Updating of Numerical Precipitation Guidance[1]

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(Manuscript received 6 June 1972, in revised form 23 August 1972)

ABSTRACT

An objective technique has been developed for modifying precipitation probability guidance forecasts received from the National Meteorological Center by means of radar information which becomes available subsequent to receipt of the guidance forecasts. Tests show improvement with respect to both the centralized guidance and the official subjective forecasts. The findings also carry implications as to the resolution necessary in radar data used in such a procedure.

1. Introduction

As a result of improvements in numerical prediction, an increasing amount of forecast guidance material is being transmitted from the National Meteorological Center (NMC) in the form of unmodified computer products. Direct output of numerical models comprises a large part of the guidance material. However, there has been little success in forecasting variables such as maximum or minimum temperature and probability of precipitation directly. Best results have been obtained through use of a statistical relationship between the predictand and variables forecast by the numerical model. Glahn and Lowry (1969) have used this approach with considerable success in what they call the Model Output Statistics or MOS method. NMC disseminates a number of products derived in this manner.

The field forecaster could improve on these MOS guidance forecasts if he could determine that forecasts for a specific *location* were biased (having been based on a generalized equation for an *area*) or if on a particular day he could isolate potential errors due to data deficiencies or other problems with the dynamic models. However, these are not promising avenues. As a result of the statistical procedures used in their development, MOS products generally do not have large bias. Furthermore, the dynamic models have become so complex that it is difficult to anticipate the effects of input errors and the occasions on which model predictions will fail in the area of concern.

The greatest opportunity for the forecaster to improve upon the centralized guidance may be through use of data not available to the models. With respect to precipitation forecasting, one source of such data is radar. Although conventional surface observations and satellite data serve as input to NMC models, the significant and extensive information represented by radar observations is not presently included. In addition, since most forecasts are issued at 6-hr intervals and the basic numerical guidance is on a two-per-day cycle, there is the possibility of capitalizing on radar information received as much as 8–9 hr later than observations used in the models.

The present experiment was therefore undertaken to examine the feasibility of using radar data in an objective manner to modify and update the probability of precipitation (PoP) guidance forecasts issued by NMC.

2. Data and procedure

The forecasts which serve as basic PoP guidance to field forecasters are based on the MOS procedure with input from the NMC Primitive Equation (PE) model (Shuman and Hovermale, 1968) and a trajectory model developed by Reap (1972). The forecasts have been referred to by the acronym PEATMOS, for Primitive Equation and Trajectory Model Output Statistics (Lowry *et al.*, 1972). Verification figures (93 U. S. stations for one year) show them to be slightly more accurate than subjective precipitation probability forecasts formerly made at NMC and which they have now replaced. The PEATMOS forecasts, based on model runs from data at the standard synoptic times of midnight and noon Greenwich mean time, are received at field offices at approximately 0730 and 1930 GMT. Our experiment made use of radar data which became available between these times and forecast release times some 3 hr later.

A portion of the area for which radar data were collected during the period December 1971 to February 1972 is shown in Fig. 1. Fig. 2 shows the scheme used to digitize the echo pattern of each radar twice per day (0900 and 2100 GMT), for a grid of 25 squares roughly 40 n mi square. The grid was designed as a subset of the

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[1] Presented at the Fourth Conference on Weather Forecasting and Analysis, 1–4 May 1972, Portland, Ore.

