New NGM-Based MOS Guidance for Maximum/Minimum Temperature, Probability of Precipitation, Cloud Amount, and Surface Wind

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ABSTRACT

In this paper, we describe the development and use of new nested grid model (NGM)-based model output statistics (MOS) guidance that has been available since 26 July 1989 for 204 stations in the contiguous United States. The new guidance, which replaced the NGM-based perfect prog package that had been operational since May 1987, consists of forecasts of max/min temperature, probability of precipitation, cloud amount, and surface wind. Guidance for all four elements is available for projections of 1 and 2 days from 0000 and 1200 UTC. The limited-area fine-mesh model (LFM)-based MOS guidance package is still available and was not affected by this change. Verification on independent data shows that NGM-based MOS and LFM-based MOS temperature forecasts are about equally accurate and that both sets of MOS guidance are clearly superior to the NGM-based perfect prog guidance. For the probability of precipitation, the NGM-based MOS guidance is consistently more skillful than the perfect prog guidance, and usually more skillful than the LFM-based MOS guidance. For cloud amount, the NGM-based MOS forecasts are more skillful than either the LFM-based MOS or the NGM-based perfect prog. Finally, the NGM-based MOS and perfect prog wind forecasts are about equally skillful, and both sets are superior to the LFM-based MOS guidance.

1. Introduction

In May 1987, the National Weather Service (NWS) implemented the first statistical guidance package (Jensenius et al. 1987) designed for application to the nested grid model (NGM) (Phillips 1979; Tuccillo and Phillips 1986). Forecast equations for max/min temperature, probability of precipitation (PoP), cloud amount, and surface wind were developed at the Techniques Development Laboratory (TDL) by using a modified perfect prog technique (Erickson 1988). In July 1989, a new NGM-based model output statistics (MOS) package (Glahn and Lowry 1972) for these same four elements replaced the perfect prog system. Here, we describe how these new forecast equations were developed, how the NGM-based MOS (NGM MOS hereafter) equations differ from the limited-area fine-mesh model (LFM)-based MOS (LFM MOS hereafter) equations, and how these differences are likely to be reflected in the statistical forecasts.

2. Background

The National Meteorological Center (NMC) of the NWS has made several significant changes to the NGM during the past few years, including a change in the normal mode initialization procedure in August 1987 (Bonner 1989) and the implementation of a hemispheric temperature correction scheme in October 1987 (Phillips 1987). The hemispheric temperature correction was particularly significant in modifying the NGM statistical characteristics because the procedure was designed to reduce a strong cold bias in the low levels of the model. Since these modifications were made, the NGM has remained relatively stable. Until the fall of 1987, the refinement of the NGM had precluded development of NGM MOS equations because experience has shown that *at least* 2 yr of stable numerical model data are needed to derive useful MOS equations. By using this criterion, we would have had to delay development of NGM MOS cool season (October–March) equations until April 1989 and warm season (April–September) equations until October 1989, with implementation delayed at least 6 months after these dates.

To reduce the waiting period and expand the database, in August 1988 we began to rerun the then-current version of the NGM for virtually all dates between October 1986 and October 1987. With the assistance of NMC, we completed the task of rerunning the NGM in January 1989. This effort yielded the second year of data needed for development. Warm season equation testing commenced immediately thereafter, and NGM MOS warm season equations for max/min temperature, PoP, wind, and cloud amount were implemented

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on 26 July 1989. We devoted the remainder of the summer to cool season equation testing and development, and NGM MOS cool season equations for the same four elements were implemented on 4 October 1989.

3. General information for all elements

The MOS approach correlates predictand data (local weather observations) to combinations of predictor data (output from numerical models, surface observations, and climatic information). A linear least-squares regression technique is used to determine statistical relationships between each predictand and the predictors. In the NGM MOS development, predictors included forecasts of temperature, thickness, temperature advection, precipitation amount, precipitable water, relative humidity, vertical velocity, horizontal wind components, wind speed, relative vorticity, vorticity advection, stability, and moisture convergence (Table 1). When appropriate, model predictors were from different levels in the troposphere. Model output was available at 6-h intervals from 6 to 48 h after initial model time. Climatic predictors included the sine and cosine of each day of the year, and station elevation, latitude, and longitude. Observed predictors, used in some of the forecast equations for projections of ≤24 h, included station reports of temperature, dew point, wind, and cloud cover. Not all predictors were used for all weather elements. We developed NGM MOS forecast equations for 204 stations across the contiguous 48 states (Fig. 1).

As mentioned in section 2, separate NGM MOS equations were developed for two 6-month seasons: 1 April–30 September for the warm season; and 1 October–31 March for the cool season for all four elements. For both seasons, however, data from outside the seasonal bounds [8 days (15 days) for the warm (cool) season] were also included in the developmental sample to increase forecast accuracy, particularly at the beginning and end of the seasons. Thus, by using NGM forecasts from October 1986 through March 1989, we had approximately 400 (600) days of data available for the warm (cool) season development. While we consider these samples to be adequate (especially for the cool season), far more data were available to develop the NGM perfect prog and LFM MOS equations.

TABLE 1. Potential model and climatic predictors used in the NGM MOS development. Except where noted, all variables were used as continuous quantities. Note that not all predictors were used for all elements.

