National Weather Service
Office of Meteorology

Technical Procedures Bulletin

Series No. 421

Subject:

NGM-Based MOS Precipitation Type Forecasts for the United States

Program Requirements and Development Division, Silver Spring, Md. 20910

FIRST BULLETIN ON THIS SUBJECT

February 10, 1995
W/OSD211:MCE

This Technical Procedures Bulletin (TPB), written by Mary C. Erickson of the Techniques Developemnt Laboratory (TDL), describes the Model Output Statistics (MOS) precipitation type guidance developed from the Nested Grid Model (NGM) for stations in the contiguous United States and Alaska. The guidance for contiguous United States was implemented on November 18, 1992, and is available in the FOUS14 KWBC message (FWC product on AFOS). The guidance for Alaska was implemented on November 16, 1994, and is available in the FOAK 13 KWBC message. The Precipitation type guidance is also included in similar bulletins to stations supported by the United States Air Force. The guidance is available twice daily around 0400 and 1600 UTC.

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

NGM-BASED MOS PRECIPITATION TYPE FORECASTS FOR THE UNITED STATES

by Mary C. Erickson

1. INTRODUCTION

On November 18, 1992, the Techniques Development Laboratory (TDL) implemented the first Model Output Statistics (MOS) (Glahn and Lowry, 1972) precipitation type prediction equations developed from the Nested Grid Model (NGM) (Hoke et al., 1989) output. These equations generate probability forecasts of freezing precipitation, snow, and liquid precipitation which are conditional upon precipitation occurring. In addition, the probability forecasts are compared to threshold values to select a categorical forecast. The categorical precipitation type, probability of freezing precipitation, and probability of snow forecasts are included in the NGM MOS forecast bulletin (Dallavalle et al., 1992) for projections valid every 3 hours from 6 to 36 hours, and every 6 hours from 42 to 60 hours after both 0000 and 1200 UTC. This Technical Procedures Bulletin summarizes the development, testing, and dissemination of the NGM MOS precipitation type forecasts. In addition, special comments on interpreting the guidance are included for the forecaster's consideration.

2. DEVELOPMENT

The MOS approach statistically relates predictand data to predictor data such as forecasts from dynamical models, surface observations, and climatic information. In the application of MOS to precipitation type, multiple linear regression was used to determine the statistical relationships.

a. Predictand Definition

The predictands in this development were obtained by dividing hourly surface observations of precipitation type (when precipitation occurred) into three categories: freezing precipitation, snow, and liquid precipitation. The "freezing" category included all pure and mixed freezing rain, freezing drizzle, and ice pellet events. The "snow" category included only pure snow events; the "liquid" category included pure rain or drizzle as well as rain or drizzle mixed with snow. Each category was treated as a binary predictand, since the defined event either occurred (e.g., snow) or did not (e.g., no snow). Separate linear regression equations were developed to predict the conditional probability of occurrence for each category. The probability equations (and subsequent forecasts) are conditional upon precipitation occurring since only precipitation cases were included in the developmental sample.

The definitions of the precipitation type categories were changed from those used in the LFM-based MOS precipitation type system. We have moved ice pellets from the frozen category to the freezing category for several reasons. First, snow is a frequent, hazardous weather event, and we believed defining a pure snow category maximizes our ability to delineate snow from other weather events. Second, ice pellets is a very rare event, and we did not have enough data to treat it as a unique forecast category. Third, we found that the NGM forecasts of temperature soundings showed very little ability to distinguish between freezing rain and ice pellet events. Finally, it was our opinion that the impact of ice pellets on the public and aviation interests was closer to freezing rain than snow.

b. Predictors

Potential predictors offered in the regression process were NGM forecasts, station geographic or climatic variables, and, for certain projections, surface observations. NGM predictors offered in the precipitation type development included several thicknesses (1000-850 mb, 850-700 mb, 700-500 mb), temperatures at constant pressure surfaces every 50 mb from 1000 mb to 700 mb, the 950- and 750-mb wet bulb temperatures, temperature advection (950 mb, 850 mb, 700 mb), mean relative humidity (surface to approximately 490 mb), and winds (950 mb, 850 mb, 700 mb).

In addition to these more commonly used model variables, several predictors created from model forecasts were included. The first was the pressure (in mb) of the freezing level. The second was a variable which indicated when the NGM was forecasting a warm layer (> 273.16 K) above a cold surface layer (≤273.16 K). This determination was based on the wet bulb temperatures between the model's surface and 500 mb. Wet bulb temperatures at constant pressure surfaces every 50 mb from 1000 mb to 700 mb, and at 500 mb were considered in the algorithm to generate the vertical profile of the wet bulb temperature. Finally, logit transformations (Erickson, 1993) were applied to the 850-mb temperature, 1000-850 mb thickness, and 850-700 mb thickness to form additional predictors.

Logit transformations were used because they provide a good method of fitting a binary predictand with a continuous predictor. In our particular application, a separate logit relationship was determined between the occurrence of snow and each of the thermal variables mentioned previously. In addition, separate logit transformations were derived for each station available in the developmental sample. When performing each logit analysis, NGM forecasts interpolated to a station and the corresponding surface observations for 18 and 24 hours after both 0000 and 1200 UTC were combined into one sample. The result of the logit transformations was the creation of predictors which essentially provide a single-station conditional probability of snow based on the NGM forecast of the 850-mb temperature, 1000-850 mb thickness, or 850-700 mb thickness.

Climatological variables offered included the conditional monthly relative frequency (computed from 10 years of observed data) of freezing precipitation and snow. Geographical variables included the station elevation, latitude, and longitude. Functions of the sine and cosine of the day of the year were also included to help infer variations within the season.

Surface observations taken two hours after 0000 or 1200 UTC were also offered to the regression for some of the forecast projections. For stations in the contiguous 48 states, observations of surface temperature and dew point may be contained in equations valid 6, 9, 12, 15, and 18 hours after 0000 or 1200 UTC. Effective January 5, 1994, observations of the surface dew point depression, the average of the temperature and dew point, and the current weather were also included as potential predictors in the equations valid 6 and 9 hours after 0000 or 1200 UTC. The current weather was offered in the form of three binary predictors: freezing precipitation/no freezing precipitation, snow/no snow, and rain/no rain. For stations in Alaska, observed predictors, including all the variables listed previously, may be included in equations valid 6 to 48 hours after 0000 or 1200 UTC.

