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An Operational Model for Forecasting Probability of Precipitation—PEATMOS PoP

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ABSTRACT

A dynamical-statistical model for use in probability of precipitation forecasting out to 60 h is described. This model has been fully operational twice daily in the National Weather Service (NWS) since January 1972. The acronym for the model is PEATMOS PoP, for *P*rimitive *E*quation *A*nd *T*rajectory *M*odel *O*utput *S*tatistics, *P*robability *o*f *P*recipitation. All inputs to the PoP model are provided at the National Meteorological Center by the normal outputs of the Primitive Equation and Trajectory models. We have continued to modify and adjust the model in the various ways described in order to improve its performance. An evaluation of performance shows that the accuracy of the forecasts produced by this model has continued to increase from year to year. PoP forecasts going to the public from NWS local offices have also improved with time. This improvement is likely the result of better guidance (PEATMOS PoP), although there was a slight adjustment period that lasted only a few months when the objective guidance was introduced.

1. Introduction

Point probability of precipitation (PoP) forecasts have been issued from the National Meteorological Center (NMC) for several years as guidance to forecasters located at National Weather Service (NWS) forecast offices. The program started in 1965. For several years these predictions were based on a subjective evaluation of meteorological information available at NMC. In January of 1972 the subjective program was replaced by an objective system in which the forecasts were computer-produced by a dynamical-statistical PoP model. This paper describes the model, the evolution of events that led to its operational use, accuracy of the forecasts, and the operational aspects involved. A geographical analysis of the physical relationships involved will be published in a separate paper at a later date.

2. Model Output Statistics approach

The Model Output Statistics (MOS) approach was introduced and developed by Glahn and Lowry (1969). This approach to statistical prediction is not complex. Indeed, in many respects it is quite simple. It requires a relatively short period of developmental data. The predictors are not the usual antecedent observations, but are prognostic data produced directly by dynamical models. The unstable output of rapidly changing dynamical models could present a serious problem to the MOS concept. The developmental data could be significantly different from the operational data. The obvious solution to this problem is to develop a dynamical model that will not change rapidly; and we prefer, in fact, that it not change at all. We started working on such a model in 1965 (Glahn and Lowry, 1967). This particular model we called the Subsynoptic Advection Model (SAM) (see Glahn and Lowry, 1972a for a complete description). When SAM was completed we were in a position to develop the first MOS system, but this initial application covered only PoP. Within a short period we added information produced by the NMC Primitive Equation (PE) model (Shuman and Hovermale, 1968). Again, the initial application covered only PoP. PoP forecasts produced by these early efforts turned out to be more accurate than forecasts going to the public (Glahn and Lowry, 1969). However, after the forecasters were able to see the MOS product and use it as guidance, they were able to improve upon it consistently (see Glahn and Lowry, 1972b for details). But the time projection and geographical limitations of SAM restricted these PoP forecasts to 24 h projections and to the eastern portion of the United States.

Next, we developed a system that provided PoP forecasts for the entire 48 states out to 60 h in advance. SAM was dropped and the Trajectory Model (TJ) (Reap, 1972) was added in order to accomplish this goal. We decided our program should be called PEATMOS (Primitive Equation And Trajectory Model Output Statistics). Again, the initial PEATMOS effort covered only PoP. The first three years (October 1970—September 1973) of the PEATMOS PoP program will be discussed in this article.

In recent years there has been widespread use of the MOS approach not just in PoP forecasting, but for

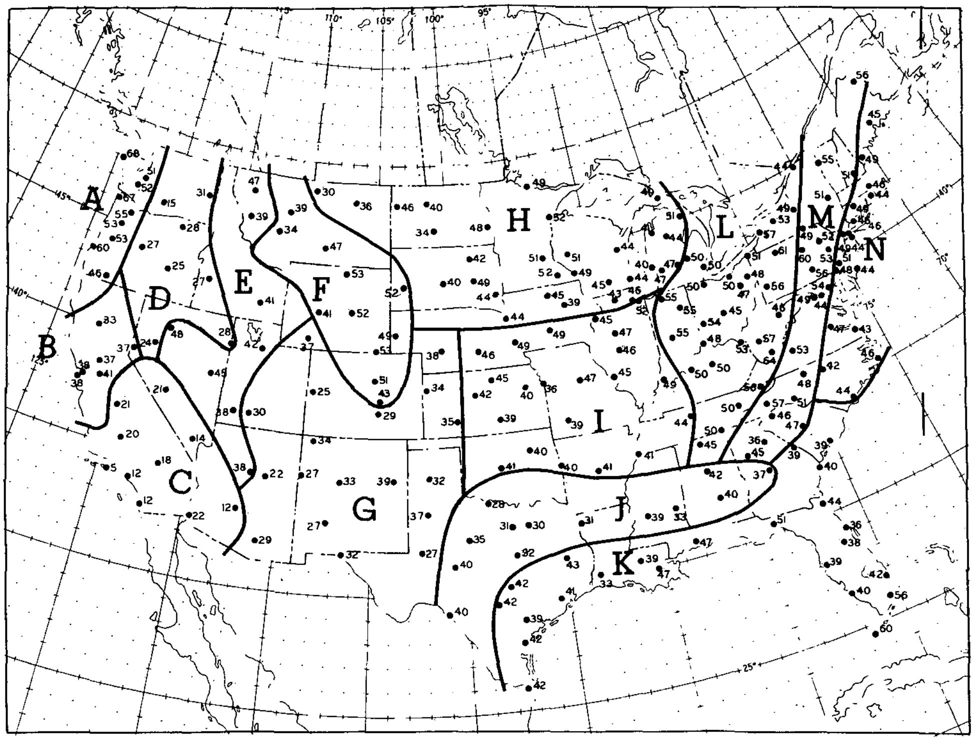

FIG. 1. Climatologically homogeneous areas (A through N) are outlined. Relative frequency of measurable precipitation values (in %) are shown for 234 stations based on two summer seasons (1971 and 1972) of data.

numerous meteorological variables. Several of these efforts are discussed by Glahn and Lowry (1972b) and still others are covered by Klein and Glahn (1974). The ultimate goal is to provide MOS-produced guidance forecasts for all common meteorological variables in matrix form as part of the Automation of Field Operations and Services (AFOS) program (Lowry *et al.*, 1974; Lowry, 1975). These forecast values are also expected to form the basis of computer-worded public forecasts (Glahn, 1970; Lowry *et al.*, 1974; Lowry, 1975) which are also included in the AFOS program.

The reason for expanded use of the MOS approach is the accuracy of the resulting forecasts. We believe the increased accuracy is realized because the system automatically takes account of average model bias. The same biases are present in the dependent data that are present in the independent data. The same cannot be said for the "perfect prog" statistical method (Klein, 1969). Julian and Murphy (1972) have called the MOS approach the leader among statistical prediction methods today. It is for the reasons above that we developed the MOS method initially and that we applied it to produce the PEATMOS PoP model described here.