Variables	Atmospheric level or layer (mb)
(a) NGM Output	
Temperature	1000, 950, 900, 850, 700
Temperature advection	950, 850, 700
Thickness	1000–500, 1000–850, 850–500, 850–700
Precipitation amount (binary)	—
Precipitable water	—
Relative humidity (continuous, binary)	1000, 950, 900, 850, 700, 500, 300, Mean (Sfc–490)
Moisture convergence	850, 700, 500
K stability index	—
Total totals stability index	—
Relative vorticity	850, 700, 500, 300
Vorticity advection	850, 700, 500
Vertical velocity	850, 700, 500, 300
U, V wind components	950, 850, 700, 500, 300, 10 meters above surface
Wind speed	950, 850, 700, 500, 300, 10 meters above surface
(b) Climatic Quantities	
Sine, cosine of each day of yr	—
Sine, cosine of twice each day of yr	—
Station lat	—
Station long	—
Station elevation	—

4. Equation characteristics for specific elements

a. *Daytime max and nighttime min temperature*

We developed NGM MOS equations to predict the daytime max and nighttime min temperature valid at projections verifying approximately 24, 36, 48, and 60 h after 0000 and 1200 UTC. For the warm season, daytime (nighttime) is defined as 0800–1900 (1900–0800) local standard time (LST). For the cool season, nighttime ends, and daytime begins, at 0900 LST. Thus, max/min temperature forecasts from the 0000 (1200) UTC cycle are valid for today's max (tonight's min), tonight's min (tomorrow's max), tomorrow's max (tomorrow night's min), and tomorrow night's min (the day after tomorrow's max). The same predictands were used for development of the corresponding LFM MOS and NGM perfect prog equations.

We developed individual (single-station) equations for 200 out of 204 stations for each forecast projection. In the single-station approach, equations for a given station are developed by using data from that station only; consequently, forecasts generated by such equations include the effects of local topography and climate. However, for four stations (Arcata, California; Long Beach, California; Lufkin, Texas; Harrisburg, Pennsylvania), the archive of observed max/min temperatures was insufficient to do a single-station derivation. For these stations, we developed regionalized max/min forecast equations (see section 4.b for additional details on regionalization).

Some of the predictors used in the development of the max/min temperature forecast equations were not available in the LFM MOS and NGM perfect prog

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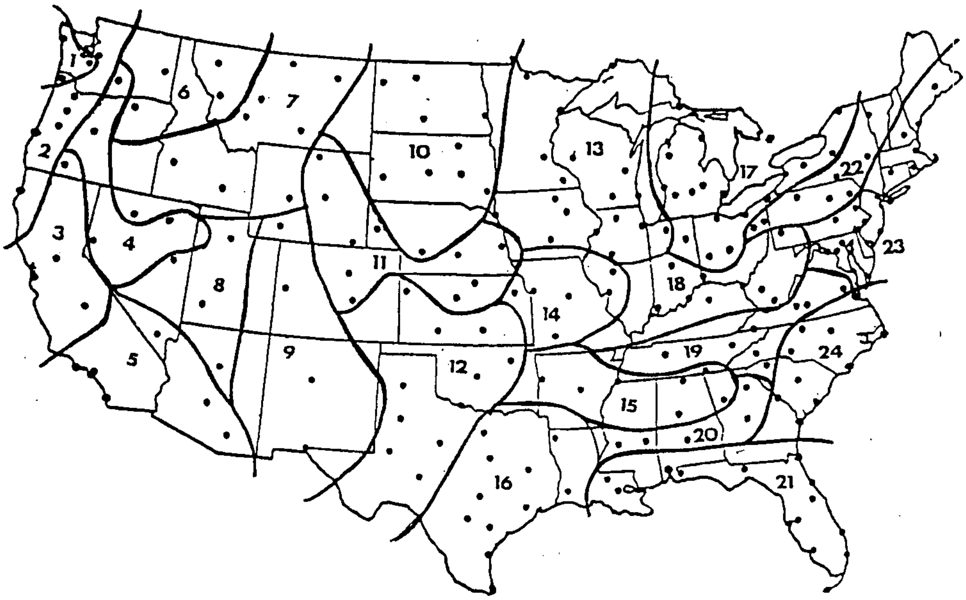

FIG. 1. The 204 stations used in the NGM MOS development. The regions for the warm season NGM MOS PoP equations are also shown.

max/min temperature developments. Examples of new potential predictors included forecasts of temperature and temperature advection at constant pressure levels below 850 mb. Except at the 60-h projection, we allowed three possible projections for each NGM predictor (12 h prior to, 6 h prior to, and concurrent with the approximate valid time of the predictand). For the 60-h max or min temperature, only model predictors valid at the 48-h projection were used.

For the forecast of today's max (tonight's min) temperature from 0000 (1200) UTC, we derived two sets of forecast equations. For the first or "primary" equation set, 0300 (1500) UTC surface observations, NGM forecasts, and climatic variables were used as potential predictors. Observed predictors included surface temperature, wind, and dew point. For the second or "backup" equation set, only NGM forecast and climatic variables were used as potential predictors. The operational system always attempts to use the primary equations, but if observations are missing, the backup equations are used to produce the forecasts.

For both the warm and cool seasons, the most frequently chosen predictor in the NGM MOS max temperature equations was a forecast of temperature at 950, 900, 850, or 700 mb; a forecast of a low-level thickness was usually chosen as the first predictor in the min temperature equations. Other predictors used frequently in both the max and min temperature equations are forecasts of the mean relative humidity (surface to approximately 500 mb), 850-mb relative vorticity, 1000–500-mb thickness, and 10-m wind components. Although observations were selected in the primary equations, the previously mentioned NGM forecasts were still chosen most often. Note that climatic predictors, such as the *sine* and *cosine* of each day of the year, were selected at all projections, but increased in importance with increasing projection.

b. PoP

We developed NGM MOS equations to predict the probability of ≥0.01 in. of liquid equivalent precipitation for 12-h periods ending at 24, 36, 48, and 60 h after 0000 and 1200 UTC. Because of the relatively infrequent occurrence of precipitation, and the binary nature of the predictand, we developed regionalized equations to forecast PoP. In the regionalized approach, we pool predictor and predictand data for all stations within a given region to develop one equation. This equation is then used operationally to produce forecasts for each station in that region for a given cycle and projection. For all elements, regions are subjectively determined by pooling stations that are similar in topography *and* have similar correlations between the predictand(s) and the most important NGM predictors. For example, for PoP, we examined the correlation between the occurrence of precipitation and the mean relative humidity forecast by the NGM. Thus, the regions do not always strictly follow topographic boundaries. We show the warm season PoP regions in Fig. 1 as an example of how regional divisions are determined.

