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This Technical Procedures Bulletin (TPB), written by Major David T. Miller, USAF, of the Techniques Development Laboratory (TDL), describes the development and implementation of the Nested Grid Model (NGM)-based Model Output Statistics (MOS) categorical ceiling height guidance for locations in the contiguous United States.

TDL has derived new regression equations to predict ceiling heights by applying the MOS technique to output from the NGM for the contiguous United States. The guidance was implemented on January 27, 1993, and is available in the FOUS14 KWBC message (FWC product on AFOS). The categorical ceiling height guidance is also provided on similar messages to stations supported by the United States Air Force. The guidance is available twice daily around 0400 and 1600 Universal Coordinated Time (UTC).

Joseph R. Bocchieri
Chief, Services Evaluation Branch

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

# NGM-BASED MOS CEILING HEIGHT GUIDANCE FOR THE CONTIGUOUS UNITED STATES

Major David T. Miller, USAF

## 1. INTRODUCTION

The Techniques Development Laboratory (TDL) of the National Weather Service (NWS) has derived regression equations to predict the probabilities of seven categories of ceiling heights. The equations were developed by applying the Model Output Statistics (MOS) technique (Glahn and Lowry 1972) to output from the Nested Grid Model (NGM) (Hoke et al. 1989). In addition to the probability forecasts, categorical forecasts are produced by a selection scheme designed to predict as many events to occur as are observed. NGM MOS ceiling height forecasts are now being made for projections from 6 to 36 hours at 3-h intervals and for projections from 42 to 60 hours at 6-h intervals after 0000 and 1200 UTC.

## 2. METHOD

The MOS approach correlates predictand data (local weather observations) with combinations of predictor data (output from dynamical models, surface observations, and geoclimatic information). In applying MOS to the prediction of ceiling height, the ceiling height was treated as a categorized predictand. In other words, the range of ceiling height values was divided into mutually exclusive and collectively exhaustive categories. The predictand was then set equal to 1 if the observation occurred within a particular category and was set equal to 0, otherwise. The number of predictands corresponds to the number of categories of ceiling height. A multiple linear regression (forward) screening procedure was then used to derive the prediction equations. Operationally, the equations produce probability forecasts of the various categories. A categorical forecast is then determined from the probabilities.

## 3. DEVELOPMENT AND DEFINITIONS

### a. Seasons

Developmental data from October 1986 through March 1992 were stratified into two, 6-month seasons: cool (October-March) and warm (April-September). Five seasons of data (approximately 900 days) were used to develop the warm season equations and six seasons of data (approximately 1100 days) were used for the cool season equations. When feasible, we also included 8 days of seasonal overlap on either side of each season. This approach attempts to smooth the transition between warm and cool season equations.

### b. Predictands

Since ceiling height has a very irregular frequency distribution, the predictand was divided into the seven categories shown in Table 1. NGM MOS ceiling height categories 1 and 2 match the aviation ceiling height definition for Low Instrument Flight Rules (LIFR), category 3 matches the definition for Instrument Flight Rules (IFR), and category 4 matches the definition for Marginal Visual Flight Rules (MVFR). Category 5 ends at 6500 ft, matching the cutoff between low and middle cloud reports. Category 6 ends at 12000 ft, reflecting the limits of Automation of Surface Observation Systems (ASOS) reports. Categories 5, 6, and 7 correspond to the ceiling height definition for Visual Flight Rules (VFR). Table 2 summarizes the LIFR, IFR, MVFR, and VFR ceiling height definitions.

TDL archives the surface reports from the hourly data for all available stations in the contiguous United States. For 440 stations available in the TDL hourly data archives and included in the MOS forecast

Table 1. NGM MOS ceiling height categories.

| | |
|---|---|
| 1 | < 200 ft |
| 2 | 200 - 400 ft |
| 3 | 500 - 900 ft |
| 4 | 1000 - 3000 ft |
| 5 | 3100 - 6500 ft |
| 6 | 6600 - 12000 ft |
| 7 | > 12000 ft |

Table 2. Aviation ceiling height categories.

| | |
|---|---|
| LIFR | < 500 ft |
| IFR | 500 - 900 ft |
| MVFR | 1000 - 3000 ft |
| VFR | > 3000 ft |

system, we extracted the ceiling height reports for the developmental period for the specific hours of 0000, 0200, 0300, 0600, 0900, 1200, 1400, 1500, 1800, and 2100 UTC. The observations valid at 0000, 0300, ..., and 2100 UTC provided the predictand data sample. These observations were used to form predictands valid every 3 hours from 6 to 36 hours and every 6 hours from 36 to 60 hours after either 0000 or 1200 UTC. Observations at 0200 and 1400 UTC were used as predictors (see Section 3.c).

