NOAA Technical Memorandum NWS TDL 53

A COMPARISON BETWEEN THE SINGLE STATION AND GENERALIZED OPERATOR TECHNIQUES FOR AUTOMATED PREDICTION OF PRECIPITATION PROBABILITY

Joseph R. Bocchieri
Systems Development Office

Techniques Development Laboratory
Silver Spring, Md.
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A COMPARISON BETWEEN THE SINGLE STATION AND GENERALIZED OPERATOR TECHNIQUES FOR AUTOMATED PREDICTION OF PRECIPITATION PROBABILITY

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A COMPARISON BETWEEN THE SINGLE STATION AND GENERALIZED OPERATOR TECHNIQUES FOR AUTOMATED PREDICTION OF PRECIPITATION PROBABILITY

Joseph R. Bocchieri

ABSTRACT. A comparison between the single station and generalized operator techniques for forecasting probability of precipitation (PoP) is presented. MOS (Model Output Statistics) is used to develop the PoP forecast equations. In MOS, the predictand is related statistically to variables which have been predicted by a numerical model or models. For the present operational PoP system, numerical model output is used from the National Meteorological Center's Primitive Equation model and the Techniques Development Laboratory's Trajectory model.

Up to the present time, the generalized operator technique has been used to develop operational PoP equations because of the small size of the dependent data sample. In this technique, data are combined from a number of stations within each of several homogeneous regions; a single equation is then derived for each region. In the single station technique, a separate forecast equation is derived for each station; therefore, any local effects are accounted for in the statistical treatment of the data for each station.

The single station and generalized operator PoP forecast systems are comparatively verified on independent data. The results of the verification indicate that the generalized operator technique is better than the single station technique. Therefore, the generalized operator technique will continue to be used in developing operational PoP equations.

INTRODUCTION

Since January 1972, automated probability of precipitation (PoP) guidance forecasts have been issued from the National Meteorological Center (NMC) twice daily out to 60 hours for the conterminous United States. Lowry and Glahn (1974) describe the development and evolution of the PoP forecast system in detail. The technique used is called Model Output Statistics, or MOS. In the MOS technique, the predictand is related statistically to variables which have been predicted by a numerical model or models. Therefore, the biases and other inaccuracies in the models are considered in the development of the relationship. The Techniques Development Laboratory's (TDL's) success in applying MOS to the prediction of most weather elements is described by Glahn and Lowry (1972a) and Klein and Glahn (1974). For the present operational PoP system, numerical model output from the NMC Primitive Equation (PE) model (Shuman and Hovermale 1968) and the TDL Trajectory (TJ) model (Reap 1972) was used.

For PoP, the year has been divided into two seasons: summer (April through September) and winter (October through March); prediction equations have been developed and updated for each season. The generalized operator technique (Harris et al. 1963 and Russo et al. 1966) has been used to develop the equations because of the small size of the dependent data sample. In the generalized operator technique, data are combined from a number of stations within each of several homogeneous regions; a single equation is then derived for each region. The method for determining the regions will be described later. In application, the equation is used at each station within the region with input data appropriate to that particular station.

One would think that the best technique to use in an objective PoP forecast system would be the single station technique. In the single station technique, a separate forecast equation is derived for each station; therefore, any local features affecting the precipitation process, that are not accounted for in the large-scale numerical models, are automatically incorporated in the statistical treatment of data for individual stations. The single station technique is also benefical if the numerical model output used as predictors showed different biases for different stations. The problem with this technique, however, is that a large enough dependent data sample must be available to allow derivation of stable single station equations. For that reason, the single station technique has not been used in the past to develop operational PoP equations.

This report describes a comparison between the single station and generalized operator techniques for the purpose of PoP forecasting. It was assummed that a sufficiently large data sample had been archived, as part of TDL's MOS system, so that stable single station equations could be developed.

GENERALIZED OPERATOR EQUATIONS

This section gives a description of the generalized operator PoP equations used in this investigation. For more detail as to the development and evolution of the MOS PoP program, see Lowry and Glahn (1974).

The generalized operator PoP equations used were operational during the winter season of 1973-74. The dependent sample for the operational system consisted of data from 234 stations in the conterminous U.S. for the winter seasons of 1970-71, 1971-72, and 1972-73. Generalized operator equations were developed within each of the seventeen regions shown in Fig. 1. These regions were determined subjectively from an analysis of the relative frequency of precipitation when the PE mean relative humidity (MRH) (surface to about 400 mb) was forecast to be 75% or greater. That is, for each of 234 stations (shown as dots in Fig. 1) for the dependent data sample, the relative frequency of precipitation was determined for all cases when the PE MRH was 75% or greater. A precipitation event at a station was defined as the occurrence of $\geq$ .01 inch in a 12-hour period.