3. Development of seasonal equations

Cold season (October–March) and warm season (April–September) forecast equations were developed starting with the cold season of 1970–71. The matching of MOS data with observed data was accomplished through multiple linear screening regression. There are several variations of this method. The forward stepwise procedure that we used has been outlined in detail by Glahn and Lowry (1972b). We will not repeat that discussion here but will mention that only binary predictors were used. The decision to do this was based on previous experience.

Our work in PEATMOS PoP forecasting has been restricted to the generalized operator approach within areas. We change the areas from season to season and increase their number as the size of the dependent data sample increases from year to year. These areas are determined semi-objectively from an analysis of the relative frequency of measurable precipitation when the PE forecast mean relative humidity is 75% or higher. The PE mean relative humidity was chosen because it is the primary predictor, or the one having the highest correlation with the predictand. An example is shown in Fig. 1 where relative frequency data are plotted for each station. In general, the groupings shown are based on these values (i.e. low vs high). There are other things to consider, however. For example, there are certain climatological homogeneous areas such as the Gulf of Mexico coast (K) and the Pacific Northwest (A) that seem to be natural choices regardless of which predictors are considered. Then there are physiographic barriers such as the Continental

Divide and Appalachian peaks that would certainly divide upslope from downslope winds. Further, there are certain meteorological variables such as precipitable water that are highly latitude dependent. It is not unreasonable, then, to separate the upper midwest (H) from the middle midwest (I) from the lower midwest (J). A combination of these semiobjective factors was used in order to determine the final groupings (A through N) for the particular summer season shown in the example.

The PEATMOS data collection was started in October 1969. This included predictand information (observations) obtained from the National Climatic Center (NCC) and predictor information from the PE and TJ models at NMC. One season of data collection is the minimum information needed to derive stable prediction equations using the MOS approach. Therefore, by October 1970 we had available one cold season and one warm season of dependent data. A total of 234 stations are included in the PEATMOS developmental data network. The data consist of measurable precipitation observations for 12 h periods covering the period of interest.

a. The first year

Initial forecasts were produced starting in October 1970 for the winter 1970–71 season. These forecasts were considered to be experimental and were not used in routine operations. In order to simplify the experiment, all forecast equations were based on 0000 GMT initial data but were applied at both 0000 and 1200 GMT. Six areas were used (see Fig. 2). It is obvious that the area breakdown is very crude, especially in the western portion of the country where there are only two areas. The 234 stations in the data network are shown as dots. Each area is seen to contain an adequate number of stations. Of course, forecasts can be obtained for any location in the conterminous United States from the appropriate regression equations. This is one advantage of a generalized operator within areas as opposed to single station equations. PE and TJ forecasts screened as potential predictors were those that would be expected to have a physical relationship with precipitation. These included mean relative humidity, boundary layer and upper air wind components, upper air heights, vertical velocities, and precipitable water, all at 6 h intervals from the PE model. TJ forecasts (available only for 24 h projections) were net vertical displacement, mean relative humidity, and 12 h precipitation amount. Some of the predictor fields were smoothed, to good effect. PE model output was more valuable than TJ model output in the screening procedure. This means the PE predictors were picked up sooner and more often than TJ predictors. Also, mean relative humidity was the most valuable predictor field. A regression equation used to produce forecasts will be shown and discussed later (see Section 5).

The first summer included in the program was 1971. Seven forecast areas were used (Fig. 3). This division shows little difference from the previous alignment ex-

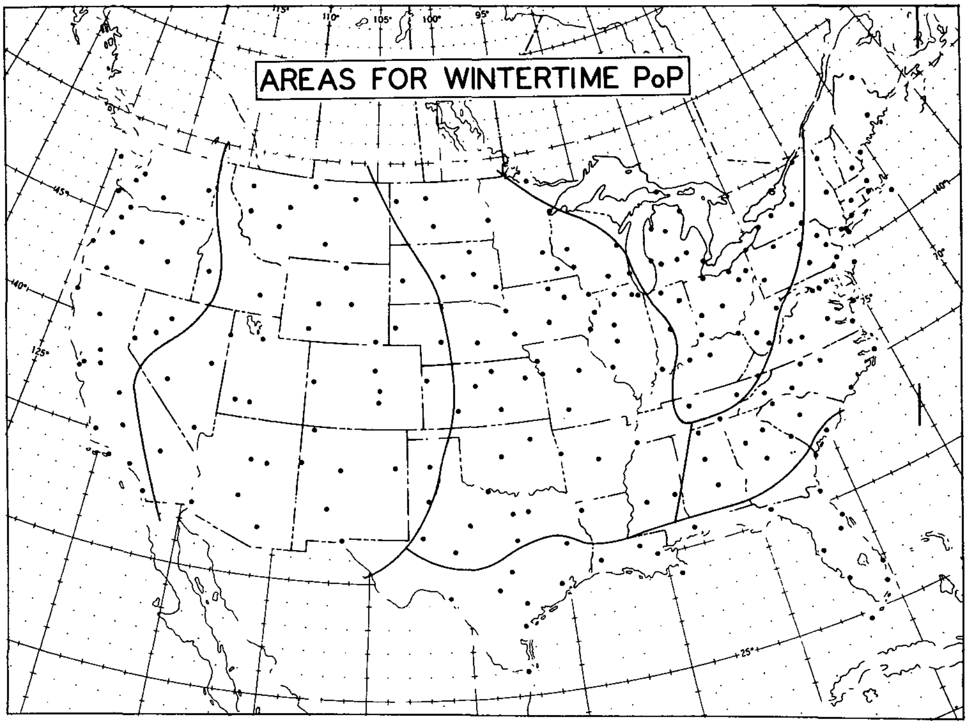

FIG. 2. The six forecast areas used during the first winter season, 1970–71.