### c. Predictors

Table 3 lists potential model predictors and climatic variables used to derive the ceiling height forecast equations. As Table 3 indicates, we used several interactive predictors: mean relative humidity times the vertical velocity at 850, 700, and 500 mb, and the mean relative humidity times the K index. We also included a number of layer relative humidities and the height of a specific dewpoint depression. The layer relative humidity is defined as the mean relative humidity in the 1000-900 mb, 950-850 mb, 900-800 mb, 850-750 mb, and 800-700 mb layers. The height of the dewpoint depression predictor is defined by an algorithm that uses dewpoint depressions at standard pressure levels from 1000 to 500 mb to find the level where a dewpoint depression of 0.5°, 1.0°, 1.5°, 2.0°, 2.5°, or 3.0°C first occurs. The algorithm converts this pressure level, if available, to a height in hundreds of feet. If not available, a default height of 35,000 ft is used.

Model predictors were available at 6-h intervals from 6 to 48 hours after either 0000 or 1200 UTC. For most of the predictand projections, the model predictors were valid at the time of the predictand observation. Thus, for example, predictors valid at 12 hours after 0000 or 1200 UTC were used for the 12-h MOS forecast equations. For the 54- and 60-h forecast equations, model predictors at 48 hours were used. Since the model forecasts were only available at 6-h intervals, we included time-averaged values of some NGM forecasts for predictand projections of 9, 15, 21, 27, and 33 hours. For example, the NGM mean relative humidity forecasts at the 6- and 12-h projections were averaged together to produce a mean relative humidity forecast nominally valid at the 9-h projection.

As potential predictors for the 6-, 9-, and 12-h forecast equations, we also considered the observed ceiling height reported 2 hours after 0000 or 1200 UTC. We used this observation to incorporate persistence into the regression equations. We also used the 0200 or 1400 UTC observations because they are usually available when the NGM MOS program is run operationally.

Climatic predictors for all projections included the first and second harmonics of the day of the year and the monthly relative frequency of ceiling height below 1000 ft at 0000, 0600, 1200, and 1800 UTC. In obtaining the monthly relative frequency, we compiled a 10-year climatology of ceiling heights below 1000 ft for the same 440 full-time reporting stations mentioned in Section 3.b. Use of these predictors attempts to account for seasonal variations in the ceiling heights not accounted for by other predictors. To explain possible differences at stations within the same region (see Section 3.d), we also included

Table 3. Potential geoclimatic and NGM predictors used in the ceiling height equation development.

| |
|---|
| Relative frequency of ceilings less than 1000 ft |
| Station latitude, longitude |
| Station elevation |
| Sine, cosine day-of-year |
| Sine, cosine 2 times day-of-year |
| Clouds at the jet level |
| K index advection |
| Mixing ratio at the 1000-, 950-, and 850-mb levels |
| Relative humidity advection at 950-, 850-, and 700-mb levels |
| Relative humidity times the K index |
| Mean relative humidity (surface-490 mb) |
| Relative humidity at the 1000-, 950-, 900-, 850-, and 700-mb levels |
| Layer relative humidity |
| Precipitation amount |
| K index |
| Height of the dewpoint depression |
| U and V wind components and wind speed at the 10-m, 950-, 850-, and 700-mb levels |
| Relative vorticity at the 850- and 700-mb levels |
| Thickness between 850-1000 mb and 700-850 mb |
| Temperature difference between 850-1000 mb and 700-850 mb |
| Precipitable water |
| Vertical velocity at the 850- and 700-mb levels |
| Relative humidity times vertical velocity at the 850-, 700-, and 500-mb levels |

station latitude, longitude, and elevation as potential predictors.

Most of the NGM predictors were space-smoothed over 5 or 9 model gridpoints at the 6-, 12-, 18-, 24-, 30-, and 36-h projections. At the 42- and 48-h projections, predictors were space-smoothed over 9 or 25 model grid points. For the 54- and 60-h MOS projections, the NGM predictors were space-smoothed over 25 model grid points. This spatial smoothing reduces some of the small-scale variability found in model forecasts that is not useful for ceiling height prediction. More smoothing is applied to the predictors at the later projections as the quality of the predictive information from the model decreases.

