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EXPERIMENTS IN THE USE OF LOCAL SURFACE AND UPPER-AIR OBSERVATIONS TO UPDATE MOS PRECIPITATION TYPE GUIDANCE

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1. INTRODUCTION

With the implementation of the Automation of Field Operations and Services (AFOS) program (Klein, 1978; Wilkins and Johnson, 1975) within the National Weather Service (NWS), the capability exists for rapid collection and analysis of local data. Within the Techniques Development Laboratory (TDL), we're experimenting with ways to use this local data processing capability to improve short-range forecasts of various weather elements. Two local sources of data that should be useful for short-range prediction of precipitation (precip) type (liquid, freezing, or frozen) are the recent radiosonde (RAOB) reports and the latest surface observations. In a previous paper (Bocchieri, 1979), we developed a statistical model to specify precip type from RAOB parameters. The results of that study should be useful in a "nowcasting" (very short range) sense. In this paper, we experiment with the use of the local RAOB and surface observations to update centrally-generated, Model Output Statistics (MOS) (Glahn and Lowry, 1972), conditional probability of precip type (PoPT) forecasts (Bocchieri, 1978). The PoPT forecasts are based on output from the Limited-area Fine Mesh (LFM) model (National Weather Service, 1971; Gerrity, 1977) and are produced twice daily at the National Meteorological Center (NMC) for about 233 conterminous United States stations.

To test the utility of the local surface and RAOB data, four types of forecast systems were developed and compared: a MOS system (similar to the operational system), a classical system, and two MOS update systems. For each system, the Regression Estimation of Event Probabilities (REEP) screening technique (Miller, 1964) was used to develop linear regression equations to forecast the conditional probability of precip type. For the classical system, the predictor input consisted of parameters derived from RAOB's and surface observations. One of the MOS update systems included RAOB parameters, surface observations, and PoPT forecasts from the MOS system. In the other MOS update system, similar input was used except that the RAOB parameters were omitted. These systems are described in section 2.

In section 3, a comparative verification is shown in which the classical and the two MOS update systems were compared to the MOS only system. The results indicate that MOS-update systems scored the best and significantly improved upon the MOS-only system for short-range forecasting of precip type.

In this paper, precip type is defined as three categories: frozen, freezing, and liquid. Frozen precip consists of snow, sleet (ice pellets), or snow mixed with sleet. Freezing precip includes freezing rain, freezing drizzle, or freezing rain or drizzle mixed with snow or sleet. The liquid category consists of rain or rain mixed with snow or sleet.

2. DEVELOPMENT OF SYSTEMS

A. Framework

The experimental systems developed in this study were designed to demonstrate their utility, or lack of utility, within the framework of the NWS operational environment. Consider, for instance, the 0000 GMT forecast cycle. The MOS PoPT guidance is available to field forecasters at about 0400 GMT. The forecaster may use this guidance in preparing the 1000 GMT public forecast. The next scheduled forecast release time is at 1600 GMT, but the MOS guidance based on 1200 GMT data is available too late to be useful for this release time. So, the forecaster might use the MOS guidance from the previous cycle (0000 GMT) and the latest possible upper-air and surface observations in preparing the 1600 GMT updated public forecast. A similar scenario applies to the 1200 GMT forecast cycle.

Each experimental system we developed produces conditional probability of precip type forecasts valid at 1800 GMT and 2400 GMT. The forecasts are conditional because the system assumes that precip occurs. In the classical (CLASSICAL) system, predictor input consisted of 1200 GMT RAOB parameters and 1500 GMT surface observations. In one MOS update system, called MOS+RAOBS+OBS, predictor input consisted of PoPT forecasts made from the 0000 GMT LFM run, 1200 GMT RAOB parameters, and 1500 GMT surface observations. In the other MOS update system, called MOS+OBS, similar input was used except that the 1200 GMT RAOB parameters were omitted. The MOS system that provided the PoPT forecasts for these experimental systems is very similar to the operational system described by Bocchieri (1978).

We used the REEP screening technique to develop the CLASSICAL, MOS+RAOBS+OBS, and MOS+OBS systems. This technique objectively selects a subset of effective predictors from a large set of potential predictors to use in multiple linear regression equations. The equations developed give estimates of the probabilities of occurrence of a given set of binary-type predictands. In this application, precip type is categorized into three binary-type predictands; liquid, freezing, and frozen. The predictands are called binary because, in the developmental phase, each predictand was assigned a value of 1 or 0 in a given case depending, respectively, upon whether that particular precip type occurred or didn't occur. The potential predictors can be either in binary or continuous form. A good description of the screening procedure can be found in Glahn and Lowry (1972); also, Klein and Glahn (1974) give applications of REEP within TDL.