While many of the predictors were offered to the regression in continuous form, others were offered either as point-binary or grid-binary (Jensenius, 1992) variables. The point-binary technique applies the binary cutoff to the value of the predictor after the variable has been interpolated to a specific station. The resulting value of the predictor is either 0 or 1. The grid-binary technique applies the binary cutoff at gridpoints, and the gridded field of 1's and 0's is then smoothed and interpolated to stations. The resulting value of the predictor is, therefore, between 0 and 1. This technique provides a smoother transition, both spatially and temporally, between the extremes of the predictor than does the point-binary approach. In the precipitation type development, the vertical profile of the wet-bulb temperature, all constant pressure level temperatures, the 1000-850 mb thickness, and the 850-700 mb thickness were offered in the grid-binary form.

In general, the predictor most often chosen first in the prediction equations was the logit transformation of the 1000-850 mb thickness. Other frequently chosen predictors included logit transformations of the 850-mb temperature and 850-700 mb thickness, the grid-binary of the 1000-850 mb thickness, various grid-binary forms of the temperature, and the vertical profile of the wet-bulb temperature.

c. Developmental Sample and Definition of Season

The developmental data consisted of precipitation type observations and NGM forecasts for 474 stations in the contiguous United States and 39 stations in Alaska. For stations in the contiguous U.S., NGM precipitation type equations were derived from 6 seasons (September 16 - May 15) of precipitation type data, starting with the 1986-1987 season and ending with the 1991-1992 season. For stations in Alaska, the NGM precipitation type equations were derived from 8 seasons (September 1 - May 31) of precipitation type data, starting with the 1986-1987 season and ending with the 1993-1994 season.

d. Regions

Since freezing rain, sleet, and snow are relatively rare events in parts of the country, stations were combined into geographic regions in order to develop stable forecast relationships. These forecast equations are applied to each station within a region. Stations were grouped on the basis of climatology, topography, and correlation of the predictand with model predictors. Figure 1 shows the 10 regions used in the development for the contiguous United States. Note that stations in southern Florida and much of California were not included in the development. Consequently, operational forecasts of precipitation type are not produced for these geographical regions. Figure 2 shows the five regions used in the development of the equations to predict precipitation type in Alaska. No freezing precipitation equations were generated for regions 2, 4, and 5 in Alaska, and region 1 in the contiguous U.S. This means no freezing precipitation probabilities are produced for stations in these regions. Finally, in region 1 in Alaska, we could not generate freezing precipitation equations for the 6-, 24-, 27-, 30-, 48-, and 54-h projections from 0000 UTC, and the 12-, 15-, 18-, 36-, 42-, and 60-h projections from 1200 UTC. Therefore, probability of freezing precipitation forecasts are missing for these projections and stations.

e. Equation Characteristics - Special Techniques

The equations to forecast the conditional probability of freezing precipitation, snow, and liquid precipitation were derived simultaneously. Thus, the forecast equations contain the same predictors although the regression coefficients vary among predictands. This technique ensures consistency among the forecasts; the resulting probabilities for a given case sum to 100%, although individual category forecasts greater than 100% or less than 0% are possible. To eliminate these latter probabilities, we post-process the raw forecasts. All raw probabilities less than 0% are set to 0%, then each probability is divided by the sum of the positive probabilities to obtain normalized values. The resulting probabilities add to 100% and individual category forecasts do not exceed 100% or fall below 0%.

As stated in Section 2.b, equations using surface observations as predictors were developed for some of the forecast projections. These equations are used operationally when the observed predictors are available. If an observed predictor is not available for a particular station, backup equations with no observed predictors are used to make the forecasts.

f. Determining Categorical Forecasts

The probability forecasts are compared to threshold probabilities in order to make a categorical forecast. These threshold probabilities are determined from the developmental sample for each projection, cycle, and region. For precipitation type, we chose thresholds that yielded unit bias on the dependent sample. In other words, for each category, the number of forecasts and the number of observations of the category were approximately equal. In making an operational forecast, we use the following procedure to choose the categorical forecast. To begin, the freezing precipitation probability is compared to the first threshold probability. If the freezing precipitation probability is greater than the threshold value, then freezing precipitation is chosen as the categorical forecast. If not, the freezing precipitation probability and snow probability are added together and compared to the next threshold value. If this threshold value is exceeded, then snow is chosen as the categorical forecast. If neither threshold value is exceeded, liquid precipitation is chosen as the categorical forecast. Because of this selection procedure, there may be cases where the freezing precipitation probability exceeds the threshold and is chosen as the categorical forecast, even though the probability of snow is greater than the probability of freezing precipitation.

g. Sample Equation

Sample regression equations to predict the probability of freezing rain and snow for region 7 (Fig.1) are included in Table 1. The equations listed are used to generate forecasts valid 24 hours after 1200 UTC. The predictors are listed in the first column of the table in the order they were selected by the regression procedure. The next column, labeled C/GB, indicates whether the predictor is continuous or based on a grid binary. The cutoffs for grid-binary predictors are indicated in the predictor description. The TAU column indicates the projection of the predictors, and the COEFF columns provide the coefficient of the predictor in the regression equation. As mentioned in Section 2.e, the predictors in the freezing rain and snow equations are the same, but the coefficients differ. The regression constant and threshold values are listed at the bottom of Table 1.

Table 1. Regression equations to predict the probability of freezing rain and snow for region 7. This equation is used to generate forecasts valid 24 hours after 1200 UTC.

PREDICTOR	C/GB	TAU	COEFF ZP	COEFF SN
850-1000 mb Thickness, Logit Transform	C	24	0.228590	0.401000
Vertical Profile - Wet Bulb Temperature	GB	24	0.174370	-0.260010
850 mb Temperature, Logit Transform	C	24	-0.181850	0.353770
Vertical Profile - Wet Bulb Temperature	GB	30	0.270200	-0.035104
Conditional Relative Frequency, ZP	C	0	0.008322	0.004297
850 mb Temperature (270.16K cutoff)	GB	18	0.102330	-0.184100
900 mb Temperature (273.16K cutoff)	GB	18	-0.086441	-0.019373
1000 mb Temperature (276.16K cutoff)	GB	24	0.022210	-0.192740
850 mb Temperature (273.16K cutoff)	GB	30	-0.066636	-0.096180
1000-850 mb Thickness (1315 m cutoff)	GB	30	0.074620	-0.042259
950 mb U wind	C	18	-0.000527	-0.003651
950 mb Temperature	C	24	0.002423	0.002061
Freezing Level (mb)	C	18	0.000299	-0.000334
900 mb Temperature (270.16K)	GB	24	-0.007328	0.158720
800 mb Temperature (270.16K)	GB	18	0.051034	-0.039485
Regression Constant = 0.052	Threshold Values = 0.2492, 0.4961			

Remember, although it is useful to know which predictors are contained in the forecast equations, meteorological interpretation of individual coefficients in a multiple linear regression equation is generally not recommended. These coefficients reflect not only the relationship of the predictand to the given predictor, but also the relationship of the given predictor to other predictors in the equation. In most instances, the predictors included in the equation are correlated with one another, so discussing the effect on the statistical forecasts of changing one predictor without considering related variables may not be of much value.

