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LFM-Based MOS Forecasts of the Probability of Precipitation (PoP)

Program Requirements and Development Division, Silver Spring, MD 20910

SIGNIFICANT CHANGES FROM LAST BULLETINS ON THIS SUBJECT, NO. 289 AND NO. 299

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Revised MOS Probability of Precipitation (PoP) forecast equations for stations in the contiguous United States were derived in early 1989 from output of the Limited-area Fine-mesh Model (LFM). The cool season equations became operational in February 1989 and the warm season equations in April 1989. These PoP equations produce forecasts of the probability of 0.01 inches or more of liquid equivalent precipitation in a 6- or 12-h period. The new forecast equations used a substantially larger developmental data sample than the one used by the old PoP equations, and they also used new predictors in addition to the old ones.

This bulletin, prepared by Dr. James C. Su of the Techniques Development Laboratory, describes the new PoP forecast equations and relevant products. Notice, in particular, Section 5 on Special Notes for MOS PoP Guidance Users.

Technical Procedures Bulletins Nos. 289 and 299 are now operationally obsolete.

Mary M. Heffernan
Chief, Services Development Branch

U.S. DEPARTMENT OF COMMERCE — National Oceanic and Atmospheric Administration

LFM-BASED MOS FORECASTS OF THE PROBABILITY OF PRECIPITATION (PoP)

by Dr. James C. Su, Techniques Development Laboratory

1. INTRODUCTION

Revised MOS Probability of Precipitation (PoP) forecast equations for stations in the contiguous United States were derived in early 1989 from output of the Limited-area Fine-mesh Model (LFM) (Gerrity, 1977; Newell and Deaven, 1981). The cool season (October-March) equations were implemented on February 8, 1989 during the 1200 UTC cycle. See National Technical Information Message (NTIM) No. 89-2, dated February 7, 1989, for the details. Warm season (April-September) equations were implemented on April 5, 1989 during the 1200 UTC cycle (refer to NTIM No. 89-4). These PoP equations produce forecasts of the probability of 0.01 inches or more of liquid equivalent precipitation in a 6- or 12-hour (h) period. PoP forecasts for 6-h periods are valid for intervals of 6-12, 12-18, 18-24, 24-30, 30-36, 36-42, 42-48, 48-54, and 54-60 hours after 0000 or 1200 UTC. PoP forecasts for 12-h periods are valid for intervals of 12-24, 24-36, 36-48, and 48-60 hours after initial time of each cycle.

The new LFM MOS PoP forecast equations were developed by using more data in the developmental sample and by including more predictors than in the old equations. Data for October 1978 through March 1988 were used to derive the cool season forecast equations. Data for April 1979 through September 1988 were used to develop the warm season forecast equations. The new sample was substantially larger than the one used for the old PoP equations. Tests on independent data indicated some improvement in the accuracy of the PoP forecasts generated from the new equations, especially for the cool season.

This Technical Procedures Bulletin describes the current operational MOS PoP forecast system. In Section 2, a general description of the development method is given. In Section 3, the development of the forecast equations is described, and the pre-implementation test results are presented. The PoP guidance products are discussed in Section 4 and guidelines on the effective utilization of the PoP guidance are summarized in Section 5. Finally, some references are listed in Section 6.

2. METHOD

In the Model Output Statistics (MOS) approach (Glahn and Lowry, 1972), a predictand or observed weather element is related to various predictors, such as numerical model forecasts, previous surface observations, or climatic variables, by a statistical procedure. For PoP, linear regression analysis is used to determine the relationships.

The predictand is the occurrence of 0.01 inches or more of liquid equivalent precipitation at a station in a 6- or 12-h period. Thus, for example, the predictand is set equal to 1 if 0.01 inches or more of precipitation occur in the 6- or 12-h period of interest; otherwise, the predictand is set equal to 0. Each PoP forecast equation then expresses the predictand in terms of a linear combination of the predictors. The equations generate forecast values of the probability of precipitation occurring, that is, PoP.

In the MOS system, predictors include forecasts from a numerical weather prediction model, surface weather observations, and climatic variables. All predictors are valid at the station where the predictand is observed. The model predictors are interpolated from the LFM grid to the station of interest and include such variables as winds, relative humidity, precipitable water, precipitation amount, and so forth. In general, the model predictors are forecasts valid at or near the time of occurrence of the predictand. Surface weather observations are also used for forecast projections of 24 hours or earlier. Finally, climatic variables such as the sine or cosine of the day of the year, the station elevation, and the station latitude or longitude may be included as predictors.

