NOAA Technical Memorandum NWS ER-61

IMPROVING SHORT-RANGE PRECIPITATION GUIDANCE DURING THE SUMMER MONTHS

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Silver Spring, Md.
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DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary /

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator /

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EDITOR'S NOTE

LFM (limited area fine mesh model) parameters are now used as predictors in the probability of precipitation forecasts, referred to as PEATMOS POP in this study. The effect of this change on the results presented here is unknown. It is recommended that the results of this study be used in a qualitative, rather than quantitative, sense.

ABSTRACT

An objective technique has been developed for modifying 12- to 24-hour precipitation guidance forecasts from the NMC primitive equation model by using manually digitized radar and the Limited Fine Mesh Model 12- to 24-hour precipitation. Developmental data were from two stations in the eastern United States for the summer season. Constructed radar variables were entered into a stepwise multiple regression program with the PE precipitation probabilities and the LFM precipitation forecast. The resulting equation yielded a 15-35% improvement in the Brier score over the PE. In comparison, subjective improvement by Eastern Region forecast offices of the National Weather Service over the PE guidance amounts to 10-15%.

INTRODUCTION

Forecasts of the probability of precipitation are prepared by computer at the National Meteorological Center and transmitted by teletype for use of the field forecaster. The time required for the collection of initial data and the preparation of the forecasts results in a delay of some 7.5 hours. During this delay period, other information becomes available to the forecaster which should offer some assistance in improving upon transmitted probability forecasts. This includes radar coverage information available by teletype and facsimile and the quantitative precipitation forecasts prepared with the limited area fine mesh model (Cooley, 1971).

This study has been directed at obtaining an objective procedure of modifying the precipitation probability forecast. It has been restricted to the summer months, in the time period between 12 and 24 hours following the observation hour, and to two stations in the northeastern United States. Furthermore, it deals only with the probability of measurable precipitation, i.e., at least .01 inch.

These computer produced forecasts are called primitive equation (PE) and trajectory model probability of precipitation forecasts (PEATMOS POP) and have been routinely available since 1972 (Glahn & Lowry, 1972). These PEATMOS POP forecasts were developed by statistically relating the occurrence of measurable precipitation to variables predicted by the PE and trajectory models. A stepwise multiple regression program screened many model output variables to obtain the twelve best predictors for inclusion into the statistical model. Most of these predictor variables are forecast vertical motion, moisture and stability parameters (Cooley, 1974). Because different equations are developed for different areas of the United States and for different seasons, the PEATMOS POP has little bias. However, no radar or LFM information is included in the transmitted PEATMOS POP.

Moore and Smith (1972) incorporated manually digitized radar information (MDR) with the PEATMOS POP for three southern stations during the winter season for short-range forecast improvement. Manually digitized radar is a scheme of providing data for the eastern two-thirds of the United States for 40 n mi grid squares. Information on intensity and coverage by echoes is encoded for each square. The latest coding scheme and the MDR data grid are given in Moore, Cummings, and Smith (1974). Areal coverage and the presence or absence of radar echoes in MDR squares 0-250 n mi west of the verifying point were the most useful variables. In this paper, areal coverage represents the ratio of MDR squares with echoes to all MDR squares, examined. When these were combined in a regression routine with the PEATMOS POP, they resulted in a 10-15% improvement in forecasting skill over PEATMOS POP alone. Independent verification of this improvement during the following winter at Atlanta, Georgia, proved successful (Peters & Barnes, 1973).

During 1971, the LFM model became available for forecast use. The LFM is essentially a PE model with a grid size one-half of the PE's and a much improved moisture initialization procedure. Because of this, forecast precipitation from this model might improve the accuracy of the PEATMOS POP. Ronco (1972, 1973) used the LFM quantitative precipitation forecast (12-24 hours after initial time) and the PEATMOS POP to obtain an improved probability forecast. His studies focused on a number of stations in New Hampshire and Maine for both winter and summer. A similar study for five other stations in the Eastern Region (National Weather Service, 1974) showed its applicability through most of the East during the summer months.

The temporal relationship of these techniques is illustrated in Figure 1. The data input time for the PE model is at 0000 GMT, but the PEATMOS POP is not received until 0730 GMT. Radar data made available at this time and LFM information from the 0000 GMT run are combined with the PEATMOS POP to obtain an updated probability (POPUP) before the public forecast release time. This POPUP is valid for the verifying period 12-00 GMT. An analogous procedure is followed at 1930 GMT for the 1200 GMT PE and LFM runs.

The question posed by this study is: Can MDR variables and LFM forecast precipitation be used to similarly update the PEATMOS POP for stations in the northeastern United States during the summer? Also, more specifically, will the improvement due to the LFM cancel or mask any possible improvement due to radar? An attempt will be made to answer these questions through a multiple stepwise regression procedure, the subject of the next section.

Figure 1. Temporal Relationship of the Predictors.

Stepwise Multiple Regression Procedure

Multiple regression is a procedure directed at fitting the best possible plane to data in n-dimensional space, where n is the total number of variables. The best plane is defined to be the plane that has the least sum of squared vertical deviations of the data from the plane. Our tentatively entertained regression model in such a situation is

$$Y = B_0 + B_1X_1 + B_2X_2 + \ldots + E \qquad (1)$$

where Y is our dependent variable, $X_1, X_2 \ldots X_{n-1}$ are the independent variables or predictors, and E is residual error. In our case Y is a 0-1 variable, zero for no rain and one for rain.