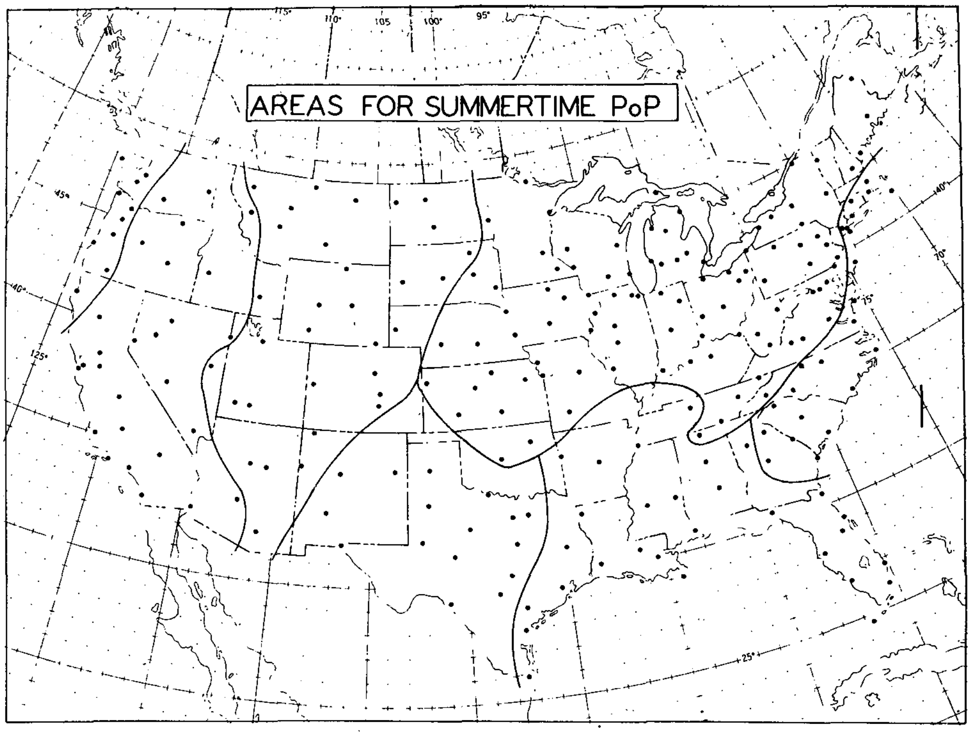

FIG. 3. The seven forecast areas used during the first summer season, 1971.

cept that the Pacific Northwest is isolated. Still, it was perhaps the best that could be made with only one year of dependent data. The predictor list was expanded to include common stability indices. This expansion was based on the known importance of the convective process during the summer to produce showers. Addition of stability was advantageous, since the correlations turned out to be fairly high.

Experimentation continued and expanded with respect to smoothing predictor fields. We used 5-, 9-, 13-, and 25-point smoothers on precipitable water and relative humidity fields. A time-dependent trend was noted whereby light (5-point) smoothing was most beneficial for the shortest time projection (period 1) and heavy (25-point) smoothing was most beneficial for the longest time projection (period 4).

b. The second year

Areas used for the second winter (1971–72) totaled nine and there was better definition than before in the western portion of the country (see Fig. 4). In addition to isolating the Pacific Northwest, we were able to isolate low frequency of occurrence stations through much of California. Also, an Appalachian area was defined for the first time. We were able to increase the number of areas because the developmental data had increased to include two years of reports.

The predictor list remained nearly the same as that for the first winter. However, it was often found advisable to shift binary limits, especially when different geographical areas were considered. For example, precipitable water values in the Rocky Mountains are not nearly as high as those over Florida. Therefore, binary limits can be allowed to shift according to the geographical area of interest.

Another type of shift is possible: a temporal shift. For example, we could, and did, offer predictors that are valid only during the 12 h period of interest. In addition, we could, and did, offer predictors valid before and after the period of interest. If the predictors chosen through screening regression are valid during the period we would conclude that the timing (speed of systems) of the model contains no bias. But if the predictors chosen are valid before the period of interest, this indicates the model is fast. Likewise, if the predictors chosen are for after the period of interest, it indicates the speed of systems is forecast too slow. The obvious method used to eliminate time biases of the models is to offer an assortment of predictors that cover the time before, during, and after the period of interest. Of course, once the speed of the model has been established it would not be necessary to continue this blanket coverage. In this case, we know from experience that the PE model moves short waves too slowly. Therefore, we merely choose predictor times accordingly.

Stability indices were found to be quite valuable as predictors during the warm season but had not been tried previously during the cold season. Screening stability for the winter proved to be of some value. Therefore, this predictor field was included in the second

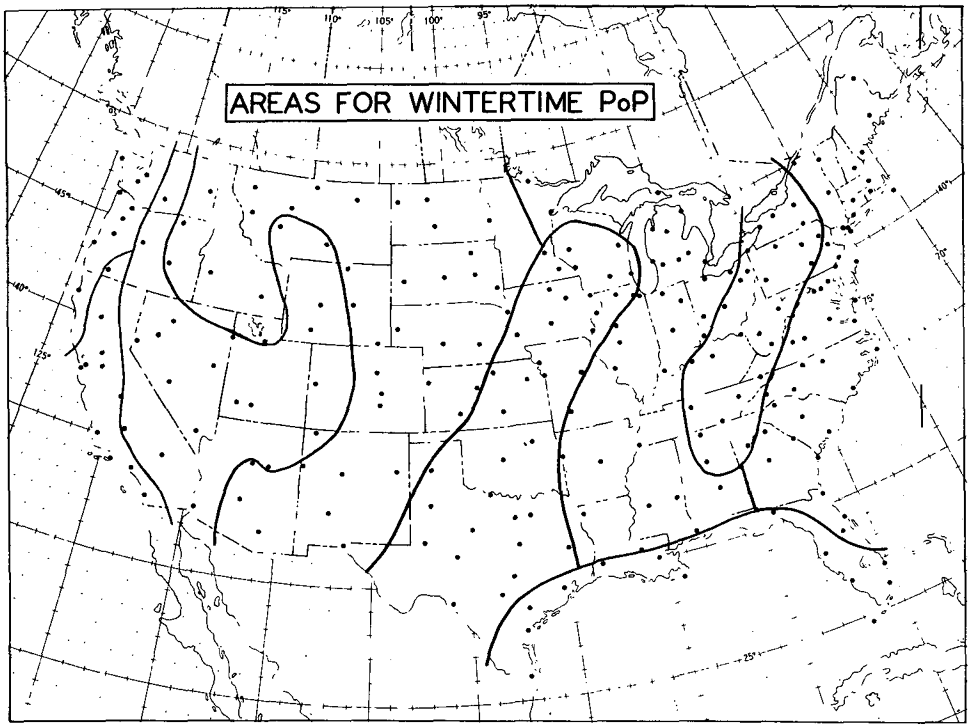

FIG. 4. The nine forecast areas used during the second winter season, 1971–72.

winter. Experimentation with smoothers continued on a limited basis. Precipitable water and relative humidity fields were again subjected to 5-, 9-, 13-, and 25-point smoothers.

There was one other important addition during the second winter. We introduced separate forecast equations for the 0000 GMT and 1200 GMT initial data computer runs.

