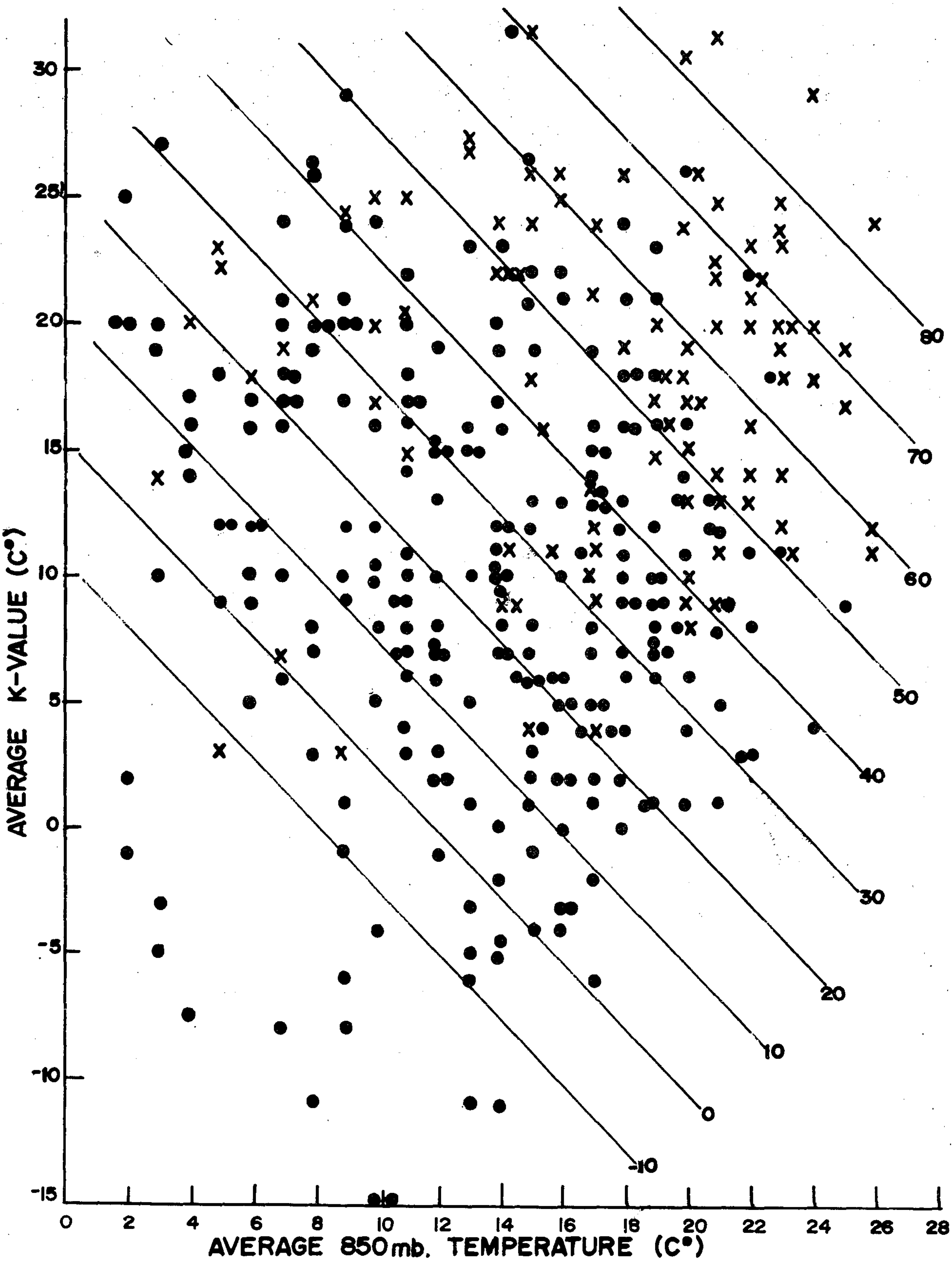

FIGURE 2. SCATTER DIAGRAM RELATING FREQUENCY OF THUNDERSTORM DAYS IN AREA A TO AVERAGE 850-MB TEMPERATURES AND AVERAGE K-VALUES COMPUTED FROM RADIOSONDE OBSERVATIONS AT BOISE, SALEM, MEDFORD, AND WINNEMUCCA. LINES REPRESENT SOLUTION OF LINEAR REGRESSION EQUATION: $\hat{Y} = 2.59 X_1 + 1.99 X_2 - 30.90$. CROSS REPRESENTS THUNDERSTORM DAY; DOT NONTHUNDERSTORM DAY.

