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PREDICTING THE CONDITIONAL PROBABILITY OF FROZEN PRECIPITATION

Harry R. Glahn and Joseph R. Bocchieri

Systems Development Office
Silver Spring, Md.
March 1974

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Frederick B. Dent, Secretary

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Robert M. White, Administrator

NATIONAL WEATHER
SERVICE
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PREDICTING THE CONDITIONAL PROBABILITY OF FROZEN PRECIPITATION

Harry R. Glahn and Joseph R. Bocchieri

ABSTRACT. A system is developed which produces objective forecasts of conditional probability of frozen precipitation for the conterminous United States. Development of the system consists of two basic steps, in each of which the MOS (Model Output Statistics) concept is used. First, for each of 186 stations, we find a "50 percent" value for each of three variables predicted by the National Meteorological Center's Primitive Equation (PE) model: 1000-500 mb thickness, boundary-layer potential temperature, and 850-mb temperature. For instance, we find the value of the 1000-500 mb thickness which indicates a 50-50 chance of frozen precipitation at a particular station, provided precipitation occurs. These 50-percent values are determined by using the logit model to fit data from three winter seasons, September 1969 through March 1972.

Secondly, the deviations from the 50-percent values are determined for each station for each variable; the relative frequency (for those cases when precipitation occurred) of frozen precipitation is then computed, again with the logit model, as a function of these new variables. In order to get stable results in this last step, data for all stations are combined. In addition to the meteorological variables, we also use the first harmonic of the day of year and station elevation as predictors. Separate logit equations are determined for each of the PE run times, 0000 and 1200 GMT, and for each of four projections, 12, 24, 36, and 48 hours.

This system was put into operation by the National Weather Service in November 1972. Both teletypewriter and facsimile products are being distributed to field offices twice daily.

A comparative verification on independent data for the 12- and 36-hr forecast projections shows the objective system produced better forecasts than those prepared subjectively at the National Meteorological Center.

INTRODUCTION

Information as to whether expected precipitation will be frozen or liquid is an important aspect of most weather forecasts issued to the public.

Numerical weather prediction models do not directly produce this kind of information; however, they do contain variables which are strongly related to precipitation type. One such variable which has been used for many years --even before the days of numerical prediction--is 1000-500 mb thickness. Studies such as that of Wagner (1957) have produced valuable aids for the practicing forecaster. This paper describes the development of a system--and its use in the National Weather Service (NWS)--which produces objective forecasts of the conditional probability of frozen precipitation (PoFP(P)).

The technique used is called Model Output Statistics, or MOS. In this 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 relationships. Consideration of the model errors is particularly important when the forecasts are to be expressed in probability form. We feel that MOS is the most practical way of approaching the objective prediction of most weather elements. This is borne out by TDL's success with forecasting probability of precipitation (Glahn and Lowry, 1969), conditional probability of frozen precipitation (Glahn and Lowry, 1972), surface wind (Glahn, 1970 and Barrientos, 1970), maximum temperature (Annett, et al., 1972), and ceiling and visibility (Bocchieri and Glahn, 1972).

Development of the PoFP(P) forecast system consisted of two basic steps. First, for each of 186 stations, we found a "50-percent" value for each of three variables predicted by the National Meteorological Center's (NMC) Primitive Equation (PE) model (Shuman and Hovermale, 1968): 1000-500 mb thickness. boundary-layer (B.L.) potential temperature,[1] and 850-mb temperature. For instance, we found the value of the 1000-500 mb thickness which indicates a 50-50 chance of frozen precipitation at a particular station, provided precipitation occurs. These 50-percent values were determined by using the logit model to fit data from three winter seasons.

Secondly, the deviations from the 50-percent values were determined for each station for each variable; the relative frequency (for those cases when precipitation occurred) of frozen precipitation was then computed, again with the logit model, as a function of these new variables. In order to get stable results in this last step, data for all stations were combined. In addition to the meteorological variables, we also used the first harmonic of the day of year and station elevation as predictors.

DEFINITION OF PREDICTAND

For our purposes, "frozen" precipitation is defined as some form of snow or sleet (ice pellets); freezing rain and mixed rain and snow are included with rain and drizzle in the "unfrozen" category. The observations we had available did not allow a more definitive breakdown or the definition of other categories such as "mixed rain and snow" or "freezing precipitation." For simplicity, in this paper the terms snow (rain) and frozen (unfrozen) precipitation will be used interchangeably.

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[1] The B.L. potential temperature will be called the B.L. temperature in this paper and will be expressed in degrees Celsius.

DERIVATION OF 50-PERCENT VALUES

The use of an equal-probability thickness value for differentiating between liquid and frozen precipitation is not new. Wagner (1957) determined equal-probability values for 1000-500 mb thickness several years ago, and his results have been used extensively. He developed a value for each of 40 stations in the conterminous U.S. from two seasons of data. For our study, we had available three seasons of data: September 1969 through April 1970, September 1970 through April 1971, and September 1971 through March 1972. Since we were using forecasts at grid points instead of calculated thickness at upper air observing stations, we could interpolate and use values at all locations where we had surface reports of precipitation type. Although we had surface reports at 234 stations, only 186 of the station records contained sufficient cases of frozen precipitation for reliable 50-percent values to be determined. These 186 stations are shown in Fig. 1 along with the other 48 stations for which very few, if any, observations of snow were available.

We used the logit model (Brelsford and Jones, 1967 and Jones, 1968) to determine the 50-percent values of three variables: 1000-500 mb thickness, 850-mb temperature, and B.L. temperature, all of which were forecast by the NMC PE numerical model. The logit model provides a means of fitting a sigmoid or S-shaped curve when the dependent variable (Y) is binary and the independent variable (X) is quasi-continuous. From it, the probability of the binary variable having the value of one, say, can be expressed

$$P[Y=1|X] = \frac{1}{1 + \exp(a + bX)} .$$

The computer program we used determines the maximum likelihood estimates for the model parameters a and b.

We will use 1000-500 mb thickness as an example of how the 50-percent values of the three variables were found. Surface observations were available at 6-hourly intervals, as were the forecasts from the PE model. The thickness forecasts, valid at the same time the observations were made, were interpolated to the station locations. Forecasts for four projection times--6, 12, 18, and 24 hours--from both the 0000 and 1200 GMT PE model runs were combined into one sample. This pooling of data insured that the sample contained an adequate number of snow cases for reliable estimation. The resulting sample sizes ranged from 90 at Tonopah, Nevada to 1600 at Traverse City, Michigan.

After the logit model constants were derived, it was a simple matter to find the value of thickness for which the probability of snow is 50-percent; this value is given by -a/b. A typical example of the analysis is shown in Fig. 2. The resulting 50-percent value of 1000-500 mb thickness for Salt Lake City is 5,432 m.

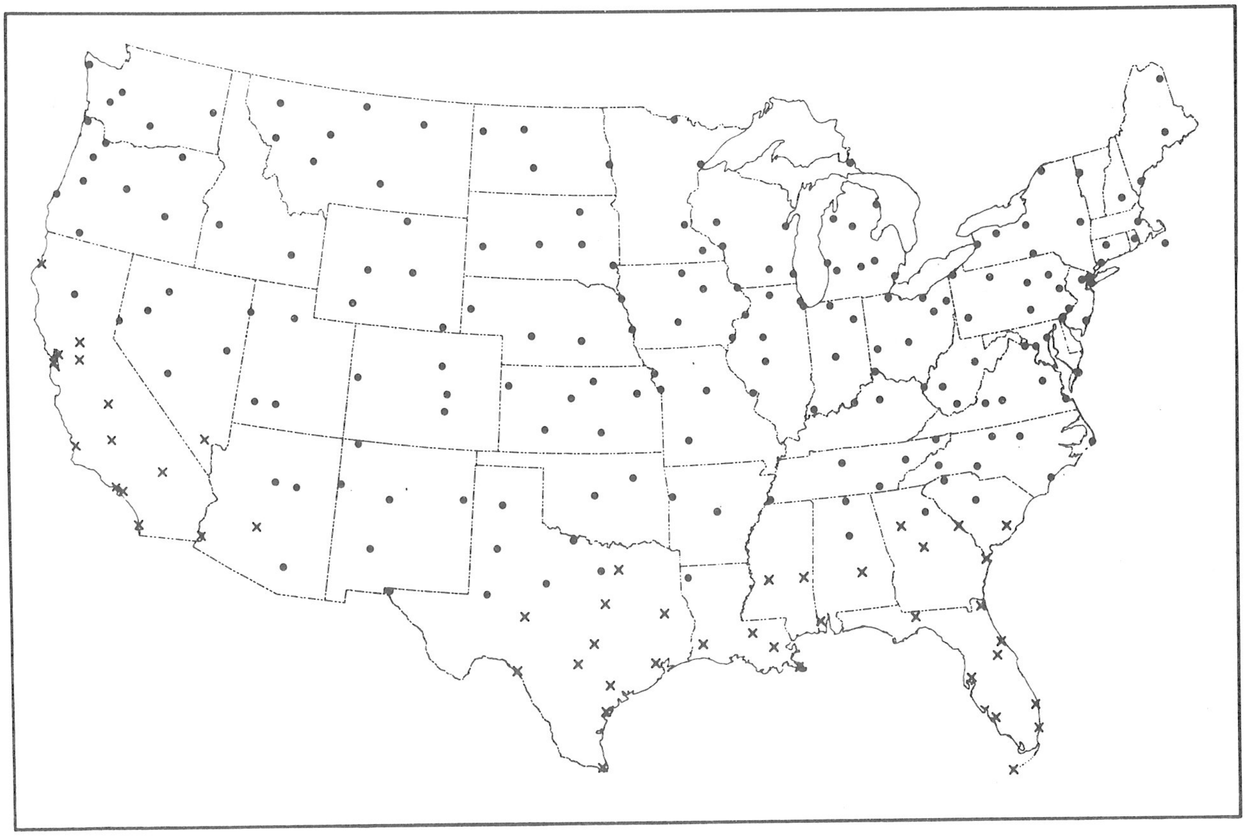
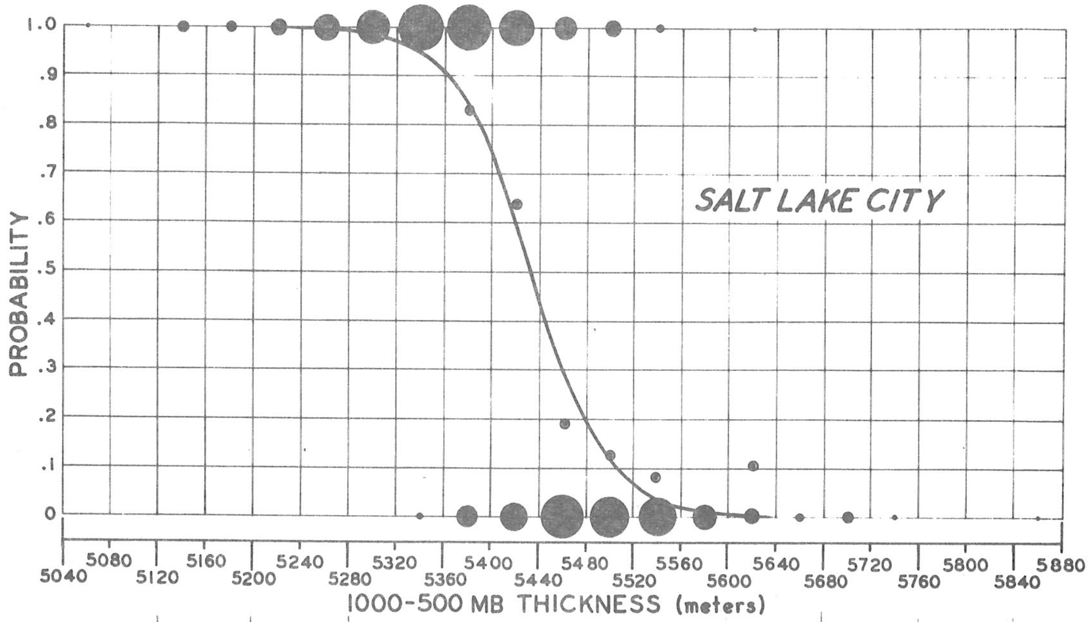


Figure 1.--The 234 stations for which observations were available. The 48 stations for which 50-percent values could not be determined statistically are shown by X's.