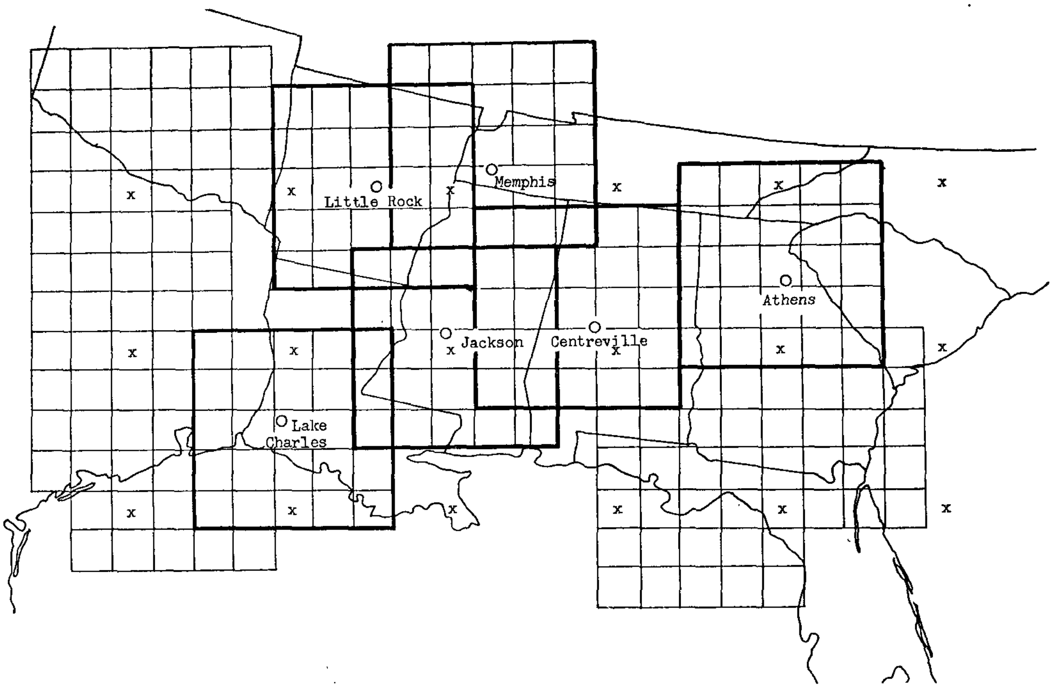


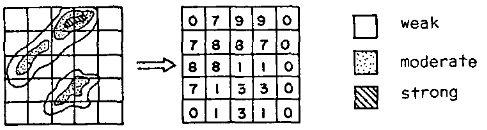
FIG. 1. Portion of the gridded area for which radar data were collected. Data from the six radars shown here were used in developing the PoP update scheme. Each radar reported data for the 25 squares enclosed by the box centered on the station. Grid length is roughly 40 n mi, PE grid points are shown by x's.

PE model grid with a resolution sixteen times greater (PE grid points are indicated in Fig. 1 by x's). The individual radars were composited to arrive at a reasonably complete echo distribution over the entire area. PEATMOS forecasts have been available on the NAFAX (National Facsimile) circuit since 1 January 1972. However, they were run routinely for several months before that date and the Techniques Development Laboratory kindly provided us with the forecasts for December 1971.

Winter precipitation regimes for Atlanta, Birmingham and Jackson are similar and the area around each station is well covered by surrounding radars. Therefore it was decided to use these stations to develop the PoP forecast update scheme. Climatological frequencies of precipitation differ little between day and night periods for each station (Fig. 3). In addition, the frequencies for the three stations are similar. These facts permit combination of day and night periods for all three stations to obtain a developmental data sample of 372 cases for the two months of December and January. Data for February were used as an independent test sample. It should be emphasized that while only three stations were used in development, the update scheme should be applicable to any station within the same general area and with the same precipitation climatology as the dependent stations.

Code Number	Character of Echo	
0	No echo	
1	< ½ coverage	weak echoes (0db)
2	≥ ½ coverage	
3	< ½ coverage	moderate echoes (21db)
4	≥ ½ coverage	
5	< ½ coverage	strong echoes (36db)
6	≥ ½ coverage	
7	line of weak echoes	
8	line of moderate echoes	
9	line of strong echoes	

Example:



0	7	9	9	0
7	8	8	7	0
8	8	1	1	0
7	1	3	3	0
0	1	3	1	0

FIG. 2. Scheme used to digitize radar patterns. Moderate and strong echoes were those remaining after attenuating the radar signal by 21 and 36 db, respectively.

3. Selection of predictors

An earlier study of the correlation between echoes and subsequent rainfall, while lacking the resolution of the present attempt, revealed that the best use of radar data would include information about the prevailing wind. Based in part on the earlier study the areas shown in Fig. 4 were selected as being those which, when echoes were present, offered the greatest potential as predictors of rain at the indicated stations (which we will call verifying points). Fig. 5 is a composite of the three areas for the period of the developmental data sample. It shows for each grid square the frequency of rain at the verifying point in the 12-hr periods beginning 3 hr after the radar observations, given an echo in the square. The relative location of the square with highest frequencies was the same in each of the three areas.

The frequency distribution and preliminary correlation analyses suggest that the area of consideration can be reduced by elimination of the shaded squares without loss of predictive information. Fig. 5 also suggests that in order to examine effects of resolution of the radar data the large area (Area I), consisting of 25 squares, can be subdivided into at least two successively smaller areas: Area II (9 squares) and Area III (1 square).