Except for the 60-h PoP equations, model predictors valid at the beginning, midpoint, and end of the 12-h-forecast period were used as potential predictors. For the 60-h equations, only model predictors valid at the 48-h projection were used. We did not include obser-

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vations as predictors for any projection because tests showed that the observations did not significantly improve the performance of the PoP equations.

The most frequently chosen predictors for the NGM MOS PoP equations were forecasts of precipitation amount and mean relative humidity. Other frequently chosen predictors were forecasts of 900- and 700-mb relative humidity, 850- and 300-mb relative vorticity, 850- and 300-mb vertical velocity, and 850- and 700-mb moisture convergence.

c. Surface wind

For surface wind, we developed NGM MOS equations for the surface wind speed, the *U* (east–west) component, and the *V* (north–south) component, valid every 6 h from 6–48 h after 0000 or 1200 UTC. Single-station equations were derived for 202 out of 204 stations. For the other two stations (Long Beach, California and Lufkin, Texas), we developed regionalized equations. Except for the 48-h projection, the potential model predictors were valid 6 h prior to, concurrent with, and 6 h after the valid time of the predictands. For the 48-h equations, only model predictors valid at the 42- and 48-h projections were used.

We used the simultaneous development approach to derive *U*, *V*, and wind speed equations for a given station, cycle, and projection. In this approach, equations for each of the three predictands contain the same predictors; however, the predictors' coefficients vary so that each equation is still tailored to the particular predictand. The simultaneous method enhances meteorological consistency among the forecasts of these elements. Note that the wind direction forecast is computed from the forecasts of *U* and *V*, and that the wind speed forecasts are inflated (Schwartz and Carter 1985) in order to forecast more occurrences of the strongest winds.

The most frequently chosen predictors in the surface wind equations included forecasts of 950-mb and 10-m wind components. These two predictors were not available to either the NGM perfect prog or LFM MOS equation developments. Other predictors chosen were forecasts of wind at various levels up to 500 mb, vertical velocity, relative vorticity, vorticity advection, stability indices, and sinusoidal functions of each day of the year. For the 6- and 12-h projections from each cycle, we developed primary and backup equation sets. The primary equations included station surface wind reports observed 3 h after model initialization as additional potential predictors.

d. Cloud amount

We developed regionalized equations to predict the cloud amount for projections at 6-h intervals from 6 to 48 h after both 0000 and 1200 UTC. The cloud amount predictand is the opaque sky cover, reported in tenths. For each projection, the equations predict the probability of clear (0 tenths), scattered (1–5 tenths), broken (6–9 tenths), and overcast (10 tenths) cloud amount. The equations were developed simultaneously for these four categories.

In addition to the probability forecasts, we provide categorical cloud amount forecasts by comparing the probabilities to three threshold values. We selected these threshold values to produce unbiased categorical forecasts, i.e., the number of forecasts of each category approximately equals the number of observations of that category. In determining the categorical forecast, we compare the probability of clear skies to the first threshold value. If the probability exceeds the threshold value, then clear is the categorical forecast. Otherwise, we add the probability of clear skies to the probability of scattered clouds, and compare this value to the second threshold. Again, if this threshold is exceeded, scattered is the predicted category; otherwise, the process continues. If none of the three thresholds is exceeded, overcast is selected as the categorical forecast.

Some of the predictors considered in the development of NGM MOS cloud amount equations were not available for the LFM MOS or NGM perfect prog developments. The most important new predictors were relative humidity forecasts for the 1000-, 950-, 900-, 850-, 700-, 500-, and 300-mb levels. All of the potential predictors were valid concurrently with the predictand. The most frequently chosen predictor in the cloud amount equations was a forecast of mean relative humidity. Forecasts of relative humidity at various levels, wind, vertical velocity, and 850-mb moisture convergence were also chosen frequently. For the 6- and 12-h projections, we developed primary and backup equation sets. The primary equations included surface observations reported 3 h after model initialization as additional potential predictors. Of the observed predictors used in the primary equations, the opaque sky cover was chosen most often.

5. Messages and schedules

The NGM MOS guidance is produced twice daily around 0330 and 1530 UTC for 204 stations. On the NWS AFOS system, this guidance is available as the FWCxxx product, where xxx are the call letters of the station requested. Note that this same product contained the now obsolete NGM perfect prog guidance. The guidance is also available through the NWS Family of Services as the FOUS14 product.

Figure 2 shows the FWC message for Washington, D.C. (DCA) from 0000 UTC data on 11 August 1989. The line following the station call letters contains the PoP (POP) and max/min temperature forecasts (MX–MN). The max/min temperature forecasts (rounded to the nearest degree Fahrenheit) follow the PoP forecasts (in percent). (For the 1200 UTC message, the order of the max and min temperature forecasts is re-

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NMCFWCHDG
FOUS14 KWBC 110333
HDNG FOUS14 NGM-MOS GUIDANCE   8/11/89  0000 UTC

DY/HR 11/06  11/12  11/18  12/00  12/06  12/12  12/18  13/00   13/12
NMCFWCDCA
FOUS14 KWBC 110333
DCA  ESC
POP/MX-MN                  90/ 74        60/ 71        50/ 80  60/ 66
WIND   0310   0311   0411   0806   1408   1106   1509   1307
CLDS 0118/4 0019/4 0109/4 1108/4 0129/4 0227/4 0136/4 0226/4
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FIG. 2. FWC message for Washington, D.C. (DCA) from 0000 UTC 11 August 1989.

