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NGM-Based MOS Snowfall Amount Forecast for the United States

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This Technical Procedures Bulletin (TPB), which was written by J. Brent Bower of the Techniques Development Laboratory, describes the Model Output Statistics (MOS) snowfall amount guidance developed from the Nested Grid Model (NGM) for stations in the contiguous United States and Alaska. The guidance for the contiguous United States was implemented on September 16, 1993, 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 FOAK13 KWBC message. The guidance is available twice daily around 0400 and 1600 UTC.

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NGM-BASED MOS SNOWFALL AMOUNT FORECASTS FOR THE UNITED STATES

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1. INTRODUCTION

The National Weather Service (NWS) has had a Model Output Statistics (MOS) (Glahn and Lowry 1972) system for forecasting snowfall amount for the contiguous United States (CONUS) since 1977 (Bocchieri 1978, 1983). The Techniques Development Laboratory (TDL) of the NWS has derived a new forecast system based on output from the Nested Grid Model (NGM) (Hoke et al. 1989) which gives a categorical forecast of snowfall amount for no snow, ≥ a trace to < 2, ≥ 2 to < 4, ≥ 4 to < 6, and ≥ 6 inches for 12-h periods and for no snow, ≥ a trace to < 2 and ≥ 2 inches for 6-h periods. The 6- or 12-h snowfall amount forecasts are valid for periods ending 12 to 60 hours following 0000 and 1200 UTC. Development of the snowfall guidance for Alaska was done separately from that of the lower 48 states. Although the two developments were similar, differences will be pointed out in the appropriate sections. The snowfall amount guidance was implemented in May 1993 for over 300 sites in the CONUS. The snowfall guidance was extended to over 500 sites in the CONUS in May 1994 and to 60 stations in Alaska for the first time for the 1994-1995 season.

2. METHOD

The MOS technique was applied to output from the NGM to derive forecast equations to predict the probability of several categories of snowfall amount. The MOS approach correlates predictand data (weather conditions to be forecast) with predictor data (output from numerical models, surface observations, remotely-sensed observations, and geographical or climatic information) by use of multiple linear regression. We use forward selection regression, which selects the predictors based on their reduction of variance of the predictand (Draper and Smith 1981). The predictor that is most correlated (produces the greatest reduction of variance) with the predictand is chosen first. The remaining predictors are evaluated and the one, in combination with the predictor already chosen, that gives the highest cumulative reduction of variance is selected next. Succeeding predictors are similarly chosen until the selected predictor's contribution to the reduction of variance is no longer deemed significant or the number of predictors reaches a pre-defined limit. The cutoff levels for reduction of variance and the number of predictors are determined by the developer.

In the application of MOS described here, the prediction equations were developed by applying multiple linear regression techniques to relate the categorical snowfall amount predictand data to the predictors. The snowfall predictand was divided into categories based on the amount of snowfall observed within a specific period of time. The predictors consisted of surface observations, MOS forecasts and combinations of MOS forecasts for probability of precipitation and conditional probability of snow, NGM forecasts, and geographical or climatic information. The prediction equations were then used to produce probability forecasts on the dependent data for each category of snowfall amount. Subsequently, a threshold probability was objectively chosen so that a "best" category snowfall amount forecast could be determined from the probabilities.

3. DEVELOPMENT

a. Predictand

The most reliable snowfall amount reports available to TDL were from archive records of the National Climatic Data Center (NCDC). We found approximately 200 stations in the CONUS and Alaska with sufficient 6-h snowfall amount data to use in development. The definition of the occurrence of snowfall was a trace (0.04 inches) or more of snow measured in a 6- or 12-h period. The predictand was divided into cumulative categories for snowfall amounts of ≥ a trace, ≥ 2, ≥ 4, and ≥ 6 inches for 12-h periods and ≥ a trace and ≥ 2 inches for 6-h periods. For each category, then, the predictand was set equal to a value of one if the snowfall amount was equal to or greater than the category limit and set equal to zero if the snowfall amount was less than the category limit. For example, a snowfall of 4.5 inches results in setting the ≥ a trace, ≥ 2, and ≥ 4 inch predictand categories to 1 with the ≥ 6 inch category set to zero. Prediction equations for the 6- and 12-h periods were developed separately. Equations for all categories within the 6-h (12-h) periods were developed together. Note, too, that the snowfall predictand was unconditional, that is, all cases (snow/no snow) were included in the regression.

b. Predictors

The potential predictors for deriving the snowfall amount forecast equations were NGM-based MOS forecasts, NGM forecasts interpolated to stations, interactive predictors from the NGM forecasts, station observations, geographic variables, and climatic variables. The NGM forecasts were archived on a grid with 190.5 km resolution at 60⁻ North. Though many different predictors were tested, only the most useful ones were used in the development. The predictors included in development for CONUS and for Alaska are listed in Table 1. Note that observed current weather (reported at 3 hours after 0000 or 1200 UTC) was used for forecast projections out to 18 hours.

Many of the predictors were available in point-binary and/or grid-binary (Jensenius 1992; Su 1993) form. Spatial smoothing was used on all of the NGM predictors. Predictors with projections out to 24 hours were smoothed with 5- or 9-gridpoint smoothers. Beyond 24 hours, most NGM predictors were 9- or 25-gridpoint smoothed. NGM fields that were more noisy and derived predictors that were more complex were smoothed more heavily. Since the predictand was defined in terms of a period of time, many predictors were time-averaged over 6-h periods. Dynamic predictors such as vorticity advection were averaged or differenced over 12-h time periods.

Since every day during the "snow" season (see Section 3.3) was included in the developmental sample, we first had to have predictors that were able to determine the occurrence of snow before we tried to predict the amount of snow that fell. Therefore, we needed moisture-related predictors to determine precipitation occurrence and thermal predictors to determine the form of precipitation. By combining into one predictor these two different conditions, both necessary for measurable snowfall, there was more information than if the predictors were used separately. The major difference between the forecast equations for the CONUS and those for Alaska was the type of combined predictors available. We used MOS forecasts of probability of precipitation (PoP) and conditional probability of snow (PoSN) to create probability of snowfall (PoSF) predictors for the CONUS forecast equations. Not having MOS PoP and PoSN forecasts available for Alaska at the time of development, we used NGM forecasts to try to accomplish the same thing. Both approaches worked reasonably well.