3. VERIFICATION

Since the NGM-based precipitation type equations were implemented in November 1992 for stations in the contiguous U.S., we have verified the operational forecasts for a portion of the 1992-93 cool season and the entire 1993-94 cool season. The verifications for the 1993-94 cool season are shown here. The verification sample consisted of forecasts made between September 16, 1993, and May 15, 1994. We computed verification scores comparing the NGM MOS to the LFM MOS categorical precipitation type forecasts (Bocchieri and Maglaras, 1982). The LFM MOS was used as a basis of comparison since the LFM MOS provides a higher level of skill than climatology. However, the LFM guidance was not operationally available to forecasters in the 93-94 cool season. We also compared the skill of the NGM MOS precipitation type forecasts to the local forecasts for the period between October 1, 1993, and March 31, 1994. Note that the precipitation type forecasts can only be verified for cases when precipitation occurred.

Figure 3 shows the Heidke skill scores (HSS) for both the NGM and LFM categorical precipitation type forecasts for projections of 6 through 60 hours after 1200 UTC. Forecasts for over 300 stations were included in this verification. A positive value of HSS indicates a skillful forecast, with a value of one occurring when all forecasts are correct. The skill level of the NGM MOS was nearly always higher than that of the LFM MOS. Figure 4 compares the NGM and LFM MOS freezing precipitation forecasts in terms of the critical success index (CSI). This score indicates the fraction of time the forecasts were correct compared to the total number of forecasts and observations of the event. CSI scores range from 0 to 1, with 1 being optimal. The NGM MOS score was higher at most projections; at the 24- and 30-h projections, the LFM MOS scores were slightly higher.

Figure 5 compares the HSS scores for the NGM MOS and local categorical precipitation type forecasts for projections of 18, 30, and 42 hours after 1200 UTC. The local forecasts are those submitted in the manually-entered forecast (MEF) matrix as part of the AFOS-Era Verification (AEV) program (Dagostaro et al., 1989). Forecasts for approximately 90 stations were included in the verification. The NGM MOS forecasts are disseminated at approximately 0400 UTC and 1600 UTC which should make them available as guidance for the local forecast. The skill level of the NGM MOS and local forecasts was nearly the same at the 18- and 42-h projections, but the NGM MOS forecasts were more skillful at the 30-h projection.

Figure 6 compares the 1200 UTC NGM MOS and local forecasts of the freezing precipitation category in terms of the CSI. At the 18- and 30-h projection, the local and NGM MOS scores were very close; at 42 hours, the CSI of the NGM MOS was significantly higher. At 0000 UTC (Fig. 7), the CSI of the local forecasts for freezing precipitation was higher at the 18-h projection; at 30 and 42 hours, the NGM MOS score was significantly higher. Note that the total number of freezing precipitation cases included in the verification (40-75) was not large, which may account for some of the fluctuation in the scores. Finally, Fig. 8 (1200 UTC) and Fig. 9 (0000 UTC) compare the NGM MOS and local forecasts of the snow category in terms of CSI. At 1200 UTC, the scores at the 18- and 42-h projections were nearly equal; at 30 hours, the NGM MOS score was slightly higher. At 0000 UTC, the scores were virtually the same at the 18-h projection, but the NGM MOS scores at 30 and 42 hours were higher. Note that all the CSI scores for snow were higher than the scores for the freezing precipitation category, reflecting both the higher frequency of the snow event at many places and the number of snow forecasts which could be considered "easy."

4. PRODUCT AVAILABILITY

NGM MOS precipitation type forecasts are available in the NGM MOS forecast bulletin distributed under the WMO header of FOUS14 KWBC and under the AFOS category of FWC. Technical Procedures Bulletin No. 408 (Dallavalle et al., 1992) describes the complete FOUS14/FWC message. These products are currently prepared for 529 stations in the contiguous United States at approximately 0400 UTC (0000 UTC forecast cycle) and 1600 UTC (1200 UTC forecast cycle) each day. A sample of the forecast bulletin is shown in Fig. 10. The categorical precipitation type is shown in the PTYPE line: Z indicates freezing precipitation, S indicates snow, and R indicates liquid precipitation. The POZP line contains the conditional probability of freezing precipitation, and the POSN line contains the conditional probability of snow.

Precipitation type symbols are also plotted on the 4-panel NGM MOS probability of precipitation (PoP) graphic available on DIFAX. The slot numbers are D068 for the 0000 UTC cycle, and D207 for the 1200 UTC cycle.

The precipitation type forecasts are only available from September 16 to May 15, and forecasts are not available for stations in southern Florida and much of California (see Fig. 1). In other words, the forecast bulletins for some stations never contain the PTYPE, POZP, and POSN lines, and the bulletins for all stations will be missing these lines from May 16 to September 15.

5. SPECIAL NOTES

The NGM MOS products provide an objective interpretation of the NGM output. This system has inherent strengths and weaknesses that forecasters should always keep in mind. In the case of precipitation type, the MOS technique statistically relates the precipitation types observed at specific times of day and specific stations to a historical sample of NGM output. This process can account for some systematic model biases, as well as the reduced skill of the model with increasing projection. The use of derived predictors in addition to direct NGM variables also helps the statistical model mimic common conceptual models used by forecasters. None of these attributes, however, allows the NGM MOS guidance to overcome a genuinely bad model forecast on any specific occasion. To the contrary, the MOS will faithfully reflect the main patterns in the NGM output. Keep in mind, too, that the NGM variables used as predictors in the MOS process are available at 6-h time steps, on a 190.5 km output grid, and with a 50-mb vertical resolution. With these scales as input, the MOS guidance is synoptic-scale, and is not likely to capture mesoscale features well. Forecasters can use detailed vertical profiles of NGM forecasts available from the National Meteorological Center together with the MOS guidance to obtain a more complete picture of the NGM forecast.