The 50-percent values for all stations were subjectively analyzed in two ways. First, all values were plotted on a map, shown in Fig. 3, and viewed for consistency with neighboring values. Secondly, all values were plotted on a graph, shown in Fig. 4, as a function of station elevation. It is apparent from Fig. 4 that the 50-percent value varies directly with elevation. Also, the points fall into 3 groups: (1) those with a strong marine influence, (2) those not included in (1) west of the continental divide, and (3) those not included in (1) east of the continental divide.

The increase of 50-percent value with station elevation is not surprising. Consider a layer immediately above a station, perhaps 100-300 m thick, and call it the "critical layer." This layer is defined such that when its mean temperature is a few degrees above 0°C, snow falling through it will melt. Because of the general dependence of free-air temperature on elevation above mean sea level, a low-level station will have, on the average, a warmer critical layer temperature for a given 1000-500 mb thickness than will a high-level station. Therefore, a low-level station will have a critical layer temperature just warm enough to melt snow with a lower 1000-500 mb thickness than a high-level station.



SNOW CASES	*1*	*0*	*7*	*6*	*9*	*20*	*37*	*74*	*73*	*44*	*16*	*8*	*4*	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*
TOTAL CASES	*1*	*0*	*7*	*6*	*9*	*20*	*37*	*77*	*88*	*69*	*84*	*68*	*53*	*18*	*9*	*4*	*7*	*2*	*0*	*0*	*1*
RELATIVE FREQUENCY	*1.00*	—	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*.96*	*.83*	*.64*	*.19*	*.12*	*.08*	*.00*	*.11*	*.00*	*.00*	*.00*	—	—	*.00*
LOGIT PROBABILITY	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*.98*	*.95*	*.84*	*.59*	*.29*	*.11*	*.03*	*.01*	*.00*	*.00*	*.00*	*.00*	*.00*	*.00*	*.00*

Figure 2.—Probability of frozen precipitation as a function of 1000-500 mb thickness at Salt Lake City, Utah. The areas of the dots on the graph represent the number of cases (snow cases are plotted at probability = 1; rain cases are plotted at probability = 0) in the 40-meter intervals. The relative frequency of snow is plotted as ⊙ in the 40-meter intervals. The number of snow cases, precipitation cases, relative frequency of snow, and logit probability in 40-meter intervals of thickness are tabulated below the graph.

The stations labeled as having a strong marine influence are all in the Pacific Northwest, west of the Cascades, except two—Cape Hatteras, North Carolina and Nantucket, Massachusetts. These stations are situated such that low-level air trajectories will usually have a recent over-water history. In those precipitation cases when the 1000-500 mb thickness indicates a 50-50 chance of snow, the temperature sounding will exhibit a steeper lapse rate at stations with a strong marine influence than at other stations. Therefore, for a given critical layer temperature, the 50-percent thickness value at Seattle is lower than at, say, Washington, D.C.

Most stations west of the continental divide, especially those in the northern latitudes, exhibit lower 50-percent values than stations at similar altitudes east of the continental divide. This probably indicates western stations have a steeper lapse of temperature than eastern stations in cases when rain and snow are about equally likely. Another possible explanation is that the PE model produces forecasts with different biases in the West than in the East.

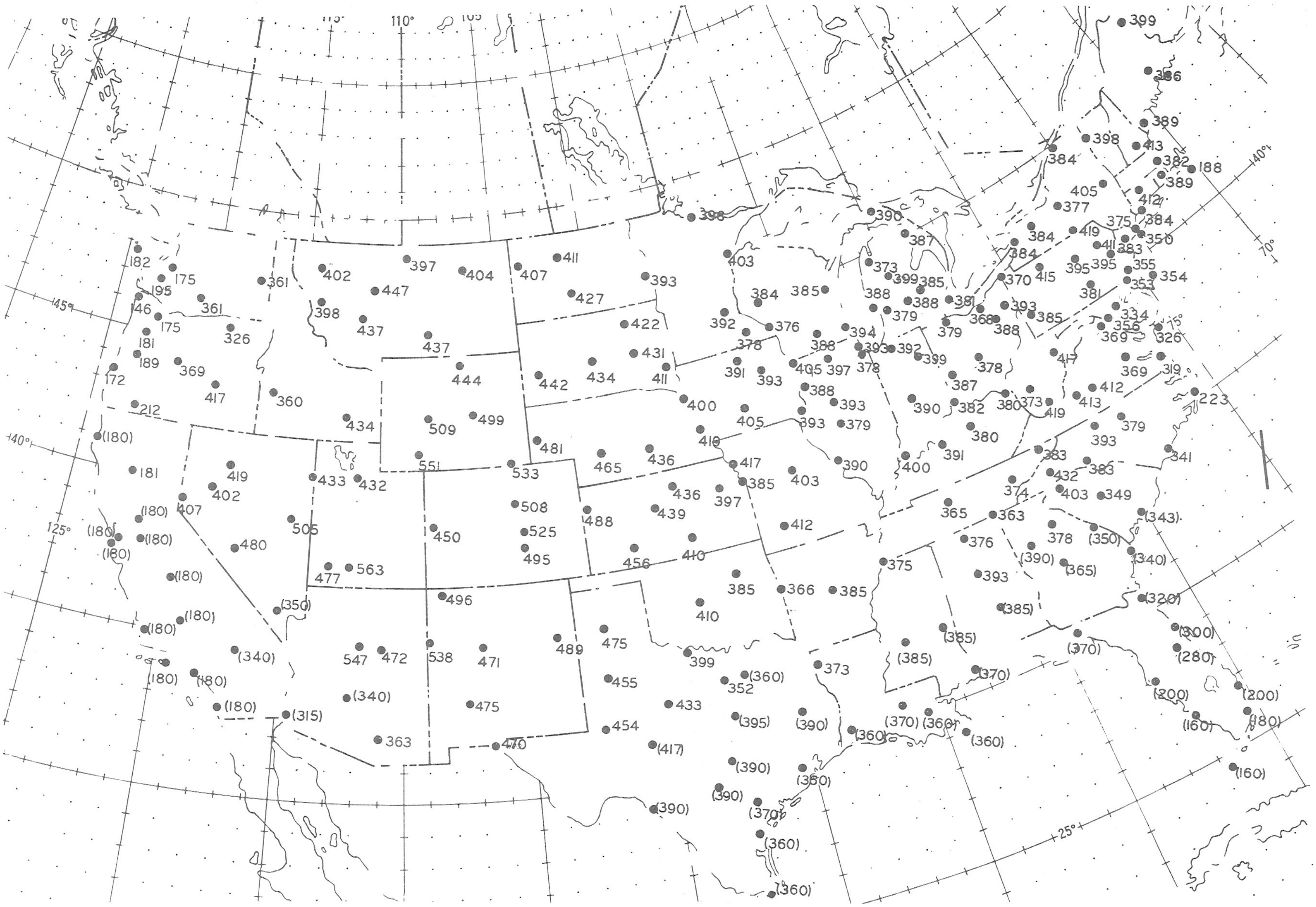


Figure 3.--50-percent values of 1000-500 mb thickness in meters with the leading 5 omitted. Estimates for stations for which 50-percent values could not be determined statistically are in parentheses.

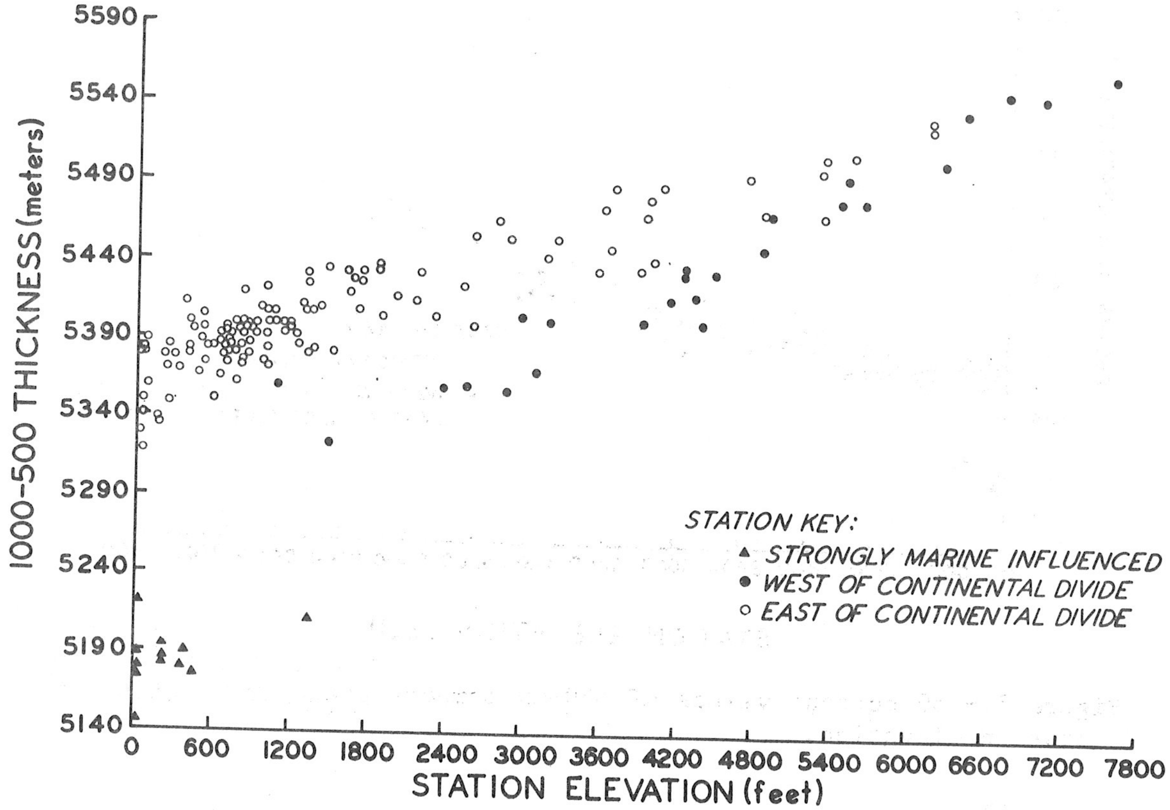


Figure 4.--50-percent values of 1000-500 mb thickness as a function of station elevation.