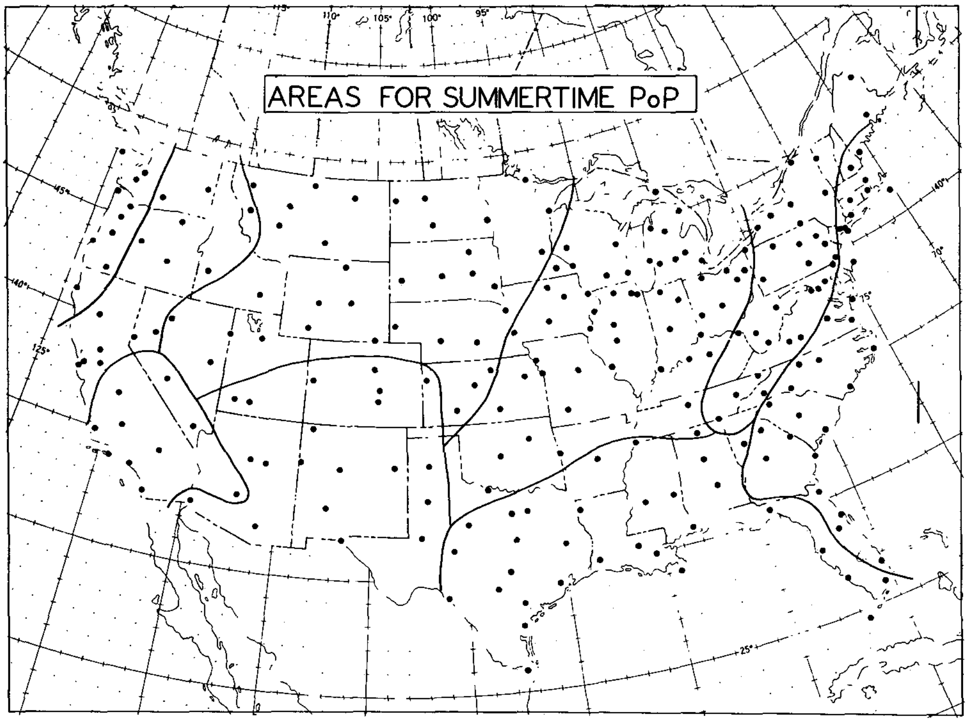

FIG. 5. The nine forecast areas used during the second summer season, 1972.

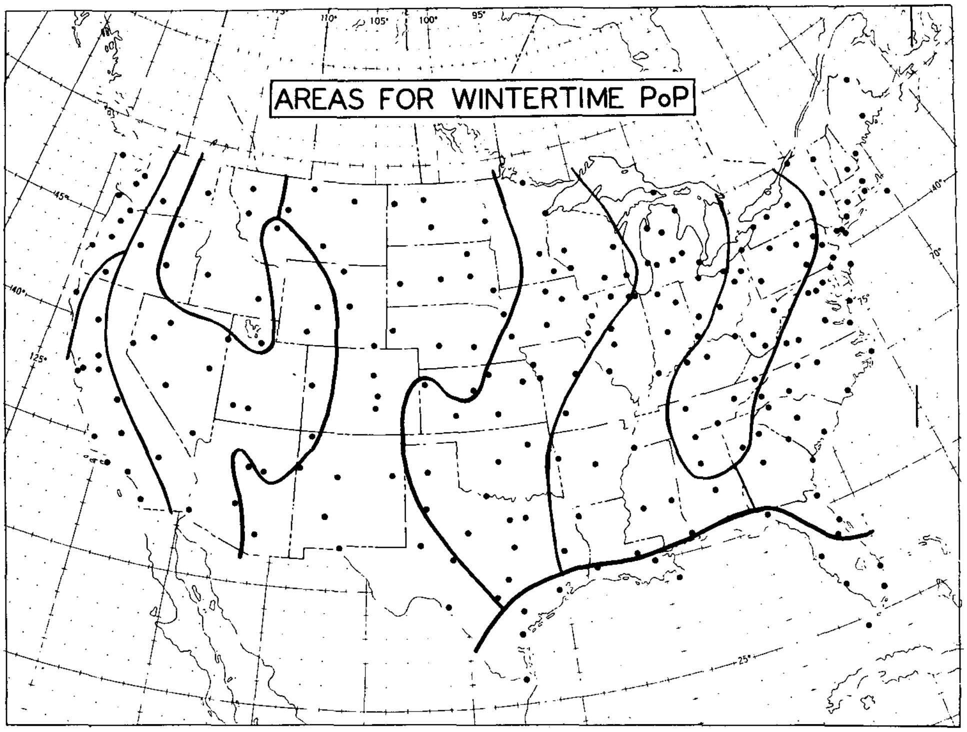

FIG. 6. The 10 forecast areas used during the third winter season, 1972–73.

The second summer was 1972. Nine forecast areas were defined (see Fig. 5). Again, the Pacific Northwest and Appalachian areas were included. We would have increased the number of areas if we had continued with two years of dependent data. However, we decided to drop back and use but one year (1971) of developmental data. This decision was based on verification data we had collected on a routine basis. The figures showed beyond any doubt that the PE model was a very dry model from October 1969 to September 1970[1]. Therefore, two years of dependent data would have been made up of one dry model year and one normal model year, resulting in a non-homogeneous sample.

Other advantages appeared in the form of moisture-related predictors when the "dry year" was eliminated. First, we were in a position to use the moisture information from layers that had recently been added to the PE model. Mean relative humidities of the three lowest layers of the PE model were still available. But now we had relative humidity of the boundary layer (a layer 50 mb thick next to the earth's surface) and the layer next to the boundary layer (up to about 700 mb). We found the additional moisture information to be quite useful. Both the mean relative humidity and individual layer relative humidities were chosen frequently through the screening process.

Second, we were now able to use PE 12 h precipitation amounts for the first time. During the dry year these forecast amounts were very small. In fact, many of the forecasts went to zero, which means nothing could be recovered through use of a scaling factor. This additional predictor was picked occasionally by the screening technique, which indicates some value or at least a contribution in the right direction.

Smoothing predictor fields continued with two changes. First, all 13-point smoothers were dropped; tests showed it was not necessary to continue both 9- and 13-point smoothing and that 9-point smoothers were slightly more valuable. Second, many unsmoothed predictors were dropped in favor of the 5-point smoother. Again, tests indicated that for most meteorological variables 5-point smoothing was better than no smoothing, even in the first forecast period. This meant that some fields such as stability indices were smoothed for the first time.

c. The third year

By this time it was possible to use two years of dependent data and still avoid the dry model year. We used data from the cold seasons 1970–71 and 1971–72 to generate equations for ten areas (see Fig. 6). These areas closely resemble those from the previous winter with one exception. We added an area in the general vicinity of Idaho at the expense of the area covering the upper plains states. This was not a matter of humidity considerations but rather an attempt to iso-

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[1] It was later determined that the dry model was the result of a PE model change made in October 1969. One year later the problem was corrected.

late different wind patterns considering the mountain ranges.

The predictor list wasn't changed except one of three stability indices was eliminated. Two indices were retained; the *K* index (George, 1960) and Total Totals index (Miller, 1972).