In our subjective evaluations of the precipitation type forecasts, we have noticed that the guidance seems deficient in the presence of very shallow cold air and/or a surface below freezing. The NGM vertical temperature profiles in these cases indicated that the model itself did not retain the low-level cold air, and the MOS forecasts reflected that. We suspect that over the entire season this situation does not occur consistently enough to be corrected by the MOS technique. When very shallow cold air or a below-freezing surface is present, forecasters should check the NGM vertical temperature profiles. If the cold air is not reflected in the NGM, the MOS guidance may need modification.

The precipitation type forecasts are <u>conditional</u> on the occurrence of precipitation. It is very important to consider the NGM MOS probability of precipitation (PoP) forecast before trying to understand the precipitation type guidance. Since the developmental samples for precipitation type contain only events where precipitation <u>did</u> occur, the MOS equations interpret the NGM variables in this context. Thus, the precipitation type guidance may seem misleading when the NGM is very dry.

We have also found it to be very helpful to use the probability forecasts (POZP, POSN) to understand the forecast of the weather event more completely. Trends in the probabilities over time and space can indicate a transition from one form of precipitation to another as well as the areal extent of a given precipitation type.

Finally, we remind forecasters that the PTYPE, POSN, and POZP forecasts will not <u>necessarily</u> be consistent with the NGM MOS forecasts of temperature, dew point, or snow amount. Although all the forecast equations have some common NGM variables as predictors, the equations also contain predictors that are specific to the individual weather elements. Consequently, the equations do produce inconsistent forecasts on occasion. For example, the temperature equations rely heavily on the 1000-850 mb thickness while the precipitation type equations use predictors that indicate the NGM vertical structure (warm air above cold). As a result, the temperature forecasts may indicate temperatures above freezing or a warming trend (warm 1000-850 mb thickness) while the precipitation type guidance indicates a freezing precipitation event. We've observed that predicted temperatures above the mid to upper 30's coincident with a forecast of freezing precipitation probably indicate freezing rain, that is, a thin cold layer is predicted at the earth's surface. Temperatures predicted to be near freezing coincident with a forecast of freezing precipitation probably indicate ice pellets or a mixed precipitation event, that is, the cold layer near the earth's surface is thick enough to refreeze aloft precipitation that has melted. Local studies may yield more concrete information on distinguishing between freezing rain and ice pellets. When the temperature, dew point, snow amount, and precipitation type forecasts are consistent, the forecaster can have increased confidence in the guidance.

6. REFERENCES

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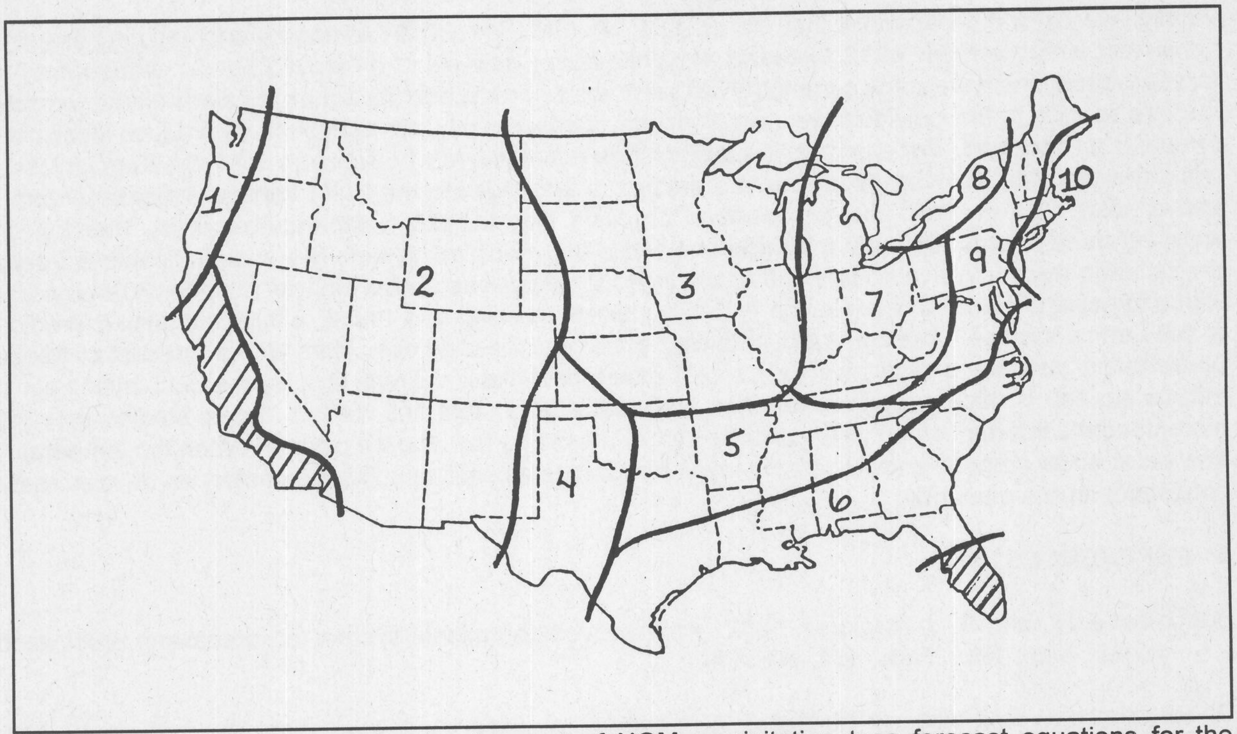

Figure 1. Regions used in the development of NGM precipitation type forecast equations for the contiguous U.S.. Precipitation type forecasts are not produced for stations in the hatched areas.