While most predictors are treated as continuous variables, some quantities such as precipitation amount or station elevation are broken into ranges and each range is represented by a binary value in the MOS PoP system. A binary predictor can only take on a value of zero or one, depending on whether the predictor exceeds a pre-determined break point or not. If, for example, the break point for precipitation amount is set at 0.10 inches, then an LFM forecast of 0.09 inches results in a predictor value of 1. On the other hand, an LFM forecast of 0.11 inches would set the binary predictor to 0. These binary predictors are particularly important for forecasts of events, like precipitation, that are themselves binary in nature.

In using the MOS approach, we develop PoP forecast equations for seasons, geographical regions, forecast cycles (0000 and 1200 UTC), and projections. The developmental data are divided into seasonal groupings so that the MOS equations more closely define the relationship between predictand and predictors. PoP forecast equations are developed for climatically similar regions. Developmental data are grouped for a set of stations and one forecast equation is derived for this set. This "regionalized equation" approach is helpful in developing stable equations to predict events that are binary in nature and that may occur relatively infrequently. These regionalized equations are then used for every station of interest in the region. While the equation coefficients remain the same for every station in the region, the predictor values vary, of course, from one station to another.

Finally, in the MOS development, we often derive simultaneously forecast equations for several weather elements. This approach ensures that the same predictors are used in each equation, although the coefficients vary from one equation to another. The simultaneous approach enhances, **but does not guarantee**, meteorological consistency among forecasts. Thus, for instance, 6-h PoP forecast equations for the 12-18 and 18-24 h projections are derived simultaneously with the 12-h PoP forecast equation for the 12-24 h projection. In this way, 12-18 and 18-24 h PoP forecasts will generally be less than or equal to the 12-24 h PoP forecasts.

3. DEVELOPMENT

a. Forecast Projections

Forecast equations were developed for PoP in 6-h periods valid 6-12, 12-18, 18-24, 24-30, 30-36, 36-42, 42-48, 48-54, and 54-60 hours after both 0000 and 1200 UTC. For PoP in 12-h periods, the MOS equations were developed for the 12-24, 24-36, 36-48, and 48-60 h projections after both 0000 and 1200 UTC. To enhance consistency in the MOS forecasts, equations were developed simultaneously for the 12-18, 18-24, and 12-24 h projections; for the 24-30, 30-36, and 24-36 h projections; for the 36-42, 42-48, and 36-48 h projections; and for the 48-54, 54-60, and 48-60 h projections.

b. Developmental Sample

The developmental data consisted of forecasts from the LFM and observed data for 222 stations in the contiguous United States. The sample was taken from the period of November 1978 through September 1988. Observed data were used as potential predictors only for projections of 24 hours or less. Developmental data were stratified into subsets for seasons and regions, and regional forecast equations were developed for both seasons.

c. Seasons

Two seasons were used in the development: cool and warm. The cool season includes October through March, and the warm season includes April through September. Developmental data were available for 10 cool and 10 warm seasons.

d. Regions

Regions in this development were identical with those used in the previous operational MOS PoP forecast equations. These regions were determined by examining the correlation between the LFM forecast and the observed relative frequency of precipitation amount greater than or equal to 0.01 inches (see a complete description of the method in Technical Procedures Bulletin No. 289 (National Weather Service, 1980)). The 26 cool season and 27 warm season regions are shown in Figures 1 and 2, respectively.

e. Predictors

Potential predictors included LFM forecasts of the mean relative humidity (surface to approximately 490 millibars (mb)); precipitation amount; precipitable water; K index; U and V wind components at 850, 700 and 500 mb; relative vorticity at 850 and 500 mb; moisture divergence at 850 and 700 mb; and the vertical velocity at 850 and 700 mb. These forecast variables were valid at the beginning and ending of the predictand period and, in the case of the 12-h PoP, at the midpoint of the 12-h interval. The PoP's valid beyond 48 hours were an exception to this rule; for the 48-54, 54-60, and 48-60 h PoP's, all of the LFM predictors were for the 48-h projection. For the 6-12, 12-18, 18-24, and 12-24 h PoP's, surface observations at the initial cycle time (0000 or 1200 UTC) were also used as potential predictors. Finally, the sine and cosine of the day of the year, the station latitude, the station longitude, and the station elevation were included as possible predictors.

Predictors frequently used in the forecast equations are relative humidity, low-level moisture divergence, precipitable water, precipitation amount, 500-mb relative vorticity, and station longitude. Time differences of relative humidity and precipitable water are frequently included.

f. Equations

For all the PoP forecast equations, 18 predictors are used. For those equations developed simultaneously for a 12-h projection period, all three equations (two 6-h PoP equations and one 12-h PoP equation) have the same predictors, but with different regression coefficients.

These equations are regional equations that were developed by using data from individual geographical regions. Each equation is used to compute the forecasts for all stations in the particular region, and for the appropriate cycle and projection.