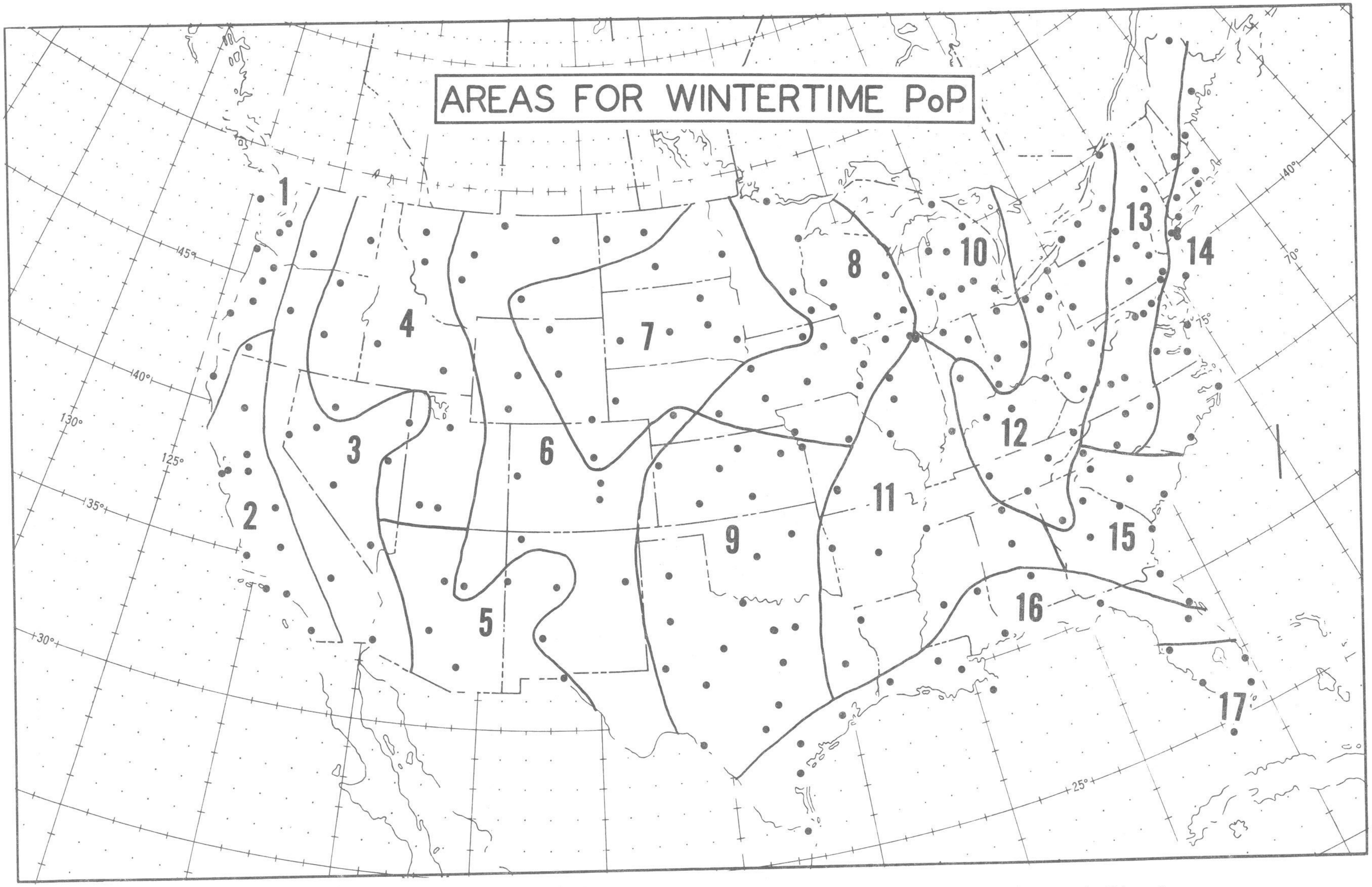

Figure 1.--The seventeen regions used for the operational PoP system during the 1973-74 winter season. The dots represent the 234 stations used in the development sample.

For instance, in Fig. 1, region 1 was differentiated from region 2 because the relative frequencies of precipitation for the stations in region 1 were similar and substantially higher than the relative frequencies of precipitation for the stations in region 2 for all cases when the PE MRH was 75% or greater.

The TDL screening regression program was used to produce PoP equations for four 12-hour periods beginning at 12, 24, 36, and 48 hours after both the 0000 GMT and 1200 GMT PE run times. Each equation contains a regression constant and 12 predictors. The predictand and predictors are in binary form; that is, they can take on only one of two possible values, 0 or 1. This application of regression has been called REEP (Regression Estimation of Event Probabilities) by Miller (1964). Within each region a standard set of the 100 most valuable binary predictors from the PE and TJ models was offered for screening by the REEP program. Different predictor sets were required for each of the four forecast periods; the set for the second period is shown in Table 1. In Table 1, U-winds are west winds and V-winds are south winds. Mean relative humidity covers a layer from the earth's surface to about 400 mb, or the three lowest layers of the PE model. Precipitation amount is a 12-hour forecast amount ending at the time shown. The PE boundary layer is the one closest to the earth's surface. The second layer extends from the top of the boundary layer up to about 700 mb. Total-totals (Miller 1972) and K (George 1960) indices are standard stability indicators. Net vertical displacements represent vertical motion as forecast by the TJ model. Certain predictors have been space smoothed by 5 or 9 points to eliminate small-scale noise.

Table 1.--One hundred binary predictors screened for PoP during second period (24-36 hours) for winter season of 1973-74. E-6 means $x10^{-6}$.

Field	Model	Smoothing (Points)	Time (hours)	Binary Limits	Units
700 Net Vertical Displacement (12 Hr)	TJ	1	24	-10, 0, 10, 20, 30, 40	Millibars
Mean Relative Humidity	TJ	5	24	35, 40, 45, 50, 55, 60, 65	Percent
850 Vertical Velocity	PE	5	24	-.0005, -.0002, .0002, .0005	Millibars/Sec
650 Vertical Velocity	PE	5	24	-.0005, -.0002, .0002, .0005	Millibars/Sec
Total Totals Index	PE, TJ	5	24	35, 40, 42, 44, 46, 48	°C
K Index	PE, TJ	5	24	5, 10, 15, 20	°C
Precipitable Water	PE	1	30	10.16, 15.24, 20.31	Kilograms/M^2
Precipitable Water	PE	5	30	10.16, 15.24, 20.31	Kilograms/M^2
850 Height	PE	5	36	1457, 1482, 1507, 1532 ,1553	M
Boundary Layer U-wind	PE	5	36	-2, 0, 2, 4	M/Sec
Boundary Layer V-wind	PE	5	36	-2, 2, 5, 7	M/Sec
Boundary Layer Vertical Velocity	PE	5	36	-.0005, -.0002, 0, .0002	Millibars/Sec
Mean Relative Humidity	PE	5	36	55, 60, 65, 70, 75, 80, 85	Percent
Mean Relative Humidity	PE	9	36	50, 55, 60, 65, 70, 75, 80	Percent
Boundary Layer Humidity	PE	5	36	55, 60, 65, 70, 75, 80, 85	Percent
Boundary Layer Humidity	PE	9	36	50, 55, 60, 65, 70, 75, 80	Percent
Second Layer Humidity	PE	5	36	55, 60, 65, 70, 75, 80, 85	Percent
Second Layer Humidity	PE	9	36	50, 55, 60, 65, 70, 75, 80	Percent
12-Hr Precip. Amount	PE	1	36	0, 762E-6, 2032E-6, 3810E-6, 6350E-6	M

Table 2 shows the first twelve predictors picked in the PoP equation for region 14 (see Fig. 1) for the second period. As a result of the screening process, no TJ predictors were picked, and PE MRH predictors were picked first. The binary predictors shown can take on values of 0 or 1 only. For example, if the PE MRH forecast at hour 36 is $\leq$ 70 percent, the first predictor takes on a value of 1; if the PE MRH at hour 36 is $>$70 percent, this predictor takes on a value of 0.