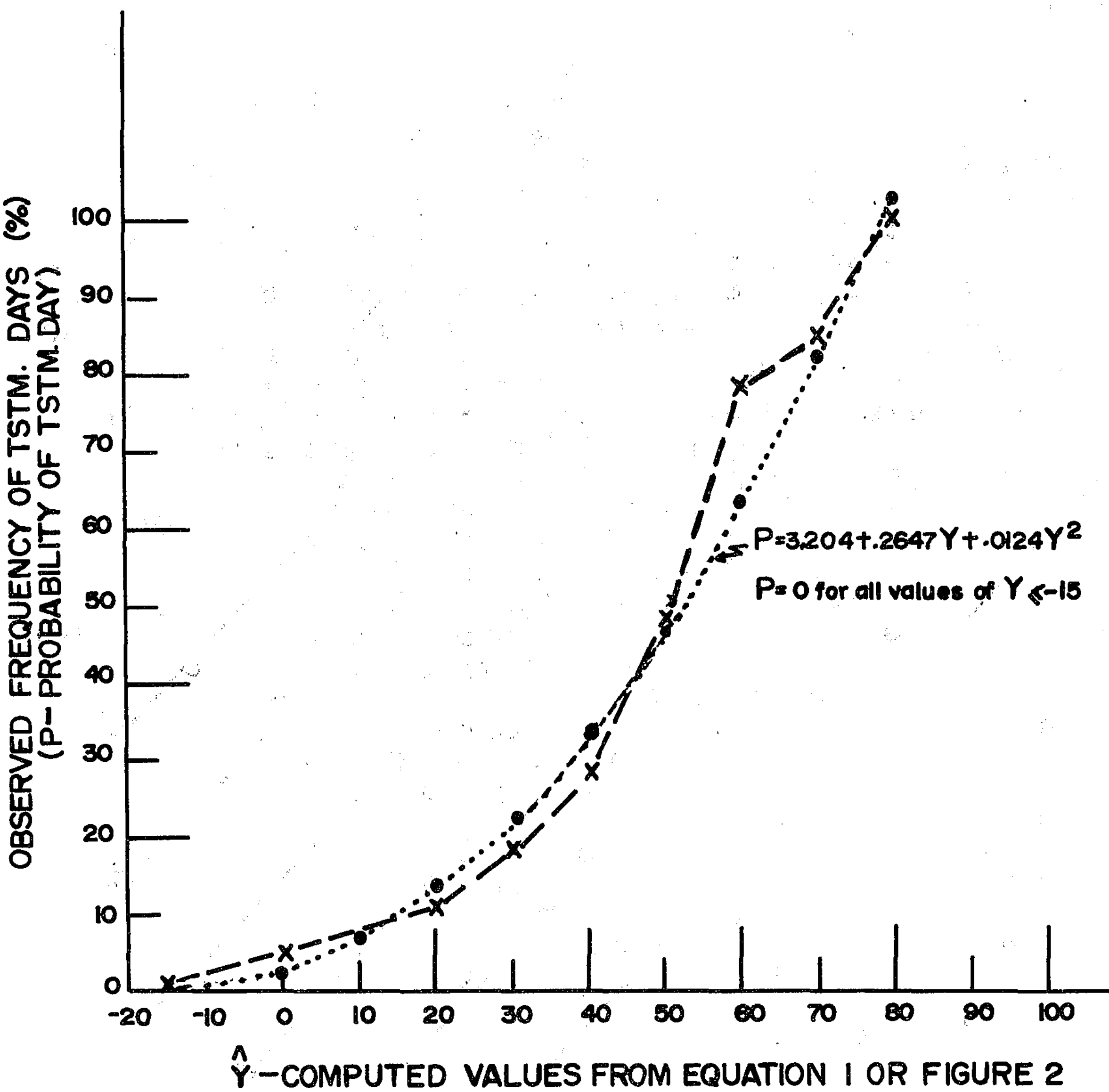

FIGURE 3. RELATIONSHIP BETWEEN COMPUTED VALUES OF Ŷ AND RELATIVE FREQUENCY OF THUNDERSTORM DAYS (CROSSES AND DASHED LINE) FOR AREA A. DOTTED CURVE REPRESENTS PARABOLA FITTED TO CROSSES.