For the 12-h, 18-h, and 24-h projections, two sets of forecast equations were developed. In the first or "primary" set, LFM variables and some surface observation variables were included as potential predictors; in the second or "backup" set, only LFM variables were used. In the operational production of the PoP guidance, we first use the primary equations. If the surface observations needed by these equations are not available, the backup equations are used.

g. Pre-implementation Test Results

Experimental equations developed from data for the period from November 1978 through September 1987 were tested on independent data for the period of October 1987 through September 1988. Note that only equations for the 12-24, 24-36, 36-48, and 48-60 h PoP's were tested. Verifications (Figure 3) show the percent improvement of the new LFM MOS PoP guidance over the old guidance in terms of the Brier scores for the cool and warm seasons. For the cool season, the maximum improvement is at the 36-h projection for the 0000 UTC cycle, and at the 48-h projection for the 1200 UTC cycle. For the warm season, the maximum improvement is at the 36-h projection for the 0000 UTC cycle, and at the 24-h projection for the 1200 UTC cycle. Generally, the guidance improved more for the cool season than for the warm season.

4. PRODUCTS AND SCHEDULES

The PoP forecast products are described in this section. Both alphanumeric and graphics products are available. Note that in the alphanumeric products, the PoP's are rounded to 0, 2, 5, 10, 20, 30, ..., 90, or 100 percent. In the graphics products, an objective analysis scheme is used to draw contours. For these reasons, the user should be aware that the PoP presented for a station in an alphanumeric message may not agree with a value interpolated to a specific site from a graphics product. The correct rounded value is the forecast available in the alphanumeric message.

a. FPC (FOUS12)

The 6- and 12-h PoP forecasts are available on AFOS in the FPC product. The same message is also available on the Family of Services' (FOS) Domestic Data Service and at the Federal Aviation Administration's Weather Message Switching Center (WMSC) as the FOUS12 bulletin. An example of a FOUS12 message is shown in Figure 4. This message was generated from LFM forecasts from the 1200 UTC cycle on May 4, 1989. The line indicated by POP06 shows the 6-h PoP forecasts; POP12 indicates the 12-h PoP forecasts. The values shown in each of these two lines are the probability of precipitation in percent. These messages are produced for dissemination around 0230 UTC for the 0000 UTC cycle, and 1430 UTC for the 1200 UTC cycle. A complete explanation of the FPC product is given in Technical Procedures Bulletin No. 325 (National Weather Service, 1983a). Note that the 6-h PoP forecasts are not transmitted for the 54- or 60-h projections.

b. AFOS Graphics Products NMCGPH04P, 06P, 08P, and 09P

The 12-h PoP forecasts are also available in graphics form on AFOS. Figure 5 shows an example of AFOS graphics product 04P. In this map, the isolines are labeled with percentage values of the probability of precipitation. The AFOS maps are available around 0300 UTC for the 0000 UTC cycle and 1500 UTC for the 1200 UTC cycle. Products 04P, 06P, 08P, and 09P correspond to the 12-24, 24-36, 36-48, and 48-60 h PoP's, respectively.

c. FOUS22

The 12-h PoP forecasts are available on the FOS and WMSC in the FOUS22 bulletin. An example of FOUS22 messages for Washington National Airport (DCA), Washington Dulles International Airport (IAD), and Baltimore-Washington International Airport (BWI) is given in Figure 6. The line indicated by POP12 shows the 12-h forecasts of probability of precipitation in percent. The FOUS22 messages are available for 267 stations around 0230 UTC for the 0000 UTC cycle, and 1430 UTC for the 1200 UTC cycle. See Technical Procedures Bulletin No. 327 for more details (National Weather Service, 1983b).

d. DIFAX Products D068 and D142

DIFAX graphics products are illustrated by an example of one panel of D142 shown in Figure 7. These products present 12-h PoP forecasts for four projections. In these maps, isolines are labeled with probability of precipitation in percent. Other symbols indicate the precipitation types. DIFAX product D068 is available around 0400 UTC for the 0000 UTC cycle; D142 is transmitted about 1600 UTC for the 1200 UTC cycle.

5. SPECIAL NOTES FOR MOS GUIDANCE USERS

For effective use of the LFM-based MOS PoP forecast guidance, some specific notes are given in this section. Advice on how to use the MOS guidance has been provided by Lowry (1980) and by Maglaras and Carter (1986). A summary of these papers as well as our own recommendations are given here.

a. The equations used for providing MOS PoP guidance were developed for two seasons: the cool season equations are valid for the period from October through March, and the warm season equations are for April through September. Each equation represents the conditions found in the developmental sample. An adjustment of the PoP guidance may be necessary if actual conditions deviate sharply from normal seasonal values.

b. The MOS system switches PoP forecast equations from cool season to warm season on April 1, and from warm season to cool season on October 1. There may be an abrupt change in MOS PoP guidance from March 31 to April 1 or from September 30 to October 1 even though the weather regime is slowly changing or persistent.