A tabulation of the presence or absence of echoes in the various areas, or combinations of areas, was used to construct binary predictors, while the degree of coverage within areas yielded continuous predictors. These were used in various combinations with the PEATMOS precipitation probability forecasts in separate screening regression analyses.

The PEATMOS PoP's were first-period forecasts for the 12-hr period beginning 12 hr after 0000 or 1200 GMT. The other predictors were based on radar observations at 0900 and 2100 GMT, 3 hr prior to the

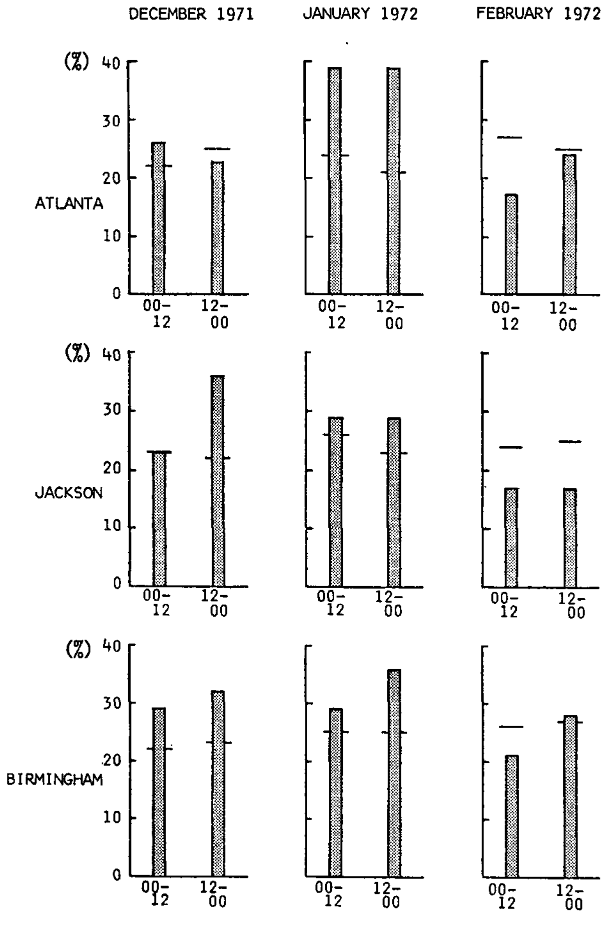


Fig. 3. Precipitation frequencies for months used in the study. Climatological frequencies are indicated by short horizontal lines. Times are GMT.

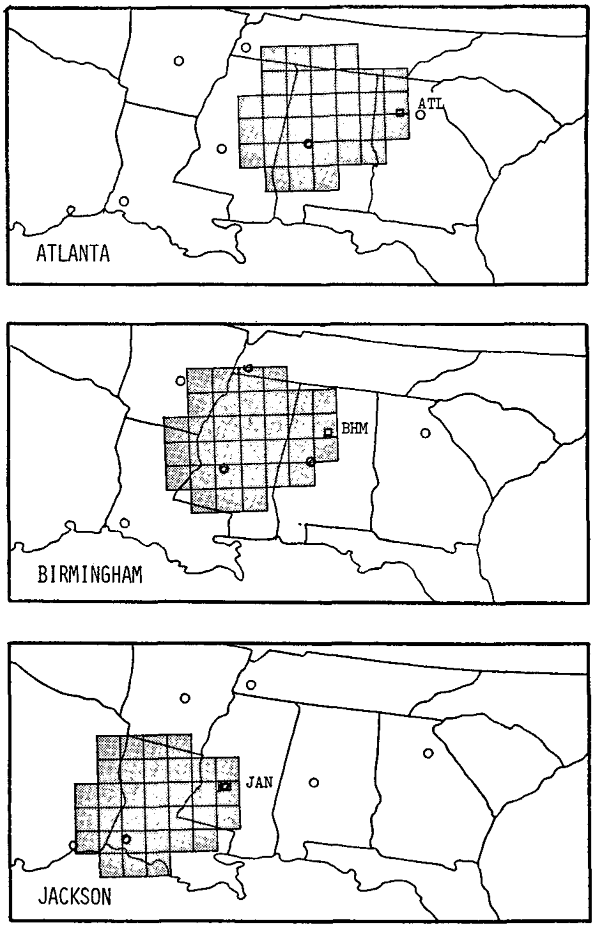


Fig. 4. Areas of highest correlation between radar echoes and precipitation occurrence at the indicated stations. Circles indicate radar sites. Note that the shape of the area is the same for all stations (which are located in the same square, relative to the area).