B. Potential predictors

Table 1 lists the potential predictors that were included in the REEP screening program. The RAOB predictors will be described only briefly here; Bocchieri (1979) discusses the physical significance of the predictors and refers to other investigators who used similar predictors.

For the RAOB predictors, heights are given in terms of height above station; also, when vertical interpolation was used, it was done linearly with respect to height. Predictors 1 through 18 are rather simple and include temperature, wet-bulb temeprature, and wind components at the surface and mean values of these parameters for various layers aloft. The mean temperature within a layer is analogous to a thickness type variable such as 1000-500 mb thickness.

For predictors 19 through 26 in Table 1, both the temperature and wet-bulb temperature profiles were examined in relation to the 0°C isotherm to derive parameters defining the warm layer (or layers) and the freezing level in the RAOB. In this respect, a warm layer is defined as a layer in which the temperature, or the wet-bulb temperature, is > 0°C. Predictors 19 and 23 define the depth of the warm layer, and predictor 20 (24) defines the area between the temperature (wet-bulb temperature) profile and the 0°C isotherm in the warm layer. In cases when more than one warm layer existed, the depths and areas were summed. The areas were approximated by using the trapezoid rule (Kaplan, 1959), a numerical integration technique. Predictors 21 and 25 define the height of the top of the warm layer; for multiple warm layers, the highest warm layer is used. Predictors 22 and 26 define the height of the lowest freezing level.

Predictors 27 through 36 were specifically designed to help discriminate freezing precip from other types. The design was based on conditions generally associated with freezing precip. Predictor 27 [ZR(T)], for instance, is a binary variable that equals 1 if the Sfc T is ≤ 0°C <u>and</u> a warm layer exists aloft; otherwise, this predictor equals 0[1]. Predictor 28 is the depth of the surface-based cold layer (temperature ≤ 0°C) when ZR(T)=1, and predictor 29 is the area between the temperature profile and the 0°C isotherm in the surface-based cold layer when ZR(T)=1. If ZR(T)=0, predictors 28 and 29 equal 0. Predictors 30 and 31 are interactive or product type variables which define the depth and area of the warm layer, with respect to temperature, when ZR(T)=1. Predictors 32 through 36 are the same as predictors 27 through 31 except that the wet-bulb temperature was used.

Sections b and c in Table 1 describe the 1500 GMT surface observations and the MOS precip type forecasts, respectively, that were used as potential predictors.

C. Data samples

The developmental sample for the CLASSICAL, MOS+OBS, and MOS+RAOBS+OBS systems consisted of data combined from the 48 stations in Table 2 for the winter seasons (September through April) of 1972-73 through 1976-77. These stations were chosen because they are the ones for which we have archived both RAOB data and surface observations. These data are obtained on a continuing basis from National Climatic Center in Asheville, North Carolina and are error-checked within TDL.

Data for the period September 1977 through February 1978 were reserved for independent testing of the experimental systems.

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[1] These conditions are not necessary for the occurrence of freezing drizzle, which is included with freezing rain in the freezing precip category. That is, Bocchieri (1979) found that about 44% of freezing drizzle cases occurred with RAOB's in which temperatures were less than or equal to 0°C at all levels.

D. The CLASSICAL system

For the CLASSICAL system, the potential predictors included the 1200 GMT RAOB parameters and the 1500 GMT surface observation listed in Table 1. Note that the 1800 (2400) GMT valid time is a 3-h (9-h) projection from the time of the surface observations and a 6-h (12-h) projection from the time of the RAOB. The developmental sample for the 1800 GMT valid time consisted of 5826 precip cases of which 60.8% were liquid precip, 2.0% were freezing precip, and 37.2% were frozen precip. For the 2400 GMT valid time, 5460 precip cases were included.