In a multivariate regression, one is always faced with the problem of which predictors should be included in the analysis. Forward stepwise multiple regression is one way of handling the order of inclusion of predictors into the analysis. The first predictor included in our regression is the X variable that has the highest correlation coefficient with Y (let's call this variable X_1). By definition, this will be the relationship that gives the highest possible reduction of variance (R^2). To test the statistical significance of this relationship between X_1 and Y an F-test is performed. If it is significant, the slope and intercept of this line of best fit is also calculated.

To obtain the next predictor for inclusion into our equation, partial correlation coefficients are computed between Y and X_2 through X_{n-1}. The predictor with the highest partial correlation is included next and the total reduction of variance is computed. This time a partial F-value is constructed to determine the significance of the added term along with a total F to test the entire regression significance. This procedure of adding variables continues until:

1. The partial F-test on the new variable fails to be significant (α=.01), or
2. The additional reduction of variance (ΔR^2) as the result of adding a new variable is less than 0.5%. Thus it is unlikely that all of the X variables would be included in our model.

This procedure was obtained by reference to standard texts on multiple regression such as Draper and Smith (1966) and Iversen (1971).

Basic regression approaches described above assure that the residuals are normally distributed. Here, however, our dependent variable is a 0-1 variable which introduces some complications. If all the X variables have extreme values, it is likely that our forecast Y will be outside of the range (0,1), thus making no physical sense. Fortunately, the occurrence of this effect in probability regressions is slight. If 1.14 or -0.03 is the forecast Y, the practical way of dealing with it is to make the forecast values 100% and 0%, respectively.

A more serious problem is illustrated next. Suppose that for low values of X_1 (say PEATMOS POP), there is a large effect of X_2 (say a radar variable) on Y. With high values of X_1, the effect of X_2 on Y is slight. Yet, a multiple linear regression model with a 0-1 variable Y variable would have to add the same effect of X_2 for all values of X_1. One way of including this effect is by inclusion of an interaction or cross product term $(X_1 * X_2)$. This effect turns out to be significant in some of the following regressions.

Another serious difficulty of not having the residuals normally distributed is that our partial F-tests become inexact. Hence, these are included as merely descriptive statistics and no inferences on statistical significance can be drawn.

A dependent 0-1 variable also raises the question of the appropriateness of correlation coefficients in such a situation. The accuracy of our correlation coefficients is essential to multiple regression since it determines which variables are selected at each step. (Editor's Note: Additional statistical analysis in the author's original thesis has been removed from this Technical Memorandum edition to make it more appropriate for the operationally oriented reader.)

<u>Selection of Radar Variables</u>

Data for only two summers (1973 and 1974) were available since the manually digitized radar program started in the spring of 1973. Also, since none of the LFM or radar variables were recorded in any form convenient for computer processing, tedious manual extraction of the data was necessary. Therefore, efforts were concentrated in a pilot study on two northeastern stations, Williamsport, Pa. (IPT) and Huntington, W.Va. (HTS), which had good upwind radar coverage.

MDR values were first tabulated for grid squares near both stations for the 0730 and 1930 GMT radar observations for the period 1 June to 30 September 1973. These are the times of the latest radar observations prior to public forecast release times. The time period was held to these three mid-summer months in order to limit our data to precipitation mainly from convective sources. The 1974 data were not used initially in order to provide a data set for independent verification of the 1973 results.

In order to select good predictive radar variables, it was necessary to determine which MDR squares have the highest association with precipitation at the verifying point (IPT or HTS) during the ensuing 12-hour period. One approach to this problem is the following: Given an echo in the indicated square, what percentage of time does precipitation verify at the individual station during the verifying period? This statistic is shown for both stations in Figure 2 using the 0730 GMT radar report. Figure 3 shows the same statistic for the 1930 GMT radar report. Radar data for the selected influence area of IPT was provided by Buffalo, N.Y., and Pittsburgh, Pa., radars and those for HTS by Cincinnati, Ohio, Evansville, Indiana, and Marseille, Illinois, radars.

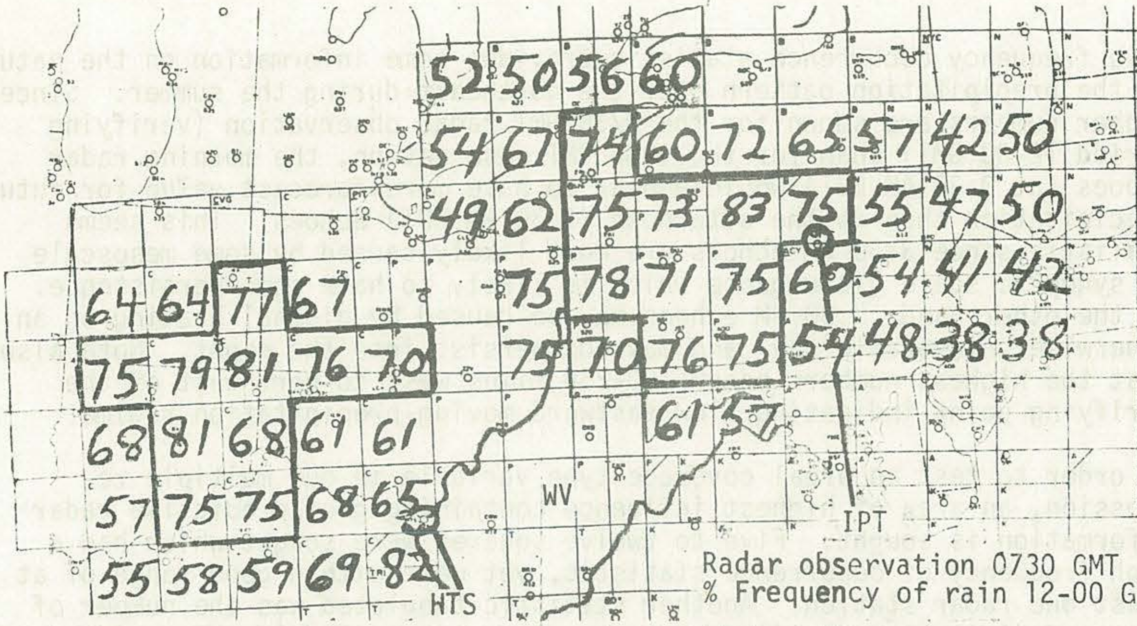


Figure 2. % Frequency of at least 0.01" of rain in 12 hrs (12-00 GMT) at Huntington, WV (HTS) and Williamsport, PA (IPT) given a 0730 GMT echo in the indicated square.