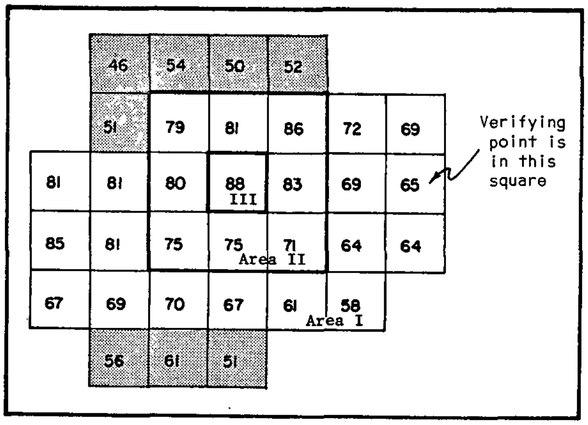


Fig. 5. Composite of the three areas shown in Fig. 4. Numbers are mean frequencies of occurrence of precipitation at the verifying point, given an echo in the indicated square. Numerals (I, II, III) indicate successively smaller areas enclosing successively increasing (average) frequencies.

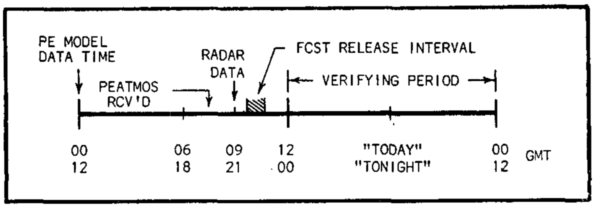


FIG. 6. Temporal relationship of predictors (PEATMOS PoP's, and radar data) and predictand (precipitation in 0000–1200 GMT or 1200–0000 GMT periods).

beginning of the verification period and 9 hr subsequent to the data on which the PEATMOS PoP's were based. Fig. 6 illustrates the temporal relationship among the predictors and the predictand, i.e., measurable rain at the verifying point during the 12-hr daytime or nighttime periods.

4. Results

One objective was the determination of the degree of independence among the predictors since this has implications with respect to the scale of the system producing the echoes and the optimum resolution in radar data applied to the particular forecast problem being examined.

The PEATMOS probability predictor alone accounts for 43.9% of the variance in the developmental data (see Table 1). While not the best single predictor we feel it is a fundamental one because many features of the general synoptic situation, such as development, are represented by this single term. Results indicate, however, that a good first period probability forecast can be made based solely on the radar data. Table 1 summarizes the contributions to reduction of variance of several terms, considered both individually and in combination with the PEATMOS predictor. Only predictors based on the presence or absence of echoes within the 40 n mi squares are considered. In general, the continuous variables appear to offer more predictive information than the binary. In fact, the degree of echo coverage generally upwind of the verifying point furnishes a better predictor than PEATMOS alone *for this data sample.*

TABLE 1. Summary of predictive information afforded by PEATMOS and presence or absence of echoes in individual squares.

Term	Reduction of variance (%)	Reduction of variance when used in combination with PEATMOS (%)	Improvement over PEATMOS alone (%)
PEATMOS	43.9	—	—
E_{I}	36.1	49.7	5.8
E_{II}	40.3	51.0	7.1
E_{III}	37.5	52.0	8.1
$\mathrm{PCT_I}$	46.4	53.6	9.7
$\mathrm{PCT_{II}}$	46.8	54.3	10.4

Binary: E_{I}, Presence or absence of echo in Area I.
E_{II}, Presence or absence of echo in Area II.
E_{III}, Presence or absence of echo in Area III.

Continuous: $\mathrm{PCT_I}$, Percent of squares in Area I with echoes.
$\mathrm{PCT_{II}}$, Percent of squares in Area II with echoes.

The table shows that knowledge of the occurrence or nonoccurrence of an echo in the smallest area (Area III) provides a basis for significantly improving the PEATMOS prediction. The percent coverage in Area I is a better predictor, in combination with PEATMOS, but even better is the percentage coverage in Area II. It is likely that the value of predictor E_{III} (presence or absence of an echo in the small central square Area III) would be enhanced if its location were a function of the prevailing flow rather than the mean flow for the season.