Table 2.--The first twelve predictors picked in the PoP forecast equation for region 14 (see Fig. 1), winter of 1973-74, 0000 GMT PE run time, second period (24-36 hours). Dependent data sample consisted of 6389 cases. See Table 1 for units.

Predictor	Time	Smoothing (Points)
1) PE MRH $\leq$ 70	36	9
2) PE MRH $\leq$ 80	36	9
3) PE MRH $\leq$ 60	36	9
4) PE Boundary Layer Vertical Velocity $\leq$ -.0005	36	5
5) PE 650 Vertical Velocity $\leq$ .0002	24	5
6) Precipitable Water $\leq$ 10.16	30	5
7) PE MRH $\leq$ 80	36	5
8) PE Boundary Layer Vertical Velocity $\leq$ -.0002	36	5
9) PE Precipitation Amount $\leq$ .00635	36	1
10) PE MRH $\leq$ 65	36	5
11) PE Boundary Layer V-wind $\leq$ 7	36	5
12) PE MRH $\leq$ 50	36	9

SINGLE STATION EQUATIONS

The MOS technique was used to develop single station PoP equations for each of 80 stations for the first and second forecast periods after the 0000 GMT PE run time. The 80 stations are listed in Table 3 and are shown in Fig. 2. The dependent data sample and the types of predictors offered to the REEP screening program were the same as those used in development of the generalized operator equations discussed above. The same set of 100 binary predictors was screened for each of the 80 stations; different predictor sets were used for each forecast period. Table 1 shows the 100 binary predictors screened for the second period. Twelve predictors were included in each equation; generally, the selected predictors were different for each station.

The first twelve predictors picked in the single station PoP equation for Boston, Mass. for the second period are shown in Table 4. Since Boston falls in region 14 in Fig. 1, the generalized operator equation shown

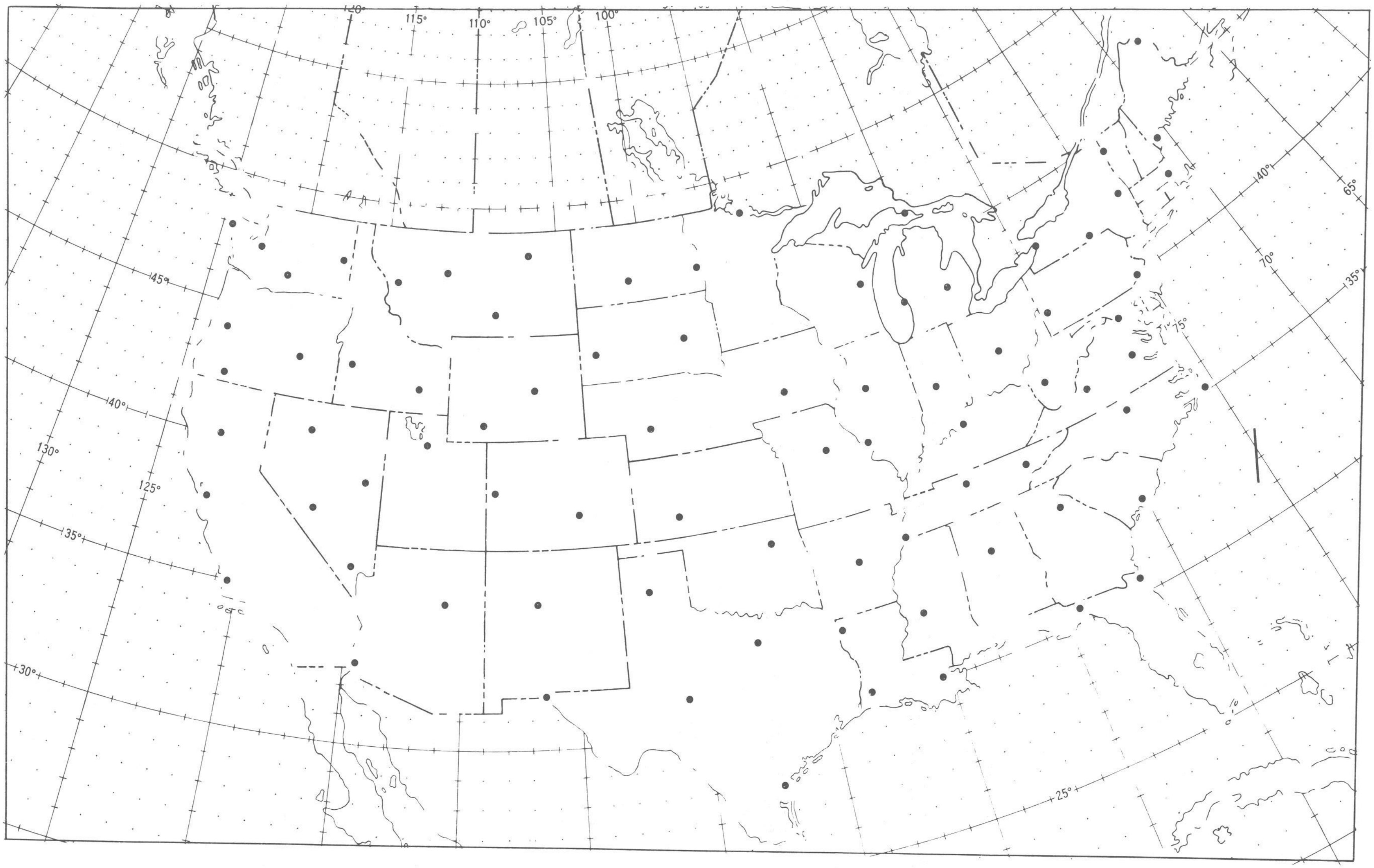

Figure 2.--The 80 stations for which single station PoP equations were derived.

Table 3.--The 80 stations for which single station PoP equations were derived.