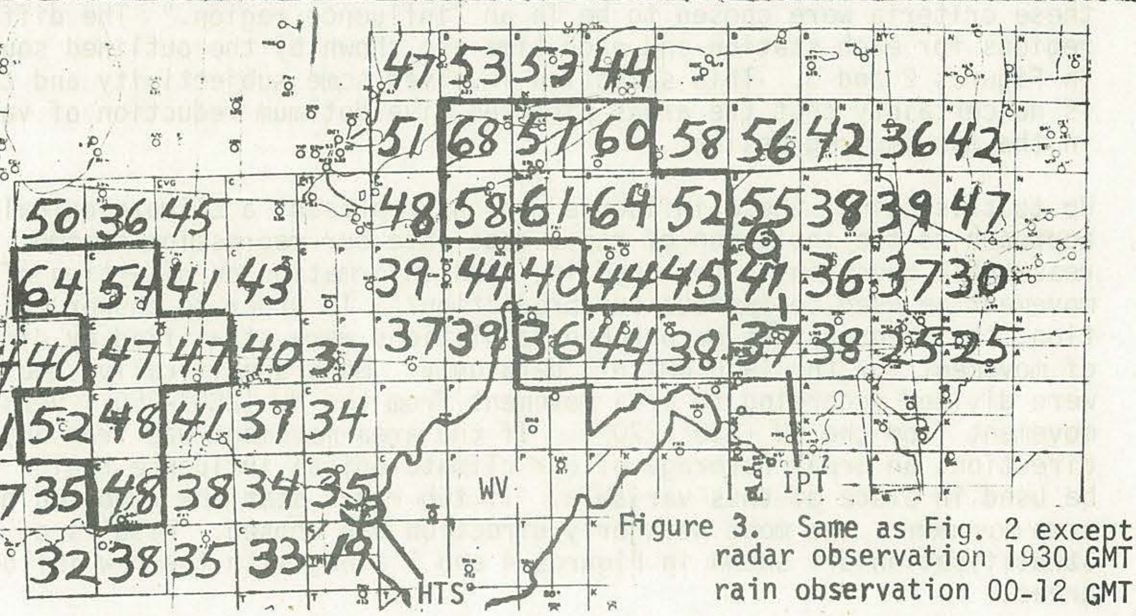
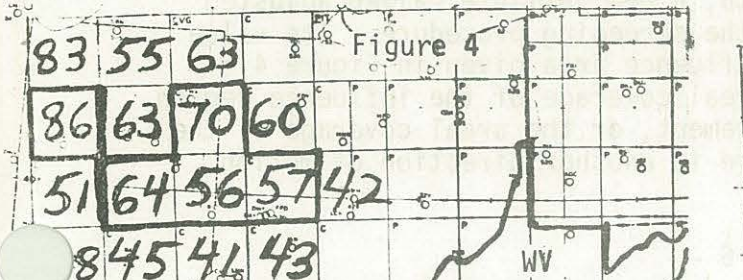


Figure 3. Same as Fig. 2 except radar observation 1930 GMT rain observation 00-12 GMT



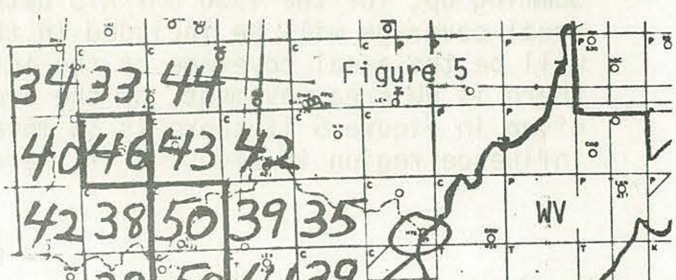


Figure 4 (left) and Figure 5 (right). Same as Figure 3 for HTS except 1930 GMT echo movement is from between 280°-360° (Figure 4), or 230°-270° (Figure 5).

This frequency occurrence statistic provides some information on the nature of the precipitation pattern over the northeast during the summer. Since higher numbers are shown for the 0730 GMT radar observation (verifying period 12-00 GMT) than for the 1930 GMT observation, the morning radar echoes (at 3:30 AM EDT) would appear to have more forecast value for future precipitation than do the afternoon (3:30 PM EDT) echoes. This seems realistic since 3:30 AM echoes are most likely caused by some mesoscale or synoptic scale disturbance which is likely to have some persistence. On the other hand, 3:30 PM echoes may be caused by diurnal heating on an otherwise unfavorable day, and may not persist into the night. Note also that the highest numbers occur 100-250 miles west to northwest of the verifying point indicating slow eastward moving precipitation regime.