The logit model did not give acceptable 50-percent values for two stations, Portland and Medford, Oregon, even though each station had quite a number of both rain and snow cases. For these two stations, a subjective estimate was made from the original station data. These subjective estimates were noted to be consistent with values at surrounding stations.

The problem at these two stations was caused by the occurrence of an unusual number of snow cases at rather high thickness values. The model, in attempting to fit all the data (rather than data only in the vicinity of the 50-percent value) gave a poor fit near the 50-percent value. Evidently, the symmetric nature of the curve is a severe restriction in some cases.

The 50-percent values for 850-mb temperature and B.L. temperature were found in a similar manner. Again they are strongly dependent on elevation. The graph for 850-mb temperature, Fig. 5, shows the same three groupings of stations as does the graph for 1000-500 mb thickness, although the groups are not as distinct. The graph for B.L. temperature, Fig. 6, shows very little recognizable grouping of stations.

The dependence of 850-mb 50-percent values on station elevation can be

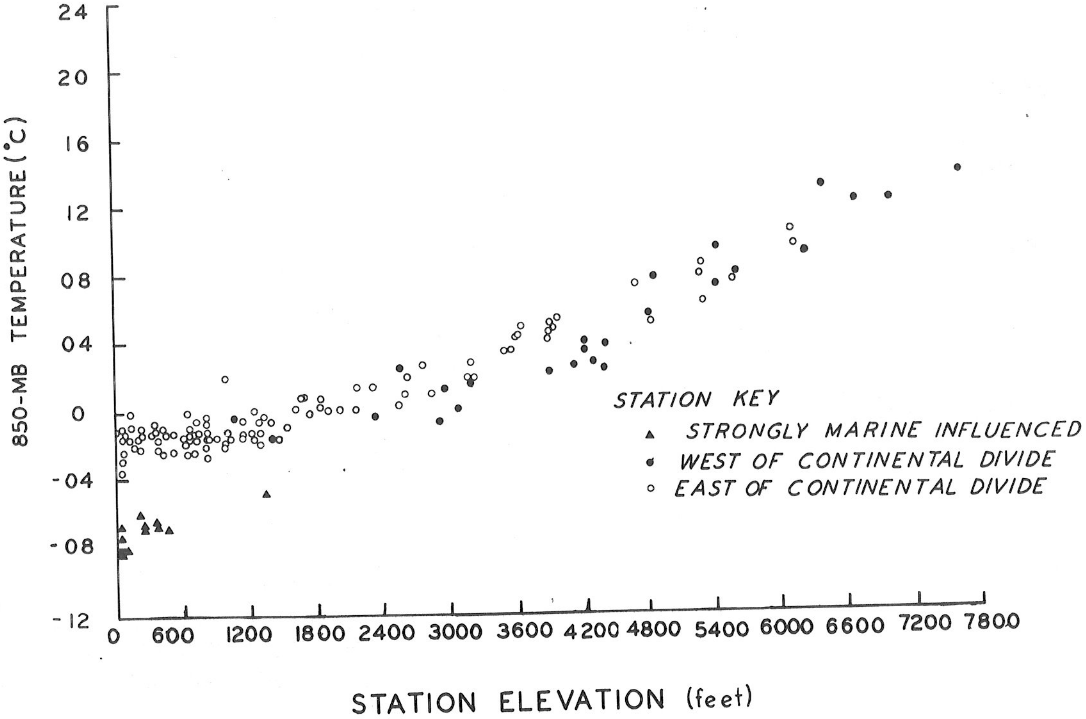


Figure 5.--50-percent values of 850-mb temperature as a function of station elevation.

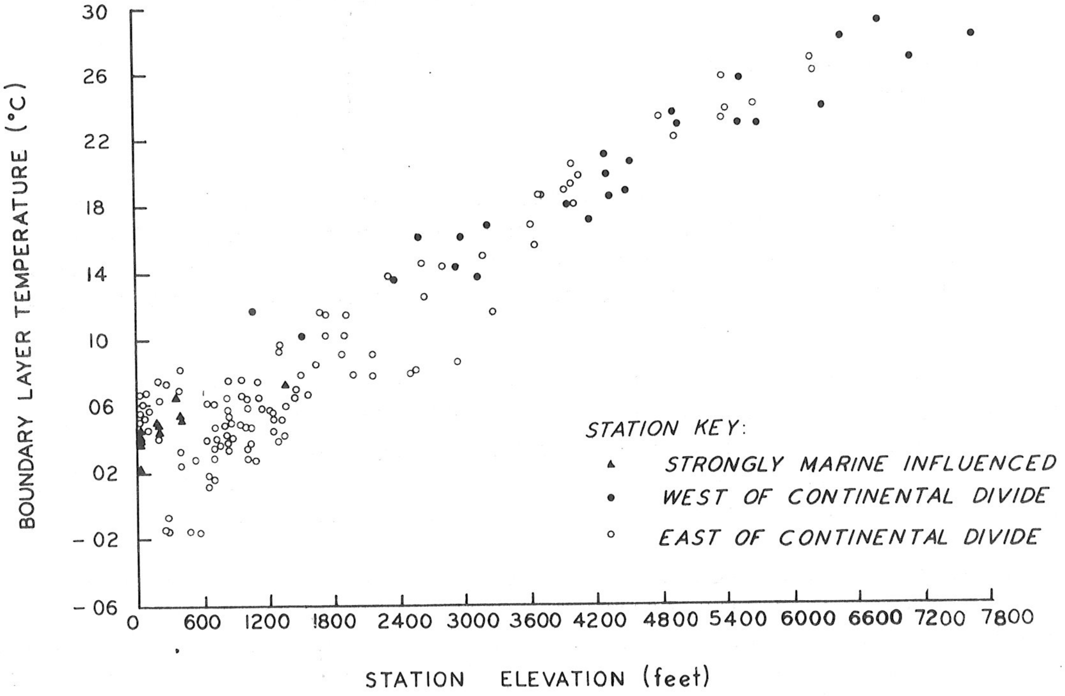


Figure 6.--50-percent values of B.L. temperature as a function of station elevation.

explained in the same manner as the dependence on elevation of 1000-500 mb thickness 50-percent values. A high-level station may have a critical layer mean temperature about equal to the 850-mb temperature, but, for the same time, the critical layer mean temperature for a low-level station would be much warmer.

The dependence of 50-percent values of PE B.L. (potential) temperature on station elevation may be due to several factors. The difference between the actual station elevation and the smoothed terrain in the PE model may be a partial explanation. However, the fact that we are dealing with potential temperature is an adequate explanation in itself. A station at a high elevation may have approximately the same 50-percent value of B.L. (or of surface) temperature as a station at a low elevation, but the potential temperature would be considerably greater for the higher station.

Fifty-percent values for 850-mb temperature and B.L. temperature are exhibited geographically in Figs. 7 and 8, respectively. There is some indication that stations in northeastern Texas, Arkansas, and western Tennessee have lower 50-percent values (about -1.0°C) for B.L. temperature than other stations of similar elevation (about +5.0°C). This may indicate that snow occurs in this area with different synoptic conditions than for other areas. On the other hand, snow occurs there only infrequently, and these values are somewhat in question.

Spar (1971) determined the critical B.L. temperature for rain-snow discrimination for a number of stations in the northeastern U.S. He, too, found that predicted B.L. temperatures on the order of 6C or higher were required before rain should be predicted rather than snow.

The 50-percent values for all three variables are listed in the appendix for easy reference.

DERIVATION OF PREDICTION EQUATIONS

The logit curves described in the preceding section could be used to estimate the conditional probability of snow in an operational environment. However, each curve uses only one independent variable, and some method would be needed to combine estimates from the three curves at each station. Also, for many stations, the estimates would not be very reliable for low and high probabilities, even though the distribution of snow-rain cases was such as to allow the determination of a 50-percent value. Further, no estimates could be made for the stations with insufficient snow cases to determine a reliable logit curve or 50-percent value.

The logit model provides a means for obtaining estimates based on more than one independent variable. The estimation equation can be written

$$P[Y=1|X_1, X_2,\ldots,X_n] = \frac{1}{1+\exp(a+b_1X_1+b_2X_2+\ldots+b_nX_n)}$$

for n independent variables.

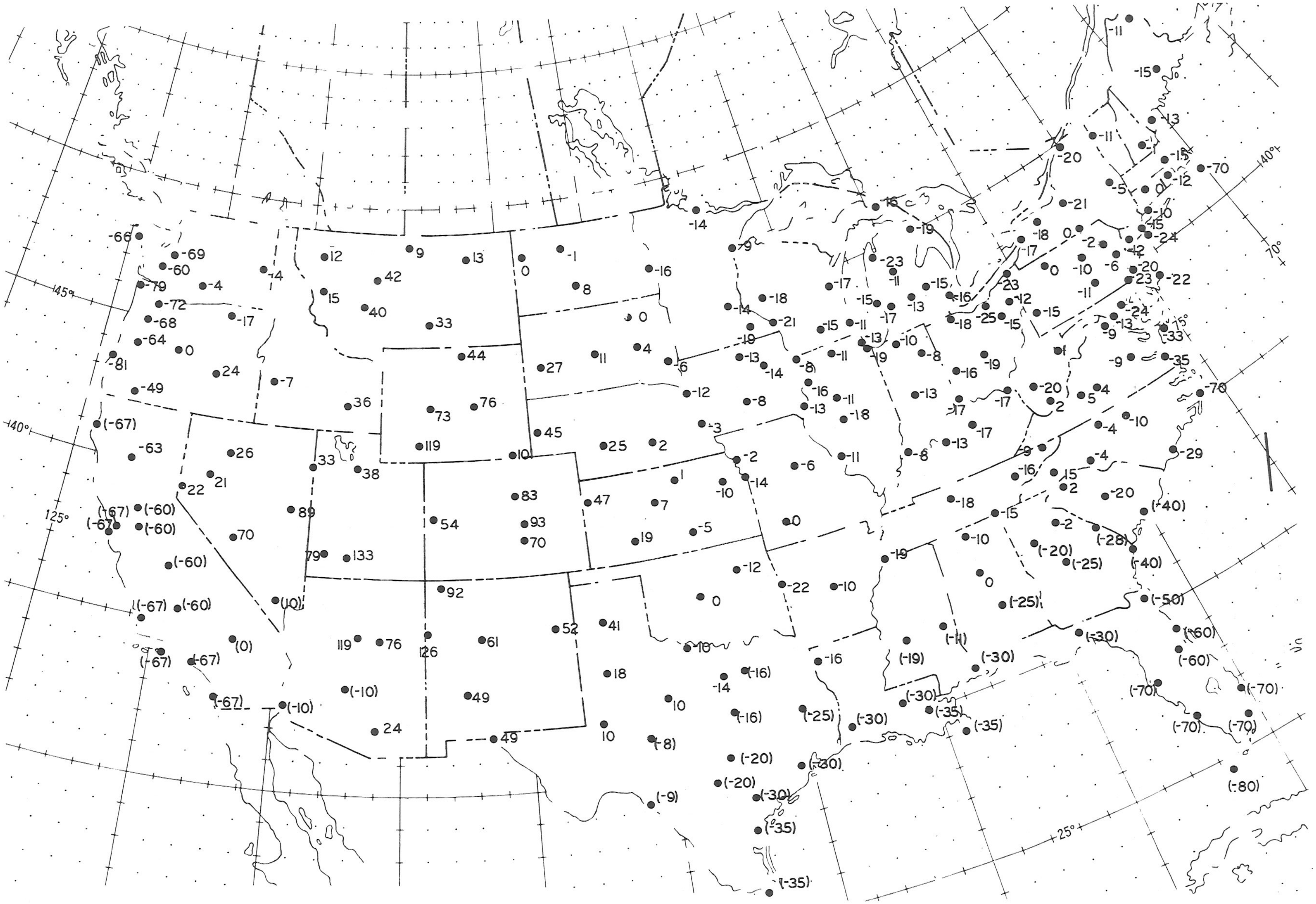


Figure 7.--50-percent values of 850-mb temperature in °C x 10. Estimates for stations for which 50-percent values could not be determined statistically are in parentheses.