c. The PoP equations were developed for 26 geographical regions in the contiguous United States for the cool season, and 27 regions for the warm season. Each equation represents overall conditions in the corresponding geographical region. The PoP guidance should be adjusted when the weather at a station is influenced by local conditions, such as the proximity of high mountains, lakes, oceans, or an urban heat island.

d. For each 12-h period, one 12-h PoP forecast equation and two 6-h PoP forecast equations for two consecutive 6-h periods were developed simultaneously. All three equations have the same predictors but different coefficients. This development method is an attempt to prevent inconsistency between the 6-h PoP and the 12-h PoP forecasts. However, inconsistencies may still occur. Thus, for example, a 6-h PoP may be higher than the 12-h PoP for overlapping projections. In this case, we believe the forecaster should follow the 6-h PoP's.

e. The forecast equations include both continuous and binary predictors. If a binary predictor has a large coefficient, the PoP forecast may show abrupt changes between two consecutive projections or between two neighboring stations. For example, if mean relative humidity with a break point of 70% is used in a forecast equation and its coefficient is -0.2, the PoP forecast decreases by 20% when only the mean relative humidity changes from 71% to 69%.

f. Surface observations such as opaque sky cover, ceiling height, or wind speed are used in some MOS PoP forecast equations for 12-h, 18-h, and 24-h projections. If errors are present in the surface observations, the MOS PoP guidance should be adjusted accordingly.

g. Knowledge of the most frequently used predictors may be helpful for diagnosing MOS PoP forecast problems.

h. The MOS PoP guidance has already been adjusted to account for many of the systematic errors (biases) of the LFM. Users do not have to adjust the MOS PoP guidance to account for these biases.

i. Few rare events, such as the passage of a hurricane over a station, are included in the developmental data base. The MOS PoP guidance may not be suitable in these cases and adjustments may be needed.

j. For extended projections, such as 48 or 60 hours, the MOS PoP forecasts tend to approach the climatic mean. The user should adjust the MOS PoP guidance for the longer-range projections when he/she thinks deviation from the climatic mean is warranted.

k. The MOS PoP guidance was developed to predict synoptic-scale precipitation, and is not suitable for predicting sub-grid scale convective precipitation. In the event of the likelihood of thunderstorms, the MOS TSTM (12-h thunderstorm probability) guidance should be considered.

l. A brief summary of the PoP system is given in Figure 8.

6. REFERENCES

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Newell, J. E., and D. G. Deaven, 1981: The LFM-II model-1980. NOAA Technical Memorandum NWS NMC-66, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, 20 pp.

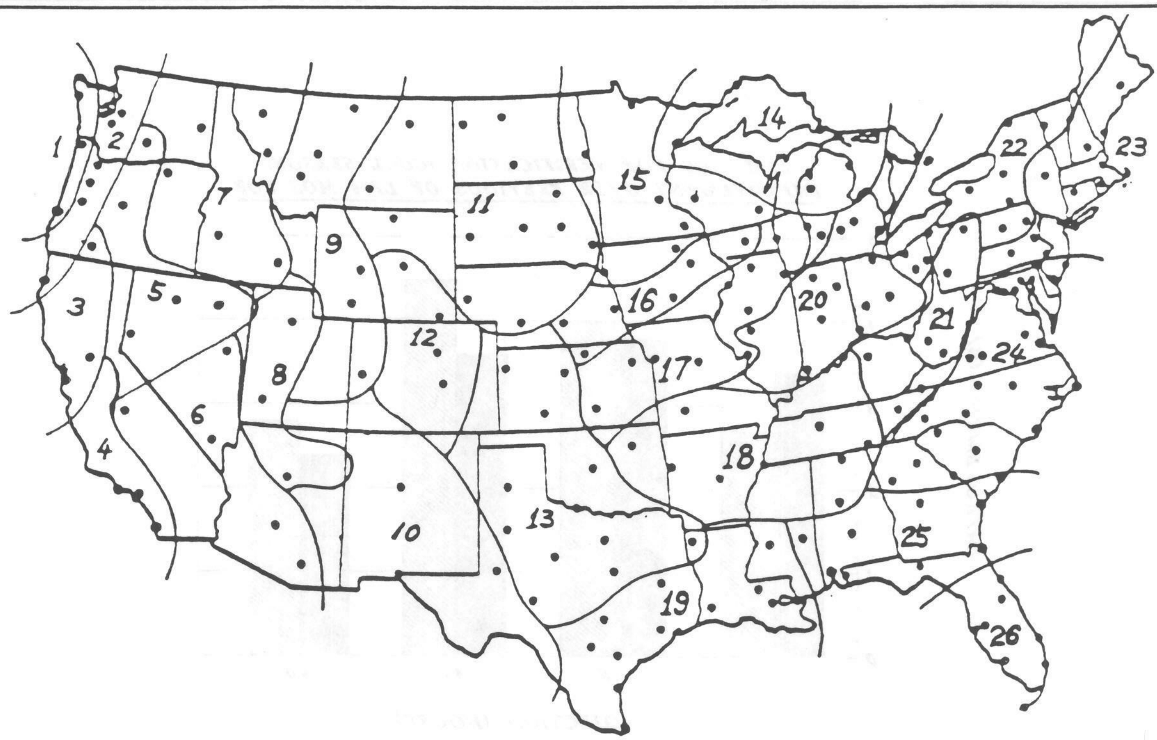


Fig. 1. The 26 geographical regions used in the development of LFM MOS PoP equations for the cool season.