Table 3 shows the 12 predictors included in the CLASSICAL system for the 1800 GMT valid time in the order determined by the REEP screening procedure. We decided to include 12 predictors based on results obtained by Bermowitz and Zurndorfer (1979), Bocchieri and Glahn (1972), and Bocchieri (1979) who found 12 predictors to be about optimum. The additional reduction of variance given by each predictor and the total reduction of variance are also shown. The screening results indicate that the 15Z Sfc T, 15Z Sfc Td, 15Z WEA, C.L. DEPTH(T), and $\overline{T}$ (Sfc-3000) accounted for most of the total reduction of variance of the three precip types. Note the importance of the 15Z Sfc T, 15Z Sfc Td, and $\overline{T}$ (Sfc-3000) for the liquid and frozen categories and the importance of the C.L. DEPTH(T), 15Z Sfc T, and 15Z WEA for freezing precip. Other predictors which contributed to a lesser extent included the C.L. AREA (T_w) and the $\overline{T}$ (Sfc-1000). The total reduction of variance for freezing precip, about 29%, was much lower than that of liquid and frozen precip, about 80% and 78%, respectively. The relatively low frequency of occurrence of freezing precip, about 2%, contributes to the difficulty in its prediction. The inclusion of freezing drizzle with freezing rain in the freezing category also causes problems, since atmospheric conditions associated with freezing drizzle can be quite different than those associated with freezing rain (see footnote 1 and Bocchieri (1979) for more details).

The screening results for the 2400 GMT valid time (not shown) indicated that the $\overline{T}$ (sfc-1000) was chosen first and accounted for a significant portion of the total reduction of variance of the liquid and frozen categories. Other important predictors included the 15Z Sfc T, 15Z Sfc Td, $\overline{T}$ (500-2500), and C.L. AREA(T); this last predictor was especially important for freezing precip. The 15Z WEA was relatively less important for the 2400 GMT valid time as compared to the 1800 GMT valid time. The total reduction of variance given by 12 predictors for the 2400 GMT valid time was 68%, 11%, and 66% for the liquid, freezing, and frozen categories, respectively.

E. The MOS update systems

For the MOS+RAOBS+OBS system, the potential predictors included the MOS probability of freezing and frozen precip forecasts, the 1200 GMT RAOB parameters, and the 1500 GMT surface observations listed in Table 1. The MOS+OBS system had similar input except that the RAOB parameters were omitted. Note that the 1800 GMT and 2400 GMT valid times represent 15- and 21-h projections, respectively, for the MOS probability of precip type forecasts used in the equations. For the MOS+RAOBS+OBS system, the developmental sample consisted of 4867 (4693) precip cases for the 1800 GMT (2400) valid time. The developmental sample for the MOS+OBS system consisted of 5912 (5502) precip cases for the 1800 GMT (2400 GMT) valid time.

Table 4 shows the 12 predictors included in the MOS+RAOBS+OBS system in the order determined by REEP screening for the 1800 GMT valid time. The MOS 15-H P(S) and MOS 15-H P(ZR) were chosen as the first and second predictors, respectively. In fact, the MOS 15-H P(S) accounted for most of the reduction of variance for the liquid and frozen precip types. Other predictors which made significant contributions include the C.L. DEPTH(T), 15Z Sfc T, 15Z Sfc Td, and the 15Z WEA. It's interesting that the combination of the two 15Z WEA predictors increased the explained variance of the freezing category by about 9%. The reason is that these two weather variables, in binary form, can isolate the event that freezing rain or drizzle is occurring at 1500 GMT. The total reductions of variance for the liquid, freezing, and frozen categories were about 83%, 31%, and 81%, respectively.

In the MOS+RAOBS+OBS equation for the 2400 GMT valid time (not shown) the MOS 24-H P(S) and MOS 24-H P(ZR) were chosen as the first and second predictors, respectively. Other predictors chosen were generally similar to those chosen for the 1800 GMT valid time except that the 15Z WEA was not included and the C.L. DEPTH(T) was replaced by the C.L. AREA(T). The total reductions of variance for 2400 GMT were slightly lower for the liquid and frozen categories, about 79% and 78%, respectively, but much lower for freezing precip, about 16%, as compared to those for 1800 GMT.

The screening results for the MOS+OBS system were generally similar to those for the MOS+RAOBS+OBS system except that the RAOB predictors weren't included.