The PoSF for a 6-h period was created by multiplying the PoP for the same 6-h period by the average of the PoSN at the beginning and end of the 6-h period. The PoSF for a 12-h period was created by multiplying the PoP for the same 12-h period by a weighted average of PoSN at the beginning, middle, and end of the 12-h period. The weighting was based on the PoPs for 6-h periods such that the PoSN's associated with the greatest 6-h PoP were weighted most heavily. See Fig. 1 for the algorithms.

For Alaskan stations, we tried many different combinations of moisture and thermal predictors. The best interactive predictors of this type were the product of the height of melting level and precipitation amount and the product of the 700-mb vertical velocity, mean relative humidity in the lower troposphere, and 1000-850 mb thickness. Other interactive predictors are listed in Table 1. Note that some parts of Alaska are so cold that thermal information is not very important for the interactive predictors.

The most important predictors used in the CONUS regression equations were PoSF, PoSN, and grid-binary transformations of precipitation amount and low-level temperatures. PoSF and PoSN predictors made up one-third to one-half of the total number of predictors in the equations. They contributed most of the reduction of variance in distinguishing snow cases from no-snow cases. The most important predictors for Alaska were the interactive predictors mentioned above, and model precipitation amount used in point-binary, grid-binary, and continuous form.

c. Seasons

Snowfall amount equations were developed for one "snow" season. The snow season for the CONUS is September 16 to May 15. The dates included in the developmental sample were from October 1986 to May 1992. For Alaska, the snow season is September 1 to May 31. The developmental sample dates were from October 1986 to May 1993.

d. Equation Development

The snowfall amount equations were developed for the projections from 0000 and 1200 UTC shown in Table 2. Note that the 12-h forecast periods are not the same for the CONUS and Alaskan sites. Forecast equations for the 6-h period were developed separately from those for the 12-h periods. This was done so that each 6-h period equation would only have predictors specifically for its particular 6-h period. Equations were developed by using the regional approach in which data for a group of stations were combined in order to increase the sample size. One equation was then derived for all the stations in the region. The size of each region was driven by the number of events needed to derive a stable equation. Stations were divided into regions based on geography, relative frequencies, and each station's correlation of the predictand with important predictors. In addition, the Alaska Region gave us information on grouping stations that was invaluable in determining regions. We divided 187 stations in the CONUS into six regions as shown in Fig. 2a. We divided 17 stations in Alaska into seven regions (Fig. 2b). Note that snowfall amount forecasts are generated for all stations depicted in Fig. 2. Only the stations shown by stars were used in development.

Limits were placed on the predictors selected for the equations by using a cutoff in the number of predictors or the additional reduction of variance. The 6- and 12-h equations for the CONUS had limits of 18 terms or 0.08% reduction of variance. The regions used in Alaska contained so few stations that we were more conservative. Hence, the 12-h equations for Alaska had limits of 18 terms or 0.20% additional reduction of variance and the 6-h equations had limits of 14 terms or 0.20% additional reduction of variance.

e. Categorical Forecasts

The forecast equations were used to make probability forecasts for each snowfall amount category for every date in the developmental sample. The probabilities for each category were then compared with the observed snowfall amount and a threshold probability was objectively determined for each category. For more details on threshold determination, see Miller (1994). Threshold probabilities were chosen such that they maximized the Critical Success Index (CSI) of the forecasts while producing a bias (the ratio of forecasts of a category to observations of that same category) within a selected range. Overforecasting rare events generally yields better CSI scores. Therefore, we used a bias of 1 for the trace to $<$ 2 inch category and a range of 1 to 1.3 for the higher categories. The exception to this rule was for equations whose projections go beyond the available model data (48 hours). For those 6- and 12-h equations, we used a bias range of 0.7 to 1.0 for the higher categories. The forecast skill for higher categories in equations valid beyond 48 hours was not very high. Tests (not shown) indicated that for these projections, forcing a bias of $\leq$ 1 greatly reduced the false alarm ratio without lowering the probability of detection, thereby, achieving a greater CSI.

In daily operations, the forecast equations produce probabilities for each snowfall amount category. A categorical forecast is then determined from the probabilities in the following way. The forecast probability for the first category, which is the greatest snowfall amount and, hence, the rarest event, is compared to a threshold probability for that category. If the forecast probability exceeds the threshold, then that category is selected as the categorical forecast or "best" category. If not, then the forecast probability for the next category is compared to its threshold and so on until a categorical threshold is surpassed. If none of the snowfall amount category thresholds is surpassed, a snowfall amount of zero is forecast. Possible categorical forecasts for the 6- and 12-h periods are shown in Table 3.

4. MESSAGES AND SCHEDULES

The NGM-based snowfall amount forecasts for the CONUS are generated twice daily around 0400 and 1600 UTC from September 16 to May 15. The guidance is disseminated in alphanumeric form for the stations given in Technical Procedures Bulletin (TPB) No. 408 (Dallavalle et al. 1992). On AFOS, the snowfall amount guidance is available in the FWCxxx product, where xxx are the call letters of the station requested. The guidance is also available on the Family of Services' Domestic Data Service and the Federal Aviation Administration's Weather Message Switching Center as the FOUS14 KWBC product and on the United States Air Force's Automated Weather Network. The forecasts products for Alaska are similar to those available in the CONUS and are available as the FOAK13 KWBC product. Note that the guidance for only a subset of all the forecast sites are disseminated in the FOUS14 product, while the guidance for all the Alaska sites is available in the FOAK13.

An example of the snowfall amount categorical forecasts is shown in Fig. 3. In this example, the FOUS14 product (Fig. 3a) is for Fort Wayne, Indiana (FWA) for the 0000 UTC forecast cycle on February 13, 1991. The forecast is for light snow to begin during the last half of the 12-h period ending 1200 UTC on the 14th, become heavier during the next two 6-h periods (the corresponding 12-h period has a forecast of ≥ 6 inches), then diminish after that. Missing snowfall amount forecasts, like in the sample FOAK13 for Anchorage, Alaska, are shown as a 9. The snowfall amount guidance is dropped from the message during the non-snow season and is not available for certain stations in Florida and California (see Section 3.4 and Fig. 2).