The updated probability of precipitation (PoPup1) based on PEATMOS and the best single predictor from Table 1 is

$$\mathrm{PoPup1} = 0.009 + 0.58(\mathrm{PEATMOS}) + 0.643(\mathrm{PCT_{II}}). \quad (1)$$

Note that the updated PoP forecast can significantly increase low PEATMOS PoP forecasts even when there is only moderate echo coverage in Area II. That this is done effectively by the update procedure will be shown below.

Little further reduction of variance was obtained by combining other predictors in Table 1 with those used in Eq. (1). In terms of total reduction of variance, the best combination of predictors, considering information in all three areas, is shown in Table 2. The predictors are listed in order of their selection by the screening program. These four predictors yield the following update equation for probability of precipitation:

$$\mathrm{PoPup2} = -0.014 + 0.332(\mathrm{PCT_{II}}) + 0.510(\mathrm{PEATMOS}) + 0.160(E_{\mathrm{I}}) + 0.169(E_{\mathrm{III}}). \quad (2)$$

In conjunction with the other variables in Eq. (2) the information provided about the smallest area (a single square) by E_{III} is not very useful. This is because the small central square is included in Area II, hence in predictor $\mathrm{PCT_{II}}$. The implication is that, for the season and type of forecasts being examined, no advantage would accrue from higher resolution than that afforded by the 40 n mi grid length. As a further test, an attempt was made to utilize the additional resolution provided by the digitization in terms of less than half- or more than half-square coverage at various intensities (Fig. 2). To date, no successful way has been found to utilize this information because of the complicating intensity factors.

The presence or absence and percent coverage of echoes of different intensities in each area, as well as the comparative coverages of different intensities within areas, could be determined, however. Intensity information alone, at least as digitized for this study, could not be made to yield a predictor anywhere near as useful

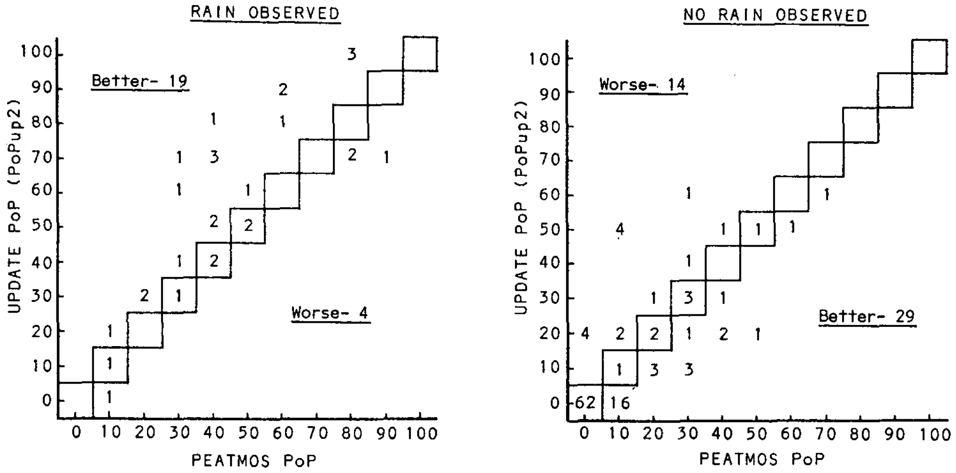


FIG. 7. Comparative performance of PEATMOS and PoPup2 forecasts for independent data sample, February 1972 (141 cases).

as those already discussed. The extent of line activity (both intensity and coverage) was investigated as a possible predictor, but line occurrence was found to be such a relatively rare event that no reliable correlation could be identified. There is a suggestion, however, that the presence of line activity is inversely correlated with subsequent precipitation downstream. This somewhat surprising result is in line with earlier unpublished investigations of the correlation between stability indices and rainfall and bears further investigation. A tentative explanation is that intense convective activity is more likely to be both transient and spotty, hence less likely to affect a particular rain gage.

Eqs. (1) and (2), developed with data for December, 1971 and January 1972, were tested on independent data for February 1972 for the same stations for which they were derived. The usefulness of the update scheme is well illustrated by the results shown in Table 3. For the combined sample of day and night forecasts of all three stations both PoPup1 and PoPup2 were superior to PEATMOS and the official (subjective) probability forecasts in terms of virtually all the standard scores.