3. COMPARATIVE VERIFICATION

We compared forecasts made by the CLASSICAL, MOS+OBS, and MOS+RAOBS+OBS systems to those made by the MOS-only system for both the 1800 GMT and 2400 GMT valid times. The 1800 GMT (2400 GMT) valid time represents a 3-h (9-h) forecast projection for each of the three experimental systems but a 15-h (21-h) forecast projection for the MOS system. The comparative verification was done for both the developmental and independent data samples which are defined in section 2c. Tables 5 and 6 show the verification results for 1800 GMT and 2400 GMT, respectively. The numbers shown are the percent improvements in Brier score (Brier, 1950) of each of the experimental systems over the MOS-only system. The percent improvements are shown for each precip type category and for the three categories combined. Note that the results for the freezing category on independent data are not very meaningful since there were only 24 cases for the 1800 GMT valid time and 16 cases for the 2400 GMT valid time.

The results for the 1800 GMT valid time can be summarized as follows: (1) Overall, the CLASSICAL system was better than the MOS system for both developmental and independent data samples. This result is not too surprising in light of the fact that this valid time represents a 3-h forecast for the CLASSICAL system but a 15-h forecast for the MOS system. However, for the frozen category, the CLASSICAL system was only slightly better for the developmental sample and worse for independent sample. (2) The MOS+OBS and MOS+RAOBS+OBS update systems were better than the MOS system for both data samples. Overall, the update systems improved upon MOS by about 20% on developmental data and 18% on independent data. (3) Overall, the MOS update systems were better than the CLASSICAL system for both data samples. However, for the freezing category, the update systems were only slightly better for the developmental sample and worse for the independent sample; this result for the independent sample is not meaningful because of the small number of cases. (4) With regard to the MOS update systems, the MOS+RAOBS+OBS system was, overall, about the same as the MOS+OBS system for the developmental sample and only slightly better for the independent sample. This result was also true for the categorical breakdown except for freezing precip for which the RAOB's seemed to be of some benefit for the developmental sample but not for the independent sample. The benefit of using RAOB's in addition to recent surface observations to update MOS forecasts for this projection is, therefore, questionable.

The results for the 2400 GMT valid time, shown in Table 6, indicate the following: (1) The CLASSICAL system was worse than MOS, especially for the liquid and frozen categories, for both developmental and independent data. This result, together with the results for 1800 GMT, indicates that the accuracy of the CLASSICAL system, relative to MOS, deteriorated rapidly with time. (2) The MOS+OBS and MOS+RAOBS+OBS update systems were better than the MOS system except for freezing precip on independent data. However there were only 16 freezing precip cases in the independent sample, so the results for this category are not meaningful. Note that the improvement of the MOS update systems over MOS at 2400 GMT (about 5 to 6% overall) was much less than at 1800 GMT (about 20%). This indicates that, as was the case for the CLASSICAL system, the usefullness of observed data deteriorated rapidly with time. (3) The MOS update systems were generally much better than the CLASSICAL system for both data samples. (4) With regard to the MOS update systems, the MOS+OBS system was generally slightly better than the MOS+RAOBS+OBS system for both data samples. That is, the inclusion of 1200 GMT RAOB predictors in addition to 1500 GMT surface observations deteriorated the accuracy of the MOS update system for this forecast projection.

4. SUMMARY AND CONCLUSIONS

We performed experiments to assess the use of upper-air and surface observations for local updating of centrally generated MOS precip type guidance within the framework of the NWS operational environment. The REEP screening procedure was used to develop regression equations to forecast the conditional probability of liquid, freezing, and frozen precip for the 1800 GMT and 2400 GMT valid times. For each valid time, a CLASSICAL system and two MOS update systems, called MOS+RAOBS+OBS and MOS+OBS, were developed.

In the CLASSICAL system, the potential predictors consisted of parameters derived from the 1200 GMT RAOB and 1500 GMT surface observations. In the MOS+RAOBS+OBS system, the potential predictors consisted of (1) MOS probability of freezing and frozen precip forecasts valid at 1800 and 2400 GMT and made from the 0000 GMT LFM cycle time, (2) parameters derived from the 1200 GMT RAOB, and (3) 1500 GMT surface observations. The potential predictors included in the MOS+OBS system were similar to those for the MOS+RAOBS+OBS system except that the RAOB parameters were omitted. All systems were developed with data combined from 48 stations within the conterminous United States for five winter seasons.