5. OPERATIONAL CONSIDERATIONS

a. Model Dependence

As is the case with all MOS forecasts, the accuracy of the snowfall amount categorical forecasts heavily depends on the accuracy of the numerical model used as input. While the MOS technique can account for some systematic biases in the NGM, MOS cannot correct for poor model forecasts. Model accuracy decreases with increasing projection and may be less in some areas of the model domain than in others, such as places where terrain effects, land-sea breezes, etc. are a factor. Since the NGM is a synoptic-scale model, mesoscale features are normally not predicted well. In addition, recall that the NGM output archive is on a coarse grid (Section 3.2) which results in some smoothing of the data fields. As a result, features like lake-effect snowstorms are not predicted particularly well by MOS. For further discussion of MOS strengths and weaknesses, see Dallavalle and Erickson (1993).

b. Inconsistencies Among Forecasts

There will be occasions when MOS forecasts of snowfall amount will not be consistent with MOS PoPs and/or Quantitative Precipitation Forecasts (QPF). One example is seen in the many snowfall forecasts of category 1 with low PoPs and zero QPFs. Verifications (not shown) indicate that the bias (ratio of forecasts to observations) of the category 1 forecasts is very near one. Recall that the predictand definition for category 1 snowfall is a trace to < 2 inches. Thus, category 1 includes very light, non-accumulating snow. Alternatively, snowfall forecasts of category 1 with high PoPs and/or QPFs may indicate rain mixed with snow. By considering the differences in the predictors and in the nature of the predictands for each of the MOS forecast products and the forecaster's own interpretation of the model, the forecaster may be able to determine which guidance is best. Indeed, each forecast product may supply a piece of the information needed to solve the forecast puzzle.

Inconsistencies also occur when a 12-h forecast is less than one of the 6-h forecasts valid within the 12-h period. In the verifications described in the next section, we found that in approximately 75% of the cases the 12-h period forecasts were correct or were closer to the correct category than the 6-h period forecasts when there were inconsistencies between the two.

c. Verification

Before implementation, we tested the NGM-based MOS snowfall amount forecasts for all projections on the 1992-93 snow season. Verifications for CONUS and Alaska were done separately. In looking at the contingency tables of MOS snowfall forecast versus observations (not shown), we saw that the MOS forecasts did well at locating the areas of snowfall (trace to < 2 inch category), even out to the last projection. Based on these contingency tables, Heidke skill scores for all the forecast projections were evaluated. All Heidke skill scores were based on discrete categories. The MOS 12-h period forecasts (Fig. 4) showed considerable skill out to the 60-h projection (54 hours for Alaska). The skill of the 6-h period forecasts was similar (Fig. 5). The forecast skill decreased with projection as expected. The CSI is shown in Figs. 6 and 7. All CSI scores were based on cumulative categories. The skill in predicting the higher categories was variable. At the 60-h projection for the CONUS, the CSI for category 6 is small. Note that the usual trend of scores decreasing with projection and with the rarer categories (greater snowfall amount) did not always occur. This may be the result of the small number of events in some categories.

In another verification on the 1992-93 snow season, we compared the NGM-based MOS snowfall amount forecasts to the local NWS forecasts taken from the AFOS-ERA Verification (AEV) data (Dagostaro 1985). Note that in this season, NGM-based MOS snowfall amount forecasts were not available to the local forecaster. In order to compare fairly the NGM-based MOS forecasts with the local NWS forecasts, we had to adjust to the differences between the two. Thus, the comparison test was restricted to the 12-24 h "best" category forecasts from both cycles. Since the lowest snowfall amount category for the AEV system is 0 to < 2 inches, the trace to < 2 inch category in the MOS system was combined with the no snowfall category. Not all the snowfall observation data were available from the AEV archives, so we supplemented with the NCDC observed data. Because observed snowfall in the AEV data is reported only to the nearest inch, we rounded the NCDC snowfall amount observations to the nearest inch for the comparison. Note that using a different observation for verification than was used for development puts the MOS forecasts at a disadvantage.

The verification results for the comparison showed that, overall, the Heidke skill scores for the NGM-based forecasts and the local forecasts were about equal (Fig. 8). In Fig. 9, the CSI for each category is shown. With the small sample size in Alaska, there were only a few of the ≥ 6 inch snowfall events, and none of the forecasts hit. The CSI for that category (0) is not shown for that reason. The CSI of the MOS forecasts for the CONUS was not as good as the CSI for the locals for most categories. For Alaska, the CSI was equal or slightly better than the CSI for the locals. For the higher snowfall amounts (≥ 6 inches in the CONUS, ≥ 4 inches in Alaska), the small number of cases eliminate any definitive conclusions about the significance of the results.

6. REFERENCES

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Table 1. Predictors used in the development of NGM-based MOS snowfall amount forecast equations for CONUS and Alaska.