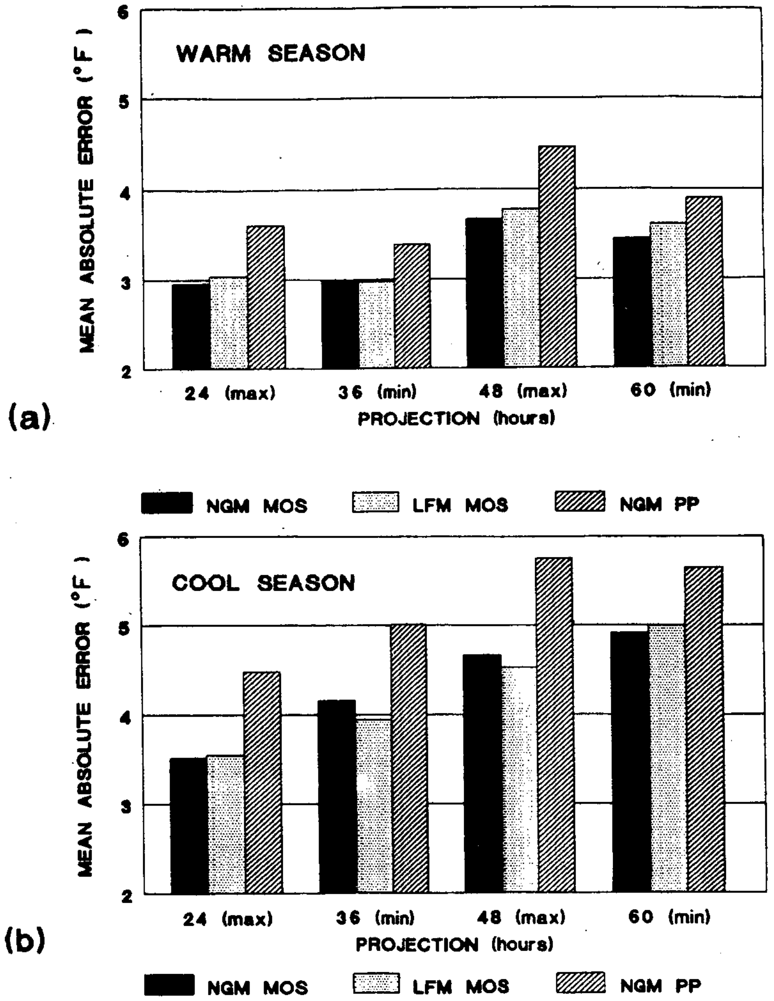

FIG. 3. Verification in mean absolute error (°F) of NGM MOS max/min temperature forecasts for (a) the warm season and (b) the cool season. The results are from August 1987 and April 1988 (October 1988–March 1989) for the warm (cool) season tests and are valid for approximately 200 stations. All forecasts were based on 0000 UTC NGM data.

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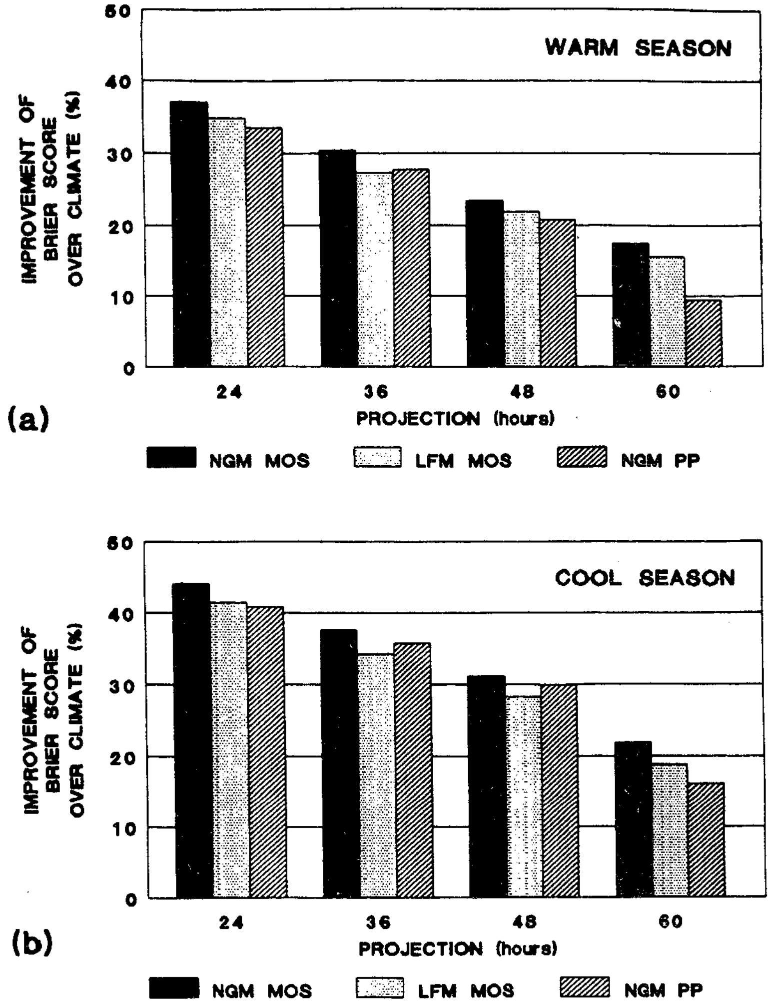

FIG. 4. As in Fig. 3, except for the percent improvement of the Brier score over climate of the PoP forecasts.

versed so that the product identifier appears as MN–MX.) The PoP forecasts are rounded to values of 0%, 2%, 5%, 10%, 20%, 30%, . . . , or 100%. The PoP and max/min temperature forecasts are separated by a slash. Surface wind forecasts (WIND) are presented in the standard DDFF format; direction is rounded to the nearest 10° and speed is rounded to the nearest knot. The first four digits in the cloud amount forecast line (CLDS) are single-digit probability forecasts (in tens of percent) for the exclusive cloud amount categories of clear, scattered, broken, and overcast. The best category cloud amount forecast is given after the slash (1 is clear, 2 scattered, 3 broken, and 4 overcast). Note that an operational check is applied to ensure that the temperature forecasts are meteorologically consistent, i.e., the max (min) temperature forecast must be equal to or greater (less) than the min (max) for adjacent projections. If a max and min forecast are inconsistent, the two forecasts are averaged, and both the max and min forecast are set equal to this average value before the guidance is transmitted.

