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AN ENHANCED PRECIPITATION TYPE GUIDANCE SYSTEM FOR SHORT RANGE FORECASTING

Luther A. Carroll III

Techniques Development Laboratory
Office of Systems Development
National Weather Service
Silver Spring, Maryland

1. INTRODUCTION

The Local AWIPS MOS Program (LAMP) under development in the Techniques Development Laboratory (TDL) provides detailed, short range statistical weather forecasts for projections from 1 to 20 hours. The forecasts are produced by regression equations that blend the most recent information from hourly weather observations, locally run advective models, and radar data with the central Model Output Statistics (MOS) guidance. LAMP produces update forecasts that are dominated by the observations at the early hours and approach the central MOS at 20 hours. Forecasts reflect a near-optimum blend of the two plus other regional and local information at the mid-range hours. LAMP forecasts will be available in the Advanced Weather Interactive Processing System (AWIPS) era for most observation sites within a forecast office's area of responsibility, and can be generated at any hour to support any forecast release time. Such a system is undergoing testing at offices in Topeka, Kansas, and Norman, Oklahoma. Glahn and Unger (1986) and Unger et al. (1989) provide detailed descriptions of LAMP.

In preparation for a planned new organizational and forecast structure within the National Weather Service, TDL is developing the Interactive Computer Worded Forecast (ICWF) program. The ICWF provides an interactive computer graphics interface that allows the meteorologist to enter and modify forecast information in a digital database from which official forecast products can be automatically formatted. In the AWIPS era, LAMP guidance will be used along with other information to initialize this forecast database, and, thus, assist in the preparation of short range public and aviation forecasts.

Presently, one part of the ICWF uses an Explicit Weather Algorithm (EWA) to infer mixed precipitation events from the central MOS temperature and probability of precipitation type (PoPT) guidance. This approach provides criteria for selecting precipitation types within the ICWF; however, a statistical assimilation of this information would likely produce more reliable results.

The central MOS system has produced conditional PoPT forecasts based on output from the Limited-area Fine Mesh (LFM) model (Gerrity, 1977) since the fall of 1982 (Bocchieri and Maglaras, 1983). This PoPT system gives conditional probability forecasts for three mutually exclusive precipitation type categories: snow or ice pellets, freezing rain or freezing drizzle, and rain (liquid precipitation). Insufficient developmental samples or lack of skill at longer projections has prevented any attempts by the central MOS system to resolve the mixed precipitation events now needed by the ICWF. As a result, mixed rain and snow has been classified as a rain event, while any mix with freezing precipitation has been classified as a freezing event.

The best regression-based statistical method to provide mixed precipitation forecasts would be to derive probabilities for each of the mixed precipitation types. However, as in the central MOS system, insufficient samples of these events in many areas of the country generally preclude this approach as a viable solution. In this paper, we describe the development and testing of a LAMP conditional PoPT system which uses an alternative approach to provide mixed precipitation forecasts. This system not only updates the three central MOS precipitation type probabilities, but provides additional categorical forecasts for mixed rain and snow, and mixed freezing rain and snow or ice pellet events. We attempt to statistically "mimic" the current EWA procedures by producing these categorical forecasts using only the three LAMP precipitation type probability statements. In addition, LAMP temperature and dew point forecasts have been included as predictors in the LAMP PoPT equations. Verification results and a case study to illustrate the spatial and temporal consistency of the LAMP PoPT forecasts are presented in this paper.

2. LAMP PoPT FORECAST SYSTEM DEVELOPMENT

2.1 The Predictand

We divided the observations of precipitation type for each forecast projection into three mutually exlusive categories. These categories are consistent with the soon to be implemented Nested Grid Model-based central MOS system described by Erickson (1992): freezing rain/drizzle, snow mixed with freezing rain/drizzle, or ice pellets (called FREEZING); snow (called FROZEN); and rain or rain mixed with snow (called LIQUID). As in the central system, the LAMP PoPT forecasts are conditional on the occurrence of precipitation. All predictands are binary such that they take on the value of one (zero) when the event is (is not) observed.