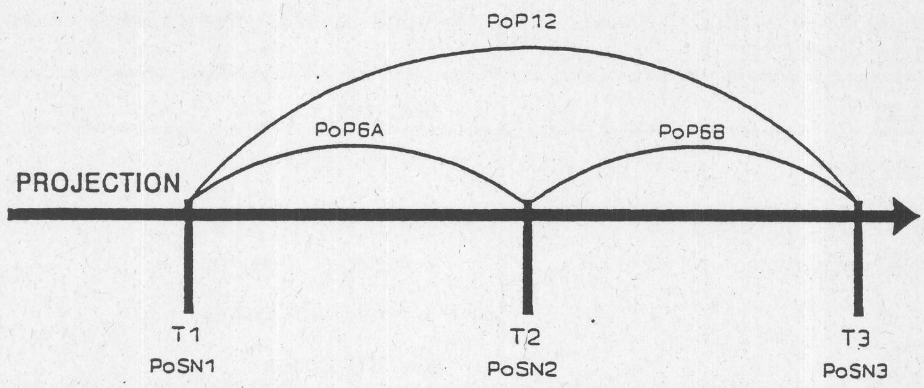
Predictor Type	Predictors
MOS Forecasts (CONUS only)	- conditional probability of snow, available in the NGM MOS precipitation type guidance (PoSN) - probability of precipitation (PoP) - probability of snowfall (PoSF), a derivation of PoSN and PoP
NGM Forecasts (CONUS and Alaska)	- precipitation amount - precipitable water - relative humidity: surface-500, 1000-900, 900-800, 800-700, 1000-700, and 850-700 mb means; 850 mb - level temperatures: 950, 900, 850, 800, and 700 mb - thickness 1000-850, 850-700, and 1000-500 mb - vertical temperature difference: 1000-850 mb - K-index - geostrophic wind components: 1000 and 850 mb - 10-m wind components - heights 850, 700, and 500 mb - height tendency: 500 mb - sea level pressure - geostrophic vorticity: 700 and 500 mb - vorticity advection by model winds: 850, 700, and 500 mb - wind divergence: 850 mb - divergence of Q-vectors: 700, 600, and 500 mb - vertical velocity: 700 and 500 mb
NGM Forecasts (Alaska only)	- logit transform of temperature: 850 mb - logit transform of thickness: 1000-850 and 850-700 mb - height of freezing level (mb) - precipitation amount grid binary (0.01") times height of freezing level grid binary (925 mb) - precipitation amount grid binary (0.01") times 700 mb vertical velocity - terrain-induced vertical velocity by model winds at 10 m, 950, 850, and 700 mb - mean relative humidity in 1000-700 mb layer times 700 mb vertical velocity - mean relative humidity in 1000-700 mb layer times 700 mb vertical velocity times 1000-850 mb thickness grid binary (1293 m) - mean relative humidity in 1000-500 mb layertimes 700 mb vertical velocity
Geographic/ Climatic	- station elevation - sinusoidal functions of the day of the year - extraterrestrial radiation - hours of sunshine - relative frequency of 12-h snowfall amounts (≥ a trace, ≥ 2", ≥ 4")

Table 2. Projections for the 6- and 12-h period NGM-based MOS forecasts of snowfall amount for CONUS and Alaska. The projections are valid after the initial model time (0000 or 1200 UTC).

6 hours	12 hours
0 = no snow	0 = no snow
1 = trace to < 2 inches	1 = trace to < 2 inches
2 = ≥ 2 inches	2 = 2 to < 4 inches
	4 = 4 to < 6 inches
	6 = ≥ 6 inches

Table 3. "Best category" amounts for the 6- and 12-h period NGM-based MOS forecasts of snowfall amount for CONUS and Alaska.

Alaska 12-h	CONUS 6-h	CONUS 12-h
6-18	6-12	12-24
18-30	12-18	24-36
30-42	18-24	36-48
42-54	24-30	48-60
	30-36	
	36-42	
	42-48	
	48-54	
	54-60	



$$\text{6-H } \overline{PoSN} = \frac{PoSN1 + PoSN2}{2}$$

IF EITHER PoP6A OR PoP6B $\neq 0$, *THEN*

$$\text{12-H } \overline{PoSN} = \frac{PoP6A}{PoP6A + PoP6B}\left(\frac{PoSN1 + PoSN2}{2}\right) + \left(\frac{PoSN2 + PoSN3}{2}\right)\frac{PoP6B}{PoP6A + PoP6B}$$

$$= \frac{PoP6A\,(PoSN1 + PoSN2) + PoP6B\,(PoSN2 + PoSN3)}{2\,(PoP6A + PoP6B)}$$

$= 0$ *IF BOTH PoP6A AND PoP6B* $= 0$

$$\text{6-H } PoSF = PoP6 \times \text{6-H } \overline{PoSN}$$

$$\text{12-H } PoSF = PoP12 \times \text{12-H } \overline{PoSN}$$

Figure 1. Schematic showing how the 6- and 12-h period probabilities of snowfall (PoSF) are calculated by using a weighted-average of PoSN. PoSN is the NGM-based MOS conditional probability forecast of snow. PoP6 and PoP12 are the NGM-based MOS PoP forecasts for 6- and 12-h, periods respectively. T1, T2, and T3 are the times that the respective PoSNs are valid and the end points of the valid period for the PoP6s and the PoP12.

a)

b)