Station	WBAN No.	Station	WBAN No.
Albany, N.Y.	14735	Las Vegas, Nev.	23169
Albuquerque, N. Mex.	23050	Little Rock, Ark.	13963
Amarillo, Tex.	23047	Louisville, Ky.	93821
Athens, Ga.	13873	Medford, Oreg.	24225
Billings, Mont.	24033	Memphis, Tenn.	13893
Binghamton, N.Y.	04725	Missoula, Mont.	24153
Birmingham, Ala.	13876	Muskegon, Mich.	14840
Bismarck, N. Dak.	24011	Nashville, Tenn.	13897
Boise, Idaho	24131	New Orleans, La.	12916
Boston, Mass.	14739	North Platte, Nebr.	24023
Buffalo, N.Y.	14733	Oakland, Calif.	23230
Burlington, Vt.	14742	Peoria, Ill.	14842
Burns, Oreg.	24134	Philadelphia, Pa.	13739
Cape Hatteras, N.C.	93729	Pittsburgh, Pa.	94823
Caribou, Maine	14607	Pocatello, Idaho	24156
Casper, Wyo.	24089	Portland, Maine	14764
Charleston, S.C.	13880	Pueblo, Colo.	93058
Charleston, W. Va.	13866	Quillayute, Wash.	94240
Columbia, Mo.	03945	Raleigh, N.C.	13722
Columbus, Ohio	14821	Rapid City, S. Dak.	24090
Corpus Christi, Tex.	12924	Red Bluff, Calif.	24216
Des Moines, Iowa	14933	Richmond, Va.	13740
Dodge City, Kans.	13985	Roanoke, Va.	13741
El Paso, Tex.	23044	Rock Springs, Wyo.	24027
Ely, Nev.	23154	Salt Lake City, Utah	24127
Eugene, Oreg.	24221	San Angelo, Tex.	23034
Fargo, N. Dak.	14914	Santa Maria, Calif.	23273
Flint, Mich.	14826	Sault Ste Marie, Mich.	14847
Ft. Worth, Tex.	03927	Seattle, Wash.	24233
Glasgow, Mont.	94008	Shreveport, La.	13957
Grand Junction, Colo.	23066	Spokane, Wash.	24157
Great Falls, Mont.	24143	St. Louis, Mo.	13994
Green Bay, Wis.	14898	Tallahassee, Fla.	93805
Huron, S. Dak.	14936	Tonopah, Nev.	23153
Indianapolis, Ind.	93819	Tulsa, Okla.	13968
International Falls, Minn.	14918	Washington, D.C.	13743
Jackson, Miss.	03940	Winnemucca, Nev.	24128
Jacksonville, Fla.	13889	Winslow, Ariz.	23194
Knoxville, Tenn.	13891	Yakima, Wash.	24243
Lake Charles, La.	03937	Yuma, Ariz.	23195

in Table 2 can also be used to forecast PoP for Boston. A comparison between Table 4 and Table 2 shows that the PE MRH and the more heavily smoothed predictors were more important in the generalized operator equation. Also, PE second layer relative humidity predictors were picked for the single station equation but were not included in the generalized operator equation. Predictors from the TJ model were not included in either equation.

COMPARATIVE VERIFICATION

A comparative verification was performed between the generalized operator and single station PoP forecast systems described above. The independent sample consisted of data for the 80 stations listed in Table 3 for the period October through December 1973. The verification was done for the first and second forecast periods from the 0000 GMT PE run time.

The verification scores used were the Brier P-score, percent correct, bias, Heidke skill score, and threat score. These scores are defined in appendix A. A PoP forecast of 50% or greater was considered a forecast of rain ($\geq$.01 inch). Tables 5 and 6 show the results for the first forecast period, while the second forecast period results are shown in Tables 7 and 8. Contingency tables are presented in Tables 5 and 7. The verification scores computed from the contingency tables and Brier P-scores for all 80 stations combined are shown in Tables 6 and 8.

Table 4.--The first twelve predictors picked in the single station PoP equations for Boston, Mass., winter of 1973-74, 0000 GMT PE run time, second period, (24-36 hours). Dependent data sample consisted of 455 cases. See Table 1 for units.

Predictor	Time	Smoothing (Points)
1) PE MRH $\leq$ 80	36	5
2) PE Boundary Layer Vertical Velocity $\leq$ -.0002	36	5
3) PE Second Layer Relative Humidity $\leq$ 65	36	5
4) PE Boundary Layer Vertical Velocity $\leq$ -.0005	36	5
5) PE Precipitation Amount $\leq$ .00381	36	1
6) PE Boundary Layer Relative Humidity $\leq$ 80	36	5
7) PE Boundary Layer Relative Humidity $\leq$ 50	36	9
8) PE Second Layer Relative Humidity $\leq$ 80	36	5
9) PE Second Layer Relative Humidity $\leq$ 85	36	5
10) PE MRH $\leq$ 75	36	5
11) PE MRH $\leq$ 70	36	5
12) PE 650 Vertical Velocity $\leq$ .0002	24	5

Table 5.--Contingency tables for single station and generalized operator PoP forecast systems for the first period (12-24 hours) from 0000 GMT PE run time. Independent data pooled for 80 stations (Table 3), October through December 1973.

Obs	Forecast				Total
	Single Station		Generalized Operator		
	Rain	No Rain	Rain	No Rain	
Rain	683	416	691	408	1099
No Rain	378	4038	300	4116	4416
Total	1061	4454	991	4524	5515

Table 6.--Comparative verification results between single station and generalized operator PoP forecast systems for the first period after 0000 GMT PE run time. Independent data pooled for 80 stations (Table 3), October through December 1973 (5515 cases).

System	Brier P-Score	Percent Correct	Bias Rain	Bias No Rain	Skill Score	Threat Score Rain
Single Station	.204	85.6	.965	1.01	.54	.462
Generalized Operator	.184	87.2	.902	1.02	.58	.494

Table 7.--Contingency tables for single station and generalized operator PoP forecast systems for the second period (24-36 hours) from 0000 GMT PE run time. Independent data pooled for 79* stations (Table 3), October through December 1973.

	Forecast				
Obs	Single Station		Generalized Operator		Total
	Rain	No Rain	Rain	No Rain	
Rain	549	455	518	486	1004
No Rain	394	3904	313	3985	4298
Total	943	4359	831	4471	5302

Table 8.--Comparative verification results between single station and generalized operator PoP forecast systems for the second period after 0000 GMT PE run time. Independent data pooled for 79* stations (Table 3), October through December 1973 (5302 cases).

System	Brier P-Score	Percent Correct	Bias Rain	Bias No Rain	Skill Score	Threat Score Rain
Single Station	.231	84.0	.939	1.01	.47	.393
Generalized Operator	.212	84.9	.828	1.04	.47	.393

*Data for Santa Maria, California were not included in this verification because precipitation observations were not available for the second period.