6. Preliminary evaluation of performance and operational considerations

a. General comments regarding the MOS technique

MOS equations are developed by using forecast data from a particular numerical model. Thus, the quality of the MOS forecasts is strongly dependent upon both the accuracy and the consistent performance of pertinent output fields from that model. While MOS equations can account for the effects of systematic model errors, MOS cannot correct for poor model forecasts that are random in nature. In addition, events that occur relatively infrequently on a scale smaller than can be resolved by the model are not likely to be accounted for by MOS forecasts. On the other hand, small-scale effects that occur regularly enough in the

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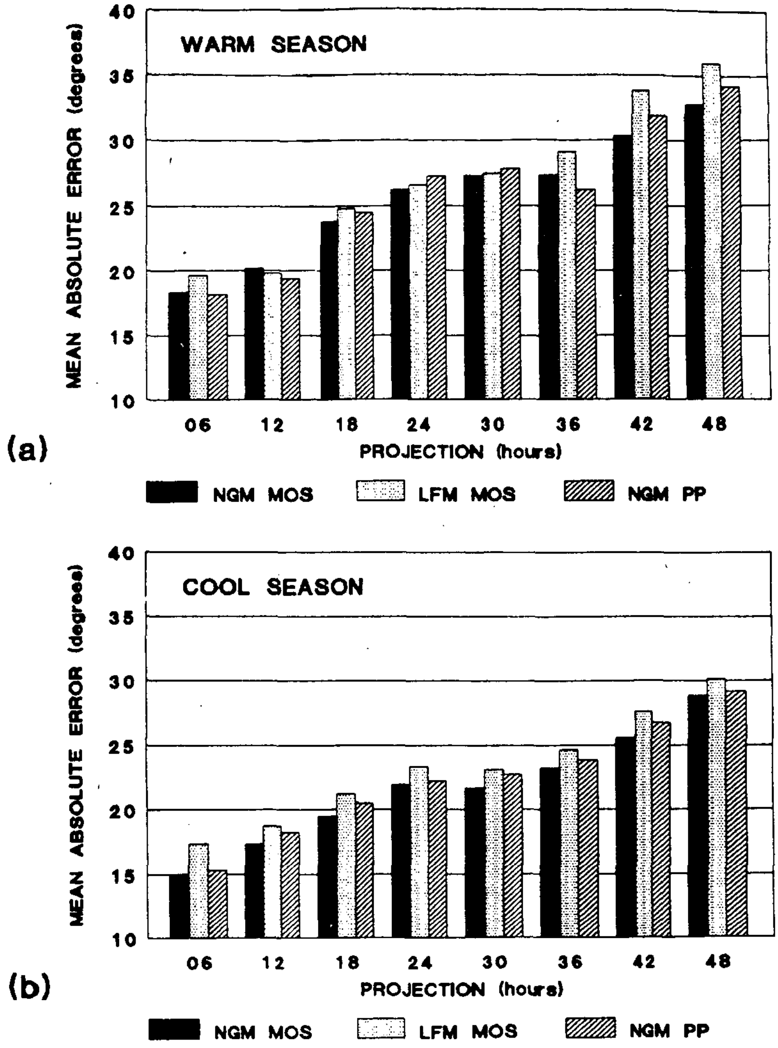

FIG. 5. As in Fig. 3, except for the mean absolute error (degrees) of the wind direction forecasts.

developmental predictand data to affect the nature of the regression equation itself can be predicted. For example, MOS max temperature forecasts may include the effects of a sea breeze during the warm season at a coastal station if sea breezes occurred fairly regularly during the developmental period. Also, MOS min temperature forecasts may account for strong nocturnal radiational cooling at a given station if such cooling occurred regularly.

Statistical forecasts can (and do) predict record conditions. However, the forecasts tend to be "conservative" during extreme situations. In addition, the MOS forecasts tend increasingly toward the mean of the predictand with increasing projection. This characteristic reflects the lack of information in model forecasts with increasing projection. While MOS may often be correct in warning the forecaster not to wander too far from climate at the longer projections, situations will arise where deviation from MOS is warranted. For example, if a record-breaking heat wave is well entrenched and the numerical model shows no evidence that conditions will change, MOS temperature forecasts may incorrectly point towards a cooling trend with increasing projection. Similarly, since the climatic relative frequency of precipitation at most stations is relatively low, the tendency of MOS forecasts to approach the climatic frequency with increasing projection may cause PoP forecasts to be too dry at 48 and 60 h.