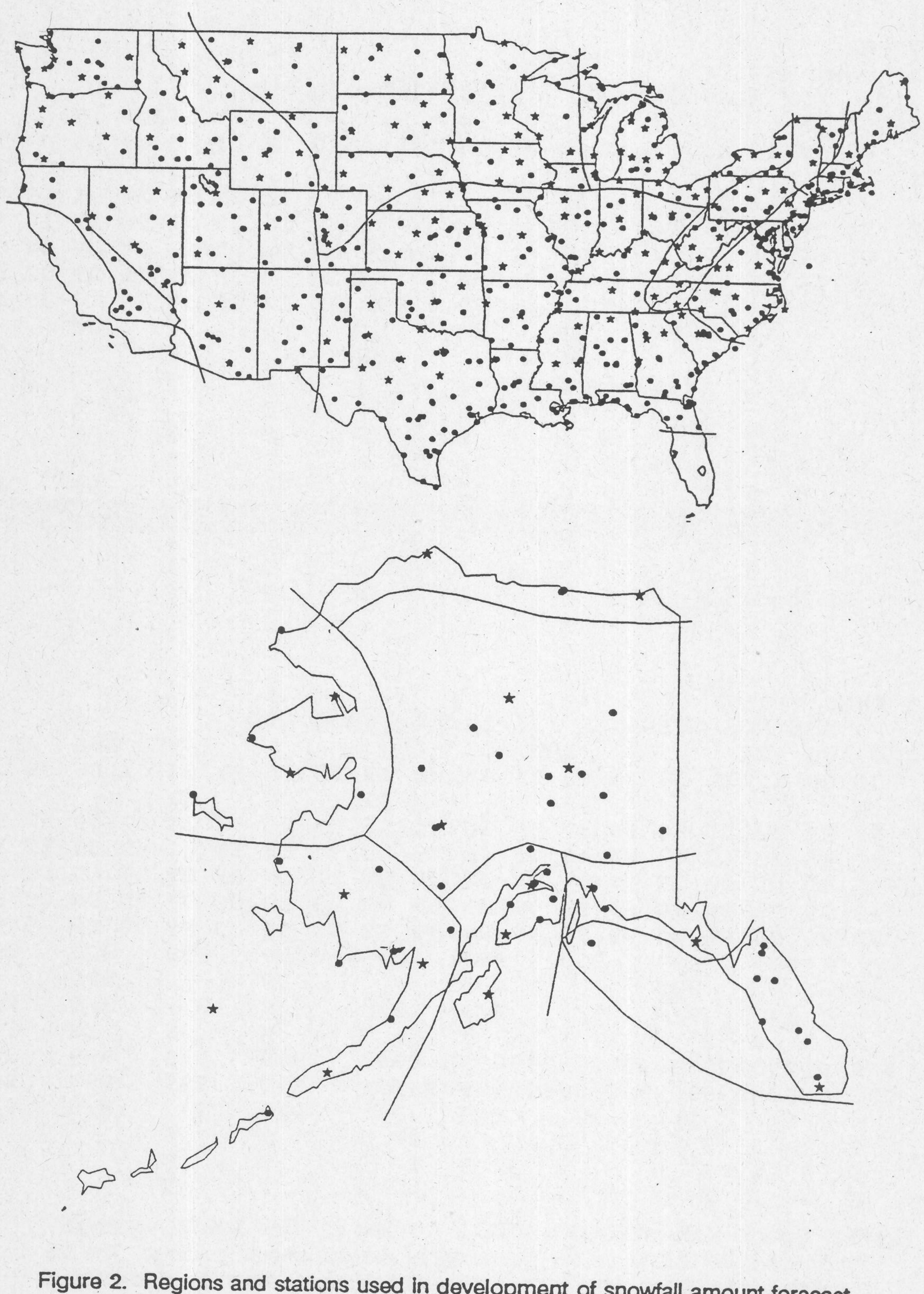


Figure 2. Regions and stations used in development of snowfall amount forecast equations for (a) CONUS and (b) Alaska. Stars represent stations used in development. Dots represent additional stations for which forecasts are generated.

a)

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NMCFWCFWA
FOUS14 KWBC 130357
FWA   EC     NGM MOS GUIDANCE   2/13/91  0000 UTC
DAY /FEB  13              /FEB  14                /FEB  15
HOUR     06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12
MX/MN                      42          33          33          16
TEMP     29 30 32 36 40 40 38 38 37 36 35 33 31 27 26 24 21 19 17
DEWPT    24 26 28 31 34 35 35 36 36 34 32 31 28 25 22 20 17 15 13
CLDS     CL OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV
WDIR     16 11 12 11 11 08 06 03 03 33 32 32 30 30 29 29 29 29 29
WSPD     03 04 04 07 10 08 10 11 09 12 15 15 17 21 18 19 18 15 15
POP06          11    69    88    82    84    69    51    36    21
POP12                      90         100          78          36
TSV06         1/ 1  8/ 0 15/ 1 15/ 1  8/ 1  2/ 2  1/ 7  1/ 0  0/ 0
TSV12               7/ 0       23/ 2        9/ 3        1/ 4
PTYPE     R  R  R  R  R  R  R  R  R  R  S     S     S     S     S
POZP     17 18 15  4  9 12 13 19 16 11  9     1     5     4     3
POSN      8  8  0  9  3  0  1  5 12 33 59    90    93    96    97
SNOW          0/    0/    0/0   0/    1/1   2/    2/6   1/    1/1
CIG       7  7  6  4  3  3  2  2  1  2  2     3     4
VIS       5  5  5  1  1  2  1  1  1  1  1     1     1
OBVIS     N  N  N  F  F  F  F  F  F  F  N     F     F
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b)

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FOAK13 KWBC 240357
ANC          NGM MOS GUIDANCE   8/24/94  0000 UTC
DAY /WED AUG  24          /THU AUG  25            /FRI AUG  26
UTC      06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12
MX/MN                      59          53          63          53
TEMP     53 51 50 50 53 56 57 56 56 55 55 54 56 59 61 61 59 57 57
DEWPT    45 45 45 45 47 48 48 47 48 49 49 51 52 53 53 52 52 52 52
CLDS     CL CL CL SC BK OV OV OV OV OV OV OV OV OV OV OV OV OV OV
WDIR     99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99
WSPD     99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99 99
POP06         999   999   999   999   999   999   999   999   999
POP12               999         999         999         999
QPF           9/    9/9   9/    9/9   9/    9/9   9/    9/9   9/
PTYPE     X  X  X  X  X  X  X  X  X  X  X     X     X     X     X
POZP     999999999999999999999999999999999   999   999   999   999
POSN     999999999999999999999999999999999   999   999   999   999
SNOW          9/    9/9   9/    9/9   9/    9/9   9/    9/9   9/
CIG       9  9  9  9  9  9  9  9  9  9  9     9     9
VIS       9  9  9  9  9  9  9  9  9  9  9     9     9
OBVIS     X  X  X  X  X  X  X  X  X  X  X     X     X
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Figure 3. Sample of the (a) FOUS14 KWBC (FWC) and (b) FOAK13 KWBC message. The lines labeled SNOW are the best category snowfall amount guidance. The 6-h forecasts are to the left of the slash and the 12-h forecasts are to the right of the slash. At the time that the FOAK13 message was created, forecasts were only available for MX/MN, DEWPT, and CLDS. The "9" and "X" characters serve as placeholders in this example.