The verification results can be summarized as follows:

1. For the first forecast period, the generalized operator equations were better for all scores except for the bias where the single station equations showed less bias (1.00 denotes no bias). Both systems underforecast the rain event (bias < 1.00).

2. For the second forecast period, the generalized operator equations were equal to or better than the single station equations for all scores except for the bias, where single station equations again showed less bias. As with the first period, both systems underforecast the rain event.

It should be noted that the computed biases are based on a 50% PoP criterion for the rain event to be forecast. Experience has shown that a 50% criterion will almost always cause underforecasting.

One desirable characteristic of probability forecasts is reliability; for instance, for all forecast probabilities in the range 45 to 55%, the relative frequency of the event should be as close as possible to the average probability forecast within that range. Fig. 3 shows the reliability of PoP forecasts for the single station and generalized operator systems for the first and second forecast periods. It can be seen that the generalized operator system was more reliable, especially in the upper forecast probability ranges, for both forecast periods. Both systems showed a tendency to overforecast.

Figs. 4 through 7 show a geographical distribution of comparative verification results between the single station and generalized operator forecast systems for the P-score and threat score. Figs. 4 and 5 show the results for the P-score for the first and second forecast periods, respectively. The results for the threat score are shown in Figs. 6 and 7 for the first and second forecast periods, respectively. The purpose of this analysis was to see if one forecast system consistently dominated the other in specific areas of the United States. One would expect, for example, that single station equations would perform better than generalized operator equations over the mountainous areas of the western United States, where local topographical features play a more important role in the precipitation process as compared to a flatter area such as the Central Plains. Inspection of Figs 4 through 7 show that this expectation was not supported; the areas where the single station forecast system was better than the generalized operator forecast system were not consistent enough from one score to the other or one forecast period to the other.

CONCLUSIONS

From the comparative verification results discussed above, it was concluded that the generalized operator PoP forecast system was generally more accurate than the single station PoP forecast system. Glahn and

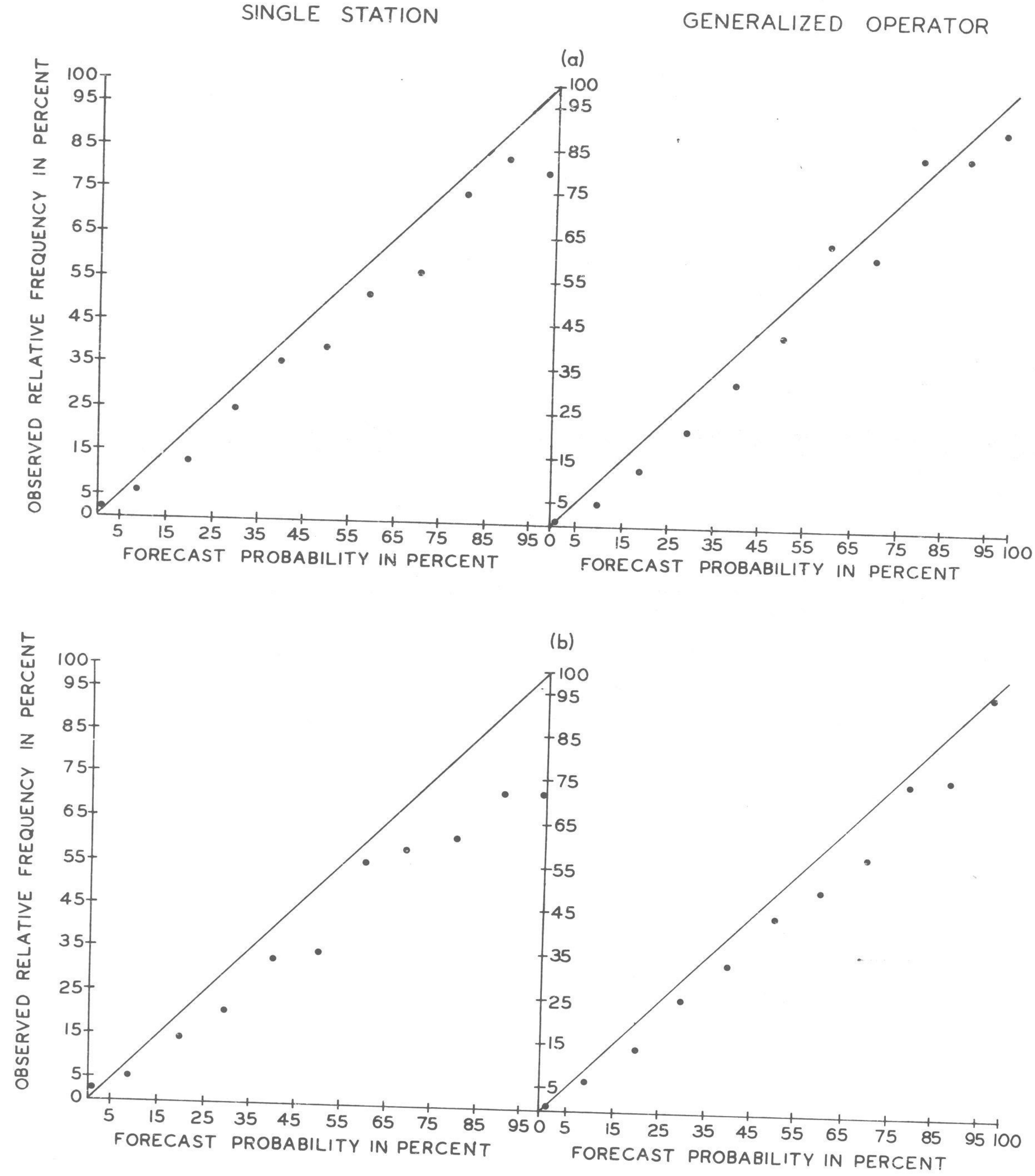

Figure 3.--Reliability of PoP forecasts for the single station and generalized operator systems for (a) the first forecast period (5515 cases), and (b) the second forecast period (5302 cases). Independent data pooled for 80 stations (79 stations for second period) (see Table 3) for the period October through December 1973. The diagonal line represents perfect reliability. Under the line represents overforecasting while over the line represents underforecasting.