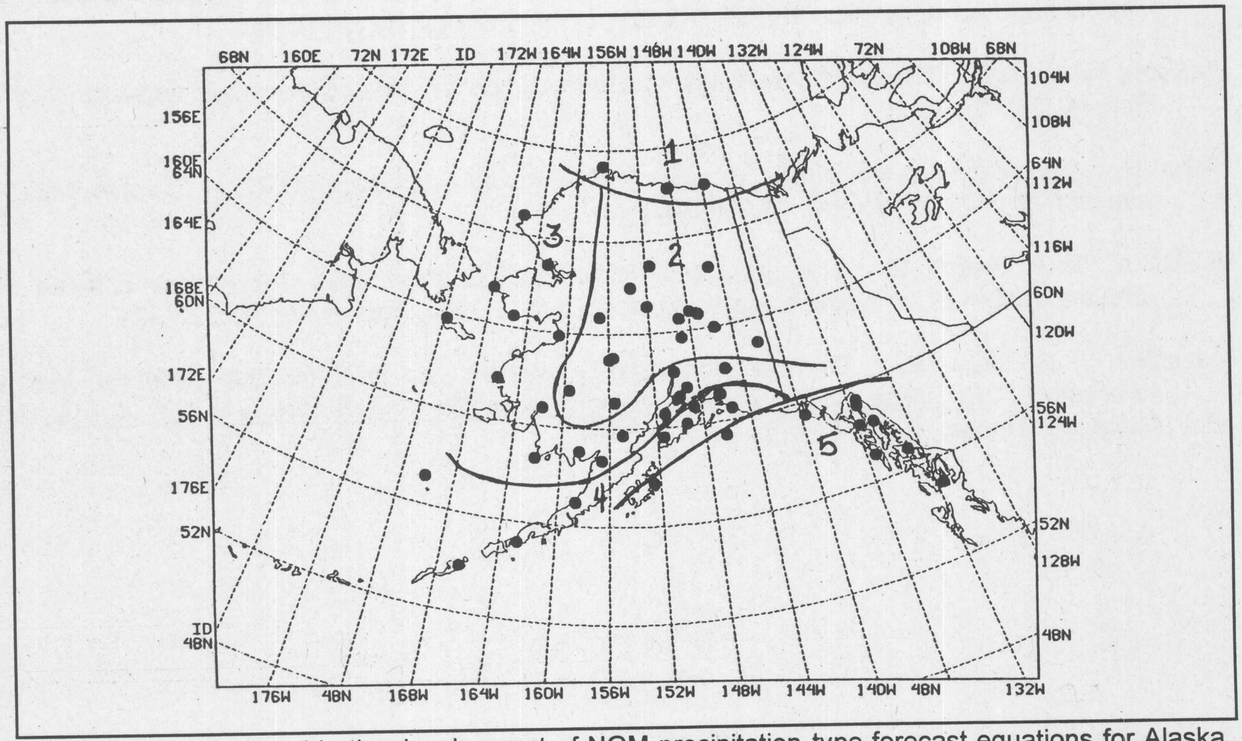

Figure 2. Regions used in the development of NGM precipitation type forecast equations for Alaska.

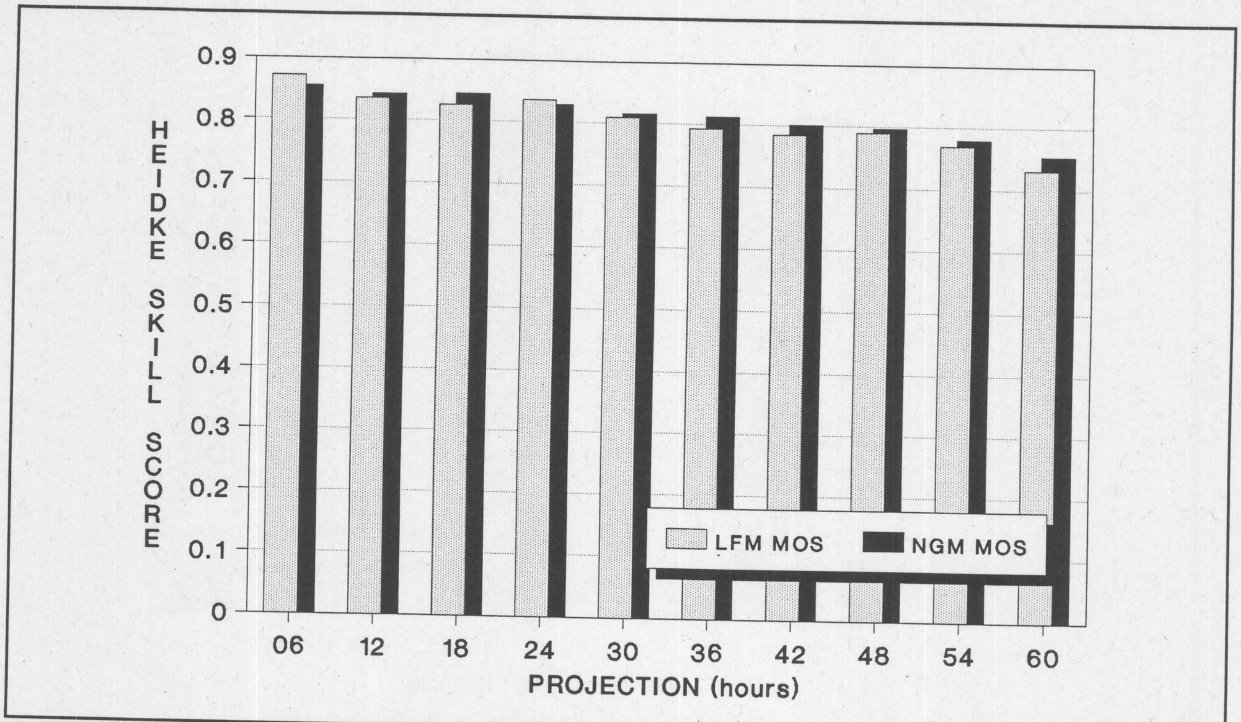

Figure 3. Heidke skill scores for LFM and NGM MOS precipitation type forecasts made from 1200 UTC data, September 16, 1993 to May 15, 1994.