2.2 The Predictors

The predictors used in the development of the LAMP PoPT forecast equations are defined and listed in Table 1. These represent the top 20 predictors selected by screening regression (see Section 2.3) in seven regions (Fig. 1) for 20 forecast projections. The centralized MOS PoPT forecasts (Bocchieri and Maglaras, 1983) were obtained from operational equations specific to the 1200 UTC LFM run. We used the MOS probabilities both in their raw form and as two types of "interactive" predictors. The first involved an interaction between MOS probabilities. These predictors are maximized when the interacting probabilities are both near fifty percent, and can partially account for non-linear predictor-predictand relationships that may exist during these situations. The second involved an interaction between observed precipitation and the indicated MOS probabilities. As explained in detail by Glahn (1986), these predictors are "indicator variables" which simulate stratification of the developmental sample into cases when precipitation is or is not initially occurring.

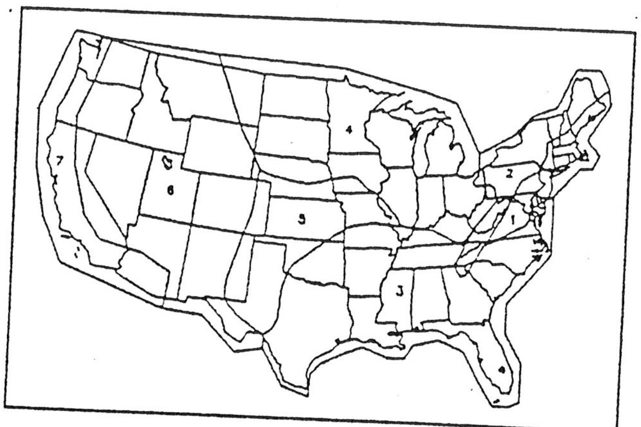

Figure 1. The seven LAMP PoPT development regions.

Surface observations of current precipitation at stations were also used as predictors. We coded these predictors to indicate whether precipitation was observed at the LAMP initialization time, and if so, the type of precipitation. These predictors are binary, taking on a value of one (zero) if a specific type of precipitation is (is not) observed. Note that we distinguish mixed precipitation type observations from other precipitation types.

We also included freezing and frozen precipitation type forecasts from the LAMP advection model. Unger et al. (1989) and Glahn and Unger (1986) give a description of this model. Briefly, observed, binary, gridpoint fields of freezing and frozen precipitation are each analyzed. The model then advects these fields with a combination of the 1000- and 500-mb geostrophic winds. The actual value of the resultant precipitation type predictor ranges between zero and one, inclusive, depending on the location within the initial analyzed field of the beginning point of the advection trajectory. These predictors provide information about the upstream conditions at the forecast initialization time.

In addition to the advection model forecasts, regression-based LAMP temperature and dew point forecasts at LAMP stations were also used as predictors. These forecasts, henceforth called predictors, are based on the same 2000 UTC LAMP initialization time as the LAMP PoPT development, and incorporate pertinent temperature and dew point information from the central MOS, latest observations, and LAMP model forecasts. We converted these predictors into binaries by breaking them into categories and giving a new dummy variable the value of one (zero) when the value of the temperature or dew point predictor is (is not) in that category. As shown in Table 1, these binary predictors are used directly, as well as interactively with the observed precipitation type predictors previously discussed. These interactive predictors prevent non-liquid precipitation observations from influencing the PoPT forecasts whenever the LAMP forecast temperatures exceed 45 degrees Fahrenheit.

2.3 Equation Development Procedures

We used screening regression in a statistical technique known as Regression Estimation of Event Probabilities (Miller, 1964) to develop the LAMP PoPT equations. The regression equations are for hourly projections from 1 to 20 hours from a 2000 UTC initial data time. The developmental sample consisted of the 8 winter seasons (October

Table 1. Predictors used in the development of the 2000 UTC LAMP PoPT forecast equations.

Class	Predictors	Definition
Centralized MOS Predictors	MOS P(ZR)	MOS probability of freezing forecasts (POZR)
	MOS P(SN)	MOS probability of frozen forecasts (POF)
	(MOS P(ZR))X(MOS P(SN))	MOS POZR multiplied by MOS POF
	(MOS P(RN))X(MOS P(SN))	MOS probability of liquid (POL) multiplied by the MOS POF
	(MOS P(ZR))X(OBS PREC)	MOS POZR when precipitation was initially observed
	(MOS P(SN))X(OBS PREC)	MOS POF when precipitation was initially observed
Surface Observations	(OBS ZR)X(LP T ≤ 45)	Observed ZR when LAMP forecast TEMP ≤ 45
	(OBS SN)X(LP T ≤ 45)	Observed snow when LAMP forecast TEMP ≤ 45
	(OBS MXZR)X(LP T ≤ 45)	Observed mixes with ZR and IP when LAMP forecast TEMP ≤ 45
	(OBS MXRN)X(LP T ≤ 45)	Observed rain and snow mixed when LAMP forecast TEMP ≤ 45
LAMP and Advective Model Predictors	FREZ PRECIP	CLAM model freezing precipitation forecasts
	FROZ PRECIP	CLAM model frozen precipitation forecasts
	LP T ≤ X	LAMP forecast temperature where X ≤ 28,32,34,36,39 degrees
	LP Td ≤ X	LAMP forecast dew point where X ≤ 25,29,32 degrees