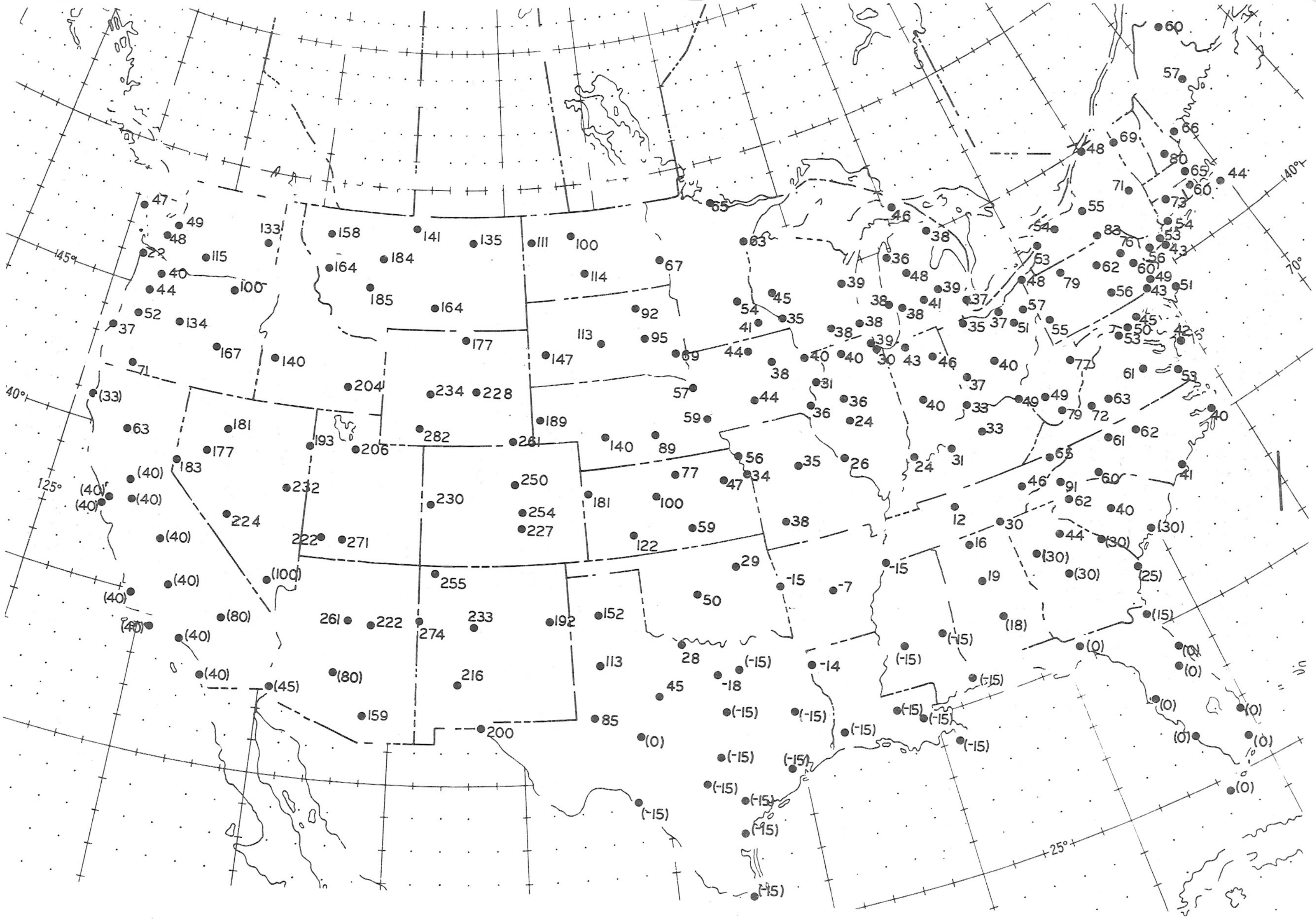


Figure 8.--50-percent values of B.L. temperature in °C x 10. Estimates for stations for which 50-percent values could not be determined statistically are in parentheses.

In order to provide an adequate data sample for fitting the constants (a and b's) in the above equation, the assumption was made that a particular deviation from a station's 50-percent value will produce the same probability of snow (or rain) at all stations. For instance, Fig. 2 shows that a 1000-500 mb thickness of 5362 m at Salt Lake City indicates about a 90 percent (conditional) probability of snow. This is 70 m below the critical thickness of 5,432 m. Our assumption is that a thickness 70 m below the critical value at any station will indicate about a 90 percent probability of snow. (The 70 m value at Salt Lake City is used for illustration only; a better value can be determined from a sample composed of data from many stations). This assumption allows data from all stations for which we have a 50-percent value to be combined into one sample. At each station, the 50-percent value of each of 1000-500 mb thickness, 850-mb temperature, and B.L. temperature was subtracted from the original record of the corresponding variable. This resulted in a large sample in which the independent variables were expressed as deviations from a station "constant."

In addition to the three meteorological variables, we also used the station elevation and the sine (SIN) and cosine (COS) of the day of the year as independent variables. These latter predictors are expressed as:

$$\mathrm{SIN} = \mathrm{Sin}\,\frac{2\pi i}{365},$$

$$\mathrm{COS} = \mathrm{Cos}\,\frac{2\pi i}{365}, \qquad \text{where } i = 1 \text{ for January 1, etc.}$$

It is not necessary to use predictions of the meteorological variables valid at the same time as the PoFP(P) forecast. For instance, if we want a probability forecast 36 hours after the 0000 GMT PE run time, we can use the PE B.L. temperature forecast valid 48 hours after run time if we so desire, or we can even use the B.L. temperature forecast valid at 36 hours and 48 hours after run time if we wish.

Separate logit forecast equations were derived for each of the PE run times, 0000 and 1200 GMT, and for each of 4 projections, 12, 24, 36, and 48 hours. Table 1 gives the predictors used for each projection. Projection, in each case, refers to the number of hours after PE run time.

The logit computer program does not provide for objective selection of a few predictors from a large group. However, a number of runs were made which constituted, in effect, a subjective screening. Addition of more predictors to the final set selected is unlikely to give substantially better results. In general, the PE predictors valid at the same time as the PoFP(P) forecast were the most important. The addition of PE predictors valid 12 hours before and after the time of the PoFP(P) forecast was also important. The 850-mb temperature was the best of any single predictor by a considerable margin. An additional predictor, the 1000-850 mb thickness, was tried and discarded since it was of no use in improving the relationships. The station elevation and day of year variables were of marginal benefit.

TABLE 1.--Predictors in the PoFP(P) equations for each of the 4 projections.

12 hr		24 hr		36 hr		48 hr	
Predictor	Projection	Predictor	Projection	Predictor	Projection	Predictor	Projection
Station Elevation	-	Station Elevation	-	Station Elevation	-	Station Elevation	-
Sin DOY	-	Sin DOY	-	Sin DOY	-	Sin DOY	-
Cos DOY	-	COS DOY	-	Cos DOY	-	Cos DOY	-
1000-500 mb thickness	12	850-mb Temp	12	850-mb Temp	24	850-mb Temp	36
850-mb Temp	12	B.L. Temp	12	B.L. Temp	24	B.L. Temp	36
B.L. Temp	12	1000-500 mb thickness	24	1000-500 mb thickness	36	1000-500 mb Thickness	48
850-mb Temp	24	850-mb Temp	24	850-mb Temp	36	850-mb Temp	48
B.L. Temp	24	B.L. Temp	24	B.L. Temp	36	B.L. Temp	48
		850-mb Temp	36	850-mb Temp	48		
		B.L. Temp	36	B.L. Temp	48		

The P-scores, defined by Eq. B1 in appendix B, on the dependent data for the 8 prediction equations are shown in Table 2. As expected, scores increased (forecasts became poorer) with projection. There is an indication that forecasts made from 0000 GMT data are better than those made from 1200 GMT data for the same projection.

Table 2.--P-scores for PoFP(P) forecasts on the 3 years of dependent data.

Projection (Hr)	Initial Data Time	
	0000 GMT	1200 GMT
12	0.107	0.118
24	.124	.125
36	.140	.153
48	.177	.180

The constants and coefficients derived for the logit prediction equations are difficult to interpret for at least two reasons. First, because of the complex interrelationships among the several variables, the effect of individual terms cannot be adequately assessed. Secondly, the logit is non-linear in form, and this complicates the interpretation of individual predictors. Therefore, the actual equations are not shown here.

VERIFICATION

The objective forecast method described above was completed in March 1973. and was implemented on September 16, 1973. However, on November 1, 1972 a similar system was made operational by the NWS. It differed from the one described above in only one important respect--it was derived on two seasons of data rather than three, the two seasons being 1969-70 and 1970-71. A minor difference is that the 50-percent values were determined in a slightly different way and were determined for 182 rather than for 186 stations.

We tested the prediction equations derived from the 0000 and 1200 GMT PE runs and made operational on November 1, 1972 on independent data--the 1971-72 winter season. The P-scores for the 182 stations for both the dependent and independent data samples are shown in Table 3. It can be seen that, as expected, the scores generally increased (forecasts became poorer) with projection. Also, overall, there was no deterioration of the scores in going from dependent to independent data.

We performed a comparative verification between the subjective forecasts produced by the Basic Weather Forecast Branch (BWFB) at NMC and the forecasts produced by the MOS PoFP(P) system made operational November 1, 1972. The

Table 3.--P-scores for MOS PoFP(P) forecasts for both dependent data (1969-70 and 1970-71 winters) and independent data (1971-72 winter). Each P-score for the independent data sample was computed from approximately 5000 cases.

Projection (Hr.)	Initial Data Time			
	0000 GMT		1200 GMT	
	Dependent	Independent	Dependent	Independent
12	0.110	0.109	0.122	0.119
24	.123	.133	.128	.123
36	.144	.132	.153	.169
48	.174	.185	.179	.178

independent verification sample consisted of data for 129 stations (a subset of the 182 stations used for development) in the conterminous U.S. for the period October 1972 through March 1973. The verification was done for 12- and 36-hour forecast projections from the 0000 GMT PE run time.