While the single-station MOS max/min temperature equations can account for the effects of a sea breeze or of enhanced nocturnal radiational cooling at a particular station, we do not generally expect the regionalized MOS cloud amount and PoP equations to account for local or topographic effects that occur on the subsynoptic scale. However, regionalized equations can resolve differences from station to station that occur on

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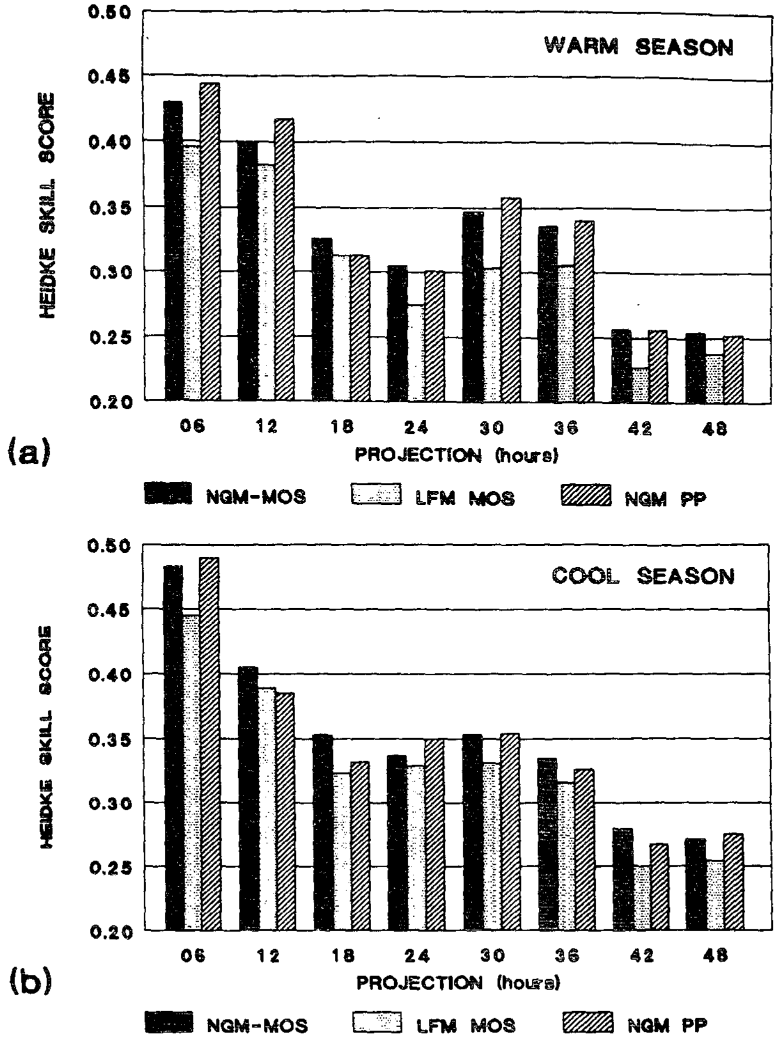

FIG. 6. As in Fig. 3, except for the Heidke skill score of the wind speed forecasts.

the synoptic scale if the model predicts meteorological variations across the region.

Finally, statistical equations "assume" that the basic climatic characteristics that define the developmental sample remain unchanged. For example, if soil moisture at a given station was generally normal over the course of the developmental sample, the max/min temperature equations derived from this sample "assume" that soil moisture will continue to be close to normal. Thus, errant forecasts can result during periods when soil moisture departs significantly from normal. If max/min temperature equations developed by using "normal" data were applied during an extended drought, one might expect the resulting max (min) temperature forecasts to be too low (high) due to the abnormally low soil moisture. On the other hand, if max/min temperature equations developed from a significant amount of "drought" data were applied to "normal" conditions, the reverse could be true. This latter scenario may apply to the warm season NGM MOS equations (see section 7). The same reasoning can be used to adjust cool season max/min temperature forecasts for situations where the observed snow cover departs significantly from normal. For example, if a station which normally has a snow cover experiences bare ground over a period of time, the MOS max and min temperature forecasts during that period may be consistently too cold. In general, a developmental database that includes as many seasons as possible is desirable because a greater variety of meteorological conditions will be represented. For this reason, a MOS system based on relatively small samples should improve as more data become available for the development of forecast equations.

b. Specific comments regarding the NGM MOS development

We generated 2 (6) months of NGM MOS test forecasts for the warm (cool) season to get a preliminary

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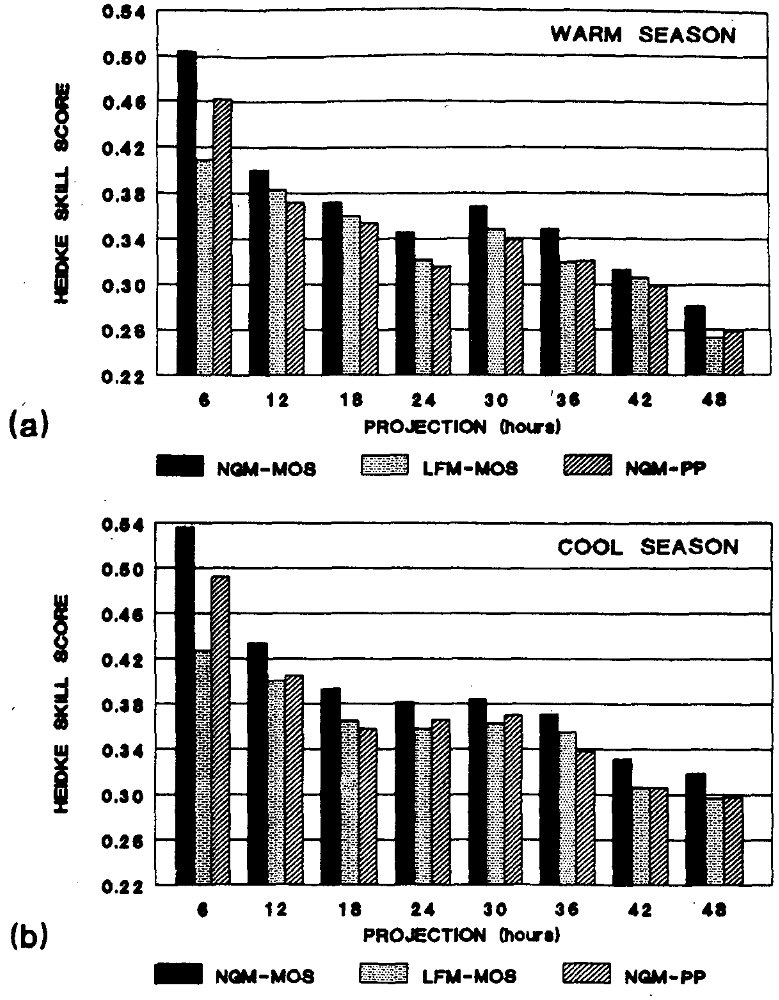