through March) of 1980-81 through 1987-88. Data from the 1988-89 and 1989-90 winter seasons were reserved for independent data testing.

Procedures presented here are those used during a nationwide LAMP PoPT development. All predictors were interpolated (if necessary) to station locations. For stations or projections where central MOS PoPT forecasts were unavailable, MOS forecasts were interpolated in both space and time as described in Unger et al. (1989). All candidate predictors (not shown) were first screened in each of seven development regions throughout the United States (Fig. 1) to determine a "master" set of predictors (Table 1). Once determined, we included these predictors in each equation for each predictand, projection, and region. Data from all stations within a development region were combined in a manner consistent with the generalized operator approach. Unless otherwise noted, all results presented in this paper are based on the equations developed for regions 4 and 5 (Fig. 1) with data from 169 and 68 stations respectively.

2.4 Categorical Selection Procedures

We developed a classification strategy that processes the three LAMP precipitation type probabilities to produce on any given case one of five categorical forecasts: freezing rain, snow, rain, mixed rain and snow (called mixed liquid), and mixed freezing rain and snow or ice pellets (called mixed freezing). In this way, we distinguish mixed freezing and mixed liquid precipitation from pure freezing rain and rain respectively. The classification strategy uses probability thresholds to determine the category to select. We used the Adaptive Threshold Estimation Procedure (ATEP), described in detail by Unger (1992), to compute the thresholds. When applied to the probabilities, these thresholds produce categorical forecasts with approximately a unit bias (an equal number of forecast and observed events).

Specifically, the classification procedure first determines three thresholds that produce near unit bias forecasts for each of the FREEZING, FROZEN, and LIQUID categories defined in Section 2.1. On any given case, each of these three categorical probabilities is compared to its corresponding threshold probability. The category with the highest probability to threshold ratio is chosen. Unger (1992) refers to this threshold application as the "ratio method." If on any given case the ratio method with these three categories chooses FROZEN, it becomes the LAMP PoPT categorical forecast. If, however, FROZEN is not chosen, we use the LAMP probability of FROZEN (POF) precipitation to determine two additional thresholds for the mixed precipitation categories. For example, if the ratio method chooses the FREEZING (LIQUID) precipitation category in the first step, we assign the POF to the mixed freezing (mixed liquid) category. The mixed liquid (mixed freezing) category in these cases is assigned a value of 0. We then use these assigned POF values to determine thresholds that produce near unit bias forecasts of mixed freezing (mixed liquid) precipitation types given that the FREEZING (LIQUID) category would have otherwise been forecast.

Thus, this strategy produces mixed precipitation forecasts when the POF is as high as possible without having the ratio method select the FROZEN category. This is reasonable since most of the mixed precipitation events in both the FREEZING and LIQUID categories involve snow. While we apply the thresholds in two steps, the ATEP tunes the five probability thresholds simultaneously. We tuned all thresholds used in this study with three passes through the dependent data sample.

3. DISCUSSION OF RESULTS

3.1 LAMP Temperature and Dew Point Predictors

To see how the LAMP temperature and dew point predictors influence the LAMP PoPT forecasts on independent data, we developed a test set of equations, replacing all LAMP temperature and dew point binary predictors with identical observed temperature and dew point predictors. All other predictors remained the same in both equations. We will refer to the equations with the LAMP temperature and dew point predictors as WTEMP, and the test equations as NTEMP. All verification samples presented in this paper were matching.

P-scores (Brier, 1950) were calculated for the FREEZING, FROZEN, and LIQUID categories combined for both equation sets and are shown by projection in Fig. 2. The WTEMP equations consistently showed improvement in the P-score over the NTEMP equations beyond the 2-h projection. Figure 3 shows the percent improvement of the WTEMP forecasts over the NTEMP forecasts. The LAMP temperature and dew point predictors provide a 5 percent improvement over the NTEMP forecasts for projections beyond 5 hours. This additional information is likely due to the ability of the single-station (data only from a particular station is used in the equation development) LAMP temperature and dew point forecasts to incorporate local effects within the regionalized LAMP PoPT equations.