The BWFB subjective forecasts of precipitation type were obtained from the operational surface prog charts (N29 and N38) which are transmitted over NAFAX. A MOS PoFP(P) forecast of 50 percent or greater was defined as a forecast of snow. Only those cases when precipitation both occurred and was forecast by BWFB were used in the verification. MOS PoFP(P) is a conditional probability and is available whether or not precipitation occurs. BWFB did not have the objective forecasts to use as guidance.

The verification scores used were percent correct, bias, Heidke skill score, and threat score. These scores are defined in appendix B. We divided the verification into two parts, A and B. For verification A, we included all cases, both the obvious and the difficult. In verification B, only those cases when the MOS and BWFB forecasts of precipitation type differed were included; therefore, some of the more difficult rain-snow forecast situations were isolated. Tables 4 through 7 and Tables 8 through 11 show the results for verifications A and B respectively. For verification A, Tables 4 and 5 present the results for the 12-hour projection, while the 36-hour projection results are shown in Tables 6 and 7. Contingency tables are presented in Tables 4 and 6. The verification scores computed from contingency tables for each NWS region and for all 129 stations combined are shown in Tables 5 and 7. As similar arrangment of tables is presented for verification B (Tables 8 through 11).

The results for verification A can be summarized as follows:

1. For each region and for all stations combined, MOS was generally better than or equal to BWFB for all scores and projections.

2. MOS had a tendency to underforecast the snow event (bias < 1.00) while BWFB had a tendency to overforecast the snow event.

3. All scores were rather high because the sample contained many cases when the form of precipitation would be rather obvious.

The results for verification B (Tables 8 through 11) are summarized below:

1. For each region and for all stations combined, MOS was generally better than or equal to BWFB for all scores and projections.

2. For all stations combined and both projections, MOS had a tendency to underforecast the snow event, while BWFB showed the opposite tendency.

3. Overall, MOS showed more improvement over BWFB than in verification A.

4. MOS was correct about 65 percent of the time when BWFB and MOS differed.

We used the binomial distribution to test the significance of the difference in number (or percent) correct between MOS and BWFB for the 12-hour projection and all stations combined in verification B (Tables 8 and 9). Since only those cases when the forecasts differed were used, only one of the systems could (and must) be correct. Therefore, it's like tossing a coin; it must come up either heads or tails. The probability of obtaining 135 or more heads (correct forecast) or 135 or more tails (incorrect forecasts) in 206 tosses (total forecasts) is:

$$2 \sum_{i=135}^{206} \binom{206}{i} .5^{i} \; .5^{206-i}$$

(The coefficient 2 makes it a two-tailed test.) However, this expression is some trouble to evaluate and for a sample as large as 206, the test can be very adequately approximated by the normal deviate test,

$$Z = \frac{\pm\, k\,(p_o - p) - .5}{\sqrt{kpq}}$$

where k = sample size, p = hypothesized success ratio, q = hypothesized failure ratio, and p_o = observed success ratio. Therefore, from data in Tables 8 and 9,

$$Z = \frac{\pm\, 206\,(.6553 - .5) - .5}{.5\sqrt{206}} = 4.39$$

Table 4.--Contingency tables for MOS and BWFB for the 12-hour forecast projection. Includes all independent data cases for 129 conterminous U.S. stations, October 1972 through March 1973 (verification A).

Obs	Fcst				Total
	MOS		BWFB		
	Snow	Rain	Snow	Rain	
Snow	756	95	750	101	851
Rain	97	1158	155	1100	1255
Total	853	1253	905	1201	2106

Table 5.--Comparative verification results between MOS and BWFB for the 12-hour forecast projection by NWS Region. Includes all independent data cases for 129 conterminous U.S. stations, October 1972 through March 1973 (verification A).

Region	System	Bias Snow	Bias Rain	Percent Correct	Skill Score	Threat Score Snow	Number of Cases
Eastern	MOS	.98	1.01	93	.83	.79	793
	BWFB	1.14	.93	90	.78	.74	
Southern	MOS	.93	1.01	93	.73	.64	262
	BWFB	.89	1.02	93	.73	.63	
Central	MOS	1.06	.93	89	.77	.82	767
	BWFB	1.11	.86	84	.68	.77	
Western	MOS	.88	1.09	89	.78	.77	284
	BWFB	.79	1.15	87	.73	.71	
All Stations	MOS	1.00	1.00	91	.81	.80	2106
	BWFB	1.06	.96	88	.75	.74	

Table 6.--Contingency tables for MOS and BWFB for the 36-hour forecast projection. Includes all independent data cases for 129 conterminous U.S. stations, October 1972 through March 1973 (verification A).

Obs	Fcst				Total
	MOS		BWFB		
	Snow	Rain	Snow	Rain	
Snow	691	101	679	113	792
Rain	89	1036	145	980	1125
Total	780	1137	824	1093	1917

Table 7.--Comparative verification results between MOS and BWFB for the 36-hour forecast projection by NWS Region. Includes all independent data cases for 129 conterminous U.S. stations, October 1972 through March 1973 (verification A).

Region	System	Bias		Percent Correct	Skill Score	Threat Score Snow	Number of Cases
		Snow	Rain				
Eastern	MOS	1.02	.99	92	.82	.78	717
	BWFB	1.12	.94	90	.77	.74	
Southern	MOS	.89	1.03	91	.72	.64	241
	BWFB	.79	1.06	89	.65	.56	
Central	MOS	1.02	.98	89	.77	.82	686
	BWFB	1.11	.86	85	.70	.78	
Western	MOS	.86	1.10	88	.74	.72	273
	BWFB	.77	1.16	79	.56	.56	
All Stations	MOS	.98	1.01	90	.80	.78	1917
	BWFB	1.04	.97	86	.72	.72	

Table 8.--Contingency tables for MOS and BWFB for the 12-hour forecast projection. Independent data pooled for 129 conterminous U.S. stations, October 1972 through March 1973. Includes only cases when MOS and BWFB forecasts differed (verification B).

Obs	Fcst MOS Snow	Fcst MOS Rain	Fcst BWFB Snow	Fcst BWFB Rain	Total
Snow	48	42	42	48	90
Rain	29	87	87	29	116
Total	77	129	129	77	206

Table 9.--Comparative verification results between MOS and BWFB for the 12-hour forecast projection by NWS Region. Independent data pooled for 129 conterminous U.S. stations, October 1972 through March 1973. Includes only cases when MOS and BWFB forecasts differed (verification B).

Region	System	Bias Snow	Bias Rain	Percent Correct	Threat Score Snow	Number of Cases
Eastern	MOS	.44	1.22	70	.15	57
	BWFB	3.12	.17	30	.24	
Southern	MOS	1.00	1.00	50	.38	20
	BWFB	.82	1.22	50	.33	
Central	MOS	1.19	.91	70	.39	84
	BWFB	2.04	.53	30	.14	
Western	MOS	.76	2.12	58	.55	45
	BWFB	.46	3.50	42	.35	
All Stations	MOS	.86	1.11	66	.40	206
	BWFB	1.43	.66	34	.24	

Table 10.--Contingency tables for MOS and BWFB for the 36-hour forecast projection. Independent data pooled for 129 conterminous U.S. stations, October 1972 through March 1973. Includes only cases when MOS and BWFB forecasts differed (verification B).

Obs	Fcst				Total
	MOS		BWFB		
	Snow	Rain	Snow	Rain	
Snow	61	49	49	61	110
Rain	27	83	83	27	110
Total	88	132	132	88	220

Table 11.--Comparative verification results between MOS and BWFB for the 36-hour forecast projection by NWS Region. Independent data pooled for 129 conterminous U.S. stations, October 1972 through March 1973. Includes only cases when MOS and BWFB forecasts differed (verification B).

Region	System	Bias		Percent Correct	Threat Score Snow	Number of Cases
		Snow	Rain			
Eastern	MOS	.84	1.08	65	.30	55
	BWFB	2.05	.44	35	.23	
Southern	MOS	.88	1.25	60	.52	25
	BWFB	.59	1.88	40	.29	
Central	MOS	.67	1.25	64	.33	84
	BWFB	1.67	.50	36	.28	
Western	MOS	.87	1.28	70	.61	56
	BWFB	.60	1.83	30	.22	
All Stations	MOS	.80	1.20	65	.44	220
	BWFB	1.20	.80	35	.25	

(The 0.5 in the numerator corrects for the discreteness of the data.) $Z = 4.39$ corresponds to a 2-tailed significance of 0.001 percent. That is, under the assumption of independent events, there is only about 1 chance in 100,000 that 135 or more or 71 or fewer correct forecasts will result if the true probability were 0.5. However, the 206 cases are, of course, not independent. A conservative estimate of independent events might be 1 in 3 or about 69. Assuming the same proportion of successes, the significance would still be about one percent. A similar result was obtained for the 36-hour projection from data shown in Tables 10 and 11.

Therefore, we are led to the conclusion that the MOS objective forecasts are significantly better than the BWFB subjective forecasts as obtained from the facsimile maps.

OPERATIONAL ASPECTS

The operational products include a 4-panel facsimile chart graphically portraying probability of precipitation (PoP) and PoFP(P) forecasts. The PoFP(P) forecasts are valid 12, 24, 36, and 48 hours after PE run time; the PoP forecasts are valid for four 12-hour periods beginning 12, 24, 36, and 48 hours after PE run time. An example of one panel from the facsimile chart is shown in Fig. 9.

A teletype bulletin, a portion of which is shown in Fig. 10, is disseminated over "Service C." The bulletin gives specific values of PoFP(P) and PoP at 154 cities for the same forecast projections as given in the facsimile chart. Forecasts for other stations are available through the Weather Message Switching Center at Kansas City, Missouri on a request/reply basis.

In order that forecasts could be made for all stations and the facsimile maps of the U.S. would not have blank areas, 50-percent values were estimated at those stations for which such values could not be determined statistically. These estimates are shown in parentheses in Figs. 3, 7, and 8. In this estimation, we took into account: (1) the relationship of 50-percent value to station elevation, such as shown in Figs. 4, 5, and 6; (2) values at neighboring stations; (3) nearness to a large body of water; and (4) most likely direction of low-level winds in snow-threat situations. Forecasts for the stations where it was necessary to make these estimates will undoubtedly be less reliable than forecasts for stations with statistically-derived 50-percent values. However, it is felt that even these less-reliable forecasts will be of use in alerting forecasters to snow-threat situations.

Fig. 11 depicts PoFP(P) forecasts made from 0000 GMT PE run of February 8, 1973. The occurrence of snow and rain at the valid time is indicated by stippling and vertical line shading respectively. The 12-hour PoFP(P) forecasts shown in Fig. 11(a) are valid at the same time as the PoFP(P) forecasts shown in Fig. 9. It should be noted that 5-, 50-, and 95-percent PoFP(P) isopleths are shown in Fig. 11(a) while 10-, 50-, and 90-percent isopleths are shown in Fig. 9. The observed areas of precipitation in Fig. 11(a) and 11(b) correspond respectively to the beginning and end of the 12-hour period for which PoP forecasts are shown in Fig. 9.