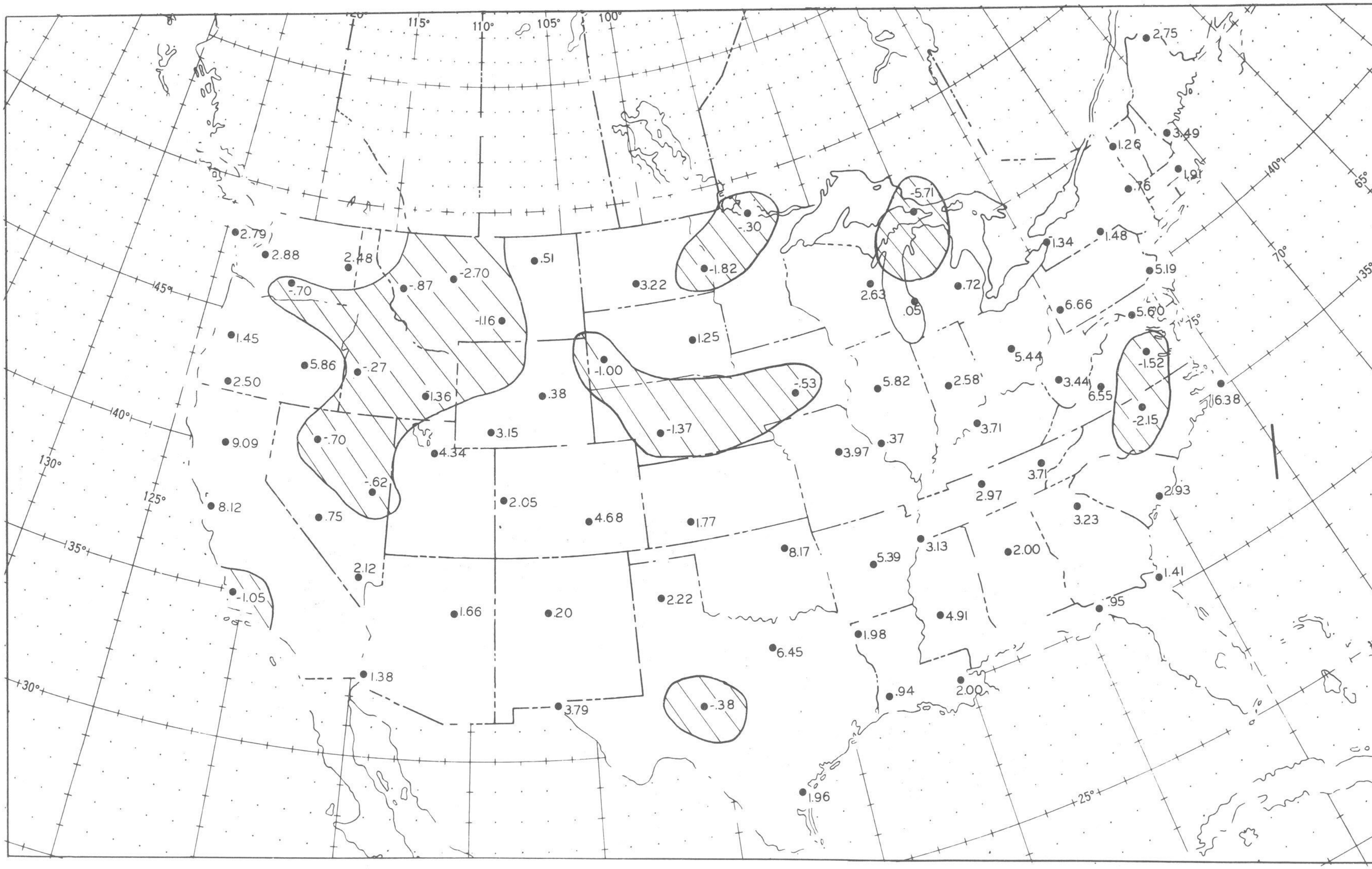

Figure 4.--Values of ([(single station P-Score) - (generalized operator P-Score)] x 100). Negative values (hatched areas) indicate single station equations had better P-Scores. First forecast period after 0000 GMT PE run time, independent data from October through December, 1973.