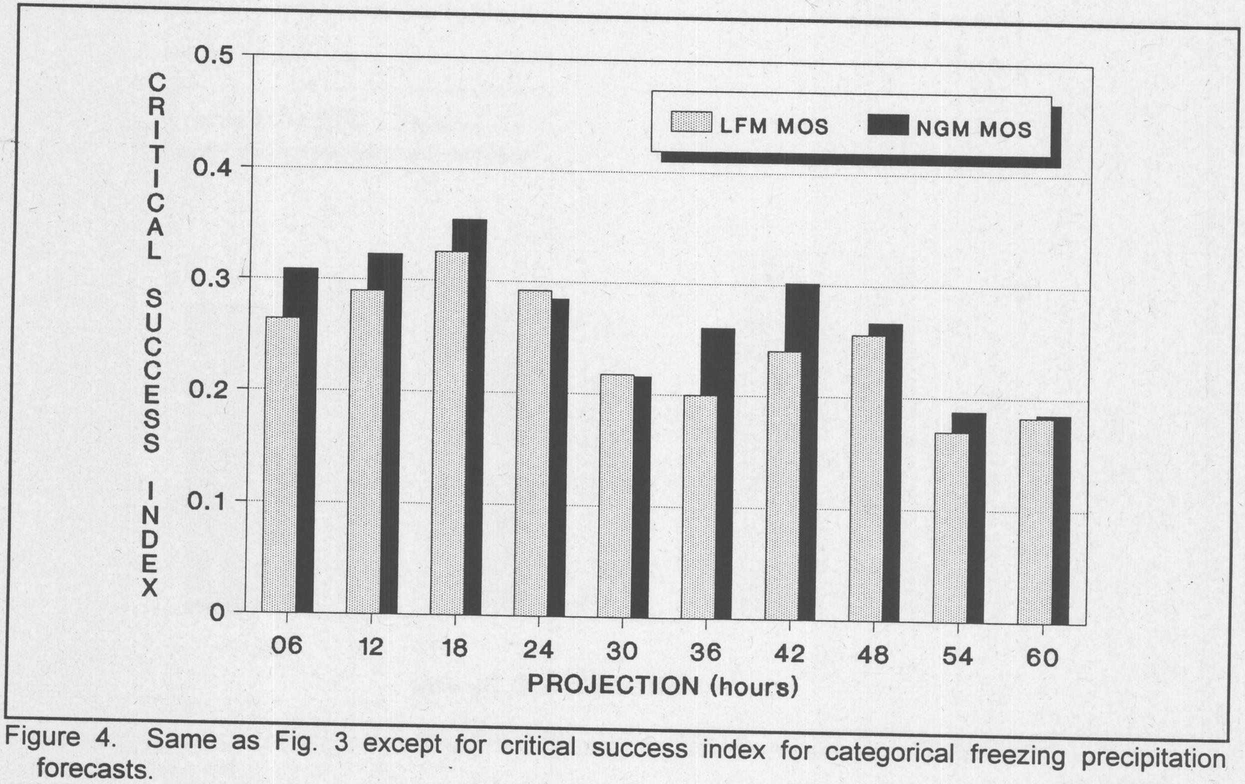

Figure 4. Same as Fig. 3 except for critical success index for categorical freezing precipitation forecasts.

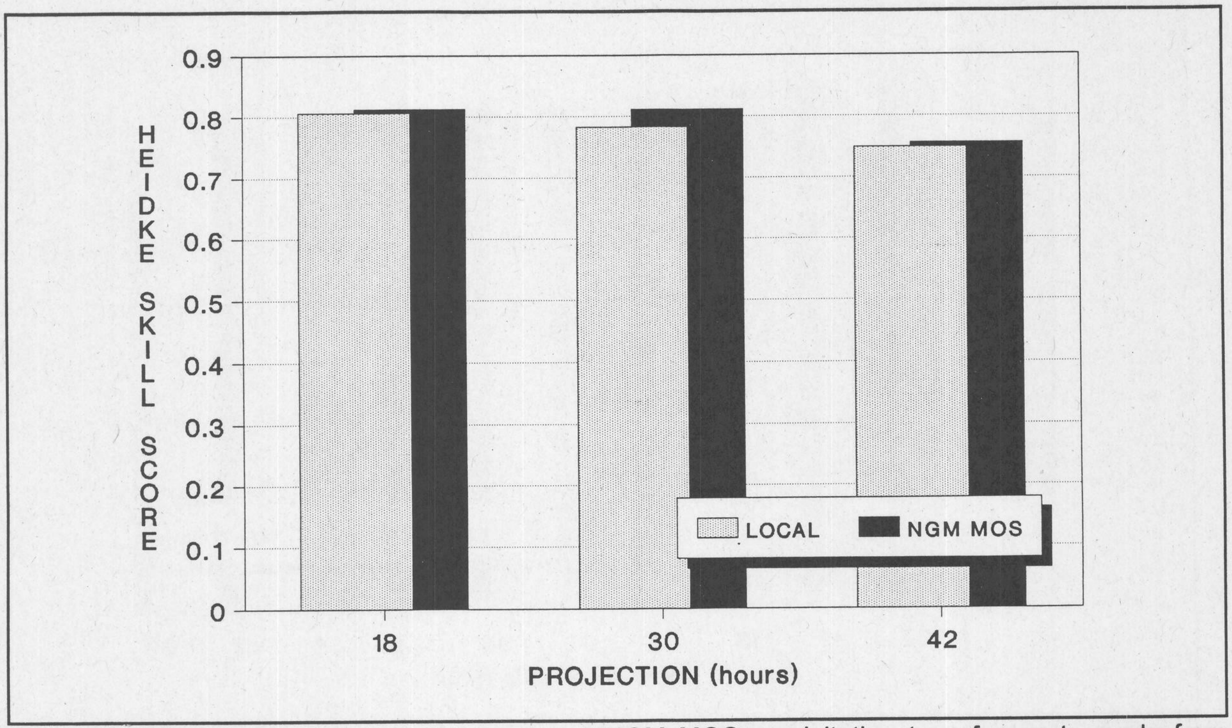

Figure 5. Heidke skill scores for the local and NGM MOS precipitation type forecasts made from 1200 UTC data, October 1, 1993 to March 31, 1994.