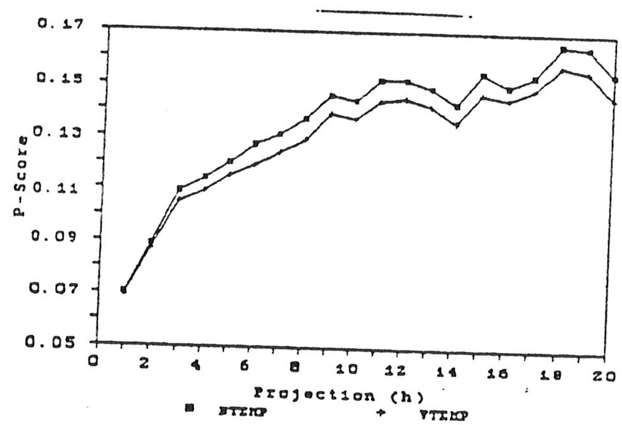

Figure 2. Independent data P-scores for the NTEMP and WTEMP equations. Scores represent the combined scores from regions 4 and 5.

In addition to producing consistently better P-scores, the WTEMP equations promoted consistency between the LAMP temperature and PoPT forecasts. Table 2 shows a composite of all the independent data 4 through 20-h rain and freezing rain categorical forecasts with the corresponding LAMP temperature forecasts. We divided the temperatures into ranges to highlight the events where inconsistent forecasts occur. For example, we define an inconsistent forecast as one for rain at temperatures below 32 degrees or for freezing rain at temperatures above 33 degrees. The categorical

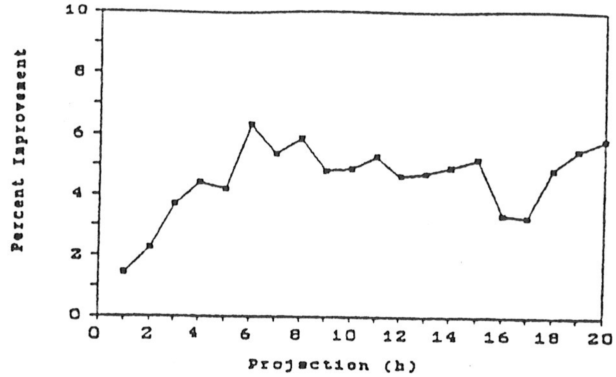

Figure 3. Independent data percent improvement in P-score of WTEMP over NTEMP for regions 4 and 5.

forecasts in this illustration represent forecasts of pure rain (RN) and of freezing rain (ZR) and were obtained with the strategy described in Section 2.4. The WTEMP system made far fewer inconsistent forecasts. Specifically, the NTEMP system produced 3.3 times as many inconsistent rain forecasts and 2 times as many inconsistent freezing rain forecasts as the WTEMP system.

Table 2. LAMP rain and freezing rain categorical forecasts within various LAMP temperature forecast ranges.

		Lamp Forecast Temperature						
Fcst.	Eqn.	< 28	28-29	30-31	32-33	34-35	35-36	> 36
RN	NTEMP	152	236	666	1473	2489	3140	-
	WTEMP	19	38	264	1347	2713	3267	-
ZR	NTEMP	-	661	821	583	318	223	190
	WTEMP	-	783	1111	591	199	103	61

3.2 LAMP PoPT Categorical Forecasts

Since the LAMP categorical classification strategy only produces a mixed freezing (mixed liquid) precipitation forecast after first selecting the FREEZING (LIQUID) category, the LAMP PoPT system can always maintain the skill of a system that does not attempt to isolate the mixed events. To determine this level of skill, as well as the degree to which these forecasts are better than the currently operational LFM MOS forecasts, we comparatively verified forecasts from both systems on the independent data sample. We included only data from the 93 MOS stations in our test region. Since the predictand definitions for the LAMP and LFM-based central MOS PoPT systems are slightly different, we verified both systems with their appropriately coded observations.

Figure 4 shows the Heidke skill scores for each system. While both systems have substantial skill, the LAMP PoPT forecasts consistently show significant improvement over the central MOS at all projections. Because the central MOS system only produces forecasts for the 4-, 10-, and 16-h LAMP projections, intermediate hour MOS forecasts are the result of linear time interpolation. This explains why the central MOS skill is less between those projections.