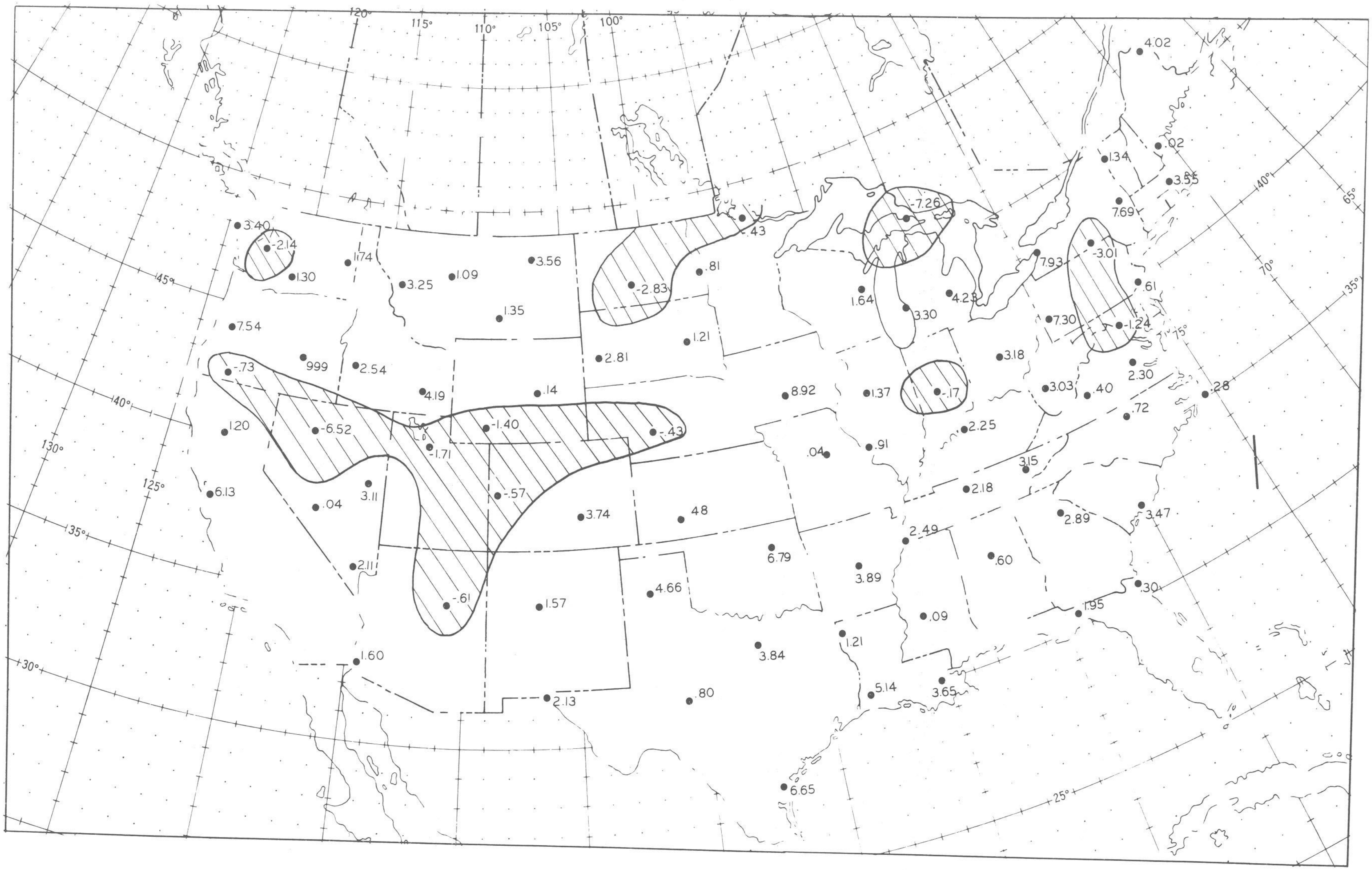

Figure 5.--Same as Figure 4 except for second forecast period after 0000 GMT PE run time.

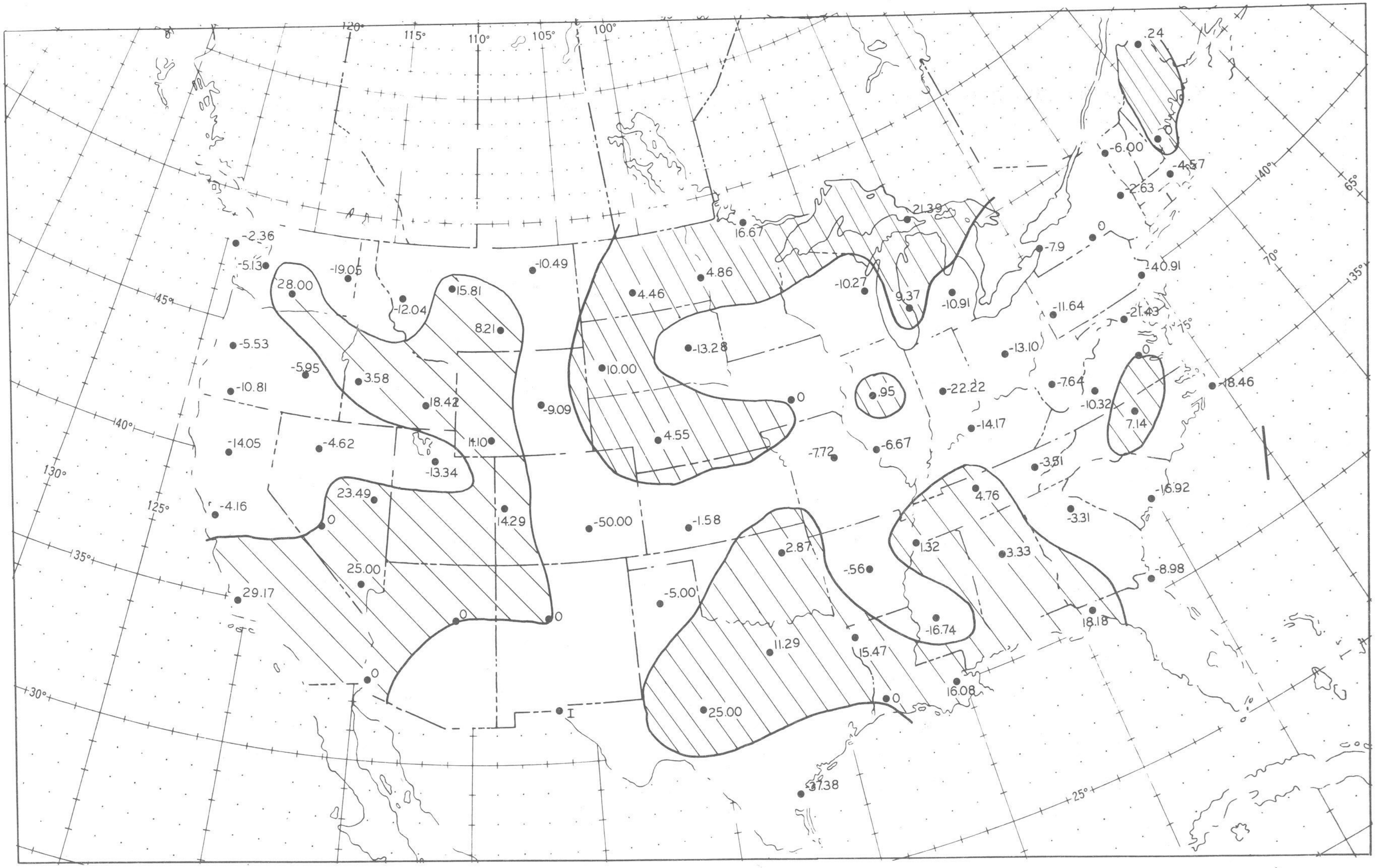

Figure 6.--Values of ([(single station threat score) - (generalized operator threat score)] x 100). Positive values (hatched areas) indicate single station equations had better threat scores. First forecast period after 0000 GMT PE run time, independent data from October through December, 1973.