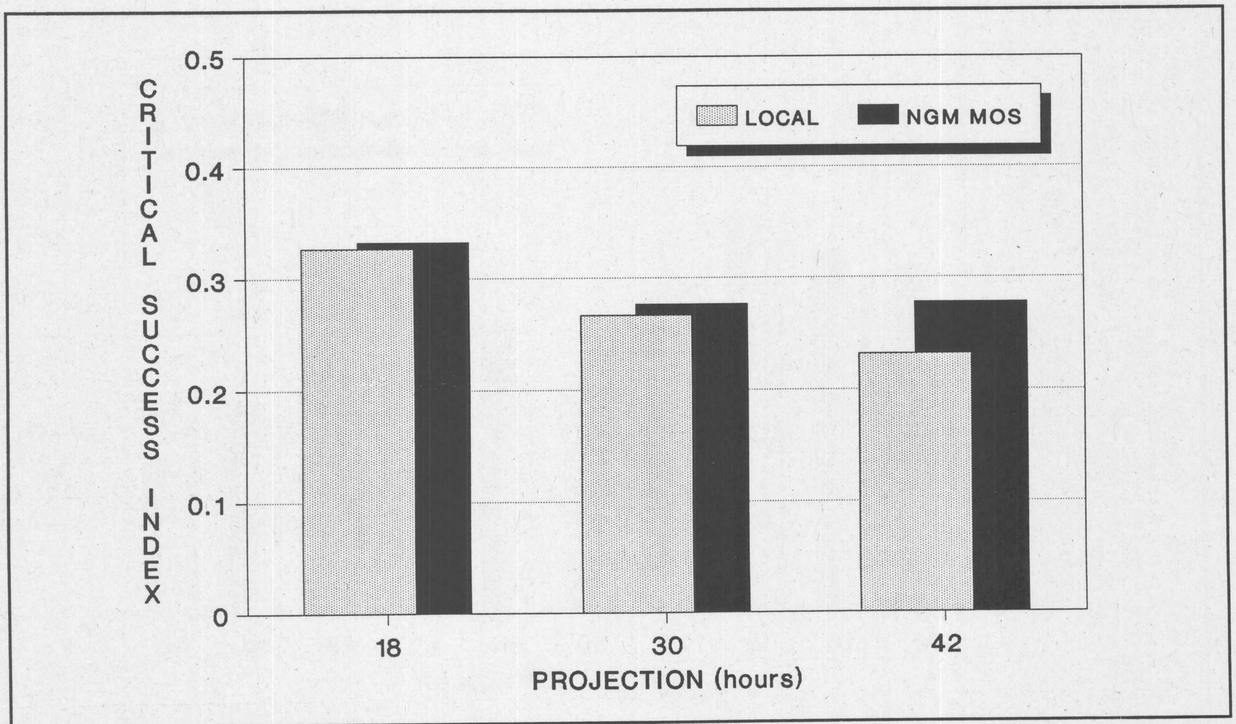

Figure 6. Same as Fig. 5 except for critical success index for categorical freezing precipitation forecasts.

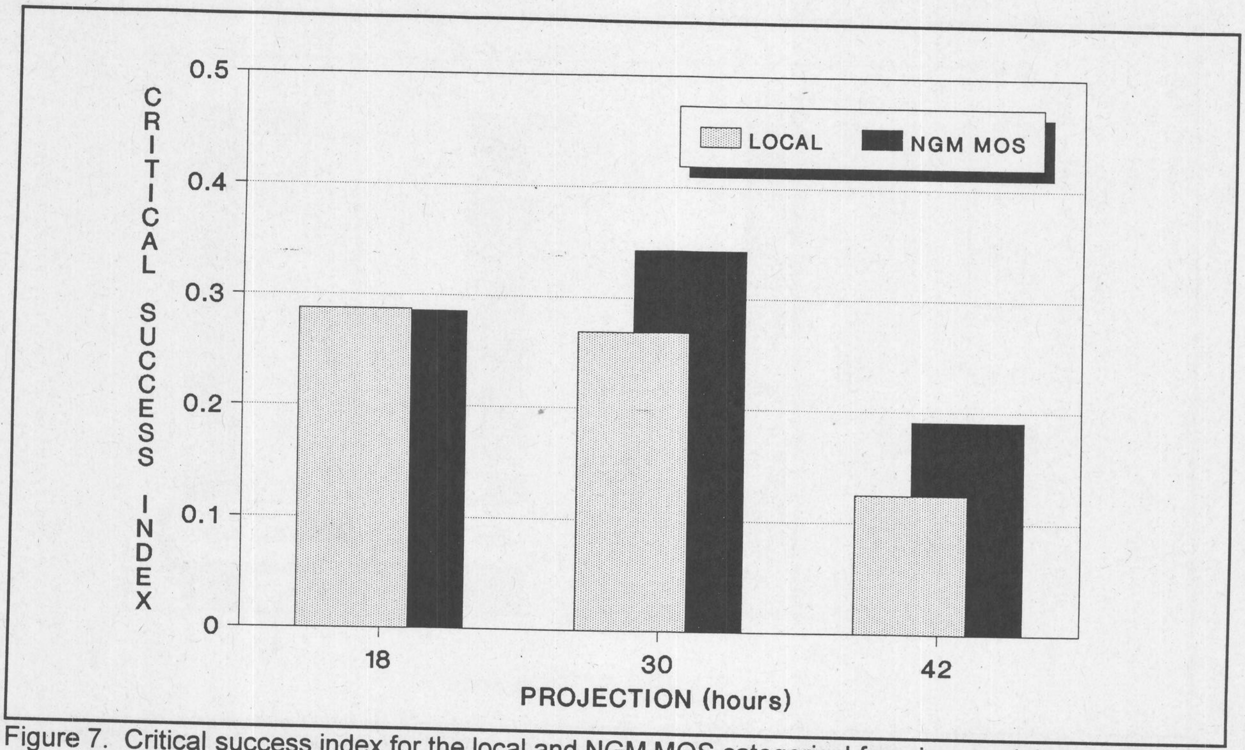

Figure 7. Critical success index for the local and NGM MOS categorical freezing precipitation forecasts based on 0000 UTC data, October 1, 1993 to March 31, 1994.