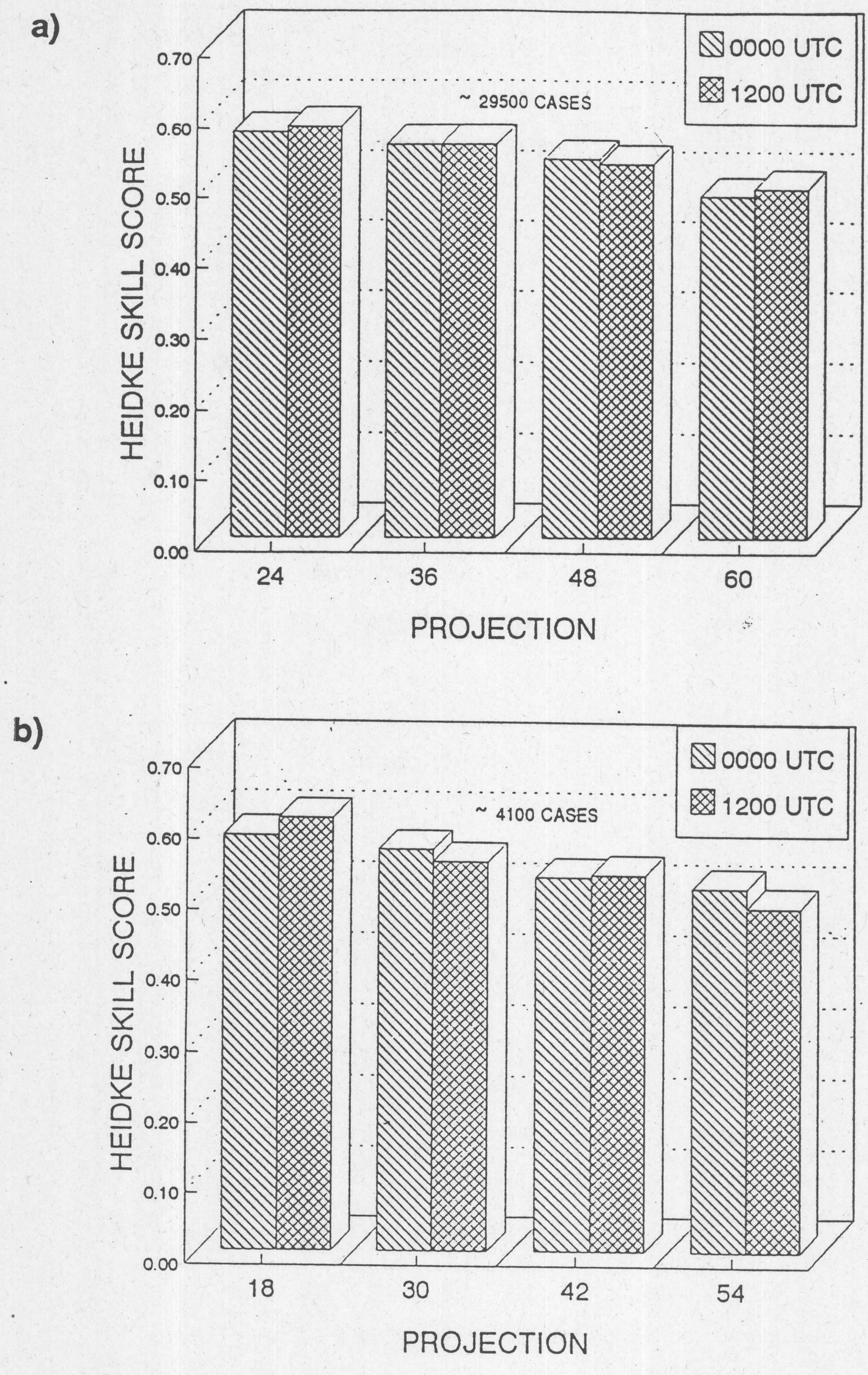
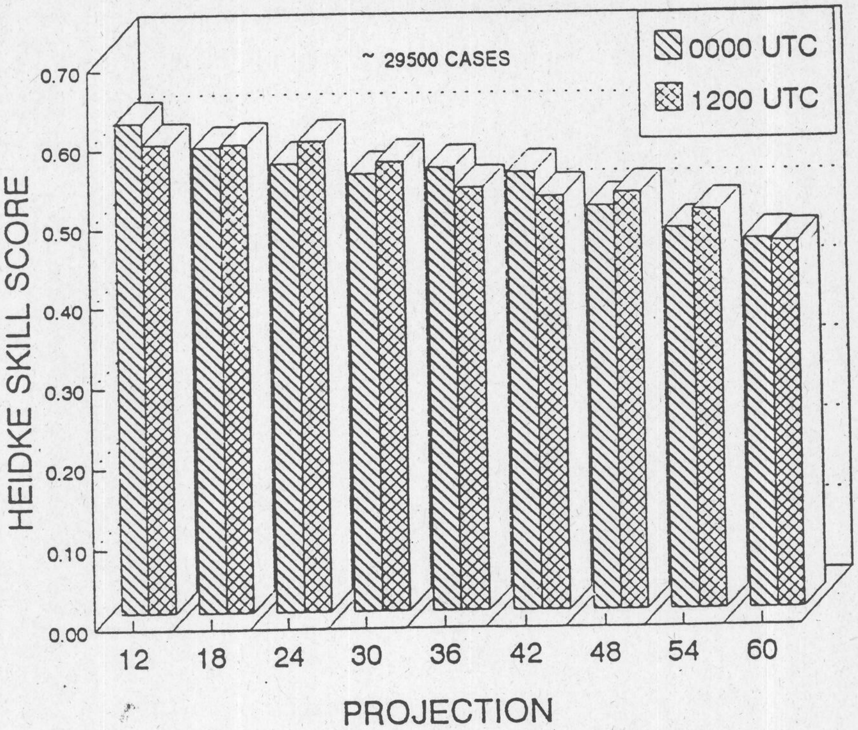


Figure 4. Heidke skill scores of 12-h snowfall amount categorical forecasts made from 0000 and 1200 UTC NGM output for (a) November 19, 1992 to May 15, 1993 (CONUS) and (b) September 1, 1992 to May 28, 1993 (Alaska). Skill scores are based on five categories (< trace, trace to < 2 in., 2 to < 4 in., 4 to < 6 in., ≥ 6 in.)

a)



b)