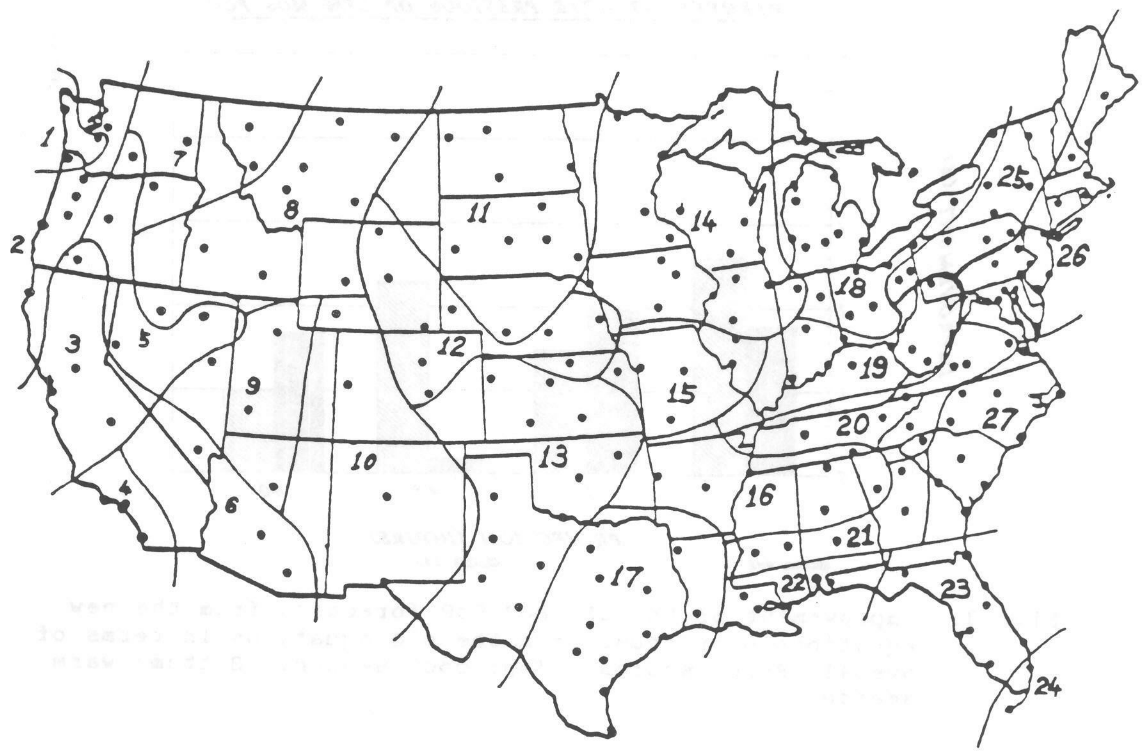
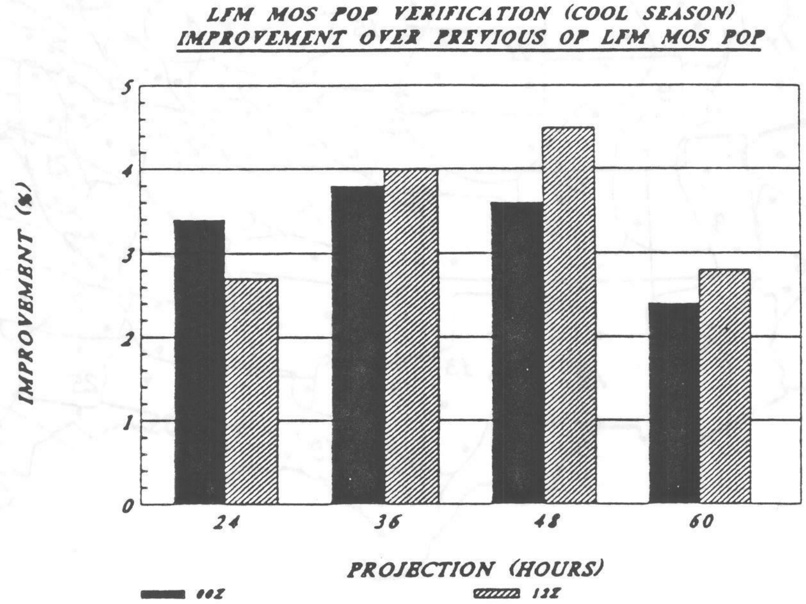


Fig. 2. The 27 geographical regions used in the development of LFM MOS PoP equations for the warm season.