Heidke skill scores were also computed for the LAMP mixed precipitation forecasts alone (Fig. 5). Because mixed precipitation is a rare event, we include here both independent and dependent data results for comparison. While the

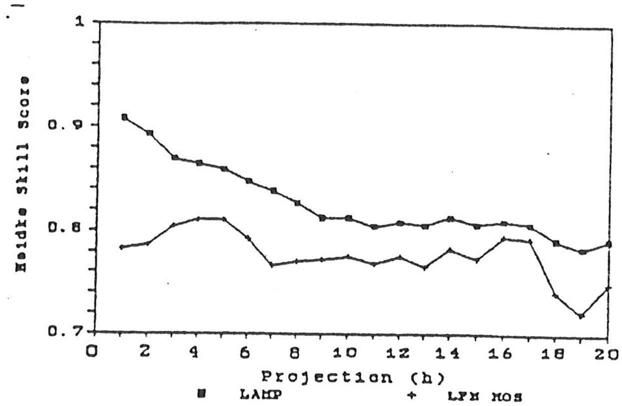

Figure 4. Independent data Heidke skill scores for both LAMP and LFM MOS PoPTs. Scores were computed for only region 4 and 5 MOS stations.

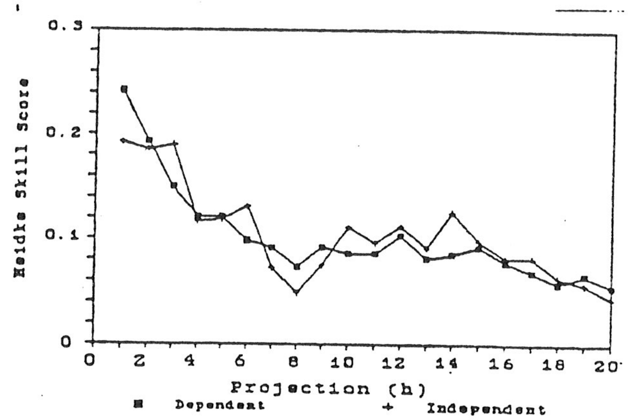

Figure 5. Independent and dependent data Heidke skill scores for LAMP mixed precipitation forecasts in regions 4 and 5.

skill is not great, the independent data mixed precipitation forecasts, in general, maintain the skill observed on the dependent data sample. The influence of the observations is evident during the first few projections.

The mixed precipitation forecast bias for each projection is shown in Fig. 6. These independent data results indicate that LAMP, on average, produces mixed precipitation forecasts about as often as the event occurs. This is important because the bias partly controls the temporal and spatial scale of the mixed precipitation forecasts. For example, if we increased the mixed precipitation forecast bias, we would increase both the spatial extent and temporal duration of the mixed precipitation forecasts. To date, the temporal and spatial scales of mixed precipitation have been undefined by guidance.

Figure 7 shows the independent data results in the form of a contingency table of the LAMP 16-h forecasts. Biases of all forecast categories are within acceptable limits, ranging from 0.87 for the freezing rain category to 1.19 for the mixed liquid category. While the number of correct forecasts in the mixed liquid and mixed freezing categories was low, 6 and 14 percent respectively, the LAMP mixed forecasts did appear to accurately identify the proper transition zones of precipitation type. For example, when the mixed liquid category was forecast and not observed, rain or snow predominated with nearly equal likelihood, 28 and 32 times respectively. Similarly, an incorrect mixed

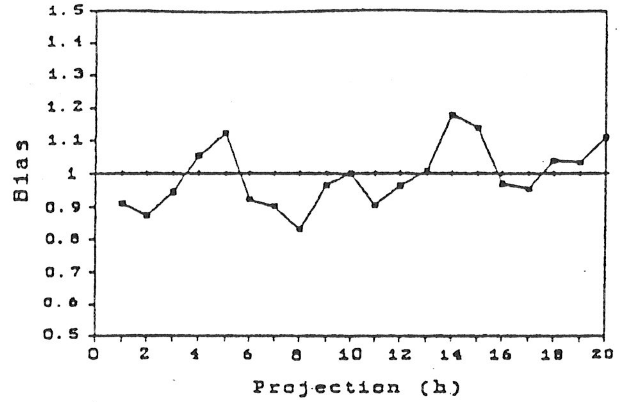

Figure 6. LAMP independent data mixed precipitation forecast bias for all stations in regions 4 and 5.