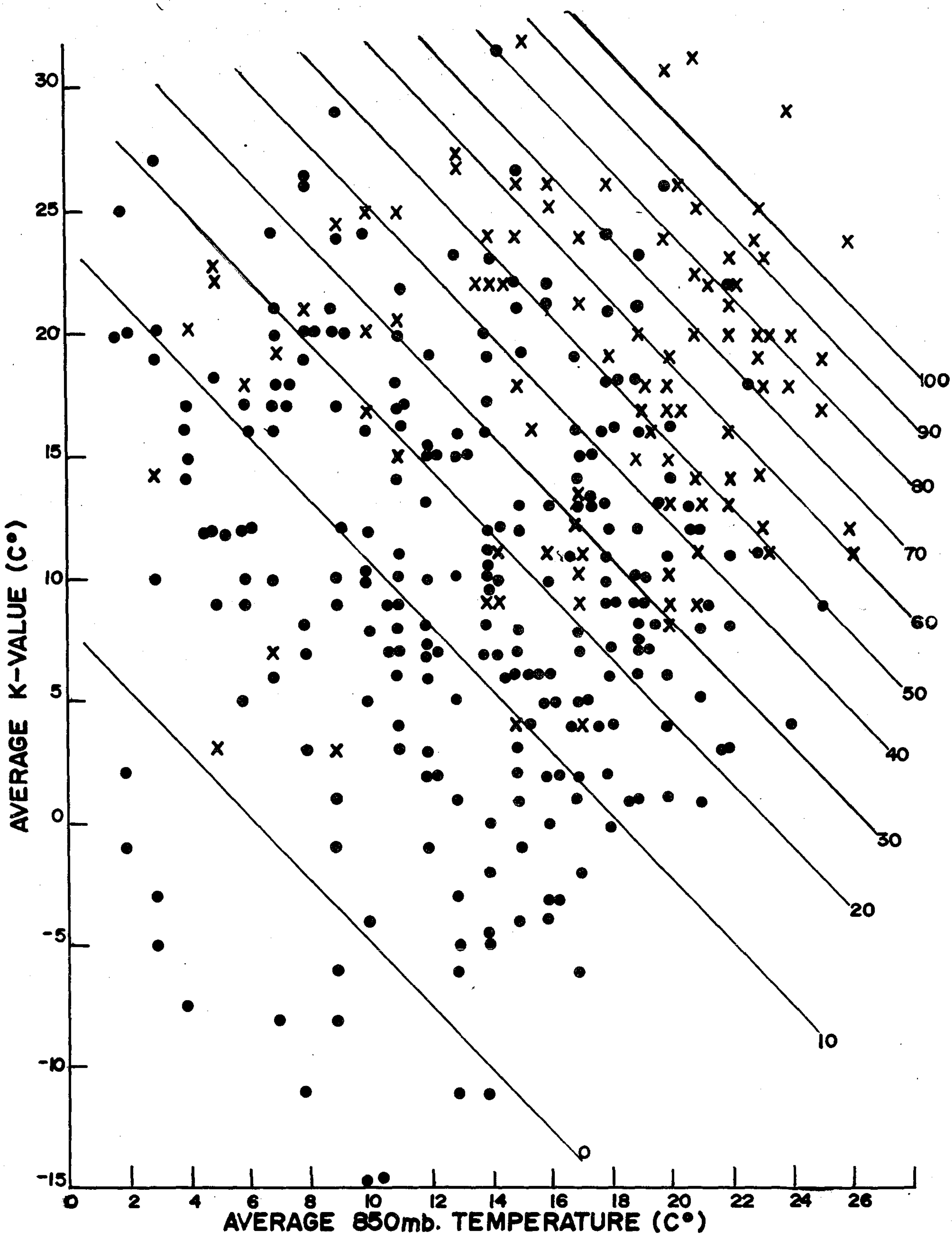

FIGURE 4. SAME AS FIGURE 2, EXCEPT LINES HAVE BEEN ADJUSTED TO REFLECT PARABOLIC RELATIONSHIP SHOWN IN FIGURE 3.