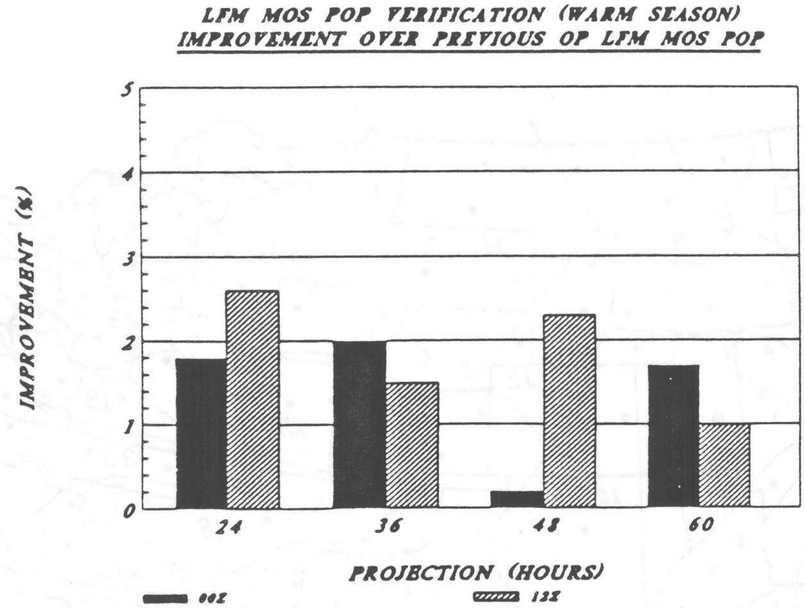


Fig. 3. Improvement of the LFM MOS PoP forecasts from the new equations over those from the old equations in terms of overall Brier scores. Top: cool season. Bottom: warm season.

NMCFPCHDG
FOUS12 KWBC 041507
HDNG FOUS12 LFM-MOS GUIDANCE 5/04/89 1200 GMT

DY/HR	04/18	05/00	05/06	05/12	05/18	06/00	06/06	06/12	07/00
NMCFPCDCA									
FOUS12 KWBC 041507									
DCA ESC									
POP06		0	5	40	90	70	50	30	
POP12				40		100		60	40
QPF06		000/1	100/1	100/1	310/3	310/3			
QPF12				2100/1		5310/3		1100/1	
TSTM				1		29		33	
MN/MX				56		68		57	70
TEMP	74 76	69 62	59 58	60 62	64 65	64 62	60 59	60 63	
DEWPT	43 42	42 45	48 50	52 55	58 60	59 58	57 56	55 54	
WIND	1207	1510	1614	1714	1815	2014	2007	2309	
CLDS	4511/1	5401/1	2224/3	0039/4	0038/4	0138/4	0225/4	0335/4	
CIG	000019	000009	001126	012232	012322	012223	012213	011115	
VIS	000009	000009	000118	002115	002116	002107	001117	001116	
C/V	6/6	6/6	6/6	4/6	3/3	2/3	2/6	3/6	
OBVIS	9000/1	9000/1	90X1/1	61X3/1	60X4/1	70X4/1	70X3/1	60X4/1	

Fig. 4. FPC (FOUS12) product for 1200 UTC, May 4, 1989.