Of particular interest are the comparative Brier scores since this provides a measure of the utility of the probability forecast. A forecast of 100% every time it rained and 0% each time it failed to rain would produce a perfect score of zero. Because the forecaster, in his local statement, is constrained to specify probabilities only to the nearest 10% (with the exceptions of 2% and 5% in some regions), PEATMOS and PoPup probabilities were likewise rounded up or down in determining the Brier scores. Clearly, both update equations improve the PEATMOS probability by increasing or decreasing it in the "right" direction, that is, it is increased on rain days and decreased on no rain days, on the average. It is noteworthy that the test shows the updated forecasts to have essentially no bias despite the fact that the weather regime for the period of development was abnormally wet and the test period abnormally dry, as indicated by Fig. 3.

TABLE 2. Results from screening regression analysis of predictors shown in Table 1.

Term	Reduction of variance if used alone (%)	Cumulative reduction of variance (%)
Percent of Area II with echoes (PCT_{II})	46.8	46.8
PEATMOS PoP	43.9	54.3
Presence or absence of echo in Area I (E_I)	36.1	55.5
Presence or absence of echo in Area III (E_{III})	37.5	56.0

TABLE 3. Scores derived from probability of precipitation forecasts for Atlanta, Birmingham and Jackson for day and night periods combined, February 1972.

	PEATMOS (NMC)	Official	PoPup 1	PoPup 2
Bias	0.55	0.78	0.89	1.00
Prefigurance	0.41	0.53	0.72	0.69
Post agreement	0.75	0.68	0.80	0.69
Brier score	0.0940	0.0928	0.0779	0.0757
Threat score	0.36	0.42	0.61	0.53
Percent correct	85%	85%	91%	87%

Bias: Number of precip forecasts/Number of precip cases.
Prefigurance: Fraction of precip cases correctly forecast.
Post agreement: Fraction of precip forecasts which were correct.

Brier score: $\frac{1}{N}\sum (f_i - o_i)^2 \begin{cases} f = \text{forecast probability} \\ o = 1 \text{ (rain) or } 0 \text{ (no rain).} \end{cases}$

Threat score: Fraction of expected and observed precip cases which were correctly forecast.
Percent correct: (Number of correct forecasts/Number of forecasts)×100.

It is difficult to assess the validity of the 50% threshold used in determining all but the Brier score. Hence, it is questionable that PoPup1 is a better forecast scheme than PoPup2, despite the better categorical scores. In any case, since the Weather Service no longer makes categorical rain forecasts, it is desirable to aim at a scheme which improves the probability forecasts, as evidenced by optimization of the Brier score. In this regard, PoPup2 would seem to be a slightly better equation than PoPup1.

It is apparent from Fig. 7 that PoPup2 improved or did not change the PEATMOS forecast in 87% of the 141 cases during the test period. PEATMOS, the forecaster's primary numerical PoP guidance, was degraded 18 times, or in only 13% of the cases. When improvement occurred it most frequently resulted from increasing or decreasing PEATMOS in the right direction only 10%. However, in the rain cases improvement was often achieved by increasing PEATMOS 30% or more. Nearly half (8) of the categorical "no rain" PEATMOS forecasts were elevated to correct "rain" forecasts.

5. Conclusions

This experiment has demonstrated a means of improving probability of precipitation forecasts by the objective use of radar information. Although the forecaster does rely on radar and other data for updating forecasts in the time frame discussed here, indications are that he needs more systematic procedures if he is to apply the information effectively. Such methods should be uncomplicated in order that they can be used quickly and easily under the pressure of operational schedules. Therefore, while it seems reasonable that additional skill could be added through more explicit consideration of advection parameters, it was considered preferable to take the radar data from a simple climatologically-oriented grid. Unusual motion of precipitation systems, as well as development, enters into the forecast procedure through inclusion of PEATMOS forecasts in the equations.

Regression equations similar to those developed in this study can be used in conjunction with radar data as presently disseminated. A desirable procedure amenable to automatic incorporation of the radar information, would be to transmit short coded messages in the proper form from the observing stations, pending availability of automatically digitized radar data envisioned for the future. Additionally, such messages would provide the potential advantage of supplementary input to initial moisture analysis for existing models.

Acknowledgments. The authors appreciate the helpful suggestions of Mr. Allen Cummings and the cooperation of radar station personnel who provided the basic data.

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