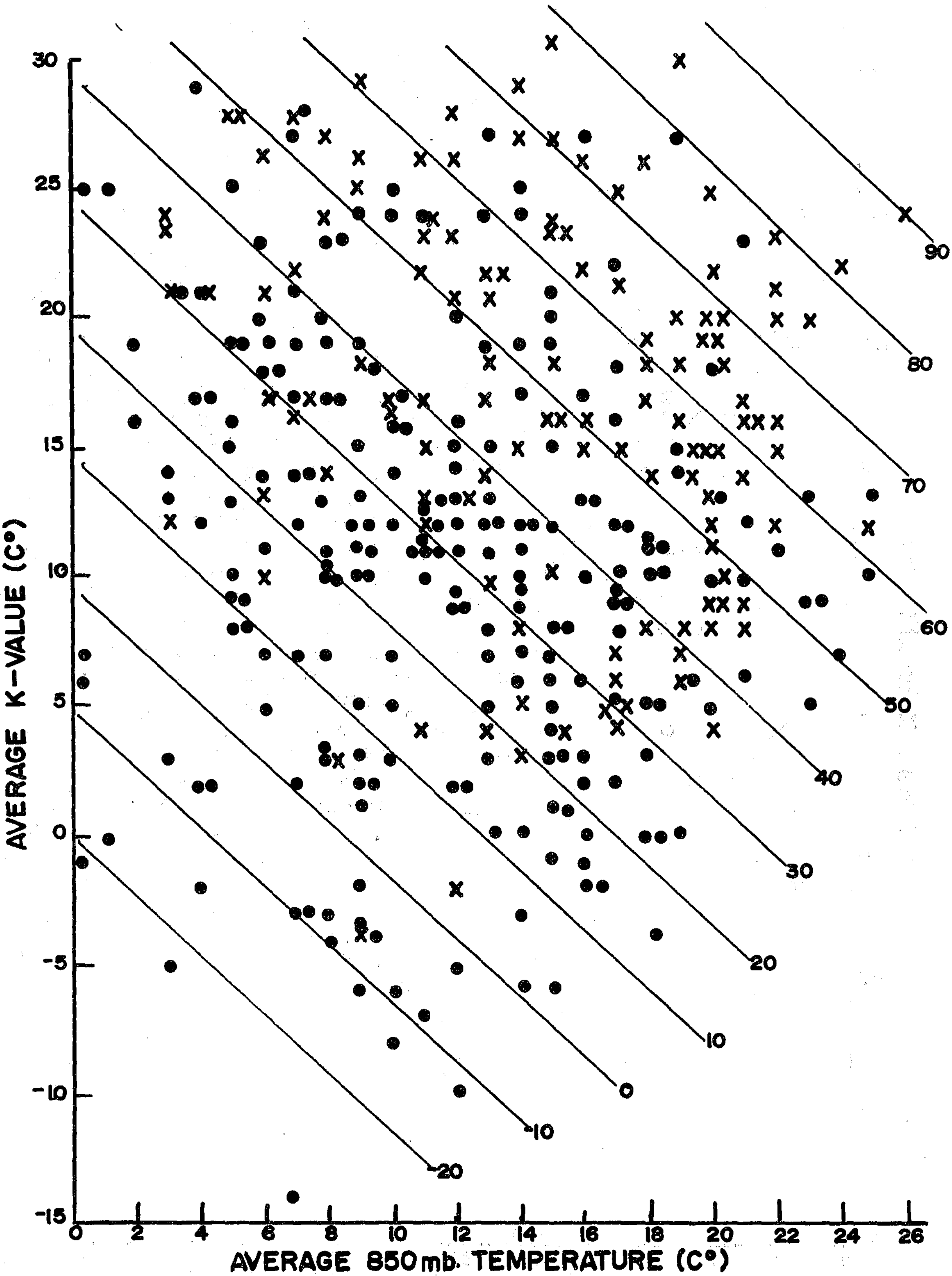

FIGURE 5. SCATTER DIAGRAM RELATING FREQUENCY OF THUNDERSTORM DAYS IN AREA B TO AVERAGE 850-MB TEMPERATURE AND AVERAGE K-VALUE COMPUTED FROM RADIOSONDE OBSERVATIONS AT BOISE, SALEM, QUILLAYUTE, AND SPOKANE. LINES REPRESENT SOLUTION OF LINEAR REGRESSION EQUATION: $\hat{Y} = 2.36 X_1 + 2.04 X_2 - 19.91$. CROSS REPRESENTS THUNDERSTORM DAY; DOT NONTHUNDERSTORM DAY.

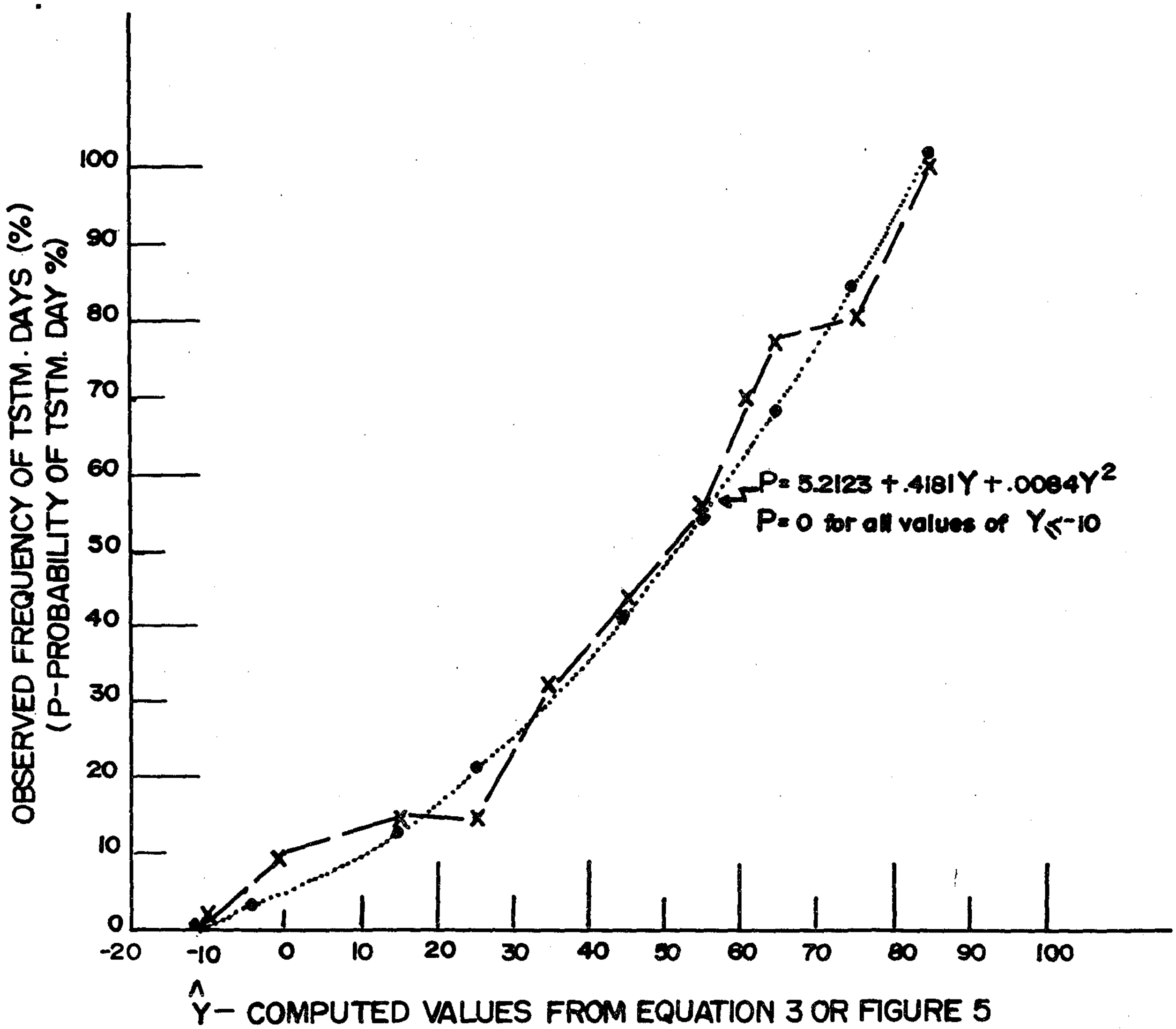

FIGURE 6. RELATIONSHIP BETWEEN COMPUTED VALUES OF $\hat{Y}$ AND RELATIVE FREQUENCY OF THUNDERSTORM DAYS (CROSSES AND DASHED LINE) FOR AREA B. DOTTED CURVE REPRESENTS PARABOLA FITTED TO CROSSES.