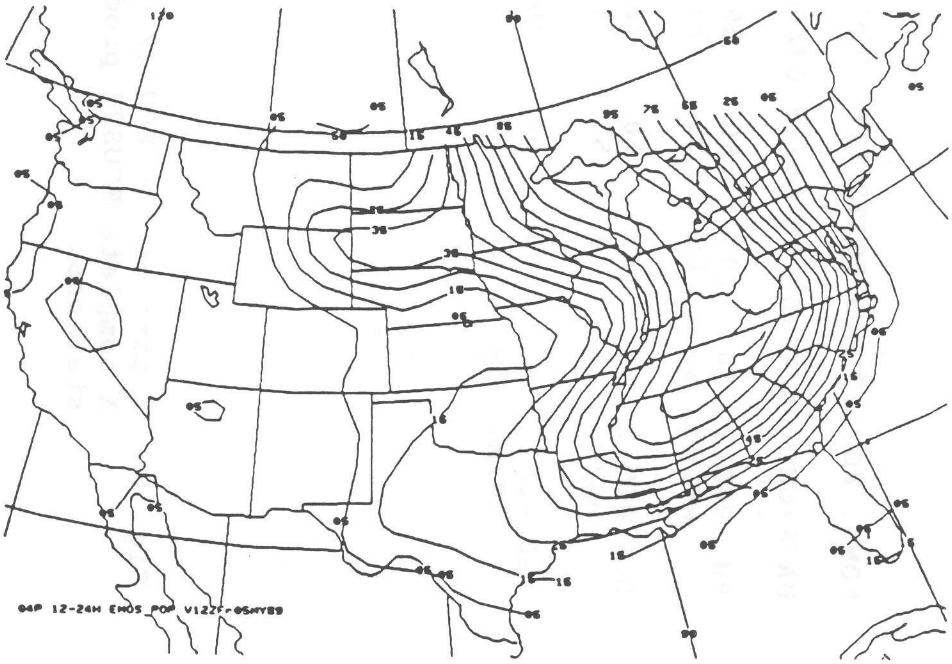


Fig. 5. AFOS product 04P valid for the 12-h period ending 1200 UTC, May 5, 1989. The forecasts were generated from 1200 UTC data on May 4, 1989.

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HDNG   FOUS22 MOS FCSTS LFM  POP          MAX/MIN  5/04/89  1200 GMT

DATE/GMT 05/12 06/00 06/12 07/00

BWI POP12   30    100    60    50
    MN/MX   52     65    55    69

DCA POP12   40    100    60    40
    MN/MX   56     68    57    70

IAD POP12   40    100    50    40
    MN/MX   54     67    53    67
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Fig. 6. A part of the FOUS22 product for 1200 UTC, May 4, 1989. A complete FOUS22 product includes forecasts for 267 stations.