In order to test an areal coverage type variable in our multiple regression, an area of highest influence containing good predictive radar information is sought. Five to twelve squares were sought which had a high frequency of occurrence statistic, yet were within good range of at least one radar station. Another statistic tabulated was the number of times precipitation verified, yet no echo was reported in this grid square. Lower values of this statistic revealed squares which have a higher degree of association with ensuing precipitation. Squares that met all three of these criteria were chosen to be in an "influence region." The different regions for each station and each time are shown by the outlined squares in Figures 2 and 3. This selection involved some subjectivity and there is no certainty that the areas pictured give optimum reduction of variance in the ensuing regression.

Up to this point, these influence regions represent a climatological approach to the inclusion of radar data into our regression scheme. A reasonable question to be asked is, "Can information on direction of area movement be used to improve our prediction?" In order to answer this question, the frequency of occurrence tabulations were stratified by direction of movement for the 1930 GMT HTS data only. More specifically, the data were divided according to area movement from the NW (280°-360°) versus movement from the SW (230°-270°). If the area movement was from any other direction, an areal coverage of our climatological influence region would be used in place of this variable. If two radar stations reported different area movements, the most northerly direction was chosen. Results of this stratification are shown in Figures 4 and 5 along with the new influence areas.

Summing up, for the 1930 GMT HTS data, a new variable called adjusted areal coverage will be included in the screening procedure. Its value will be the areal coverage of the influence area given in Figure 4 if there is NW area movement, or the areal coverage of the influence region given in Figure 5 if there is SW movement, or the areal coverage of the influence region in Figure 3 if there is another direction of motion.

1930 GMT Williamsport Regression

One hundred and twenty-two days from 1 June to 30 September 1973 that had complete 1930 GMT radar reports and PEATMOS POPs were used to arrive at a regression plane explaining the variation between the chance of rain and our predictors. On only 110 of these days was LFM information available, so pairwise deletion was used in determining correlation coefficients. Hence, a missing value for a particular variable causes that case to be eliminated from calculations involving that variable only. Table 1 lists the variables screened for this regression, their range, the variables retained and their order of inclusion, the reduction of variance and the final analysis of variance table. Notice that two other radar variables that were screened were Sum DR, the sum of the MDR numbers in the influence region, and E_1, the presence or absence of an echo in our highest frequency of occurrence square. Neither of these variables explains as much of the variance of Y as does an areal coverage type variable.

Table 1. 1930 GMT Williamsport Regression

A listing of variables screened, variables selected, their partial F upon inclusion, the reduction of variance (RD), the final regression equation, and the final analysis of variance (ANOVA) table.

Tentatively Entertained Model:

$\hat{Y}=a+bX_1+c(\text{dum})X_1+dX_2+eX_3+fX_4+gX_5$

Where: dum=0 if PEATMOS POP less than 20%,
dum=1 if PEATMOS POP equal or greater than 20%

	Variables	R^2	Partial F-Value	Range
X_1	Areal coverage	Not Included	--	.00-1.00
$(\text{dum})X_1$	Selected Ar.Cvrg.	44.1%	85.057	.00-1.00
X_2	LFM QPF	6.3%	13.516	0=no rain 1=.01"-.49" 2=.50" or greater
X_3	PEATMOS POP	Not Included	-	0-100
X_4	Sum DR	Not Included	--	0-81
X_5	E_1	Not Included	--	0 or 1
		50.4%		

Final Equation: $\hat{y}=.0438+.516(\text{dum})X_1+.314X_2$

Final ANOVA Table:

Source	df	SS	MS	Total F-Value
Regression	2	9.532	4.766	54.215
Residual	107	9.406	.087	

df = degrees of freedom
SS = sum of squares
MS = mean squares

The variable that has the highest correlation coefficient with Y is a selected areal coverage. This is the number of squares that have echoes in them divided by the total number of squares in our influence region only if the PEATMOS POP is 20% or greater. This variable was included for screening when a cross-tabulation of these three variables revealed that it rarely rained if PEATMOS POP was less than 20%, no matter how large our areal coverage was. This is an "abrupt" type of interaction effect that can be represented as a 0-1 dummy variable times areal coverage in our initial regression model. Perhaps the "abruptness" of the interaction here is due to our small sample size or an idiosyncrasy of station locale.

The only other variable included in our model was the LFM QPF. The partial F for the LFM was 13.516. This is greater than the 1% significance level $F_{1,107}=6.93$ ($\alpha=.01$). At the end of step two, the next highest partial correlation coefficient is PEATMOS POP with a partial F of 2.484. This term was not included in our model since a partial F of this value meant that there was an 11.8% probability that this term could have been included by chance. Inclusion of this term would further reduce the variance by only 1.1%. Even though the PEATMOS POP does not explicity enter in the final equation, information from it was used in our selected areal coverage term.

1930 GMT Huntington Regression

One hundred and twenty-four days from 1 June to 30 September 1973, that had complete 1930 GMT radar reports and PEATMOS POP values were used in the Huntington regression analysis. Again, on only 114 of these 124 days was the LFM QPF available, so pairwise deletion was used when computing correlation coefficients. Table 2 lists vital information for this regression plus the results. Note that we are screening both a climatological areal coverage and an adjusted one. The "climatological areal coverage" is defined to be the percentage of those seven influence region squares indicated in Figure 3 that have echoes reported. The "adjusted areal coverage" is defined to be the percentage of those influence region squares in Figures 4 and 5 that have echoes (stratified according to echo movement, as discussed earlier). The adjusted areal coverage is the first term included in the stepwise regression procedure because it had the highest correlation coefficient with Y (.665). The climatological areal coverage had only a .544 correlation coefficient with Y, thus indicating the value of stratifying according to echo movement. The initial overall F is 88.622.