FIG. 7. As in Fig. 3, except for the Heidke skill score of the cloud amount forecasts.

indication of how NGM MOS compares with the operational LFM MOS and the now obsolete NGM perfect prog. We produced forecasts for approximately 200 of the 204 stations, and for both cycles, all projections, and all four predictands. The test dates for the warm season were from August 1987 and April 1988, while the period of October 1988–March 1989 was used as the independent sample for the cool season tests. Despite the limited developmental database available for the NGM MOS equations, the overall accuracy of the NGM MOS forecasts for all elements was approximately equal to that of the LFM MOS forecasts. This result is likely attributable to the predictive skill and increased resolution of the NGM.

Of all elements, our test results suggest that the NGM MOS max/min temperature forecasts will exhibit the greatest improvement over NGM perfect prog. Figure 3 depicts the mean absolute errors of the test forecasts from 0000 UTC for the warm and cool season. (The results for the 1200 UTC forecasts, not shown here for any of the elements, are similar to the 0000 UTC results.) The NGM MOS max/min temperature forecasts were more accurate than the corresponding NGM perfect prog forecasts nationwide, and, in some cases, were slightly more accurate than the LFM MOS max/min temperature forecasts.

Figure 4 shows the improvement over climate of the Brier score (Brier 1950) for the NGM MOS, LFM MOS, and NGM perfect prog PoP forecasts based on UTC data. Note that the Brier score is the mean square error of a probability forecast. For both the warm and cool seasons, NGM MOS forecasts exhibited a greater improvement over climate at all projections than did forecasts produced by LFM MOS and NGM perfect prog. For the 1200 UTC forecasts (not shown), NGM MOS was consistently more skillful than perfect prog and usually more skillful than LFM MOS.

Our test results for wind were not as conclusive as for max/min temperature and PoP. For the wind direction forecasts (Fig. 5), NGM MOS was more accurate overall in terms of mean absolute error than either LFM MOS or NGM perfect prog. For speed forecasts, NGM MOS produced more forecasts of strong winds and was generally more accurate in dif-

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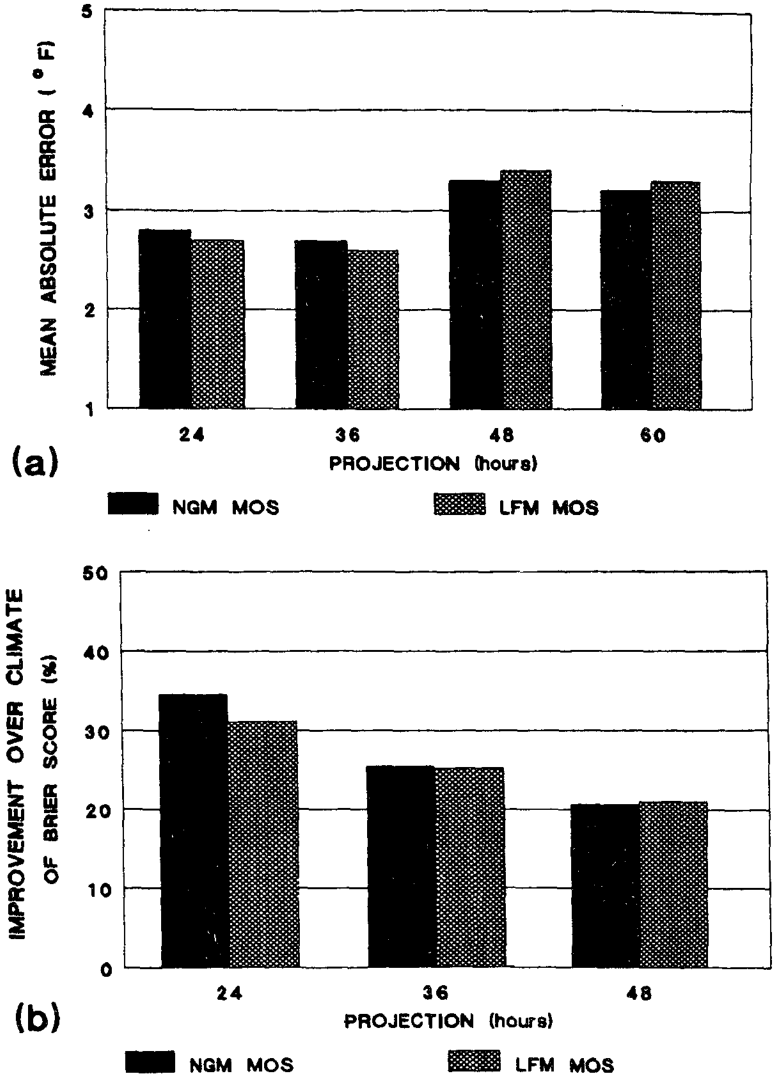

FIG. 8. Verification of operational NGM MOS forecasts of (a) max/min temperature and (b) PoP for August–September 1989 for the 94 AEV stations. All forecasts were based on 0000 UTC NGM data.

ferentiating between strong (≥22 kt) and weak (<22 kt) winds than either LFM MOS or NGM perfect prog (not shown). However, in all speed categories for both the warm and the cool season, the Heidke skill score (Erickson 1988) of NGM MOS and NGM perfect prog wind speed forecasts was approximately equal overall (Fig. 6). Both sets of NGM wind forecasts were almost always more skillful than LFM MOS. (The Heidke skill score, which is higher for a more skillful forecast, indicates the percentage of correct category forecasts after the number of correct forecasts due to chance is removed.) We used the following categories for the verification of speed forecasts: ≤7, 8–12, 13–17, 18–22, 23–27, 28–32, and >32 kt.