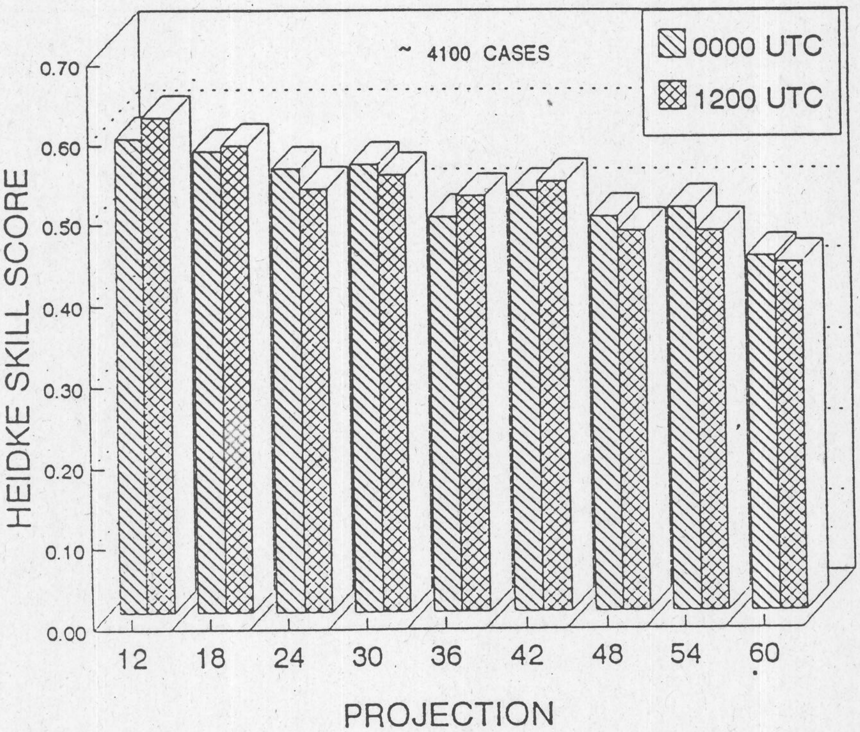


Figure 5. Same as Fig. 4 except for 6-h snowfall amount forecasts based on three categories (< trace, trace to < 2 in., ≥ 2 in.).

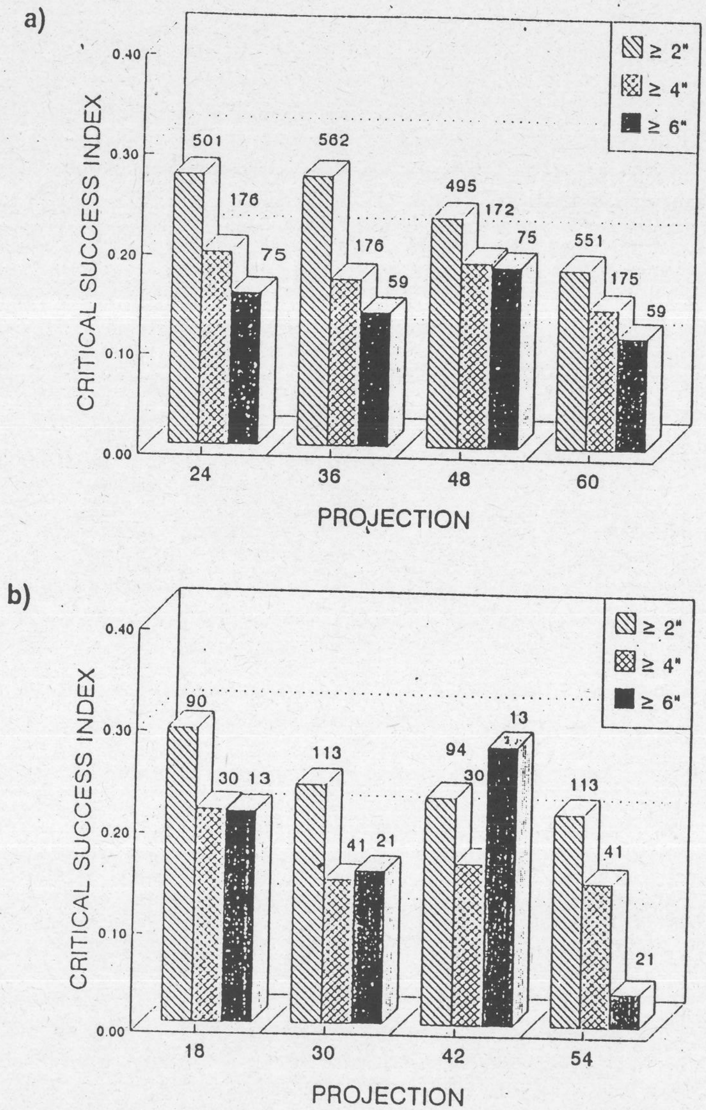


Figure 6. Critical success index of 12-h snowfall amount categorical forecasts made from 0000 UTC NGM output for (a) November 19, 1992 to May 15, 1993 (CONUS) and (b) September 1, 1992 to May 28, 1993 (Alaska). Scores for three categories (≥ 2 in., ≥ 4 in., and ≥ 6 in.) are shown. Numbers plotted are the number of observed events in each category.

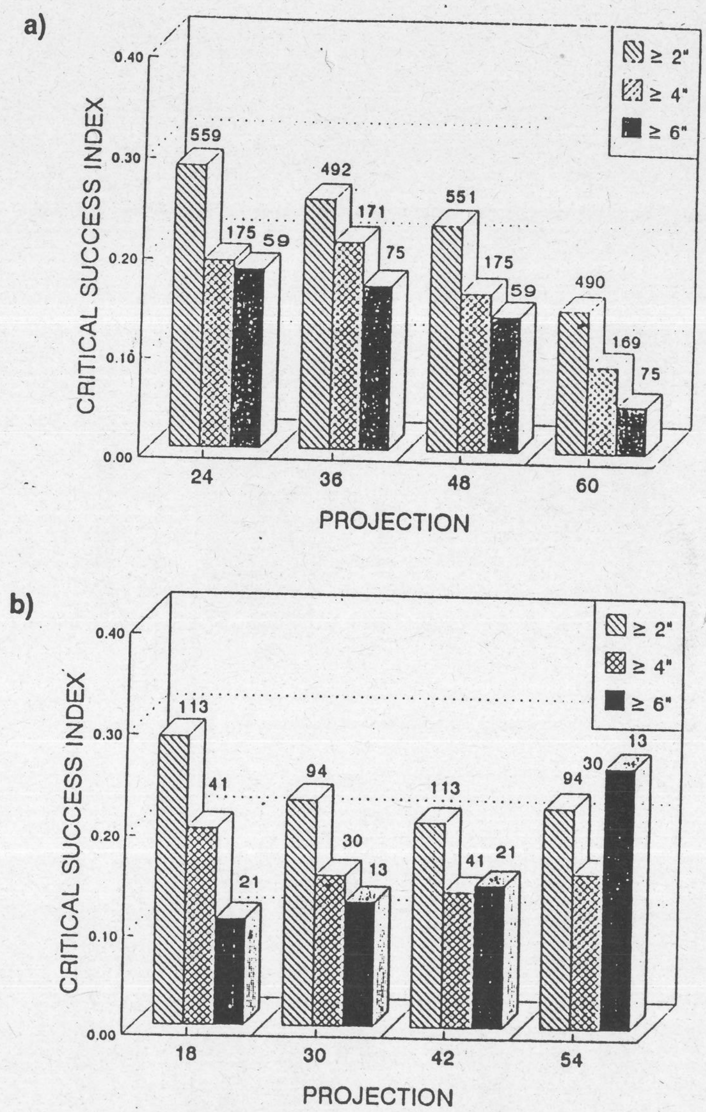


Figure 7. Same as Fig. 6, except for 1200 UTC.