The next variable selected was the LFM QPF because its partial F is 22.045, and the overall F is 63.66. This is the final step because our highest partial F at the end of step 2 is 1.64 (this variable is X_2*X_3 interaction). This partial F in no way warrants its inclusion and this extra term would have increased R^2 only by another 0.7%. Notice that the PEATMOS POP does not even enter into this regression equation.

Table 2. 1930 GMT Huntington Regression

Tentatively Entertained Model:

$\hat{Y}=a+bX_1+cX_2+dX_1X_2+eX_3+fX_3X_2+gX_4+hX_5$

	Variables	R^2	Total F-Value	Range
X_1	Climatological Areal Coverage	Not Included	--	.00-1.00
X_2	PEATMOS POP	Not Included	--	0-100
X_1X_2	Interaction	Not Included	--	.00-100.00
X_3	Adjusted Areal coverage	44.1%	88.622	.00-1.00
X_4	LFM QPF	9.3%	22.045	0,1, or 2 (as before)
X_5	Sum DR	Not Included	--	0-63
X_2X_3	Interaction	Not Included	--	.00-100.00
		53.4%		

Final Equation: $\hat{y}=.0205+.562X_3+.317X_4$

Final ANOVA Table:

Source	df	SS	MS	Total F-Value
Regression	2	10.722	5.361	63.660
Residual	111	9.348	.084	

0730 GMT Williamsport Regression

One hundred and fourteen summer days from 1 June to 30 September 1973, had complete 0730 GMT radar observations that were used as our data base for this regression. A cross-tabulation of areal coverage versus frequency of occurrence of precipitation reveals an interesting jump in frequency between .00 and .10 coverage (see Figure 6). Considering that a large percentage of our data has .00 or .10 echo coverage, this represents a significant departure from linearity. A similar graph for the 1930 GMT areal coverage (unmodified) versus frequency of occurrence reveals no such trend here (see Figure 7). While sampling error is still a possibility, the graphs shown, which are based on two summers, are essentially the same as those based on the data for the individual summers. Also, there may be a good physical explanation of this trend.

Notice in Figure 6 that after the jump in frequency between .00 and .10 coverage, additional increase in coverage to .40 does not bring any increase in the frequency. The abrupt increase between .00 and .10 coverage may be due to the fact that even one small echo at 3:30 AM could indicate the presence of a feature likely to persist. But, why then doesn't the frequency keep on increasing past .10 coverage?

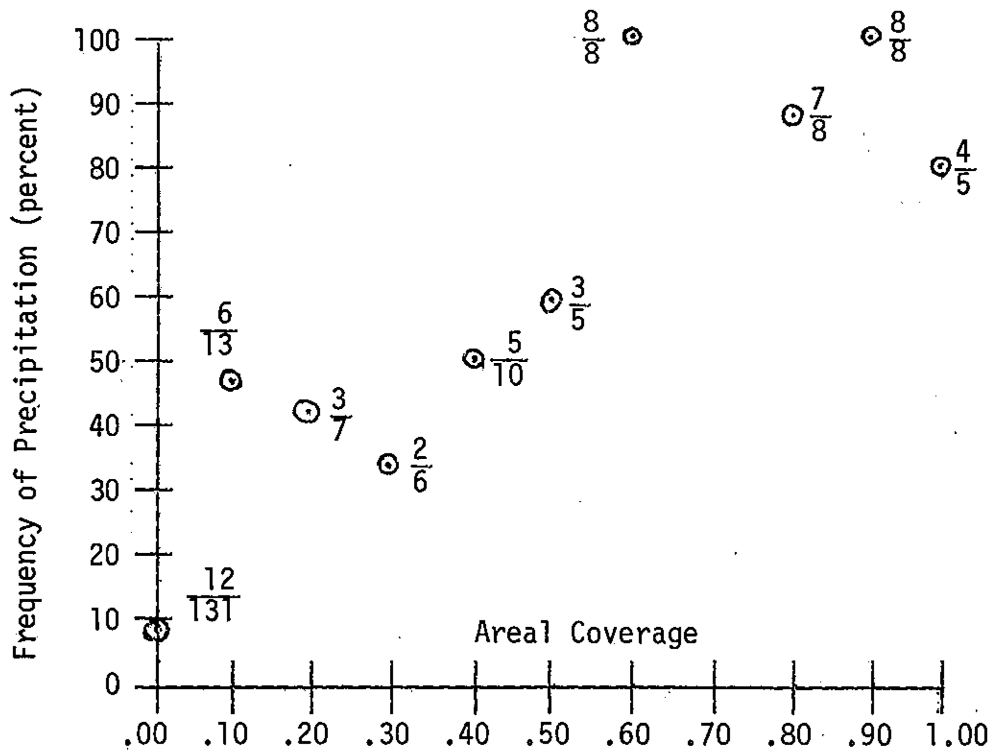


Figure 6. Frequency of Precipitation, 12-00 GMT, at Williamsport, PA versus 0730 GMT Radar Areal Coverage. Data is from 1 June to 30 September 1973, and 16 May to 12 July 1974. Number of precipitation cases divided by total cases is shown for each areal coverage.