The REEP screening results indicate the following: (1) For the CLASSICAL system, the most important predictors generally included the mean temperatures in the surface-1000 m, surface-3000 m, and 500 m - 2500 m layers; the depth of the surface-based cold layer with respect to temperature (when a warm layer exists aloft); the area between the wet-bulb temperature profile and the 0°C isotherm in the surface-based cold layer; and the surface weather, temperature, and dew-point observed at 1500 GMT. (2) For the MOS update system, the most important predictors were the MOS probability of freezing and frozen precip forecasts; other predictors chosen were similar to those chosen for the CLASSICAL system.

For the 1800 GMT and 2400 GMT valid times, we compared probability forecasts made by the CLASSICAL, MOS+OBS, and MOS+RAOBS+OBS systems to those made by a MOS-only system for both developmental and independent data samples. The comparative verification results suggest the following conclusions: (1) The CLASSICAL system was, overall, better than the MOS system for the 1800 GMT valid time but much worse than MOS for the 2400 GMT valid time. The fact that the CLASSICAL system beat MOS for the earlier valid time is not too surprising since that valid time represents only a 3-h forecast for the CLASSICAL system but a 15-h forecast for MOS. (2) The MOS+OBS and MOS+RAOBS+OBS update systems were, overall, much better than the CLASSICAL system for both the 1800 GMT and 2400 GMT valid times. (3) For the 1800 GMT valid time, the MOS update systems were about 18% to 21% better than the MOS only system. However, the benefit in using RAOB parameters in addition to recent surface observations to update MOS forecasts for this valid time is questionable. (4) For the 2400 GMT valid time, the MOS+OBS system was slightly better than the MOS+RAOBS+OBS system and improved upon the MOS only system by about 5% to 6%. (5) The benefit in using local observations to update MOS forecasts seems to deteriorate rapidly with time. As noted above, the improvement from updating decreased from about 20% to about 5% in 6 hours.

More development and testing with larger data samples needs to be done to better assess any value the RAOB's might have, in addition to surface observations, in a MOS updating scheme. It might be possible to derive better predictors from the RAOB's, especially for freezing drizzle. Also, it's possible that the RAOB information would be helpful in updating MOS forecasts for projections within 6 hours from the time of the RAOB; the experiments in this study didn't address this time period.

The potential exists for implementing local updating systems similar to those described herein on the AFOS minicomputer. Also, more benefit could probably be derived from observed data if it could be analyzed and if simple numerical models, such as an advective type model, could be run locally.

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Table 1. The potential predictors used to develop the CLASSICAL, MOS+OBS, and MOS+RAOBS+OBS forecast systems.

Predictor	Description
a) 1200 GMT RAOB parameters	
1. Sfc T	Surface temperature.
2. $\overline{T}$ (sfc-500)	Mean temperature in the surface-500 m layer.
3. $\overline{T}$ (sfc-1000)	Mean temperature in the surface-1000 m layer.
4. $\overline{T}$ (sfc-1600)	Mean temperature in the surface-1600 m layer.
5. $\overline{T}$ (sfc-3000)	Mean temperature in the surface-3000 m layer.
6. $\overline{T}$ (sfc-6000)	Mean temperature in the surface-6000 m layer.
7. $\overline{T}$ (500-2500)	Mean temperature in the 500-2500 m layer.
8. Sfc T_w	Same as 1 except wet-bulb temperature was used.
9. $\overline{T}_w$ (sfc-500)	Same as 2 except wet-bulb temperature was used.
10. $\overline{T}_w$ (sfc-1000)	Same as 3 except wet-bulb temperature was used.
11. $\overline{T}_w$ (sfc-1600)	Same as 4 except wet-bulb temperature was used.
12. $\overline{T}_w$ (sfc-3000)	Same as 5 except wet-bulb temperature was used.
13. $\overline{T}_w$ (sfc-6000)	Same as 6 except wet-bulb temperature was used.
14. $\overline{T}_w$ (500-2500)	Same as 7 except wet-bulb temperature was used.
15. Sfc U	Surface "u" wind component.
16. Sfc V	Surface "v" wind component.
17. $\overline{U}$ (500-2500)	Mean "u" in the 500-2500 m layer.
18. $\overline{V}$ (500-2500)	Mean "v" in the 500-2500 m layer.
19. W.L. DEPTH(T)	Warm layer depth with respect to temperature profile.
20. W.L. AREA(T)	Area between the temperature profile and the 0°C isotherm in the warm layer.
21. W.L. TOP(T)	Height of the top of warm layer with respect to the temperature profile.

Table 1. Continued.