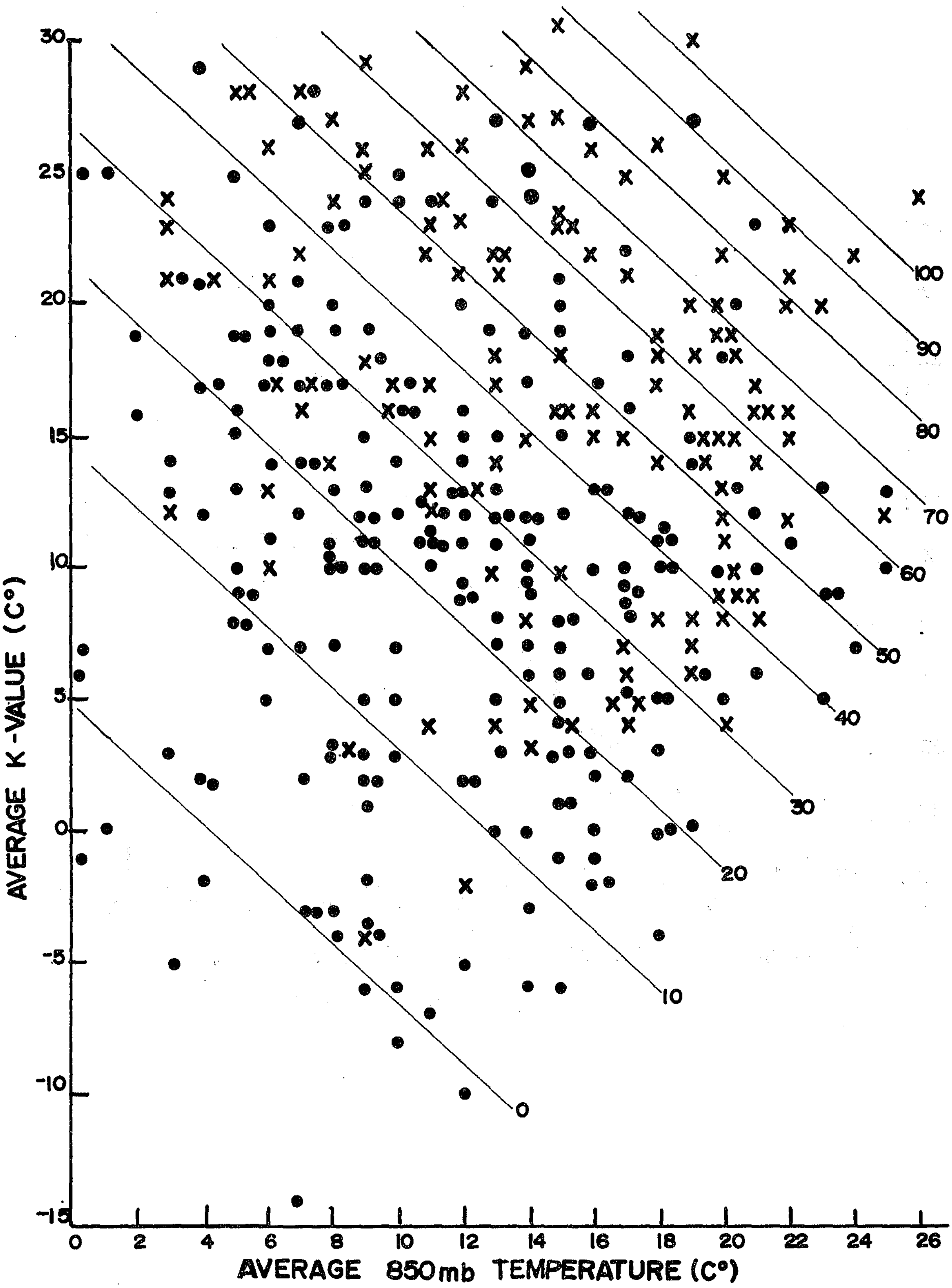

FIGURE 7. SAME AS FIGURE 5, EXCEPT LINES HAVE BEEN ADJUSTED TO REFLECT PARABOLIC RELATIONSHIP SHOWN IN FIGURE 6.