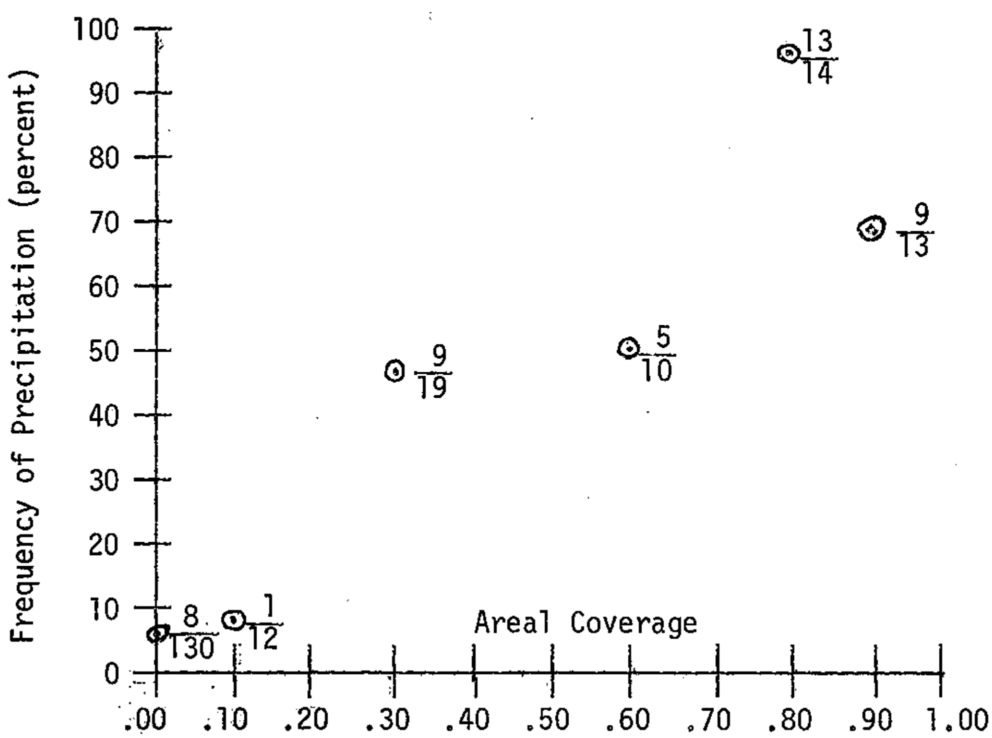


Figure 7. Same as Figure 6 using 1930 GMT radar observations and 00-12 GMT frequency of precipitation.

Consider a circular area of precipitation 20 miles in diameter. If it is completely in one square, our areal coverage variable would be .10. However, if it were centered within 10 miles of a corner of our grid, an areal coverage of .40 is recorded. Yet, we would not expect any increase in frequency of precipitation because the real area of the precipitation remains the same. So it is possible to have values of .40 areal coverage with only small areas of precipitation. Larger coverages would have to mean larger areas (on the order of 50 miles diameter) or smaller cells scattered throughout five or more squares. Perhaps this is why the frequency increases markedly in the region .40 to .60 areal coverage.

Regardless of whether we truly have the real physical explanation or not, we must take the irregularities into account in our statistical analysis. Obviously, linear regression would not give us a good fit here, our estimate ($\hat{y}$) would overforecast the .00 and .40 areal coverage cases, but would underforecast the .10 cases. One solution is to treat the .00 coverage cases separately in a contingency table approach and to treat cases with coverage greater than or equal to .10 in a linear or curvilinear regression. This approach can handle the jump in frequency between .00 and .10 well and it is simple to utilize.

Table 3 shows the frequency of precipitation for different values of PEATMOS POP when there is no areal coverage. For 0, 10, and 20% PEATMOS POP, it rains 3, 11, and 13% of the cases, respectively. There is very little data for POP values, $\geq$ 30%. Hence, no change in the PEATMOS POP is suggested here.

Table 3. Frequency of Precipitation for PEATMOS POP values when 0730 GMT areal radar coverage=zero. Data is for Williamsport, Pa., 1 June to 30 September 1973.

PEATMOS POP	Frequency of Precipitation 12-00 GMT
0 & 2	1/32=03%
10	2/18=11%
20	3/23=13%
30	0/9 =00%
40	1/2 =50%
50	No Data
60	0/2 =00%
70	No Data
80	No Data
90	No Data
100	No Data

Table 4 shows the results of the regression approach taken when coverage is greater than .00. The total number of cases is only 36, so it would be hard for more than one term to have a high partial F statistic. Consequently, less of a premium was placed on high F-values, as long as the terms reduced the variance. Notice that in the final equation, the areal coverage, a transformation of the PEATMOS POP, and an interaction term are included, but not the LFM QPF. The total reduction of variance is small because these 36 cases represent some of the most widely deviant behavior of the summer. The total F is only 3.03 and this is the equation that undergoes independent verification.

Table 4. 0730 GMT Williamsport Regression for 1973 data only.
36 cases when areal coverage is not zero.

Tentatively Entertained Model:

$$\hat{Y}=a+bX_1+cX_2+dX_3+e(\text{Log}_{10}X_1)+f(\text{Log}_{10}X_1)*X_2$$

	Variables	R^2	Partial F-Value	Range
X_1	PEATMOS POP	Not Included	--	0-100
X_2	Areal Coverage	10.3%	3.89	.00-1.0
X_3	LFM QPF	Not Included	--	0,1, or 2
$\text{Log}_{10}X_1$		4.6%	1.80	1.0-2.0
$\text{Log}_{10}X_1*X_2$		7.3%	2.98	0.0-2.0
		22.2%		

Final Equation:

$$\hat{Y}=-.6965+2.575X_2+.7603(\text{Log}_{10}X_1)-1.356(\text{Log}_{10}X_1)*X_2$$

Final ANOVA Table:

Source	df	SS	MS	Total F-Value
Regression	3	1.774	.5913	3.039
Residual	32	6.225	.1945	

After using the 1974 data for independent verification, we added this new data to our regression, bringing the total number of cases to 60. The results of this regression are presented in Table 5. Notice that the total reduction of variance and final F-value are much higher due to the added data, and perhaps to the effect of some new variables. One Square is the radar variable that is selected first. It is a 0-1 variable indicating the presence or absence of an echo in the one highest frequency square NW of IPT. Other terms included are the LFM QPF, a transformation of the PEATMOS POP, and an interaction effect.