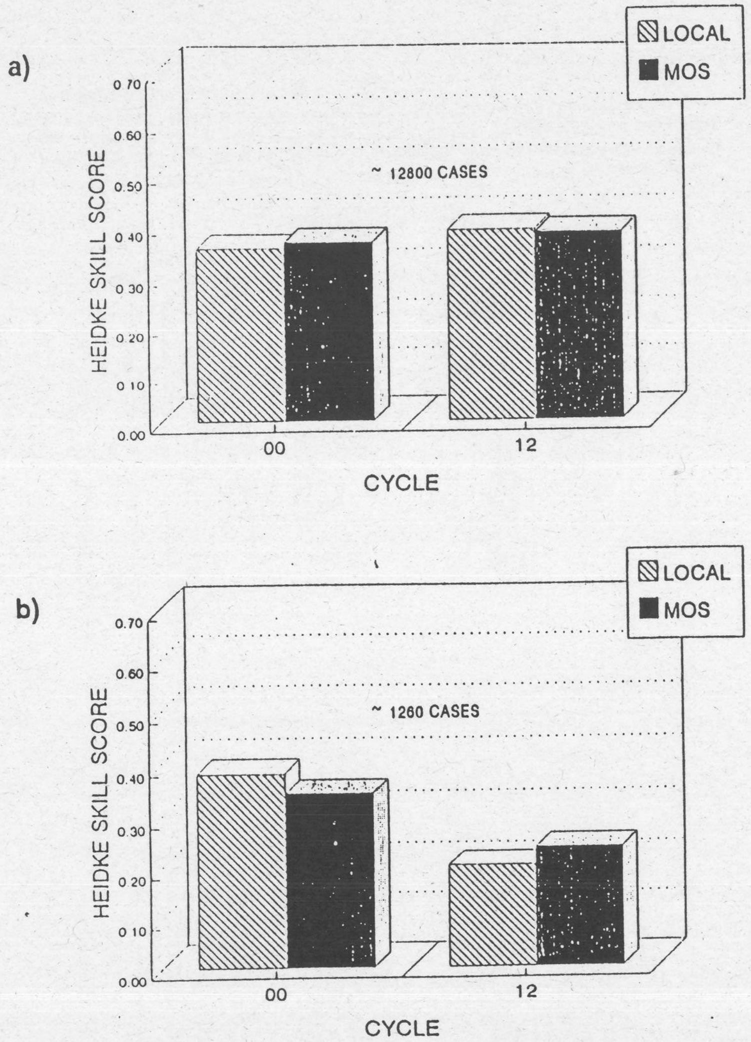


Figure 8. Same as Fig. 4, except for 12-24 h MOS forecasts compared with NWS local forecasts and based on four categories (< 2 in., 2 to < 4 in., 4 to < 6 in., ≥ 6 in.).

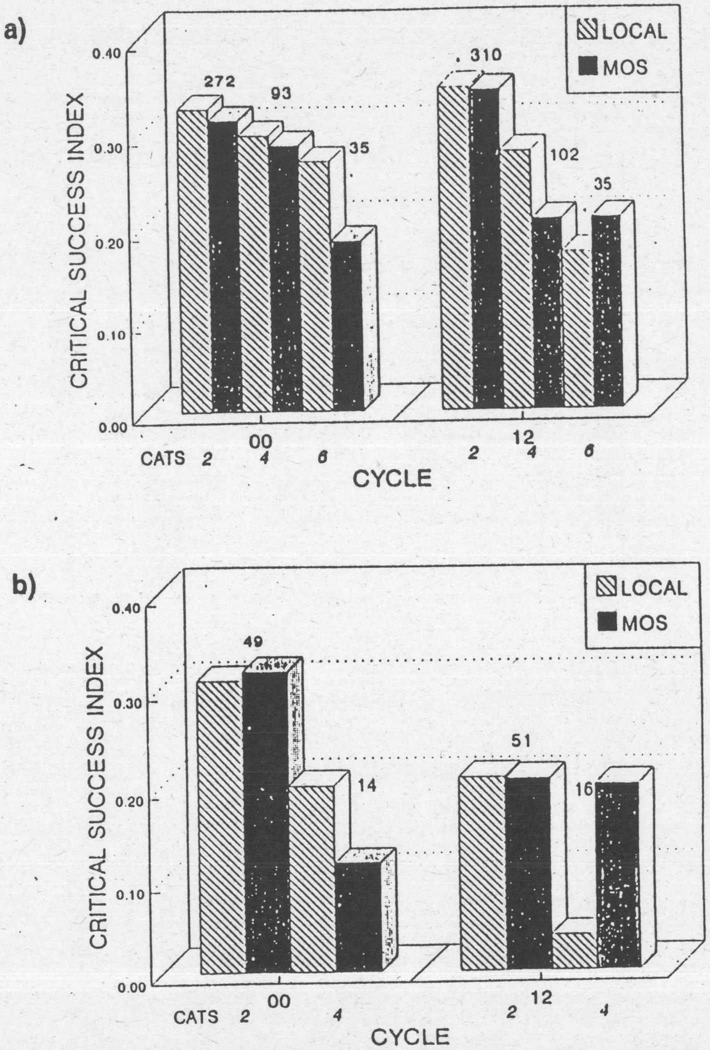


Figure 9. Same as Fig. 6, except for 12-24 h MOS forecasts compared with NWS local forecasts.