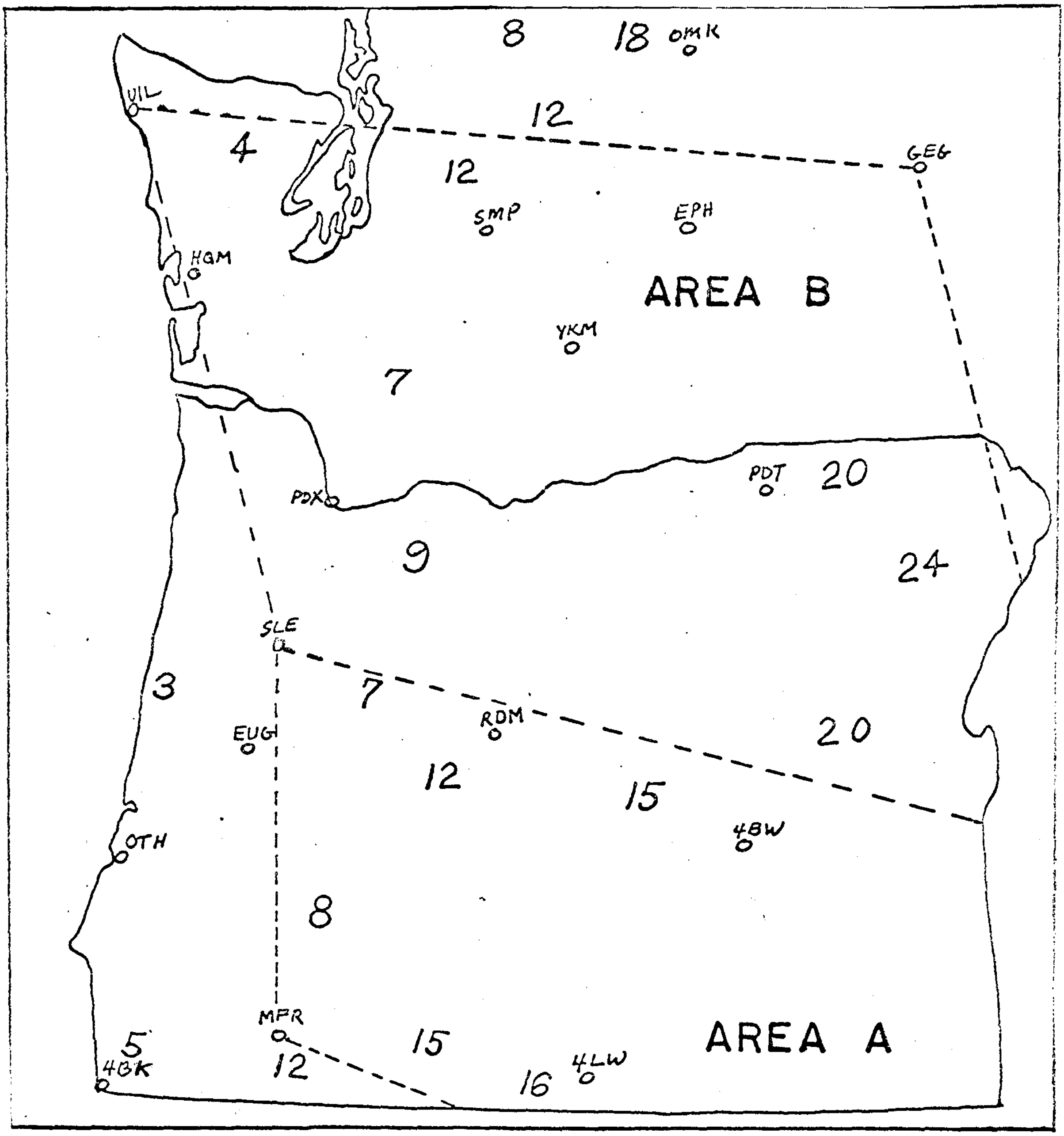

FIGURE 8. MEAN NUMBER OF THUNDERSTORM DAYS IN U. S. NATIONAL FORESTS IN WASHINGTON AND OREGON FROM 1 JULY TO 15 SEPTEMBER 1950-1966 AND 1968.