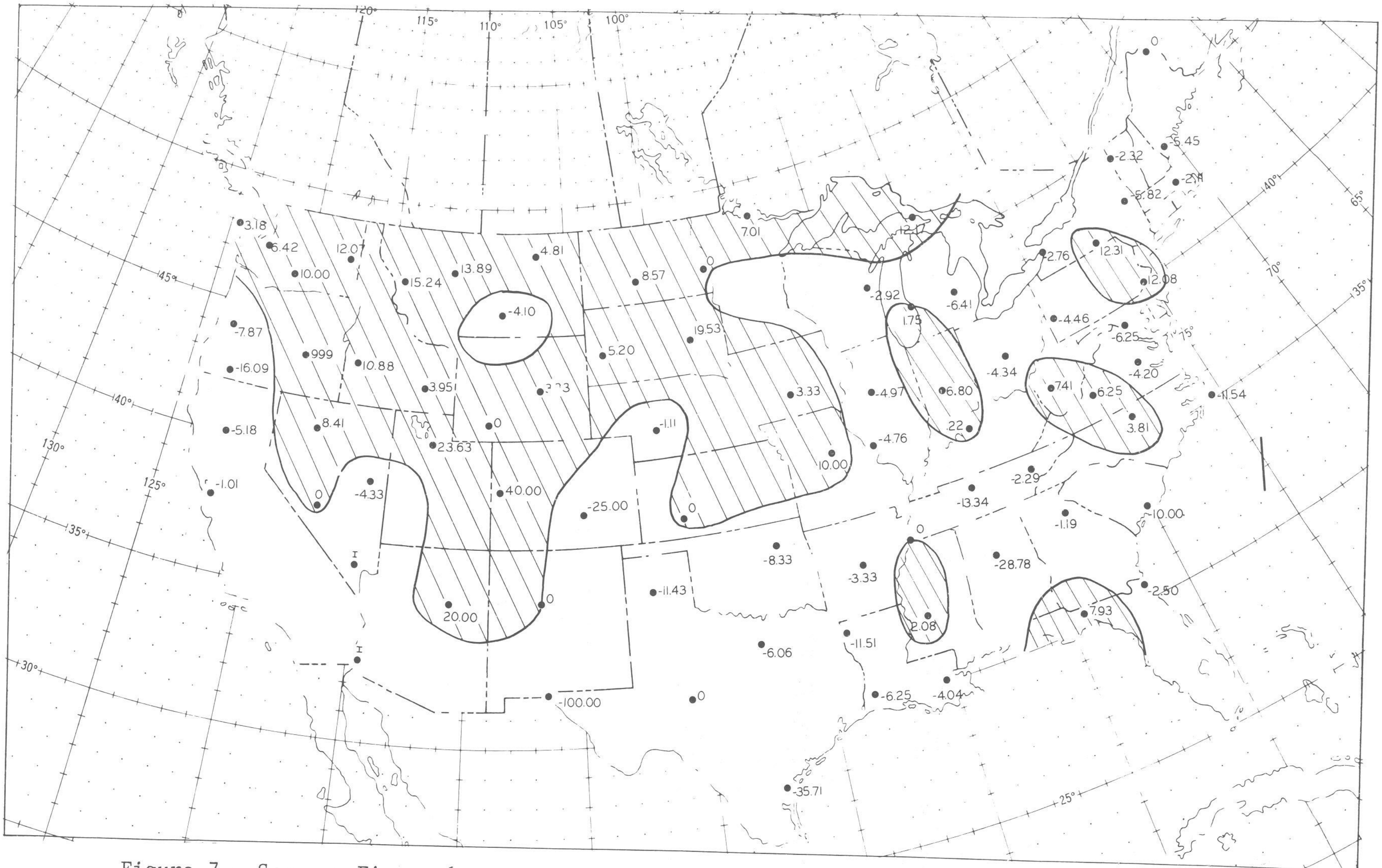

Figure 7.--Same as Figure 6 except for second forecast period after 0000 GMT PE run time.

Annett (1974) found a similar result for a PoP system which utilized forecast output from TDL's Subsynoptic Advection Model (SAM)* (Glahn and Lowry 1972b) and the PE model. The comparative verification involved single station equations for about 100 stations in the eastern United States and one generalized operator equation for the same area. As in this study, about three years of data were used to develop the equations.

The poorer scores of the single station system in this experiment were likely due to the lack of a large enough dependent data sample. It is felt that, when the dependent data sample size becomes sufficiently large, the single station system should prove to be superior. This investigation may be repeated in a few years when a larger dependent data sample is available. However, considering changes in operational numerical models and other improvements in the MOS system, a dependent data sample larger than that used in this study (3 seasons) may not soon be available.

For the present, we will continue to develop generalized operator equations within regions for PoP. With each new season, it is likely that the PoP forecasts will become more accurate as the number of regions is increased and the regions become better defined.

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Appendix

The verification scores used in this report are defined below:

The Brier P-Score (P) (Brier, 1950) is given by

$$P = \frac{1}{N} \sum_{j=1}^{r} \sum_{i=1}^{N} (f_{ij} - Z_{ij})^2 , \qquad \text{(A1)}$$

where on each of N occasions an event can happen in only one of r possible classes, and f_{i1}, f_{i2},. . . f_{ir} represent the forecast probabilities that the event will occur in classes 1, 2,. . .,r, respectively. If the r classes are chosen to be mutually exclusive and exhaustive,

$$\sum_{j=1}^{r} f_{ij} = 1 \qquad \text{(A2)}$$

for each and every i = 1,2,. . .N. Z_{ij} takes the value 1 or 0 according, respectively, to whether the event occurred in class j or not. For perfect forecasting, the Brier P-Score will have a value of zero and, for the worst possible forecasting, a value of two.

The percent correct, bias, Heidke skill score, and threat score are computed from contingency tables. A typical contingency table has the form shown in Table A1.

Table A1. A typical two-category contingency table.

		Forecast Category 1	Forecast Category 2	Total
Observed Category	1	A	B	C
	2	D	E	F
	Total	G	H	I

The percent correct (PC) of the total number of forecasts (I) is computed by

$$PC = \frac{R}{I} \times 100, \qquad (A3)$$

where the number of correct forecasts (R) is given by

$$R = A + E. \qquad (A4)$$

The Heidke skill score (SS) is computed by

$$SS = \frac{R - J}{I - J}, \qquad (A5)$$

where J is the number of forecasts expected to be correct by chance and is given by

$$J = \frac{CG + FH}{I}. \qquad (A6)$$

The bias (BIAS) for each category is computed by

$$BIAS\ (1) = \frac{G}{C}, \qquad BIAS\ (2) = \frac{H}{F}. \qquad (A7)$$

The threat score (TS) for each category is given by

$$TS\ (1) = \frac{A}{C + C - A}, \quad TS\ (2) = \frac{E}{H + F - E}. \qquad (A8)$$

(Continued from inside front cover)

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