Predictor	Description
22. HGT FREEZ LEV(T)	Height of the lowest freezing level with respect to temperature. If the Sfc T $\leq$ 0°C, then this parameter equals 0.
23. W.L. DEPTH(T_w)	Same as 19 except wet-bulb temperature was used.
24. W.L. AREA(T_w)	Same as 20 except wet-bulb temperature was used.
25. W.L. TOP(T_w)	Same as 21 except wet-bulb temperature was used.
26. HGT FREEZ LEV(T_w)	Same as 22 except wet-bulb temperature was used.
27. ZR(T)	A binary predictor that equals 1 if Sfc T $\leq$ 0°C <u>and</u> a warm layer exists aloft; otherwise, it equals 0.
28. C.L. DEPTH(T)	The depth of the surface-based cold layer, with respect to temperature, when ZR(T)=1.
29. C.L. AREA(T)	Area between temperature profile and the 0°C isotherm in the surface-based cold layer when ZR(T)=1.
30. ZR(T)·W.L. DEPTH(T)	The product of predictors 19 and 27.
31. ZR(T)·W.L. AREA(T)	The product of predictors 20 and 27.
32. ZR(T_w)	Same as 27 except wet-bulb temperature was used.
33. C.L. DEPTH(T_w)	Same as 28 except wet-bulb temperature was used.
34. C.L. AREA(T_w)	Same as 29 except wet-bulb temperature was used.
35. ZR(T_w)·W.L.DEPTH(T_w)	Same as 30 except wet-bulb temperature was used.
36. ZR(T_w)·W.L. AREA(T_w)	Same as 31 except wet-bulb temperature was used.
b) 1500 GMT surface observations	
37. 15Z WEA	Weather.
38. 15Z Sfc T	Surface temperature.
39. 15Z Sfc T_d	Surface dew-point.
40. 15Z CIG	Ceiling.
41. 15Z Sfc U	"u" wind component.
42. 15Z Sfc V	"v" wind component.

Table 1. Continued.

Predictor	Description
c) MOS precip type forecasts from 0000 GMT LFM run	
43. MOS 15-H P(ZR)	MOS 15-h probability of freezing precip.
44. MOS 21-H P(ZR)	MOS 21-h probability of freezing precip.
45. MOS 15-H P(S)	MOS 15-h probability of frozen precip.
46. MOS 21-H P(S)	MOS 21-h probability of frozen precip.

Table 2. The 48 RAOB stations used in the development of the CLASSICAL, MOS+OBS, and MOS+RAOBS+OBS systems.

WBAN NO.	STATION	WBAN NO.	STATION
3860	Huntington, W. Va.	23044	El Paso, Tex.
3937	Lake Charles, La.	23047	Amarillo, Tex.
3940	Jackson, Miss.	23050	Albuquerque, N. Mex.
12912	Victoria, Tex.	23062	Denver, Colo.
13723	Greensboro, N.C.	23066	Grand Junction, Colo.
13873	Athens, Ga.	23154	Ely, Nev.
13880	Charleston, S.C.	23194	Winslow, Ariz.
13897	Nashville, Tenn.	24011	Bismarck, N. Dak.
13963	Little Rock, Ark.	24021	Lander, Wyo.
13967	Oklahoma City, Okla.	24023	North Platte, Neb.
13985	Dodge City, Kans.	24090	Rapid City, S. Dak.
13996	Topeka, Kans.	24127	Salt Lake City, Utah
14607	Caribou, Maine	24128	Winnemucca, Nev.
14733	Buffalo, N.Y.	24131	Boise, Idaho
14735	Albany, N.Y.	24143	Great Falls, Mont.
14764	Portland, Maine	24157	Spokane, Wash.
14826	Flint, Mich.	24225	Medford, Oreg.
14842	Peoria, Ill.	24232	Salem, Oreg.
14847	Sault St Marie, Mich.	93729	Cape Hatteras, N.C.
14898	Green Bay, Wisc.	93739	Wallops Island, Va.
14918	Intl Falls, Minn.	94008	Glasgow, Mont.
14936	Huron, S. Dak.	94240	Quillayute, Wash.
22010	Del Rio, Tex.	94789	New York, N.Y.
23023	Midland, Tex.	94823	Pittsburgh, Pa.