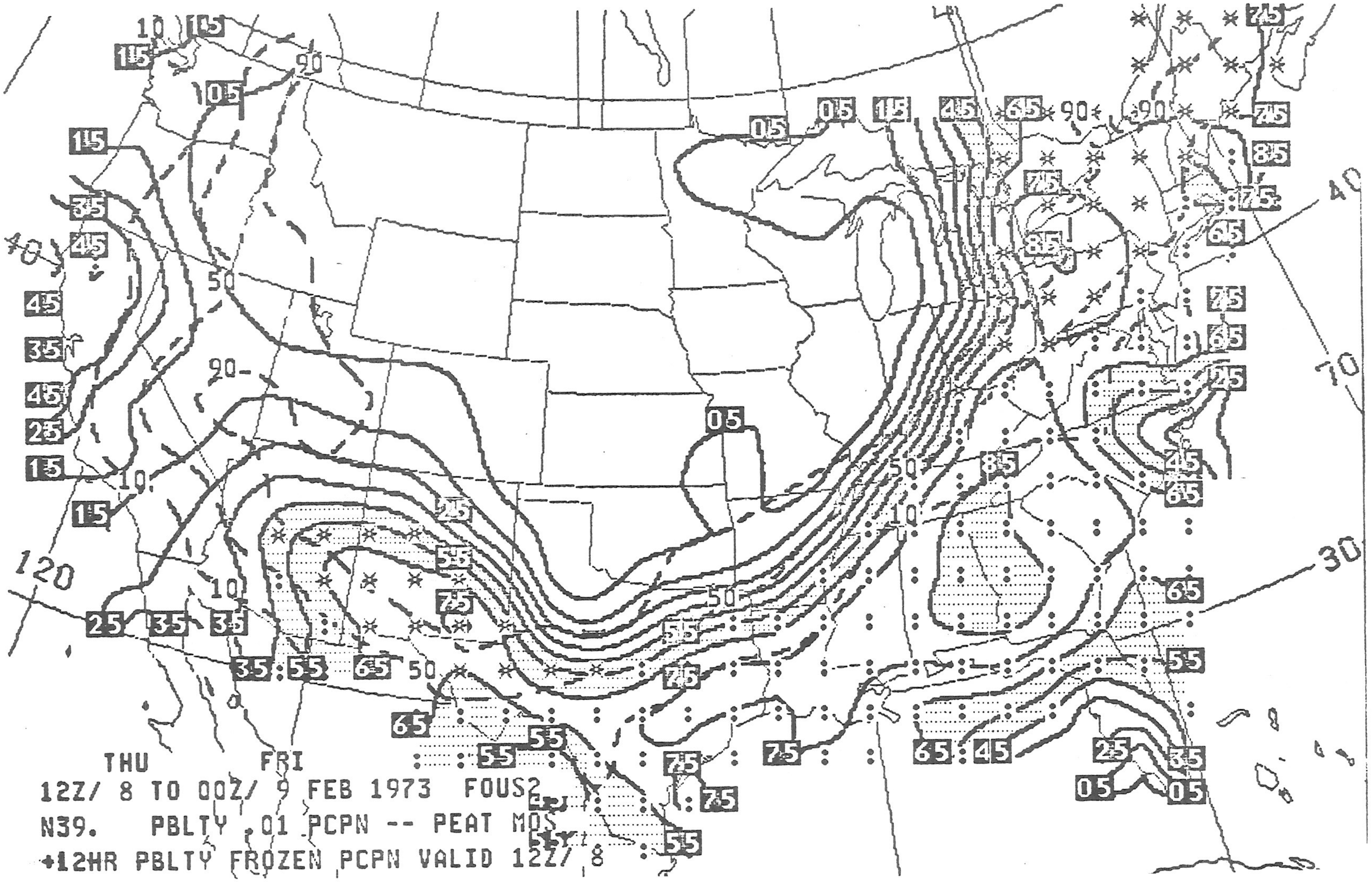
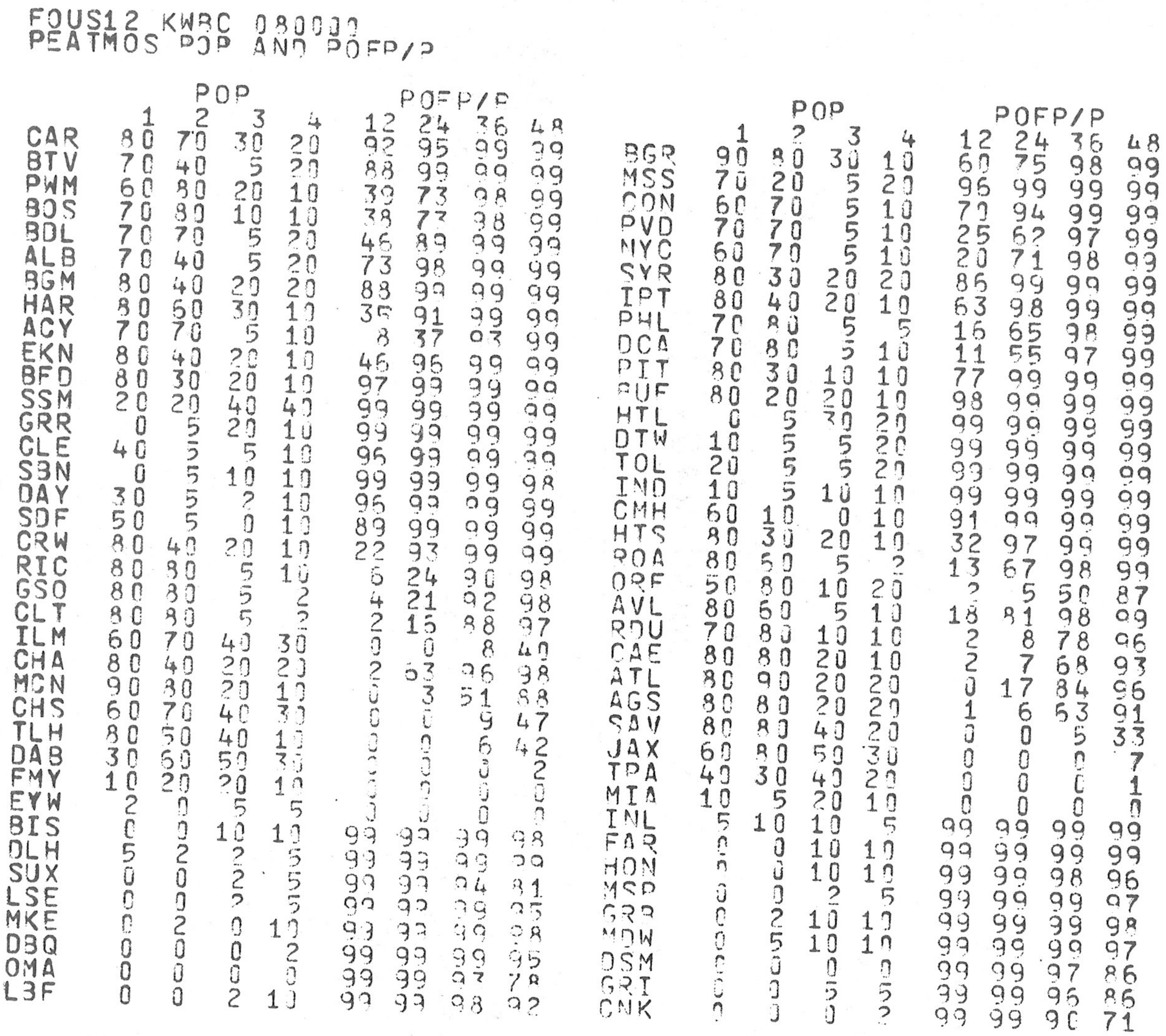


Figure 9.--An example of a panel from an operational facsimile chart showing PoP and PoFP(P) forecasts made from the 0000 GMT February 8, 1973 PE run. The PoP forecasts, shown as solid lines at 10-percent intervals, are valid for the period 1200 GMT February 8 to 0000 GMT February 9. The PoFP(P) forecasts shown as dashed lines for values of 10, 50, and 90 percent, are valid at 1200 GMT February 8. The areas defined by PoP isopleths 45 to 65 percent and greater than 85 percent are shaded. Areas where snow or rain may be expected are indicated by asterisks or dots respectively.



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FOUS12 KWBC 080000
PEATMOS POP AND POFP/P