Figure 7 depicts how the NGM MOS best-category cloud forecasts for the warm (cool) season based on 0000 UTC initialization performed relative to the corresponding LFM MOS and NGM perfect prog forecasts. As can be seen, the NGM MOS best-category cloud forecasts had higher skill scores than LFM MOS and NGM perfect prog best-category forecasts at all projections.

After the new NGM MOS system became operational in July 1989, the NGM MOS max/min temperature and PoP forecasts were verified for August and September 1989. Verifications were obtained for 94 AFOS-era verification stations (Dagostaro 1985). Figure 8a shows a comparison of the operational NGM MOS and LFM MOS max/min temperature forecasts based on 0000 UTC initialization for this 2-month period. As before, the 1200 (not shown) and 0000 UTC results are similar. Corresponding PoP verification results for the 24-, 36-, and 48-h projections from 0000 UTC are shown in Fig. 8b. Note that the accuracy of

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the operational NGM MOS and LFM MOS max/min temperature forecasts over the 2-month period was roughly equal, matching closely the results from the previously described warm season tests. The skill of the 24-h NGM MOS PoP forecasts from 0000 UTC over this period was greater than that of the corresponding LFM MOS PoP forecasts; for the 36- and 48-h projections, both sets of MOS guidance had virtually the same level of skill.

7. Discussion

The NGM MOS system was implemented in July 1989. Preliminary evaluation indicates that NGM MOS is, overall, at least as accurate as LFM MOS. However, we recommend that the warm season NGM MOS max/min temperature and PoP forecasts be watched especially carefully at stations where the heat and drought conditions of 1988 were most pronounced. Because the developmental sample only extended from 1987 to 1988 and the drought was especially pervasive during 1988, a good portion of the developmental data for these stations departed significantly from normal. Thus, for these stations, NGM MOS max temperature forecasts for the warm season may exhibit a warm bias, while the min temperature forecasts may be too cool when applied during periods when soil moisture conditions are close to normal. *Please note that this is only educated speculation; we cannot be certain that this effect will actually be observed.*

Although the test results are promising on a nationwide basis, we do not expect that NGM MOS will necessarily be the most accurate statistical guidance in every situation. For example, we produced NGM MOS forecasts at Buffalo, New York and Cleveland, Ohio for April 1989 and found that the NGM MOS max temperature forecasts would have been much too warm on days when the surface wind trajectory was off Lake Erie. Meanwhile, the LFM MOS max temperature forecasts were considerably more accurate for these cases. We suspect that because the LFM MOS max/min temperature equations are available for four individual seasons (spring equations were developed by using data from 1 March through 31 May), the effect of the cold lake on the max temperature is better predicted by the LFM MOS spring equations than by the NGM MOS warm season equations. When the NGM MOS warm season equations are redeveloped, we will attempt to correct for this deficiency by the use of additional predictor variables.

Based partially on input from NWS forecasters, we did similar case studies to evaluate how the NGM MOS guidance performed under other warm-season synoptic regimes. For example, we evaluated the max temperature guidance for an extreme Santa Ana event, for a situation where a strong warm front was positioned across the Northern Plains and Great Lakes, and when a late season cold air outbreak intruded into Montana. We also examined the performance of the min temperature guidance during a radiational cooling situation in Texas. We expected that the NGM MOS guidance would be clearly superior to LFM MOS in these situations (especially the Texas and Montana cases, where shallow cold air dominated the weather), but this was not the case. Of course, these tests were by no means exhaustive, and we will continue to monitor the performance of the NGM MOS guidance.

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REFERENCES

Bonner, W. D. 1989. NMC overview: Recent progress and future plans. *Wea. Forecasting* **4:** 275–285.
Brier, G. W. 1950. Verification of forecasts expressed in terms of probability. *Mon. Wea. Rev.* **79:** 1–3.
Dagostaro, V. J. 1985. The national AFOS-era verification data processing system. *Office Note* 85-9, Techniques Development Laboratory, National Weather Service (NOAA), 47 pp.
Erickson, M. C. 1988. Development and evaluation of perfect prog guidance based on output from the Nested Grid Model. *Preprints Eighth Conference on Numerical Weather Prediction,* Baltimore: American Meteorological Society 572–579.
Glahn, H. R., and D. A. Lowry. 1972. The use of Model Output Statistics (MOS) in objective weather forecasting. *J. Appl. Meteor.* **11:** 1203–1211.
Jensenius, J. S., Jr., G. M. Carter, J. P. Dallavalle and M. C. Erickson. 1987. Perfect prog maximum/minimum temperature, probability of precipitation, cloud amount, and surface wind guidance based on output from the Nested Grid Model (NGM). Technical Procedures Bulletin 369, National Weather Service (NOAA), Silver Spring, Maryland, 12 pp.
Phillips, N. A., 1979. The Nested Grid Model. *NOAA Technical Report* NWS 22, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 80 pp.
——, 1987. Temperature calculations in the Nested Grid Model. Technical Procedures Bulletin 373, National Weather Service (NOAA), Silver Spring, Maryland, 8 pp.
Schwartz, B. E., and G. M. Carter. 1985. The use of model output statistics (MOS) for predicting surface wind. Technical Procedures Bulletin 347, National Weather Service (NOAA), Silver Spring, Maryland, 11 pp.
Tuccillo, J. J., and N. A. Phillips. 1986. Modeling of physical processes in Nested Grid Model. Technical Procedures Bulletin 363, National Weather Service (NOAA), Silver Spring, Maryland, 24 pp.

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