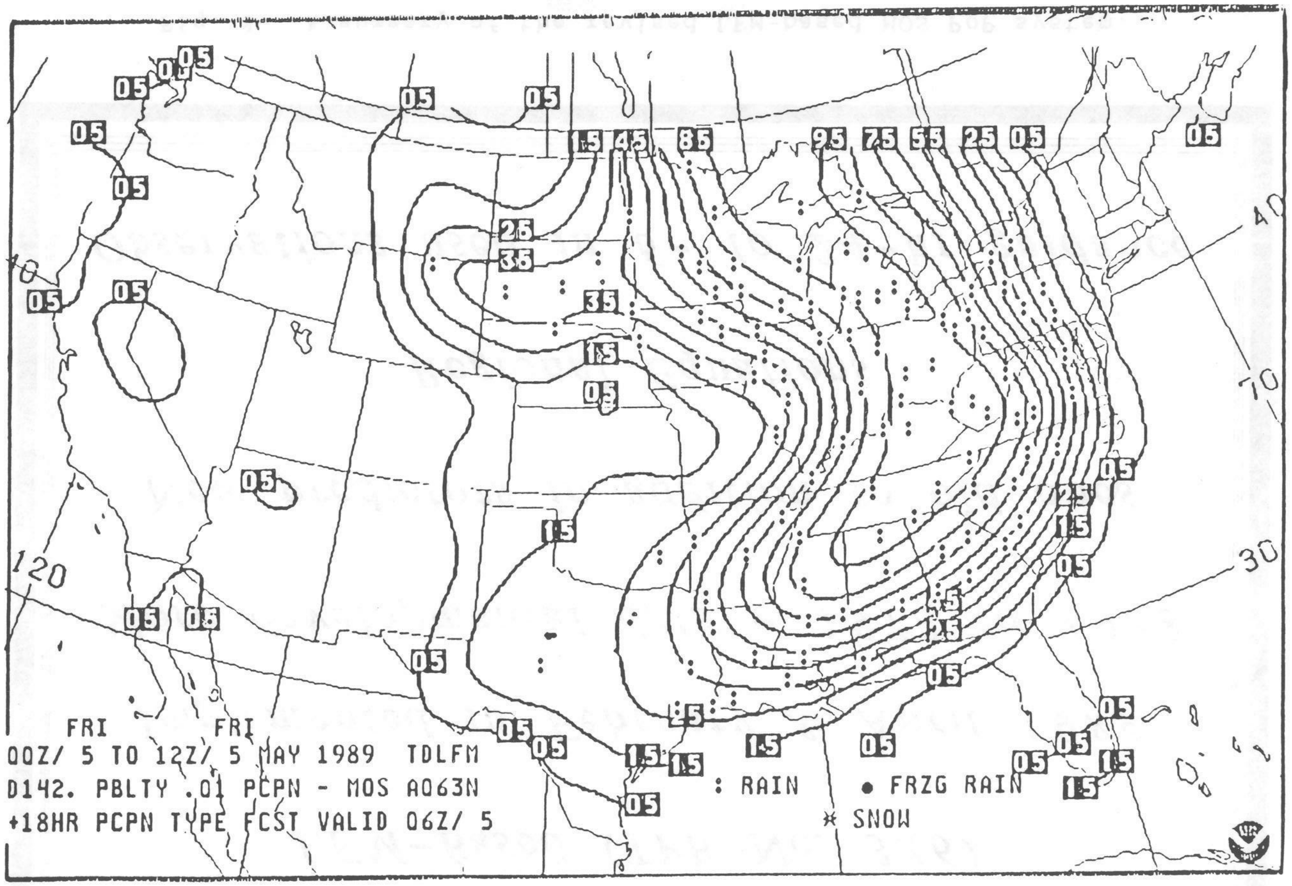

Fig. 7. A panel from DIFAX product D142 that was valid for 0000 UTC, May 5, 1989 through 0000 UTC, May 7, 1989. The guidance was generated from 1200 UTC LFM forecasts on May 4, 1989.

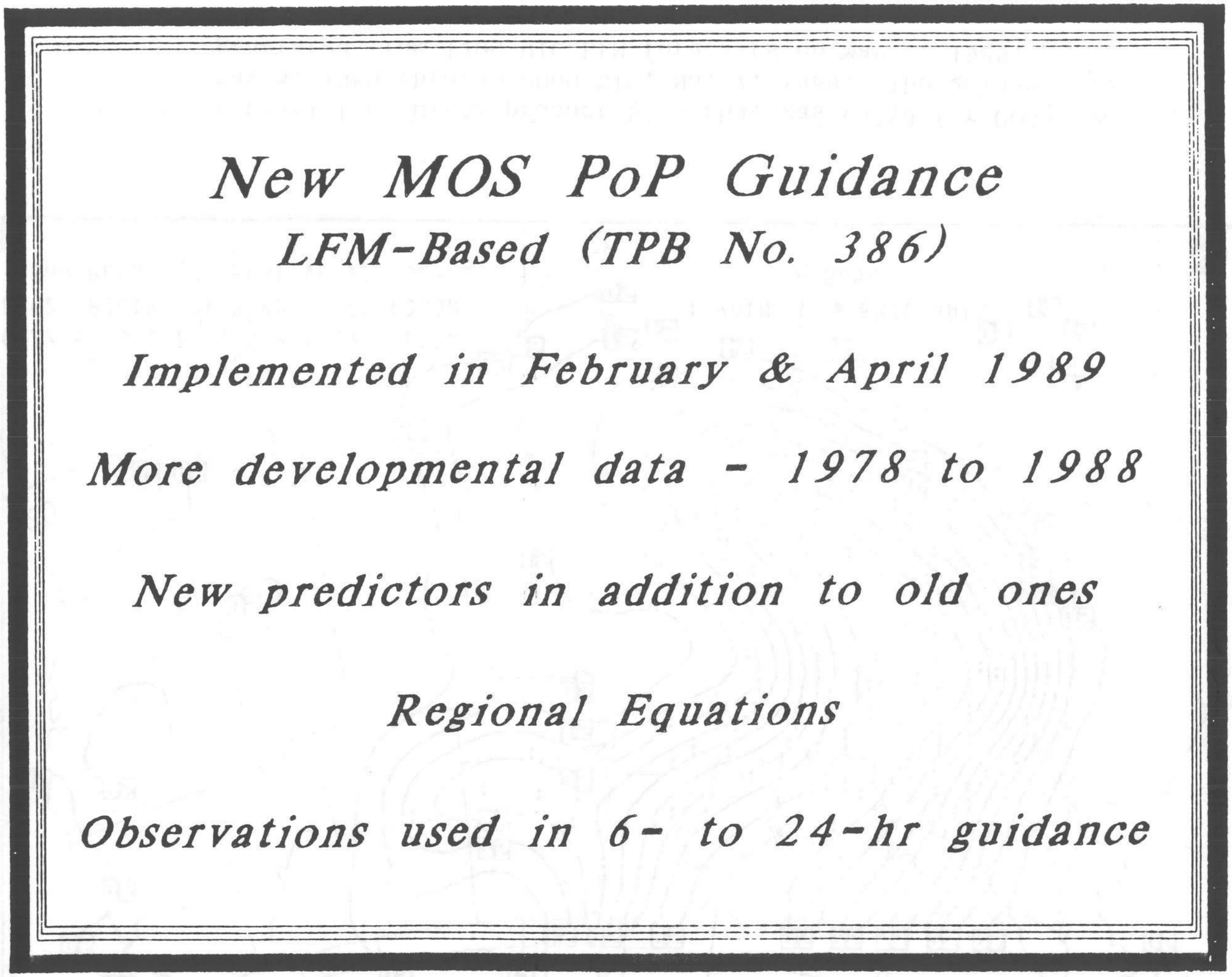

Fig. 8. A summary of the revised LFM-based MOS PoP system.