Other in-house studies showed us that somewhere from 10 to 12 predictors was the optimum number that would hold up when tested on independent data. So we decided to allow 12 predictors to be chosen for each area for each of the four periods. This was another step toward standardizing the procedure. But we did continue to allow the binary limits to shift according to geographical area.

The third summer we continued to standardize in several ways. We held the predictor list exactly as it was during the previous season (winter). We continued with allowing 12 predictors to be chosen in all cases. In addition, we also used a completely standard set of binary limits for all areas. This eliminated the shifting of limits that had been helpful, but we didn't really sacrifice anything since our standard set offered blanket coverage. All computer screening runs were offered 100 predictors where each binary limit is considered a separate predictor.

Two years of dependent data were available (1971 and 1972). We used these data to develop forecast equations for fourteen areas (see Fig. 7). The western portion of the country was divided into finer areas than during any previous season. This was an attempt to capture some of the high variability we know exists there. Also, we tried to divide the Appalachian area into two areas, one to the east and one west of the peaks.

The evolution and fine tuning of the procedure through these three years (six seasons) evidently was in the right direction. There is evidence that the accuracy of the forecasts continued to increase during this period.

4. Accuracy of the PoP forecasts

The accuracy of PEATMOS PoP forecasts has been compared countrywide to that of local forecasts issued to the public by NWS local offices. Verification figures for 96 stations have been computed by seasons for each of three periods (12–24, 24–36, 36–48 h) covered in public forecasts. No comparison is possible beyond 48 h. The verification statistic used is the Brier score.

The Brier score is commonly used in the NWS to measure the goodness of probability forecasts. This score is one-half the "*P*" score defined by Brier (1950) as:

$$P=\frac{1}{N}\sum_{j=1}^{r}\sum_{i=1}^{N}(F_{ij}-E_{ij})^2$$

where on each of N occasions an event can occur in only one of r possible classes, and $F_{i1}, F_{i2}, \ldots, F_{ir}$ represent the forecast probabilities that the event will occur in classes 1, 2, ..., r, respectively. If the r classes are

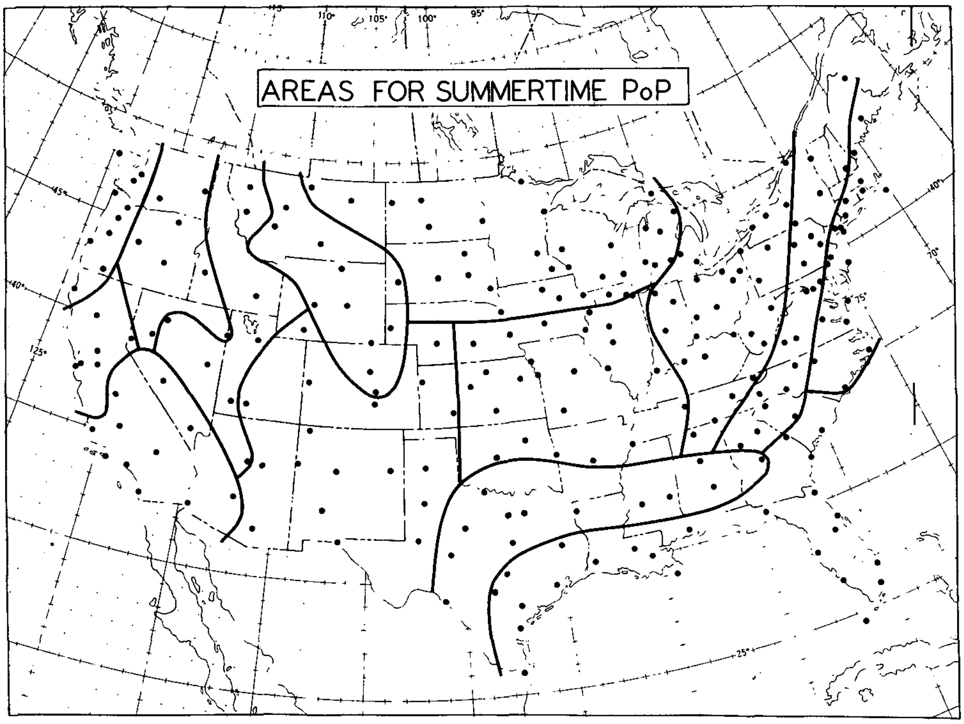

FIG. 7. The 14 forecast areas used during the third summer season, 1973.

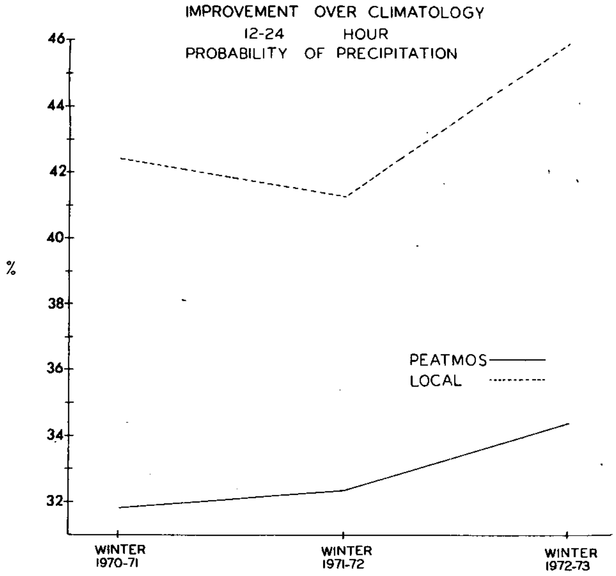

FIG. 8. First period verification scores.

chosen to be mutually exclusive and exhaustive,

$$\sum_{j=1}^{r} F_{ij}=1$$

for each and every $i=1, 2, \ldots, N$. E_{ij} takes the value 1 or 0 according to whether the event occurred in class j or not. For perfect forecasting the P score will have a value of zero and for the worst possible forecast a value of two. The Brier score, then, has a range of zero to one. But raw Brier scores will naturally vary from one section of the country to the next because of the relative frequency of occurrence of the event (in this case measurable precipitation). So we decided to show Brier scores in terms of percent improvement over climatology. Another way to look at it is the Brier score of the forecasts compared to the Brier scores produced by climatological forecasts. Climatology is defined as the relative frequency of precipitation by month and by station determined from a 15-year sample (Jorgensen, 1967).

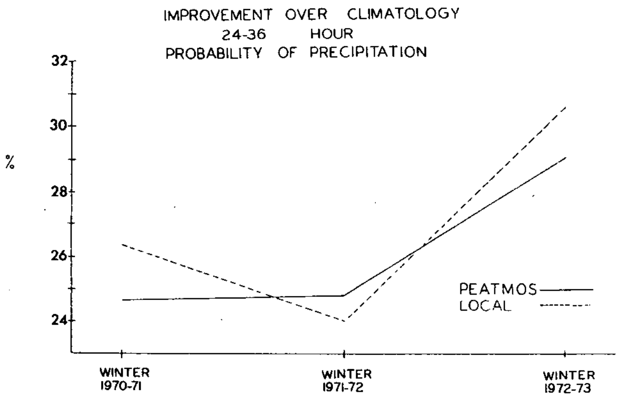

FIG. 9. Second period verification scores.