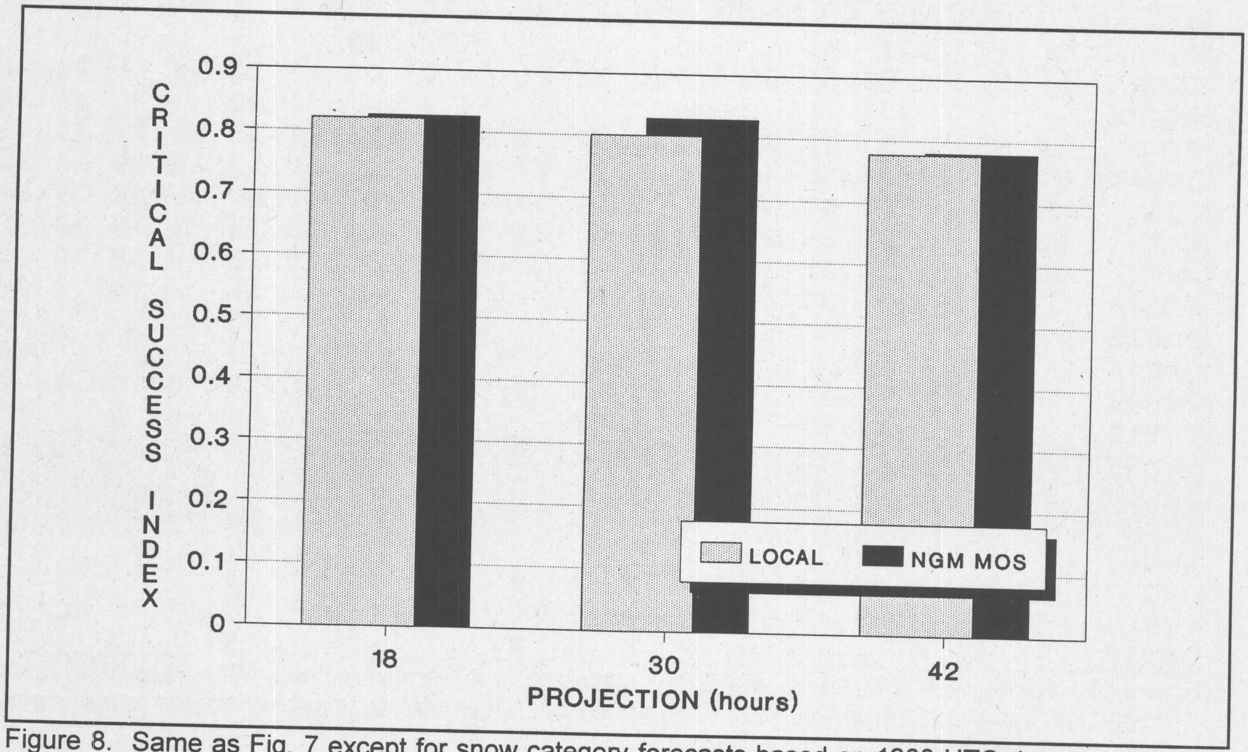

Figure 8. Same as Fig. 7 except for snow category forecasts based on 1200 UTC data.

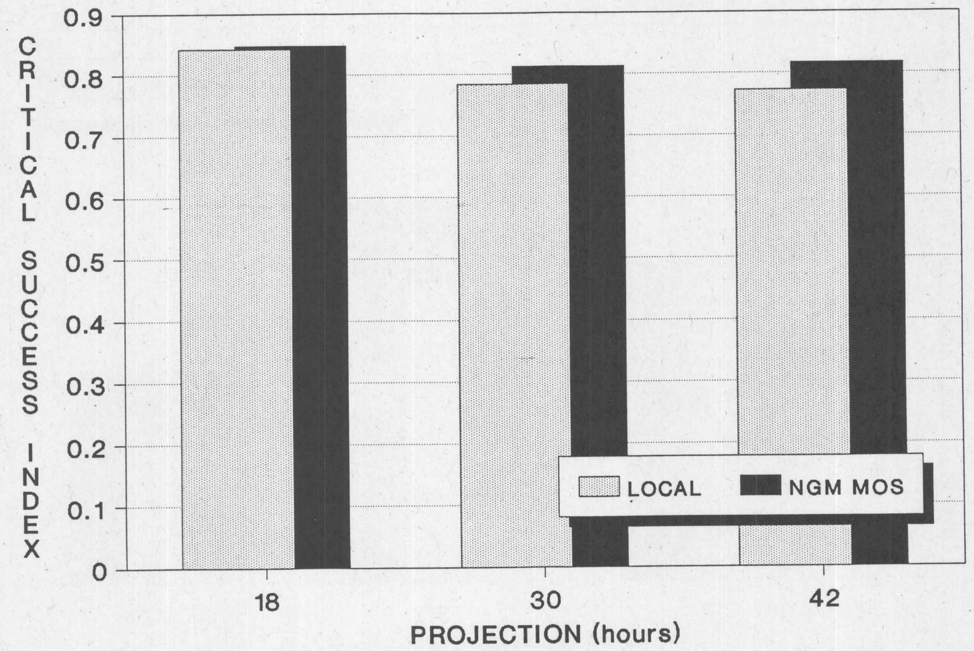

Figure 9. Critical success index for the local and NGM MOS snow category forecasts based on 0000 UTC data, October 1, 1993 to March 31, 1994.

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INL   C     NGM MOS GUIDANCE  10/27/93  1200 UTC
DAY /OCT   27 /OCT  28                /OCT  29                 /
HOUR    18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00
MN/MX                     34          40          20          28
TEMP    35 39 39 37 38 38 37 40 38 35 32 28 26 24 23 22 25 26 23
DEWPT   22 25 28 30 33 35 34 34 30 27 25 23 22 20 19 16 14 13 12
CLDS    OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV BK OV BK
WDIR    23 19 19 19 19 24 28 29 31 31 32 33 33 33 33 33 33 32 30
WSPD    13 16 13 14 12 14 13 14 19 19 11 18 18 16 15 17 18 20 12
POP06         55    93    94    67    59    60    45    34    24
POP12                    100          84          70          41
QPF           1/    2/    2/3   1/    1/1   1/    1/1   0/    0/0
TSV06       7/ 6 11/10  4/ 1  1/ 0  1/ 6  0/ 1  0/ 0  0/ 0  1/ 0
TSV12            13/11        5/ 0        2/ 7        0/ 0
PTYPE    S  S  S  S  R  R  R  S  S  S  S     S     S     S     S
POZP     3  0  5  4  0  0  0  0  0  0  0     1     0     0     0
POSN    77 62 58 51 35 34 49 58 69 90 90    96    94    96    96
SNOW          1/    1/    1/2   1/    1/1   1/    1/1   1/    1/1
CIG      4  5  4  4  2  2  2  2  4  4  4     4     4
VIS      5  5  3  3  3  3  3  3  3  4  4     4     5
OBVIS    N  N  N  F  N  F  F  F  N  N  N     N     N
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Figure 10. Sample FOUS14 KWBC (FWCINL) message for International Falls, Minnesota (INL) for the 1200 UTC cycle on October 27, 1993. The precipitation type forecasts are highlighted in the stippled area of the message.