Table 5. 0730 GMT Williamsport Regression for 1973 and 1974 data combined. 60 cases when areal coverage is not zero.

Tentatively Entertained Model:

$$\hat{Y}=a+bX_1+cX_2+dX_3+fX_4+gX_5+h(Log_{10}X_1)+i(Log_{10}X_1)*X_2+j(X_1*X_2)$$

	Variable	R^2	Partial F-Value	Range
X_1	PEATMOS POP	Not Included	--	0-100
X_2	Areal Coverage	Not Included	--	0.00-1.00
X_3	LFM QPF	22.9%	17.20	0,1, or 2 (as before)
X_4	Sum DR	Not Included	--	0-90
X_5	One Square	5.3%	4.21	0=no echoes 1=1 or more echoes
$Log_{10}X_1$		2.2%	1.78	1.00-2.00
$Log_{10}X_1*X_2$		Not Included	--	0.00-2.00
X_1*X_2		4.2%	3.51	0.0-100.0
		34.6%		

Final Equation: $\hat{Y}=-.140+350X_3+.317X_5+.454(Log_{10}X_1)-.0076(x_1*x_2)$

Final ANOVA Table:

Source	df	SS	MS	Total F-Value
Regression	4	4.358	1.089	7.269
Residual	55	8.242	.150	

0730 GMT Huntington Regression

One hundred and thirty-two cases from 15 May to 30 September 1973, served as our data base for this regression. Again, a graph of areal coverage versus frequency of verification revealed a jump in frequency between .00 and .10. The frequency at .00 is 12% while the frequency for .10 and .20 grouped together is 40%. The same method of dealing with this problem is carried out as before.

Table 6 shows frequency of precipitation for various PEATMOS POP values when coverage=zero. The table reveals a trend similar to that observed for Williamsport. Hence, no change in the PEATMOS POP.

For the 48 days when coverage is not zero, a regression approach is taken. The first term selected for inclusion in the model is the PEATMOS POP, Areal Coverage interaction effect with an initial F of 11.795. The next variable included is the LFM QPF with a partial F of 4.738. After this step, none of the other variables has a partial F greater than one, so we stop here.

Table 6. Frequency of Precipitation for PEATMOS POP values when 0730 GMT areal radar coverage=zero. Data is for Huntington, WV, 15 May to 30 September 1973. There were no cases with POP greater than 80%.

PEATMOS POP	Frequency of Precipitation 12-00 GMT
0	4/33=12%
10	0/11=00%
20	3/21=14%
30	1/6 =17%
40	0/8 =00%
50	1/2 =50%
60	0/1 =00%
70	0/1 =00%
80	1/1 =100%

Table 7. 0730 GMT Huntington Regression

Tentatively Entertained Model:

$\hat{Y}=a+bX_1+cX_2+d(Log_{10}X_1)+e(Log_1 0X_1)*(X_2)+fX3$

Variables		R^2	Partial F-Value	Range
X_1	PEATMOS POP	Not Included	--	0-100
X_2	Areal Coverage	Not Included	--	.00-1.00
$Log_{10}X_1$		Not Included	--	1.00-2.00
$Log_{10}X_1*X_2$		20.4%	11.795	0.00-2.00
X_3	LFM QPF	7.6%	4.738	0, 1, or 2
		28.0%		

Final Equation: $\hat{Y}=0.167+0.226*(Log_{10}X_1)*X_2+0.405*X_3$

Final ANOVA Table:

Source	df	SS	MS	Total F-Value
Regression	2	3.213	1.607	8.746
Residual	45	8.266	.184	

Measuring Forecast Improvement - The Brier Score

Since radar and LFM information were included in all of our regression equations, we would expect to see improvement in forecasting accuracy over PEATMOS POP. But, how large is this additional increase in accuracy? Is it worth the effort? Also, is this improvement over PEATMOS POP less than or greater than made subjectively by NWS forecasters?

One common way of measuring skill in probability forecasting is the Brier score (Brier, 1950),

$$B = [\sum_{i=1}^{n} (F_i - O_i)^2] / N$$

where: F_i=Forecast probability for each case, rounded to the nearest 10%,

O_i=1 (Rain) or 0 (No Rain) observed for each case,

N = Total number of cases.

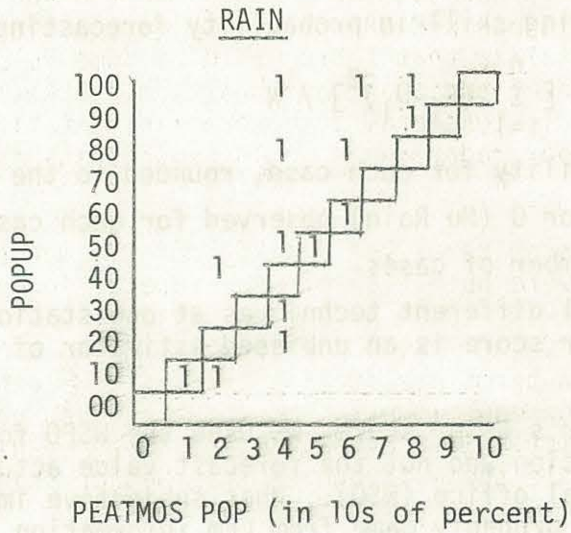
For comparison of several different techniques at one station for the same period of time, the Brier score is an unbiased estimator of forecast accuracy.