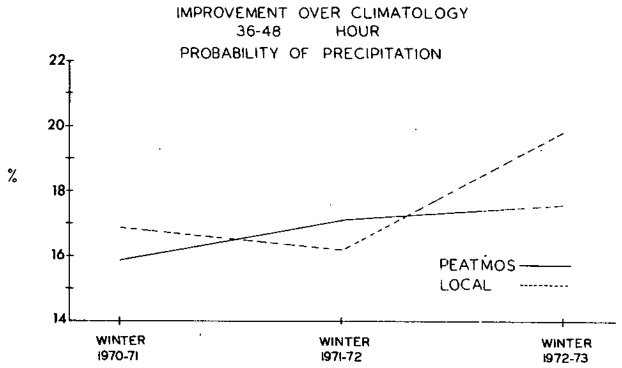

FIG. 10. Third period verification scores.

First period (12–24 h) winter scores are shown in Fig. 8. The most striking feature is the spread between the PEATMOS and the local scores (about 10 percentage points). This is most likely a direct result of the local forecasters having 8–9 h of later data. The spread shows that the forecasters are able to use these later data effectively. We can see from Fig. 9 that this spread was greatly reduced by the second period. The same is true for the third period (see Fig. 10). This series of winter verification scores shows several interesting features. Keep in mind that the forecasters did not see PEATMOS PoP guidance during the first winter, saw it for half of the second winter, and saw it during the entire third winter.

First, PEATMOS forecasts during each period improved each year over the previous year. We feel this trend was the direct result of year-to-year refinements discussed earlier. These include larger dependent data samples, more areas, and additions such as stability, smoothers, etc. Second, local forecasts were more accurate than PEATMOS during the first winter, got worse for all periods during the second winter, then were much better for all periods during the third winter. We cannot say exactly why the bad year. However, a month by month breakdown shows the problem to be

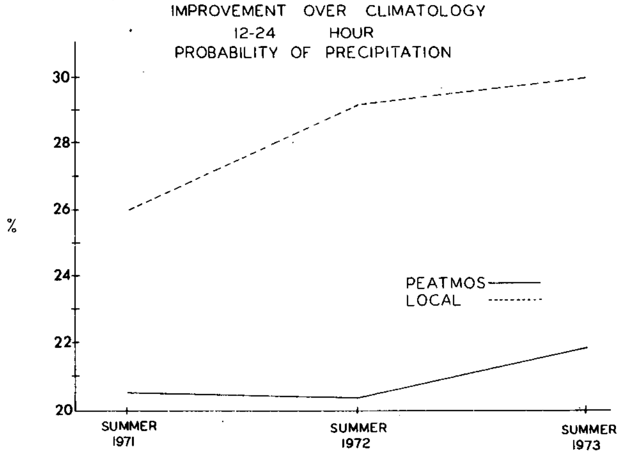

FIG. 11. First period verification scores.

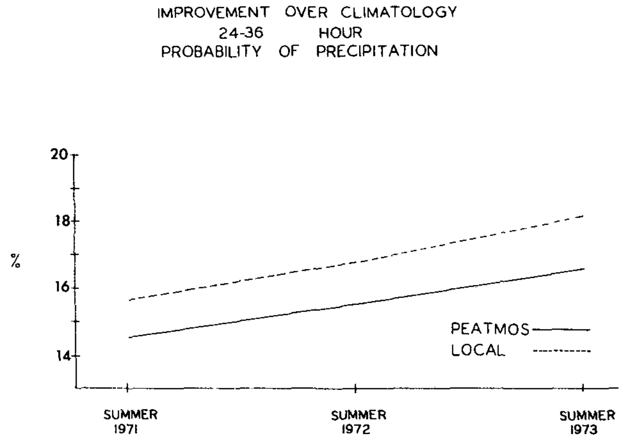

FIG. 12. Second period verification scores.

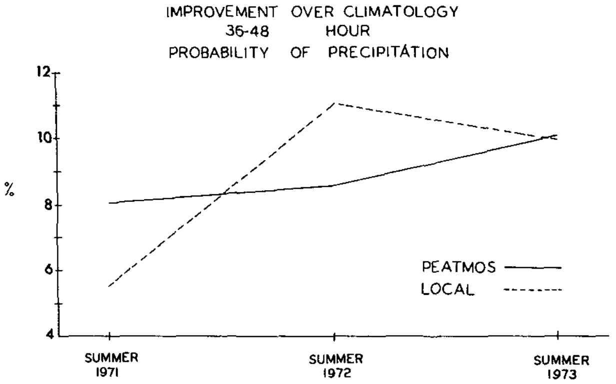

FIG. 13. Third period verification scores.

concentrated in the months of January, February, and March 1972. The evidence suggests that it took about three months for the forecasters to adjust to the new guidance material. We will show later that this adjustment period did not spill over into the summer of 1972. It is heartening that the local forecasters did so well during the third winter. We would like to believe that this was due to the improved guidance. After all, not only did PEATMOS improve each year for each period, but by the third winter PEATMOS, except for the first period, had greater improvement over climatology than the local forecasts had in the first winter. In short, this means that not only is the trend for both products in the right direction, but guidance in 1972–73 was better than the final product had been in 1970–71. Of course, we must be careful when speaking of trends over such a short period. For example, we know that some years will turn out to be easier than others to forecast PoP. It is possible that the third winter was an easy season that would account for some of the good scores.

Summer scores for the first period (Fig. 11) show several interesting features. Improvement over climatology in percent is much less than in winter for both PEATMOS and local forecasts. This relates to the fact it is harder to forecast precipitation in summer than in winter. Summer precipitation patterns are not nearly as well organized as those in winter.

Considerable spread in the first period continues into the summer. But this spread again drops off to less than 2% by the second period (see Fig. 12) as it did in the winter. In a practical sense, this graph represents the ideal relationship between final product and guidance. Both continue to improve with time and the final product is always somewhat better than the guidance. Third period scores (see Fig. 13) are difficult to explain unless we remember that our improvement is in the range of 5 to 11% and a few forecasts can have a sizable effect on the score. But except for isolated deviations there are certain features shown in the summer scores (see Fig. 12 for a good example). PEATMOS and local forecasts continued to improve each year to such a degree that the third summer guidance was superior to first summer local forecasts. This is consistent with winter results and brings us to the conclusion that: 1) PoP forecasts going to the public are now more accurate than in previous years, and 2) this improvement is most likely the result of improved guidance (PEATMOS PoP), although there was a slight adjustment period that lasted only a few months when the objective guidance was introduced.