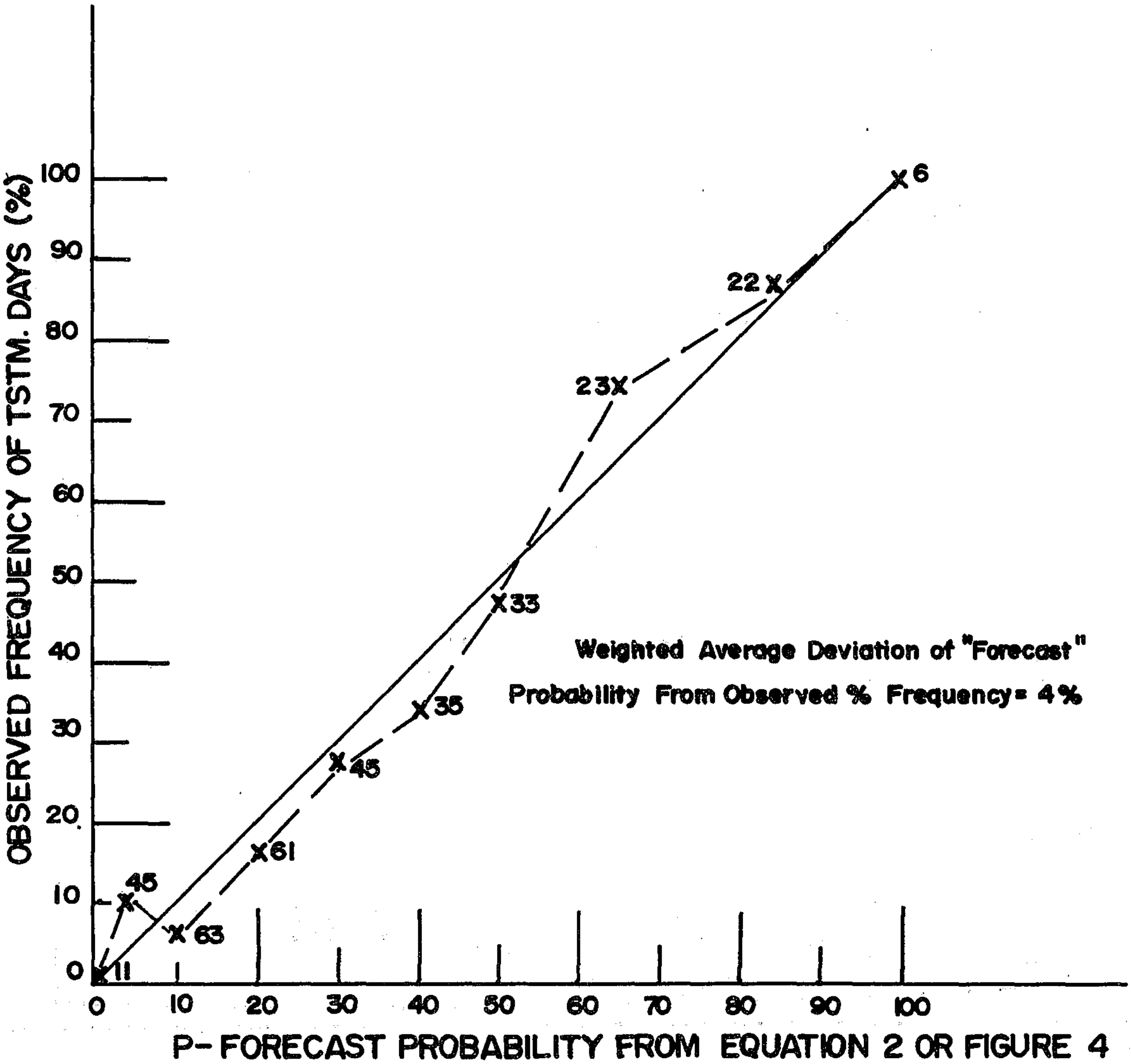

FIGURE 9. RELIABILITY GRAPH RELATING "FORECAST" PROBABILITIES FOR AREA A TO OBSERVED RELATIVE FREQUENCY OF OCCURRENCE OF THUNDERSTORM DAYS. NUMBER BESIDE EACH POINT IS NUMBER OF CASES IN FORECAST PROBABILITY CATEGORY (SEE TABLE 3).

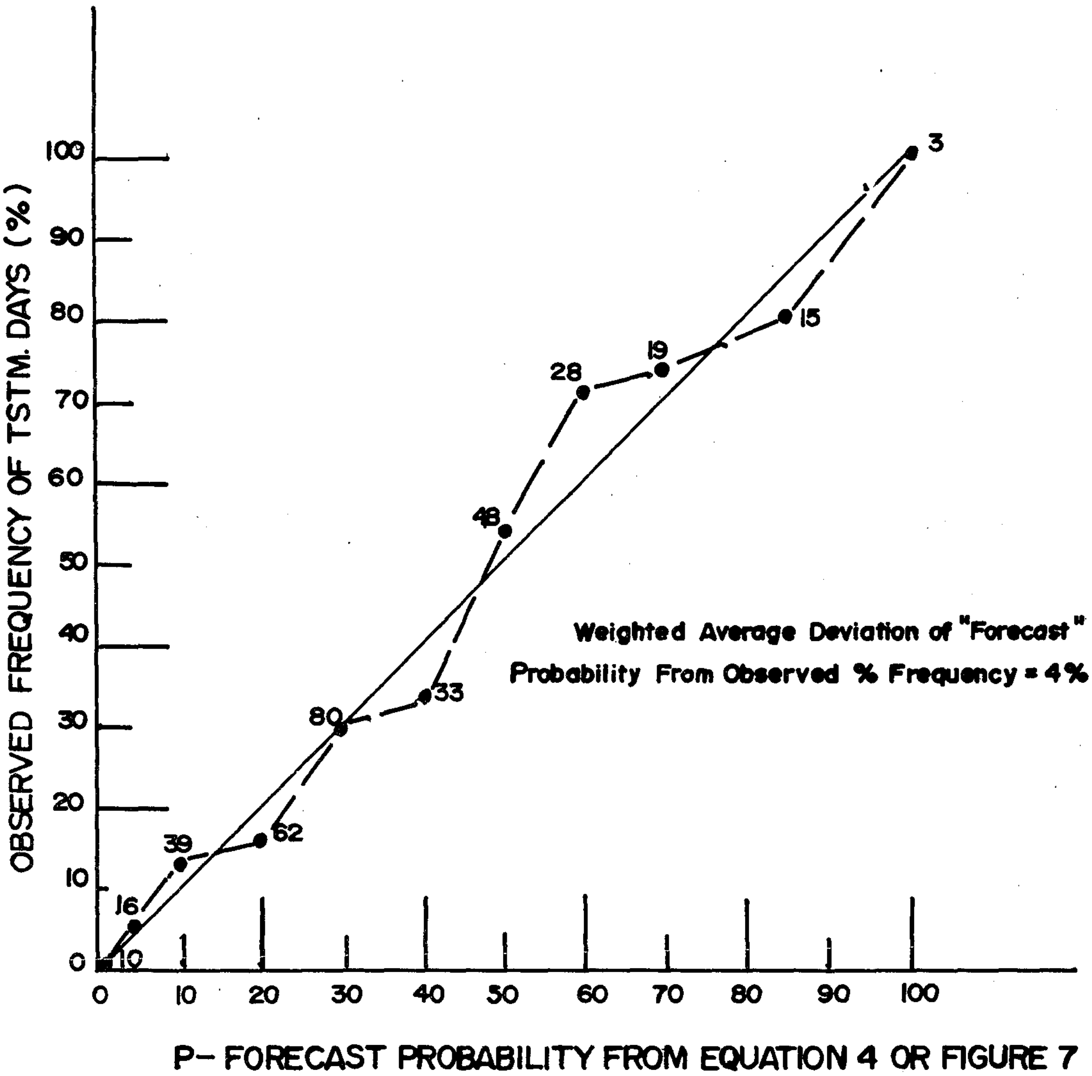

FIGURE 10. RELIABILITY GRAPH RELATING "FORECAST" PROBABILITIES FOR AREA B TO OBSERVED RELATIVE FREQUENCY OF OCCURRENCE OF THUNDERSTORM DAYS. NUMBER BESIDE EACH POINT IS NUMBER OF CASES IN FORECAST PROBABILITY CATEGORY (SEE TABLE 4).