To compute the forecaster's Brier score, we used the WSFO forecaster's probability of precipitation and not the forecast value actually released to the public by the local office (WSO). What subjective improvement was made to PEATMOS POP most probably came from LFM information, radar indications, and a good regional analysis. Table 8 shows the percent decrease in Brier score over the PEATMOS POP for both POPUP and the forecasters. This statistic was computed for both stations, both times of day, and for both dependent data (1973, used to develop the regressions) and independent data (summer 1974). The POPUP technique results in about twice the improvement made subjectively by the forecasters. Thus, it appears that forecasters were not utilizing LFM and radar information to the fullest extent possible.

Table 8. Percentage Improvement in Brier Score Over PEATMOS POP.

	0730 GMT EQN.	1930 GMT EQN.
Dependent Sample - IPT		
POPUP	30.5%	24.6%
Forecaster's	11.5%	6.9%
Independent Sample - IPT		
POPUP	32.9%	19.9%
Forecaster's	10.6%	9.6%
Dependent Sample - HTS		
POPUP	22.2%	41.0%
Forecaster's	11.3%	5.7%
Independent Sample - HTS		
POPUP	15.3%	17.8%
Forecaster's	14.7%	9.4%

Figure 8 shows POPUP versus PEATMOS POP for two months of independent data at Williamsport. It helps to graphically show the improvement; POPUP forecasts higher than PEATMOS POP on days that rain occurred, and vice versa. Also, it is noteworthy that in 16 of the 56 cases in Figure 8, POPUP is the same as PEATMOS POP, while in another 20 of the cases POPUP differs by only 10%. Thus, a majority of the improvement comes on the remaining 20 days.



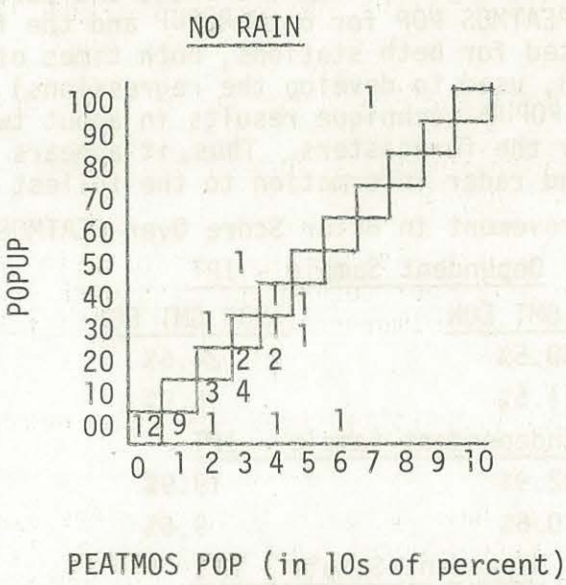


Figure 8. POPUP versus PEATMOS POP for days when precipitation occurred and days when it didn't. 1930 GMT IPT Equation from 5/16/74 to 7/12/74. Number of cases are shown for joint values of POPUP and PEATMOS POP.

CONCLUSIONS

1. A 15-35% improvement in Brier Score over PEATMOS POP is likely with the POPUP scheme in summer. Improvement over forecaster's subjective forecasts is also likely.

It has been earlier stated that LFM improvement over PEATMOS POP occurs at a variety of stations throughout the East during the summer (National Weather Service, 1974). Since LFM QPF is a key term in our POPUP scheme, it is reasonable to generalize that there would be some POPUP improvement throughout the entire mid-Atlantic and northeastern states. Improvement due to radar information is less easy to generalize. Stations whose influence regions lie in poor radar range would expect less forecast improvement due to this term.

2. Inclusion of interaction terms between PEATMOS POP and areal coverage plus the use of LFM QPF were both vital in the forecasting ability of this model.

The fact that interaction terms are statistically significant show us that the relationship is by no means linear. More data should help us if certain irregularities persist. If they do, perhaps a three-dimensional contingency table would handle these irregularities better than would a regression approach.

3. The improved forecasting skill of the POPUP technique is attributed to:

A. later information available through use of radar data,

B. incorporation of sub-synoptic information through radar data and to some extent through LFM.

4. Radar improvement fails with fast moving precipitation areas that move greater than 250 miles in a 12-hour period and also with precipitation motion from unusual directions. Improvement could still take place due to LFM information in these cases.

5. The precision of manually digitized radar data was necessary to obtain this forecast improvement.

Current radar summary charts have a tendency to mask the exact pattern that appears on the radarscope (Moore, Cummings & Smith, 1974). Indeed, much of the information on exact cell location and intensity is not carried by this code. A study on the forecast value of radar summary charts (Wilson & Kessler, 1963) showed that translation forecasts based on these charts could barely beat persistence after only six hours. Surprisingly, they recommend a manually digitized radar data scheme much like the present one to overcome these weaknesses.

6. Prospects for the future include POPUPs centrally computer produced and smaller MDR gridding. For the next few years, POPUPs can be computed manually at the forecast office. Prior experience by Peters and Barnes (1973) indicates that POPUP can be evaluated quickly in routine operating conditions. However, all of the variables in POPUP can be stored on magnetic tape for many different locations, and thus implement a nation-wide POPUP effort. Smaller gridding may help highlight areas of enhanced convection in the summer season and therefore be of some forecast value.

7. Use of satellite information in early morning hours could be helpful in establishing daytime probabilities of precipitation.

Purdom and Gurka (1974) have shown several cases where the low level cloud cover in the early morning helps inhibit afternoon convection while neighboring clear spots are the first to experience shower development. This is physically consistent with the principle of differential solar heating. This may be an especially significant factor in the southeastern United States where uniform instability and moisture patterns exist for most of the summer. Perhaps some way of including this information into a POPUP scheme could be developed.

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