5. Operational aspects

Now for a look at a typical equation. The one shown in Table 1 was used for the area along the east coast during the third winter for the first period from 0000 GMT initial data. This example was chosen because it is typical. It can be seen that for the first time period 5-point smoothers are the most valuable and that 9-point smoothers were chosen through screening a couple of times. The PE model is far more valuable than the TJ model. This is not surprising since the TJ model was not designed for precipitation forecasting. The mean relative humidity (MRH) is by far the most important single predictor. Precipitation amount,

TABLE 1. Operational forecast equation used during the 1972–73 cold season for the first 12-hour PoP period based on 0000 GMT data along the east coast. Mean relative humidity (MRH) values are in %, precipitation and precipitable water (PW) in hundredths of inches, stability in °C, and vertical velocity (VV) in microbars per second where negative values relate to upward motion.

Predictor	Contribution to PoP(%)	Cumulative reduction of variance
Constant	89.1	
1. PE 5-pt MRH $\leqslant 75\%$ at hour 24	−11.9	0.342
2. PE 9-pt MRH $\leqslant 60\%$ at hour 24	−5.4	0.393
3. PE 5-pt Precipitation $\leqslant 1$ at hour 24	−12.7	0.422
4. PE and TJ 5-pt K-Index $\leqslant 5$°C at hour 24	−3.6	0.434
5. PE 9-pt MRH $\leqslant 80\%$ at hour 24	−9.0	0.444
6. TJ 5-pt Precipitation $\leqslant 0.002$ at hour 24	−8.6	0.450
7. PE 5-pt 850 VV $\leqslant -0.5$ at hour 24	8.3	0.454
8. PE 5-pt PW $\leqslant 60$ at hour 18	−6.4	0.458
9. PE 5-pt MRH $\leqslant 55\%$ at hour 24	−7.8	0.460
10. PE 5-pt MRH $\leqslant 65\%$ at hour 24	−7.0	0.461
11. PE 5-pt MRH $\leqslant 85\%$ at hour 24	−10.7	0.463
12. PE and TJ 5-pt Total Totals $\leqslant 46$°C at hour 24	−5.9	0.464

(Probability range is 0% to 97%)

precipitable water, stability, and vertical velocities are important enough to be chosen once or twice. The higher the reduction of variance the better the relationship.

The relation of Table 1 to the regression equation,

$$\hat{Y}=C+a_1X_1+a_2X_2+\cdots+a_{12}X_{12},$$

is as follows: the estimate of Y (the predictand) is equal to the regression constant (89.1) plus $a_1X_1+a_2X_2$, etc. Listed in the column "Contribution to PoP" just under the constant are the values for $a_1, a_2, \ldots, a_{11}, a_{12}$. Since all predictors are binary, the X's take on a value of one if the criteria listed is met and zero if it is not met. It follows that the forecast probability range when this equation is used is 0% up to 97%.

When the new product first appeared on the National Facsimile (NAFAX) circuit, objective forecasts were hand-traced (see Fig. 14). Nearly a year later NMC gained the capability to machine-trace the PEATMOS PoP charts (see Fig. 15). At that time, we decided to add the conditional probability of frozen precipitation forecasts [PoFP(P)]. We also transmitted a teletype message twice daily on Service C listing PoP and PoFP(P) values for 152 stations. See Glahn and Bocchieri (1975) for a full description of PoFP(P) and the teletype message.

What steps should be taken by the forecaster in order to improve upon this type of guidance? Perhaps the most important rule to remember is what not to do. In general, *Do not try to remove systematic errors of the models.* Most of these errors have already been removed by use of the MOS approach.

What should be done to improve the objective probabilities is difficult to pinpoint but here are some ideas on the subject.

1) When the PE and TJ models are in agreement (i.e., both wet, both dry, etc.), think twice before changing the forecast. When the two are in disagreement, study the situation in detail to determine which one is probably correct and adjust the forecast accordingly. Agreement can produce forecasts throughout the probability range. Disagreement will usually produce a forecast in the middle of the range. Therefore, one should be careful about changing high or low forecasts, but look for a chance to change a forecast in the middle.

2) If non-systematic errors in the PE and TJ models can be identified, a subjective adjustment to the PoP forecasts would be in order.

3) The edges of spreading or moving precipitation areas can be watched. This can give a model of the day (i.e., if it is raining at one station where the forecast was 40%, it can just as easily rain at a nearby station where the PoP forecast was also 40%). This is mainly a first-period adjustment based on later data.

4) Be alert to locate tight gradients in the PoP forecast field. Even a slight shift of the system could mean a large difference in the PoP value.

5) Try to add local effects within areas. The present

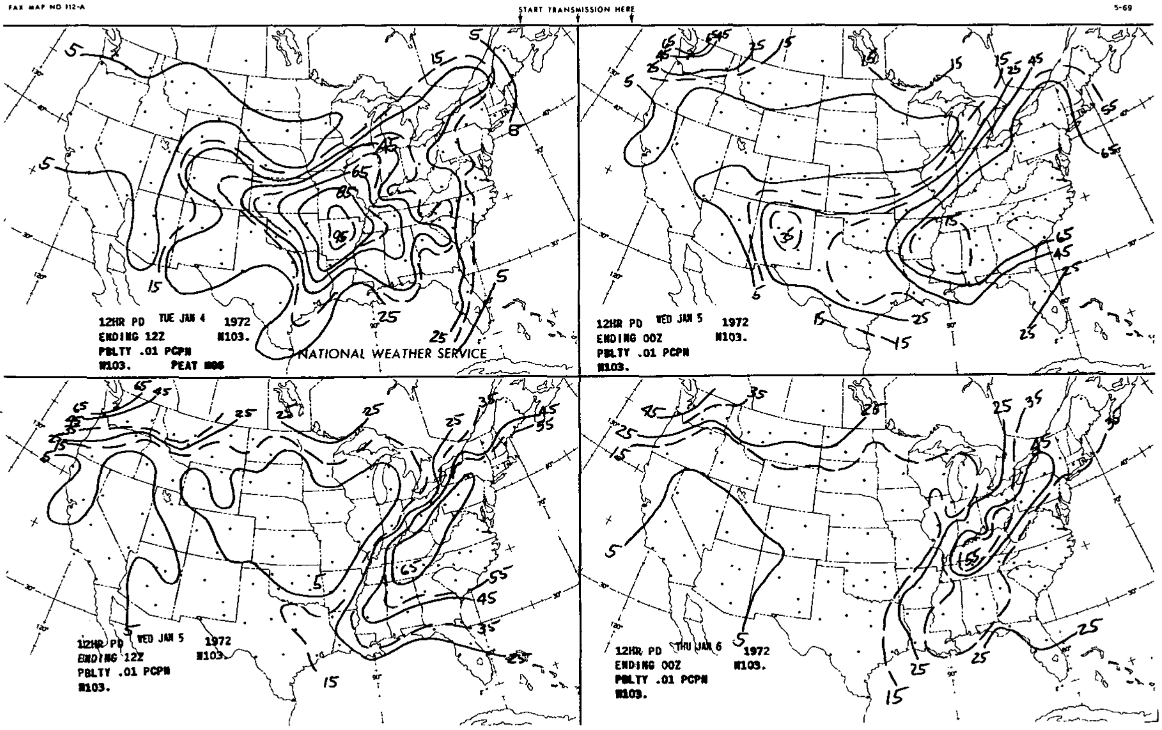

FIG. 14. Probability of measurable precipitation (%) for times shown. Isolines are hand drawn.