TABLE 1

PERCENT FREQUENCY OF OCCURRENCE OF THUNDERSTORM DAYS IN AREA A IN CATEGORIES OF $\hat{Y}$

$\hat{Y}$	Total	No. of TSTM Days	%
≤-15	13	0	0
-14 to +14	67	4	5
15 to 24	55	6	11
25 to 34	58	11	18
35 to 44	51	15	29
45 to 54	49	23	47
55 to 64	22	17	77
65 to 74	23	19	83
≥ 75	6	6	100

TABLE 2

PERCENT FREQUENCY OF OCCURRENCE OF THUNDERSTORM DAYS IN AREA B IN CATEGORIES OF $\hat{Y}$

$\hat{Y}$	Total Cases	No. of TSTM Days	%
≤-10	10	0	0
-9 to +9	31	3	10
10 to 19	33	5	15
20 to 29	56	8	14
30 to 39	77	24	31
40 to 49	46	20	43
50 to 59	52	28	54
60 to 69	30	23	77
70 to 79	15	12	80
≥80	3	3	100

TABLE 3

PERCENT FREQUENCY OF OCCURRENCE OF THUNDERSTORM DAYS
IN AREA A BY CATEGORIES OF P

P(%)	Total	No. of TSTM Days	% Freq.
0	11	0	0
1-6	45	5	11
7-14	63	4	6
15-24	61	10	16
25-34	45	12	27
35-44	35	12	34
45-54	33	16	48
55-64	15 }23	13 }17	74
65-74	8	4	
75-84	15 }22	13 }19	86
85-94	7	6	
≥95	6	6	100

TABLE 4

PERCENT FREQUENCY OF OCCURRENCE OF THUNDERSTORM DAYS
IN AREA B BY CATEGORIES OF P

P	Total Cases	No. of TSTM Days	% Freq.
0	10	0	0
1-6	16	1	6
7-14	39	5	13
15-24	62	10	16
25-34	80	24	30
35-44	33	11	33
45-54	48	26	54
55-64	28	20	71
65-74	19	14	74
75-84	9 }15	8 }12	80
85-94	6	4	
≥95	3	3	100

TABLE 5

LIST OF EQUATIONS*

N	=	Total cases
TO	=	Number of occurrences of thunderstorm days
TF	=	Number of forecasts of thunderstorm days
TC	=	Number of correct thunderstorm forecasts
H	=	Total correct forecasts (thunderstorm and non-thunderstorm days)
P	=	Probability
E	=	0 for non-thunderstorm event
E	=	1 for thunderstrom event
C	=	Long-term climatological probability of TSTM days
CS	=	Sample climatology of thunderstorm day (observed frequency of occurrence of thunderstorm days in data sample)
BF	=	Brier Score for forecasts
BC	=	Climat Brier Score
BCS	=	Sample Climat Brier Score
S	=	Improvement over climatology
PF	=	Prefigurance
PA	=	Post Agreement
TS	=	Threat Score
% Cor.	=	Percent of categorical forecast correct

Equations:

1. $$BF = \sum_{1}^{N} \frac{(P - E)^2}{N}$$

2. $$BC = (C - CS)^2 + CS(1 - CS)$$

3. $$BCS = CS\ (1 - CS)$$

4. $$S = \frac{BC - BF}{BC}(100)$$ Improvement over climat

   $$S = \frac{BCS - BF}{BCS}(100)$$ Improvement over sample climat

5. $$\%\ Correct = \frac{H}{N}(100)$$

6. $$PF = \frac{TC}{TO}$$

7. $$PA = \frac{TC}{TF}$$

8. $$TS = \frac{TC}{TF + TO - TC}$$

*See [6] and [7]

TABLE 6

SCORES FOR PROBABILITY "FORECASTS" FROM DEPENDENT DATA

Probability Forecasts	Area A	Area B
Total Cases	344	353
No. TSTM Days	101	126
Brier Score	.1450	.1765
Climat Brier Score	.2148	.2316
Sample Climat Brier Score	.2074	.2295
Improvement over Climat	32.50%	23.79%
Improvement over Sample Climat	30.74%	23.09%
Average Fcst Prob. for TSTM Days	51%	49%
Average Fcst Prob. for Non-TSTM Days	21%	27%

TABLE 7

SCORES FOR CATEGORICAL "FORECASTS" FROM DEPENDENT DATA
P≥40% USED AS FORECAST OF TSTM EVENT

AREA A

		Forecast		
		TSTM	No-TSTM	TOTAL
OBS	TSTM	65	36	101
	No-TSTM	35	208	243
	TOTAL	100	244	344

% Correct = 273/344(100) = 79.3%
Prefigurance = 65/101 = .643
Post Agreement = 65/100 = .650
Threat Score = 65/136 = .477
Bias = 100/101 = .990

AREA B

		Forecast		
		TSTM	No-TSTM	TOTAL
OBS	TSTM	83	43	126
	No-TSTM	50	177	227
	TOTAL	133	220	353

% Correct = 260/353(100) = 73.6%
Prefigurance = 83/126 = .658
Post Agreement = 83/133 = .624
Threat Score = 83/176 = .471
Bias = 133/126 = 1.055

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