Table 3. The predictors included in the regression equations for the CLASSICAL system for the 1800 GMT valid time. The order of the predictors was determined by the REEP screening procedure. The developmental sample consisted of data combined from 48 stations (Table 2) for the winter seasons of 1972-73 through 1976-77. The number in brackets refers to the predictor as listed in Table 1. The 15Z WEA is represented by the following symbols: R(rain), ZR(freezing rain), ZL(freezing drizzle), IP(ice pellets), S(snow).

Predictor	Binary Limit	Additional Reduction of Variance (%) Liquid	Freezing	Frozen
15Z Sfc T [38]	≤ 33°F	70.82	2.91	64.16
C.L. DEPTH(T) [28]	≤ 250 m	0.28	9.88	2.05
$\overline{T}$ (sfc-3000) [5]	≤ -4°C	4.84	0.61	5.97
15Z Sfc T_d [39]	≤ 31°F	2.88	0.11	2.62
15Z WEA [37]	None, R, ZR, ZL, IP, or IP+S	0.62	1.08	1.19
15Z WEA [37]	None or R	0.00	7.39	0.53
15Z WEA [37]	None, R, ZR, or ZL	0.00	3.66	0.35
C.L. DEPTH(T) [28]	≤ 300 m	0.00	0.88	0.08
C.L. AREA(T_W) [34]	≤ 4000°C·m	0.00	0.90	0.07
$\overline{T}$ (sfc-1000) [3]	≤ -1°C	0.79	0.26	0.57
$\overline{T}$ (sfc-3000) [5]	≤ -7°C	0.08	0.61	0.25
15Z Sfc T [38]	≤ 29°F	0.16	0.86	0.02
	Total Reduction of Variance =	80.47	29.13	77.87

Table 4. The same as Table 3 except that the predictors included in the MOS+RAOBS+OBS system are shown.

Predictor	Binary Limit	Additional Reduction of Variance (%) Liquid	Freezing	Frozen
MOS 15-H P(S) [45]	continuous	76.35	0.00	77.56
MOS 15-H P(ZR) [43]	continuous	1.43	13.36	0.03
C.L. DEPTH(T) [28]	$\leq$ 250 m	0.46	4.15	0.01
15Z Sfc T [38]	$\leq$ 33°F	3.32	1.28	2.29
15Z Sfc T [38]	$\leq$ 30°F	0.07	0.93	0.00
15Z Sfc T_d [39]	$\leq$ 31°F	0.73	0.26	0.51
15Z WEA [37]	None or R	0.28	0.65	0.09
15Z WEA [37]	None, R, ZL, or ZR	0.00	8.63	0.82
C.L. DEPTH(T) [28]	$\leq$ 300 m	0.00	0.91	0.06
C.L. DEPTH(T) [28]	$\leq$ 600 m	0.00	0.52	0.07
15Z WEA [37]	None, R, or ZL	0.02	0.31	0.00
C.L. AREA(T_w) [34]	$\leq$ 4000°C m	0.00	0.26	0.01
	Total Reduction of Variance =	82.68	31.26	81.45

Table 5. The percent improvements in Brier score of the CLASSICAL, MOS+OBS, and MOS+RAOBS+OBS systems over the MOS-only system for the 1800 GMT valid time. The scores are shown for each precip type category and for all three categories combined (Overall). The developmental (D) and independent (I) samples are defined in section 2c. The number of cases is shown in parentheses.

Forecast System	Category						Overall	
	Liquid		Freezing		Frozen			
	D (2901)	I (528)	D (96)	I (24)	D (1870)	I (473)	D (4867)	I (1025)
CLASSICAL	12.8	18.1	17.0	31.2	1.5	-3.3	8.5	10.7
MOS+OBS	24.0	22.5	18.2	23.2	18.5	9.8	20.8	17.7
MOS+RAOBS+OBS	23.6	24.8	20.6	22.7	18.1	11.3	20.9	19.2

Table 6. The same as Table 5 except that the results are shown for the 2400 GMT valid time.

Forecast System	Category						Overall	
	Liquid		Freezing		Frozen			
	D (3088)	I (581)	D (80)	I (16)	D (2071)	I (456)	D (5239)	I (1053)
CLASSICAL	-42.5	-26.5	-2.3	-7.5	-51.9	-43.8	-42.0	-30.8
MOS+OBS	6.2	8.6	4.6	-1.5	4.4	7.3	5.1	6.5
MOS+RAOBS+OBS	5.8	7.5	4.6	-2.2	3.6	4.5	4.7	4.7