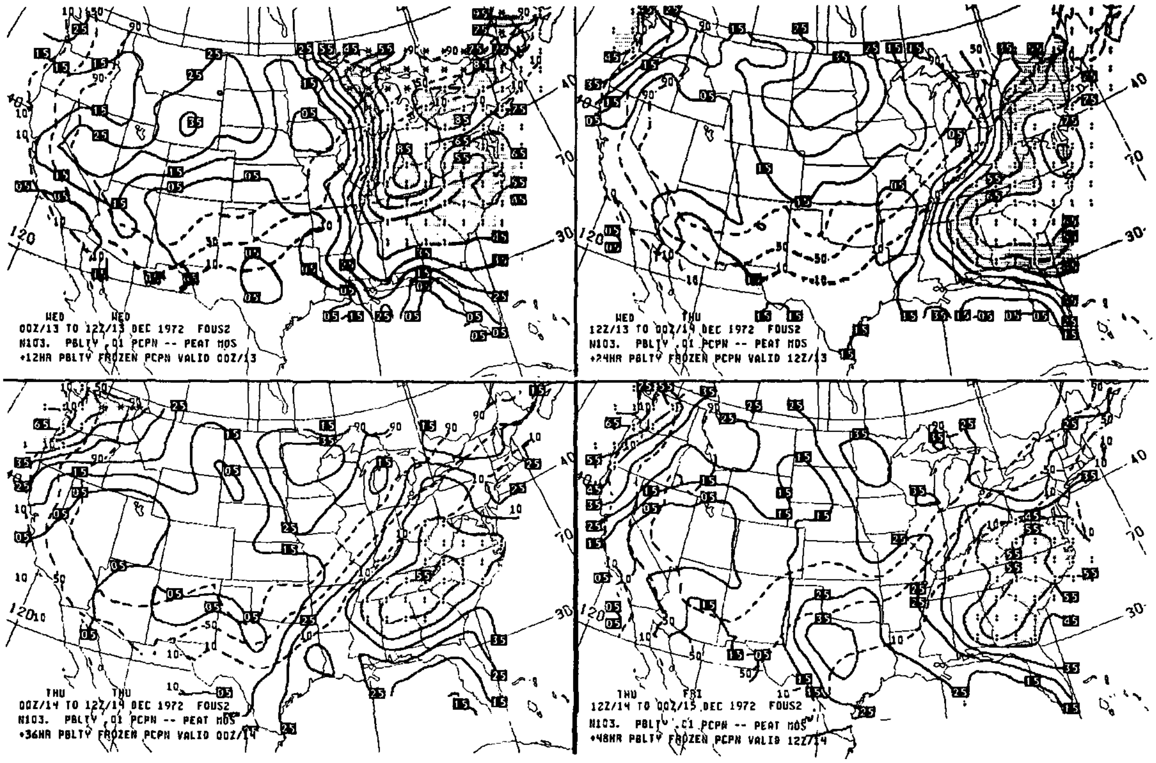

FIG. 15. Probability of measurable precipitation (% in solid lines) and frozen precipitation (% in dashed lines) for times shown. Isolines are machine (computer) drawn.

equations cannot do this because they are generalized by areas. This means that the same forecast equations are applied at all stations in a given area.

6) Evidence to date indicates the PEATMOS PoP forecasts can be improved subjectively in the vicinity of tropical storms.

6. Additional research

Additional research efforts aimed at further objective improvement of PEATMOS PoP forecasts can take several forms. One obvious area deals with the use of data that become available between the time PEATMOS PoP is produced and forecast release time. These data deteriorate rapidly with time and are relevant mainly to the first period. A successful scheme, introduced by Moore and Smith (1972), updates PEATMOS PoP forecasts by using the latest available radar reports. Further testing of this procedure was done by Peters and Barnes (1973) and by Moore, Cummings, and Smith (1974).

Additional numerical models appear on the operational scene from time to time. A good example is the Limited Area Fine Mesh Model (LFM) (Howcroft and Desmaris, 1971). Studies by Ronco (1972, 1973) showed that model output from the LFM contained additional predictive value not contained in PEATMOS PoP. Large scale testing of this concept by Glahn and Bocchieri (1976) revealed some inconsistencies but they concluded that the LFM output will probably be suitable for operational use in MOS in the near future. They also concluded that the addition of the sine and cosine of the day of year and continuous predictors to the usual binary predictors will increase the accuracy of PoP forecasts. Perhaps further predictors could be found.

Another numerical model that holds much hope for the future is the updated version of SAM called the Subsynoptic Update Model (SUM) (Grayson and Bermowitz, 1974). Model outputs are being archived for future testing with the MOS system.

Still another area for future research lies in the collection of additional years of model outputs from the current models. This, of course, will increase the size of the dependent data sample. This, in turn, will lead to more and shorter seasons or to more and smaller forecast areas. The ultimate is many seasons and single station equations. However, much testing will be needed to determine if many seasons and single station PoP equations will be desirable.

7. Summary and conclusions

We developed a stable numerical model (SAM) in order to introduce and test a new concept in statistical prediction. The tests were related to probability of precipitation (PoP) forecasting. Experimental results were quite successful: we called our system Model Output

Statistics (MOS). Application of MOS to two basic NMC models produced PEATMOS. And the application of PEATMOS to PoP produced the subject of this paper, PEATMOS PoP. MOS has since been used by a number of investigators covering a wide range of meteorological variables. The ultimate goal is to provide MOS-produced forecasts of all common meteorological variables to form the basis of computer worded forecasts in the AFOS program.

Development of the seasonal equations has been evolutionary in order to aim at continued improvement of the system. Accuracy of forecasts produced by this model has continued to increase with time. This gives some indication that the continuous changes introduced were in the right direction. PoP forecasts going to the public from NWS local offices have also improved with time. This improvement is likely the result of better guidance (PEATMOS PoP) although there was a slight adjustment period that lasted only a few months when the objective guidance was introduced.

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