                 POP                    POFP/P
          1    2    3    4        12   24   36   48
CAR      80   70   30   20        92   95   99   99
BTV      70   40    5   20        88   99   99   99
PWM      60   80   20   10        39   73   98   99
BOS      70   80   10   10        38   73   98   99
BDL      70   70    5   20        46   89   99   99
ALB      70   40    5   20        73   98   99   99
BGM      80   40   20   20        88   99   99   99
HAR      80   50   30   10        35   91   99   99
ACY      70   70    5   10         8   37   93   99
EKN      80   40   20   10        46   96   99   99
BFD      80   30   20   10        97   99   99   99
SSM      20   20   40   40        99   99   99   99
GRR       0    5   20   10        99   99   99   99
CLE      40    5    5   10        95   99   99   99
SBN       0    5   10   10        99   99   99   98
DAY      30    5    2   10        95   99   99   99
SDF      50    5    0   10        89   99   99   99
CRW      80   40   20   10        22   93   99   99
RIC      80   80    5   10         6   24   90   98
GSO      80   80    5    2         4   21   92   98
CLT      80   80    5    2         2   15   88   97
ILM      60   70   40   30         0    0    8   40
CHA      80   40   20   20         2   63   96   98
MCN      90   80   20   10         0    3   51   88
CHS      60   70   40   30         0    0    9   47
TLH      80   50   40   10         0    0    6   42
DAB      30   60   50   30         0    0    0    2
FMY      10   20   20   10         0    0    0    0
EYW       2    0    5    5         0    0    0    0
BIS       0    0   10   10        99   99   99   98
DLH       5    2    2    5        99   99   99   99
SUX       0    0    2    5        99   99   94   81
LSE       0    0    2    5        99   99   99   95
MKE       0    2    0   10        99   99   99   98
DBQ       0    0    0    2        99   99   99   95
OMA       0    0    0    0        99   99   93   78
LBF       0    0    2   10        99   99   98   92
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                 POP                    POFP/P
          1    2    3    4        12   24   36   48
BGR      90   80   30   10        60   75   98   99
MSS      70   20    5   20        96   99   99   99
CON      60   70    5   10        70   94   99   99
PVD      70   70    5   10        25   62   97   99
NYC      60   70    5   10        20   71   98   99
SYR      80   30   20   20        85   99   99   99
IPT      80   40   20   10        63   98   99   99
PHL      70   80    5    5        16   65   98   99
DCA      70   80    5   10        11   55   97   99
PIT      80   30   10   10        77   99   99   99
BUF      80   20   20   10        98   99   99   99
HTL       0    5   30   20        99   99   99   99
DTW      10    5    5   20        99   99   99   99
TOL      20    5    5   20        99   99   99   99
IND      10    5   10   10        99   99   99   99
CMH      60   10    0   10        91   99   99   99
HTS      80   30   20   10        32   97   99   99
ROA      80   50    5    2        13   67   98   99
ORF      50   80   10   20         2    5   50   87
AVL      80   50    5   10        18   81   98   99
RDU      70   80   10   10         2    8   78   96
CAE      80   80   20   10         2    7   68   93
ATL      80   90   20   20         0   17   84   96
AGS      80   80   20   20         1    6   53   91
SAV      80   80   40   20         0    0    5   33
JAX      60   80   50   30         0    0    0    7
TPA      40   30   40   20         0    0    0    1
MIA      10    5   20   10         0    0    0    0
INL       5   10   10    5        99   99   99   99
FAR       0    0   10   10        99   99   99   99
HON       0    0   10   10        99   99   98   96
MSP       0    0    2    5        99   99   99   97
GRB       0    2   10   10        99   99   99   98
MDW       0    5   10   10        99   99   99   97
DSM       0    0    0    0        99   99   97   86
GRI       0    0    5    5        99   99   96   86
CNK       0    0    0    2        99   99   90   71
```

Figure 10.--A portion of the operational teletype bulletin transmitted over Service C showing specific values of PoP and PoFP(P) for the PE run time of 0000 GMT February 8, 1973. The PoP forecasts are valid for four 12-hour periods beginning at 12, 24, 36, and 48 hours after PE run time. The PoFP(P) forecasts are valid at the specific times 12, 24, 36, and 48 hours after PE run time. PoFP(P) values of 99 indicate either 99 or 100 percent.

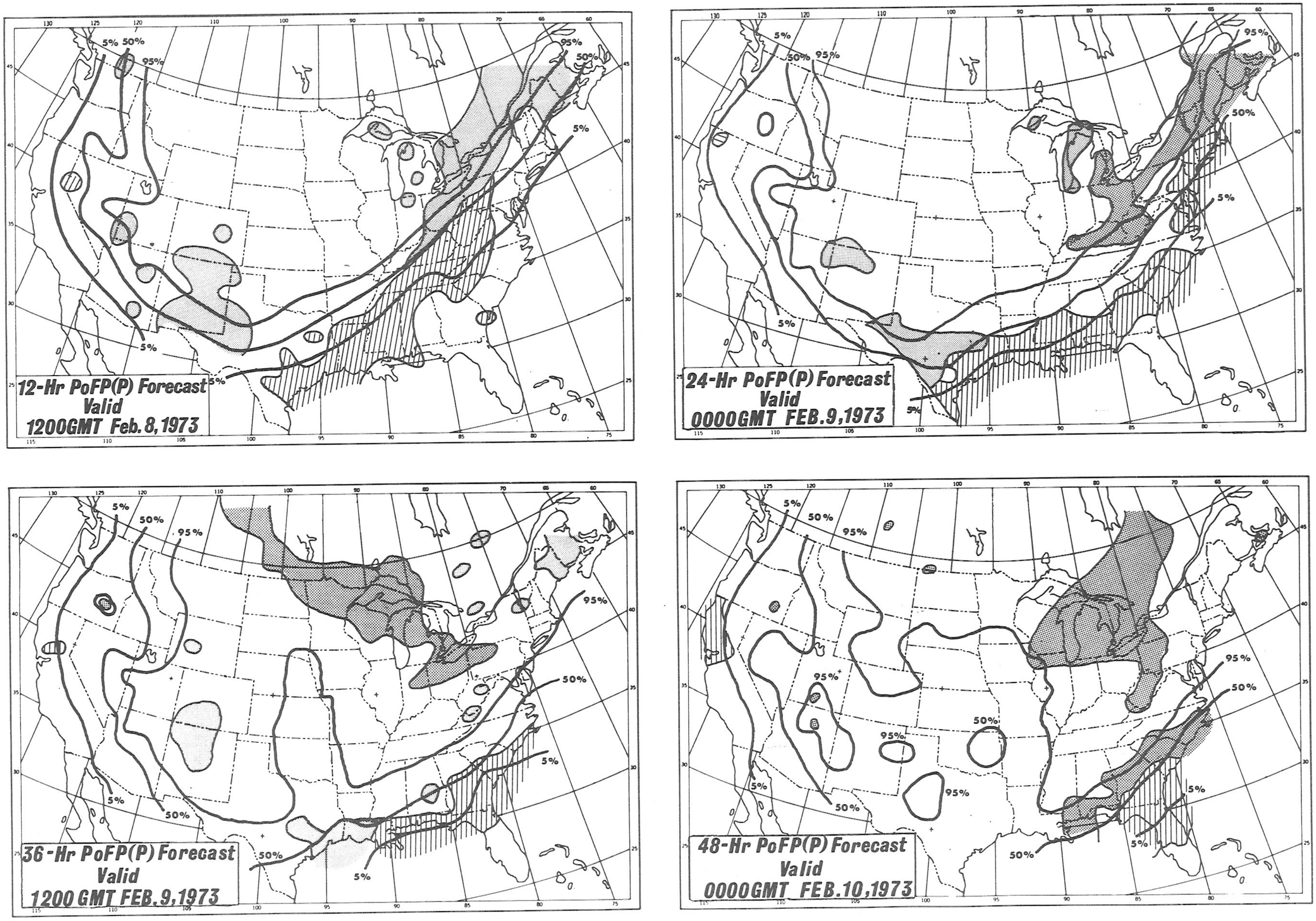

Figure 11.--PoFP(P) forecasts made from the 0000 GMT PE run of February 8, 1973, valid at (a) 12-, (b) 24-, (c) 36-, and (d) 48-hour projections. Probability lines of 5-, 50-, and 95-percent are shown. The occurrence of snow and rain at the valid time is indicated by stippling and vertical line shading respectively.

In the case depicted in Fig. 11, considerable change in temperature occurred over the eastern U.S., and an unusually large amount of snow fell in Georgia and North Carolina. This figure shows: (1) no rain occurred in areas where the conditional probability of rain was 5 percent or less, (2) no snow occurred in areas where the conditional probability of snow was 5 percent or less, and (3) the actual rain-snow line was usually rather close to the 50-percent probability line.

SUMMARY AND CONCLUSIONS

The system we have developed for forecasting the conditional probability of frozen precipitation shows much promise of furnishing substantial guidance to local forecasters. It is an extension of the successful work of Wagner (1957) in four ways: (1) several predictors were used rather than only 1000-500 mb thickness; (2) 186 stations were used instead of 40; (3) forecasts from the PE model valid at or near the time of the desired forecast were used instead of observations, and (4) three years of data were used rather than two.

We believe this is the first significant use of the logit model in meteorology; with very few exceptions, it performed well.

We performed a comparative verification on independent data between the MOS PoFP(P) operational product and subjective forecasts produced by the Basic Weather Forecast Branch at NMC. The verification scores used were the percent correct, bias, Heidke skill score, and threat score. The results indicated that the objective system produced significantly better forecasts than those prepared subjectively. It should be emphasized that NMC did not have the objective forecasts to use as guidance.

Accuracy of objective PoFP(P) forecasts can be improved in several ways, including the following, listed in order of importance: (1) improved forecasts of temperature and thickness from numerical models; (2) development of unique prediction equations for a number of "homogeneous" areas of the U.S., rather than development of only one equation for the whole area; and (3) determination of better 50-percent values through use of a larger data sample.

The usefulness of the guidance forecasts will be enhanced when we can deal with additional categories, such as "freezing precipitation" and "sleet." A possible category of "mixed rain and snow" is of doubtful importance, since a probability of snow near 50 percent is in itself a tipoff to possible rain and snow mixed. Categories of precipitation type other than those used in this study may have to be dealt with differently, since a simple logit curve may not be adequate to fit the data.

ACKNOWLEDGMENTS

We wish to thank the many members of the Techniques Development Laboratory who contributed to the development of the PoFP(P) forecasting system and this paper in various ways, including careful error-checking of the basic data, computer programming, drafting, typing, and general technical support. We are indeed indebted to Professor Richard Jones of the University of Hawaii for providing us with a copy of his logit computer program. Capt. Frank Globokar (USAF) assisted in a portion of the work; the system was made operational by Mr. Frank Lewis.

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Appendix A

This appendix contains 50-percent values of 1000-500 mb thickness, 850-mb temperature, and B.L. temperature. The values for stations for which 50-percent values could not be determined statistically are in parentheses.

Station Name	1000-500 Mb Thickness (M) (leading 5 omitted)	850-Mb Temperature (°C x 10)	B.L. Temperature (°C x 10)
ABERDEEN. S DAK	422	0	92
ABILENE, TEX	433	10	45
AKRON-CANTON, OHIO	388	-15	51
ALBANY. NY	405	-5	71
ALBUQUERQUE. N MEX	471	61	233
ALLENTOWN. PA	395	-6	60
ALPENA, MICH.	387	-19	38
AMARILLO. TEX	475	41	152
ARCATA. CALIF	(180)	(-67)	(33)
ASHEVILLE, NC	432	15	91