OBSERVED CATEGORY	FORECAST CATEGORY 1	2	3	4	5	Total
1	54	74	50	2	25	205
2	52	3365	157	32	43	3649
3	48	76	1900	28	10	2062
4	2	22	31	4	0	59
5	22	45	21	3	13	104
Total	178	3582	2159	69	91	6079
Bias	0.87	0.98	1.05	1.19	0.87	

Figure 7. Contingency table of LAMP 16-h PoPT categorical forecasts. Categories are coded as follows: freezing rain (1), snow (2), rain (3), mixed liquid (4), and mixed freezing (5).

freezing forecast was more than four times as likely to verify as snow than rain, while an incorrect freezing rain forecast verified as snow and rain with equal likelihood.

3.3 An Example Forecast - March 3, 1989

We selected an example independent data forecast to illustrate the spatial and temporal coherency of the LAMP precipitation type forecasts. Daily Weather Maps issued by the Climate Analysis Center for the two winter seasons 1988-89 and 1989-90 were perused for potential mixed precipitation events in the study region. We selected the March 3, 1989, case without any prior knowledge about the LAMP PoPT forecast system performance.

On March 2, 1989, arctic high pressure was located over Minnesota; a stationary front streched southeastward from northeastern Colorado to central Oklahoma. As a vigorous 500-mb trough began to develop over the western half of the United States, a low pressure system formed over southeastern Colorado. This low produced widespread overrunning precipitation in the forecast area throughout the LAMP forecast period.

Figures 8, 9, 10, and 11 show the forecast and observed precipitation types for the LAMP 4- and 16-h projections over the study area. Note the forecast and observed areas of freezing and

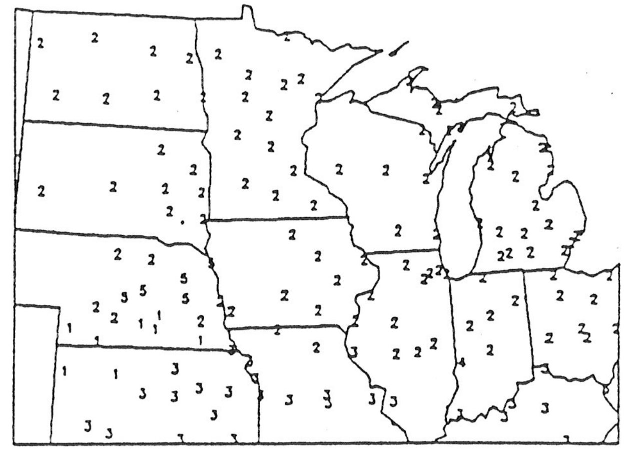

Figure 8. LAMP 4-h projection categorical forecasts valid 0000 UTC March 3, 1989. The forecast codes are the same as in Fig. 7.

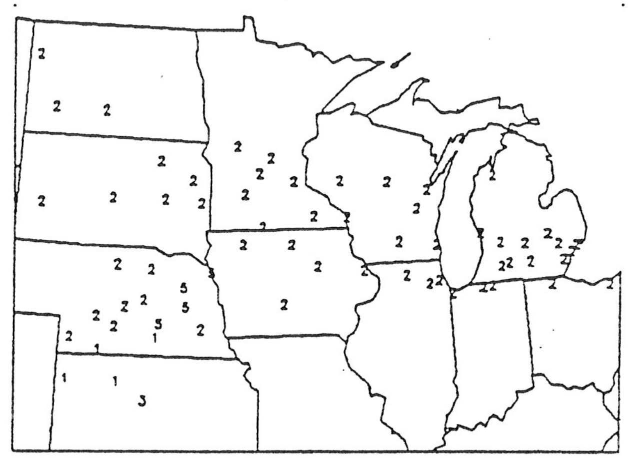

Figure 9. Observed precipitation types valid 0000 UTC March 3, 1989.

mixed freezing precipitation located over eastern Nebraska at 0000 UTC March 3, 1989. At the same time, a widespread area of both forecast and observed snow existed to the north and east. By 1200 UTC March 3, 1989, the LAMP guidance indicated that, if precipitation occurred, a very narrow band of mixed freezing precipitation would develop over northern Indiana eastward through central Ohio. The guidance also indicated that the mixed freezing precipitation over eastern Nebraska would continue. The placement of the mixed precipitation forecasts is consistent with forecast snow to the north and freezing rain to the south. At 1200 UTC March 3, 1989, mixed freezing precipitation was observed over northern Indiana, central Iowa, and eastern Nebraska. While only two of the eastern Nebraska stations precisely verified for the 16-h mixed freezing forecasts, the duration, placement, and areal extent of the mixed precipitation zones were generally consistent with the observations.