ASTORIA, OREG	146	-79	22
ATHENS, GA	378	-2	44
ATLANTA, GA	(390)	(-20)	(30)
ATLANTIC CITY. NJ	354	-22	51
AUGUSTA, GA.	(350)	(-28)	(30)
AUSTIN. TEX	(390)	(-20)	(-15)
BAKERSFIELD, CALIF	(180)	(-60)	(40)
BALTIMORE, MD.	334	-24	45
BANGOR. ME	386	-15	57
BATON ROUGE, LA	(370)	(-30)	(-15)
BECKLEY, W VA	419	2	79
BILLINGS. MONT	437	33	164
BINGHAMTON. NY	419	0	83
BIRMINGHAM. ALA	393	0	19
BISMARCK. N DAK	427	8	114
BOISE, IDAHO	360	-7	140
BOOTHVILLE. LA	(360)	(-35)	(-15)
BOSTON. MASS	382	-15	65
BRADFORD. PA	415	0	79
BRIDGEPORT. CONN	384	-10	54
BRISTOL, TENN	383	-9	65
BROWNSVILLE. TEX	(360)	(-35)	(-15)
BRYCE CANYON, UTAH	563	133	271
BUFFALO. NY	384	-17	53
BURLINGTON. IOWA	393	-13	36
BURLINGTON. VT	398	-11	69
BURNS. OREG	417	24	167
CAPE HATTERAS, NC	223	-70	40

Station Name	1000-500 Mb Thickness (leading 5 omitted)	850-MB Temperature (°C x 10)	B.L. Temperature (°C x 10)
CARIBOU. ME	399	-11	60
CASPER. WYO	499	76	228
CEDAR CITY. UTAH	477	79	222
CHARLESTON. SC	(343)	(-40)	(30)
CHARLESTON. W VA	373	-20	49
CHARLOTTE. NC	383	-4	60
CHATTANOOGA. TENN	363	-15	30
CHEYENNE. WYO	533	101	261
CHICAGO MIDWAY, ILL	393	-13	39
CHICAGO. ILL	378	-19	30
CINCINNATI. OHIO	382	-17	33
CLEVELAND. OHIO	368	-25	37
COLORADO SPGS. COLO	525	93	254
COLUMBIA. MO.	403	-6	35
COLUMBIA. SC	349	-20	40
COLUMBUS. OHIO	378	-19	40
CONCORDIA, KANS	436	1	77
CONCORD, NH	413	-1	80
CORPUS CHRISTI, TEX	(360)	(-35)	(-15)
DAGGETT, CALIF	(340)	(0)	(80)
DALLAS. TEX	(360)	(-16)	(-15)
DAYTONA BEACH. FLA	(300)	(-60)	(0)
DAYTON. OHIO	387	-16	37
DEL RIO, TEX	(390)	(-9)	(-15)
DENVER. COLO	508	83	250
DES MOINES. IOWA	405	-8	44
DETROIT, MICH	381	-16	37
DODGE CITY, KANS	456	19	122
DUBUQUE. IOWA	405	-8	40
DULUTH. MINN	403	-9	63
EAU CLAIRE. WIS	384	-18	45
ELKINS. W VA	417	1	77
ELY. NEV	505	89	232
EL PASO, TEX	470	49	200
ERIE. PA	370	-23	48
EUGENE. OREG	189	-64	52
EVANSVILLE, IND	400	-8	24
FARGO. N DAK	393	-16	67
FARMINGTON. N MEX	496	92	255
FLAGSTAFF. ARIZ	547	119	261
FLINT. MICH	385	-15	39
FORT MYERS. FLA	(160)	(-70)	(0)
FORT SMITH. ARK	366	-22	-15
FORT WAYNE. IND	399	-8	46
FORT WORTH. TEX	352	-14	-18
FRESNO. CALIF	(180)	(-60)	(40)
GLASGOW. MONT	404	13	135
GOODLAND. KANS	488	47	181
GRAND ISLAND. NEBR	436	2	89

Station Name	1000-500 Mb Thickness (leading 5 omitted)	850-Mb Temperature (°C x 10)	B.L. Temperature (°C x 10)
GRAND JUNCTION, COLO	450	54	230
GRAND RAPIDS. MICH	379	-17	38
GREAT FALLS. MONT	447	42	184
GREENSBORO. NC	393	-4	61
GREENVILLE. SC	403	2	62
GREEN BAY. WIS	385	-17	39
HARRISBURG. PA	381	-11	56
HARTFORD. CONN	412	0	73
HAVRE. MONT	397	9	141
HELENA. MONT	437	40	185
HOUGHTON LAKE. MICH	399	-11	48
HOUSTON, TEX	(360)	(-30)	(-15)
HUNTINGTON, W VA	380	-17	49
HUNTSVILLE. ALA	376	-10	16
HURON. S DAK	431	4	95
INDIANAPOLIS. IND	390	-13	40
INTL FALLS, MINN	396	-14	65
JACKSONVILLE. FLA	(320)	(-50)	(15)
JACKSON, MISS	(385)	(-19)	(-15)
KALISPELL. MONT	402	12	158
KANSAS CITY, MO.	385	-14	34
KEY WEST, FLA	(160)	(-80)	(0)
KNOXVILLE. TENN	374	-16	46
LACROSSE, WIS	376	-21	35
LAKE CHARLES. LA	(360)	(-30)	(-15)
LANDER. WYO	509	73	234
LANSING, MICH	388	-13	41
LAS VEGAS, NEV	(350)	(10)	(100)
LEXINGTON. KY	380	-17	33
LITTLE ROCK. ARK	385	-10	-7
LONG BEACH. CALIF	(180)	(-67)	(40)
LOS ANGELES. CALIF.	(180)	(-67)	(40)
LOUISVILLE. KY	391	-13	31
LOVELOCK. NEV	402	21	177
LUBBOCK. TEX	455	18	113
LUFKIN. TEX	(390)	(-25)	(-15)
LYNCHBURG, VA	412	4	63
MACON. GA	(365)	(-25)	(30)
MADISON, WIS	388	-15	38
MASON CITY. IOWA	391	-13	44
MASSENA, NY	384	-20	48
MEDFORD. OREG	212	-49	71
MEMPHIS. TENN	375	-19	-15
MERIDIAN, MISS	(385)	(-11)	(15)
MIAMI. FLA	(180)	(-70)	(0)
MIDLAND, TEX	454	10	85
MILWAUKEE, WIS	394	-11	38
MINNEAPOLIS. MINN	392	-14	54
MINOT. N DAK	411	-1	100

Station Name	1000-500 Mb Thickness (leading 5 omitted)	850-Mb Temperature (°C x 10)	B.L. Temperature (°C x 10)
MISSOULA, MONT	398	15	164
MOBILE, ALA	(370)	(-30)	(-15)
MOLINE, ILL	388	-16	31
MONTGOMERY, ALA	(385)	(-25)	(18)
MUSKEGON, MICH	388	-15	38
NANTUCKET, MASS	188	-70	44
NASHVILLE, TENN	365	-18	12
NEWARK, NJ	383	-12	56
NEW ORLEANS, LA	(360)	(-35)	(-15)
NEW YORK, NY	350	-24	43
NEW YORK, NY	375	-15	53
NORFOLK, VA	319	-35	53
NORTH BEND, OREG	172	-81	37
NORTH PLATTE, NEBR	465	25	140
OAKLAND, CALIF	(180)	(-67)	(40)
OKLAHOMA CITY, OKLA	410	0	50
OLYMPIA, WASH	195	-60	48
OMAHA, NEBR	419	-3	59
ORLANDO, FLA	(280)	(-60)	(0)
PENDLETON, OREG	326	-17	100
PEORIA, ILL	393	-11	36
PHILADELPHIA, PA	355	-20	49
PHOENIX, ARIZ	(340)	(-10)	(80)
PIERRE, S DAK	434	11	113
PITTSBURGH, PA	385	-15	55
POCATELLO, IDAHO	434	36	204
PORTLAND, ME	389	-13	66
PORTLAND, OREG	175	-72	40
PROVIDENCE, RI	389	-12	60
PUEBLO, COLO	495	70	227
QUILLAYUTE, WASH	182	-66	47
RALEIGH-DURHAM, NC	379	-10	62
RAPID CITY, S DAK	442	27	147
REDMOND, OREG	369	0	134
RED BLUFF, CALIF	181	-63	63
RENO, NEV	407	22	183
RICHMOND, VA	369	-9	61
ROANOKE, VA	413	5	72
ROCHESTER, MINN	378	-19	41
ROCHESTER, NY	384	-18	54
ROCKFORD, ILL	397	-11	40
ROCK SPRINGS, WYO	551	119	282
RUSSELL, KANS	439	7	100
SACRAMENTO, CALIF	(180)	(-60)	(40)
SALEM, OREG	181	-68	44
SALT LAKE CITY, UTAH	432	38	206
SANTA MARIA, CALIF	(180)	(-67)	(40)
SAN ANGELO, TEX	(417)	(-8)	(0)
SAN ANTONIO, TEX	(390)	(-20)	(-15)

Station Name	1000-500 Mb Thickness (leading 5 omitted)	850-Mb Temperature (°C x 10)	B.L. Temperature (°C x 10)
SAN DIEGO, CALIF	(180)	(-67)	(40)
SAN FRANCISCO, CALIF	(180)	(-67)	(40)
SAULT ST MARIE, MICH	390	-16	46
SAVANNAH, GA	(340)	(-40)	(25)
SCOTTSBLUFF, NEBR	481	45	189
SEATTLE-TACOMA, WASH	175	-69	49
SHERIDAN, WYO	444	44	177
SHREVEPORT, LA	373	-16	-14
SIOUX CITY, IOWA	400	-12	57
SIOUX FALLS, S DAK	411	-6	69
SOUTH BEND, IND	392	-10	43
SPOKANE, WASH	361	-4	133
SPRINGFIELD, ILL	379	-18	24
SPRINGFIELD, MO	412	0	38
STOCKTON, CALIF	(180)	(-60)	(40)
ST JOSEPH, MO	417	-2	56
ST LOUIS, MO	390	-11	26
SYRACUSE, NY	377	-21	55
TALLAHASSEE, FLA	(370)	(-30)	(0)
TAMPA, FLA	(200)	(-70)	(0)
TOLEDO, OHIO	379	-18	35
TONOPAH, NEV	480	70	224
TOPEKA, KANS	397	-10	47
TRAVERSE CITY, MICH	373	-23	36
TRUTH OR CONS, N MEX	475	49	216
TUCSON, ARIZ	363	24	159
TUCUMCARI, N MEX	489	52	192
TULSA, OKLA	385	-12	29
VICTORIA, TEX	(370)	(-30)	(-15)
WACO, TEX	(395)	(-16)	(-15)
WALLOPS ISLAND, VA	326	-33	42
WASHINGTON, DC	356	-13	50
WASH-DULLES, VA	369	-9	53
WATERLOO, IOWA	393	-14	38
WB SCRANTON, PA	411	-2	76
WENDOVER, UTAH	433	33	193
WEST PALM BEACH, FLA	(200)	(-70)	(0)
WICHITA FALLS, TEX	399	-10	28
WICHITA, KANS	410	-5	59
WILLIAMSPORT, PA	395	-10	62
WILLISTON, N DAK	407	0	111
WILMINGTON, DEL	353	-23	43
WILMINGTON, NC	341	-29	41
WINNEMUCCA, NEV	419	26	181
WINSLOW, ARIZ	472	76	222
YAKIMA, WASH	361	-4	115
YOUNGSTOWN, OHIO	393	-12	57
YUMA, ARIZ	(315)	(-10)	(45)
ZUNI, N MEX	538	126	274

Appendix B

The verification scores used in this report are defined below:

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

$$P = \frac{1}{N} \sum_{j=1}^{r} \sum_{i=1}^{N} (f_{ij} - Z_{ij})^2 , \qquad \text{(B1)}$$

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,

$$\sum_{j=1}^{r} f_{ij} = 1 \qquad \text{(B2)}$$

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 B1.

Table B1.--A typical two-category contingency table

		Forecast Category		
		1	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

$$PC = \frac{R}{I} \times 100, \qquad \text{(B3)}$$

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

$$R = A + E. \qquad \text{(B4)}$$

The Heidke skill score (SS) is computed by

$$SS = \frac{R - J}{I - J}, \qquad \text{(B5)}$$

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

$$J = \frac{CG + FH}{I}. \qquad \text{(B6)}$$

The bias (BIAS) for each category is computed by

$$BIAS\ (1) = \frac{G}{C}, \qquad BIAS\ (2) = \frac{H}{F}. \qquad \text{(B7)}$$

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

$$TS\ (1) = \frac{A}{G + C - A}, \quad TS\ (2) = \frac{E}{H + F - E}. \qquad \text{(B8)}$$

(Continued from inside front cover)

WBTM TDL 25 Charts Giving Station Precipitation in the Plateau States From 850- and 500-Millibar Lows During Winter. August F. Korte, Donald L. Jorgensen, and William H. Klein, September 1969. (PB-187-476)

WBTM TDL 26 Computer Forecasts of Maximum and Minimum Surface Temperatures. William H. Klein, Frank Lewis, and George P. Casely, October 1969. (PB-189-105)

WBTM TDL 27 An Operational Method for Objectively Forecasting Probability of Precipitation. Harry R. Glahn and Dale A. Lowry, October 1969. (PB-188-660)

WBTM TDL 28 Techniques for Forecasting Low Water Occurrences at Baltimore and Norfolk. James M. McClelland, March 1970. (PB-191-744)

WBTM TDL 29 A Method for Predicting Surface Winds. Harry R. Glahn, March 1970. (PB-191-745)

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WBTM TDL 31 Persistence of Precipitation at 108 Cities in the Conterminous United States. Donald L. Jorgensen and William H. Klein, May 1970. (PB-193-599)

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