4. SUMMARY AND CONCLUSIONS

The development and testing of enhancements to the LAMP PoPT forecast system have been discussed. This system uses as input the latest information from the observations; central MOS; and simple, locally-run numerical models to produce

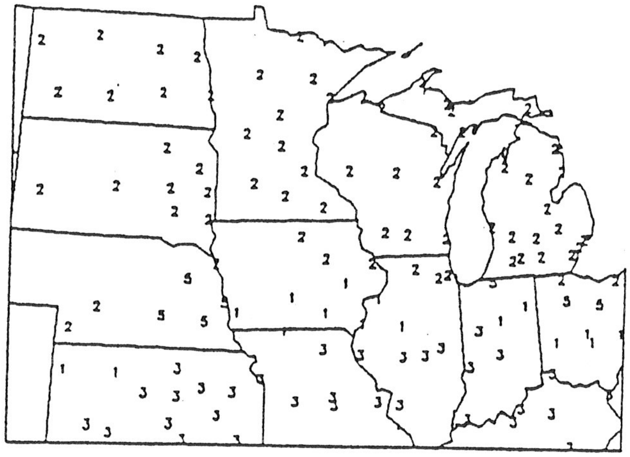

Figure 10. Same as Fig. 7, but for the 16-h projection valid 1200 UTC March 3, 1989.

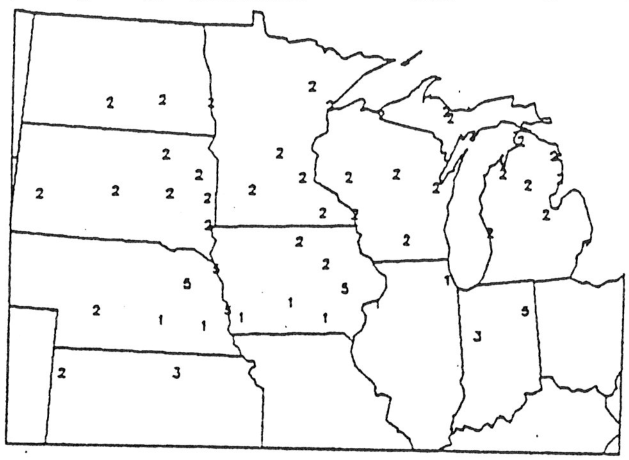

Figure 11. Observed precipitation types valid 1200 UTC March 3, 1989.

update forecasts of the three central MOS precipitation type probabilities. The system has been enhanced for short range forecasting by including the LAMP temperature and dew point forecasts as predictors, and by providing additional mixed precipitation categorical forecasts.

This strategy uses the ATEP to produce five categorical forecasts from the three LAMP precipitation type probabilities for FREEZING, FROZEN, and LIQUID precipitation. The five categorical forecasts are: freezing rain, snow, rain, mixed rain and snow, and mixed freezing rain and snow or ice pellets. It was demonstrated on independent data that the mixed precipitation forecasts had skill in identifying precipitation type transition zones. In addition, the mixed precipitation types were forecast about as often as they were observed without degrading the overall skill of the LAMP PoPT system. An example forecast demonstrated the spatial and temporal coherency of these forecasts.

Independent data verifications showed that including the LAMP temperature and dew point forecasts as predictors not only improved P-scores for all LAMP forecast projections, but also promoted consistency between the LAMP temperature and PoPT forecasts. Considerably fewer forecasts of FREEZING precipitation with forecast temperatures above 33 degrees Fahrenheit or of LIQUID precipitation with forecast temperatures below 32 degrees Fahrenheit were observed in the enhanced LAMP PoPT system.

In the AWIPS era, LAMP guidance will be used in part to initialize a database of forecasts from which official forecast products can be automatically generated. The enhancements made to the LAMP PoPT forecast system will provide the basis for more accurate guidance that operational meteorologists can use to forecast the temporal and spatial evolution of precipitation types.

5. ACKNOWLEDGEMENTS

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