While many of the potential predictors were continuous variables, others were either 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 observed ceiling height, for instance, was considered as a binary predictor. 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 ceiling height equation development, the mean relative humidity and the relative humidity at the 1000-, 950-, 900-, 850-, and 700-mb levels were used as grid-binary predictors.

### d. Regions

Since the occurrences of the lower three ceiling height categories (Table 1) were relatively infrequent (rare events), we combined stations into geographic regions in order to develop stable forecast relationships. In this regional equation approach, the predictand and predictor data from several stations within a similar geographical or climatic area are pooled, and one set of equations is derived for the region. Regional boundaries were established by first grouping stations which displayed similar frequencies of the occurrence of ceiling below 1000 ft. We then adjusted the boundaries for similarities in predictor selection and geographic boundaries. After completing the adjustments, we established 17 regions for the warm season (Fig. 1a) and 21 regions for the cool season (Fig. 1b). The forecast equations derived for a region are applied to each station within that region.

**e. Equation Development**

As previously mentioned, we derived probability equations for seven categories of ceiling height. Equations were developed for both forecast cycles (0000 and 1200 UTC), all projections (6, 9, 12, ..., 33, 36, 42, 48, 54, and 60 hours), and both seasons (warm and cool). Two sets of equations were derived for the 6-, 9-, and 12-h projections. In the first ("primary") set, surface weather observations at 0200 or 1400 UTC, NGM forecasts, and climatic variables were included as predictors. In the second ("backup") set, we used only NGM forecasts and climatic variables as predictors. In operations, the primary equations are used whenever possible to generate the forecasts. However, when the observations are unavailable as predictors in a particular equation, the backup equation is used.

During equation development, we allowed the regression process to continue until a maximum of 15 predictors was chosen or until none of the remaining predictors contributed an additional 0.1% to the reduction of variance for any one of the seven predictands. For most regions and projections, 15 predictors were chosen. In the 6-, 9-, and 12-h projections (primary equations), the ceiling height observations were often chosen first. At later projections, the height of the dewpoint depression, the mean relative humidity, the relative humidity multiplied by the vertical velocity, and the relative frequency of ceilings less than 1000 feet contributed most of the reduction of variance. Additional frequent predictors included wind components at levels below 700 mb, 1000- and 950-mb relative humidities, advection of relative humidity, and relative vorticity or vertical velocity at levels below 500 mb. Time-averaged predictors were often chosen for the forecast projections of 9, 15, 21, 27, and 33 hours.

**f. Equation Characteristics**

The probability equations for seven categories of ceiling height 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%.

**g. Transformation of Probability Forecasts to Categorical Forecasts**

The prediction equations produce probability forecasts for each ceiling height category. In daily operations, we make a categorical forecast based on the probability distribution. In our processing, when the forecast probability of a given category exceeds a certain critical value (threshold probability), that category is chosen. The procedure first compares the forecast probability of category 1, the rarest event, to the threshold probability for category 1. If the forecast probability exceeds the threshold, then category 1 is selected as the categorical forecast. If the forecast probability for category 1 does not exceed the threshold probability, then the forecast probability of category 2, the next rarest event, is added to the forecast probability of category 1 to obtain the cumulative probability. It is then compared to the threshold probability for categories 1 and 2 combined. The process then continues in a stepwise manner through the probabilities for the first six categories. If the threshold probabilities are never exceeded for the first six categories, then category 7, the most common event, is selected as the categorical forecast.

Cumulative threshold probabilities are required for categories 1 to 6, for each region, projection, cycle, and season, and for both primary and backup equations. We explored several techniques for obtaining the threshold probabilities and finally developed an objective, iterative routine which produced threshold probabilities for a user-specified bias within a certain tolerance. In this context, the bias is defined as the ratio of the number of forecasts of an event to the number of observations of the event during a specified sample. The iterative routine, which uses the developmental sample, begins with the rarest event and produces categorical forecasts based on a first-guess threshold probability of 0.5. The number of forecasts for that category are then divided by the number of observations of that category, producing a bias for the category. The routine compares the category bias to the user-specified bias. If the difference between the two biases doesn't fall within a certain tolerance, the routine produces a new threshold probability based on a binary search method. This process is continued until a threshold probability is found which produces a bias within tolerance to the user-specified bias. The routine uses the same process for all but the most common category, category 7, which is the default choice when no other category is appropriate. For all ceiling height categories, we set a bias of 1.0 as the user-specified bias.

### h. Sample Equation

Sample regression equations to predict the probability of ceiling height categories for region 16 (Fig. 1b) are included in Tables 4 and 5. The equations listed are used to generate forecasts valid 12 hours after 0000 UTC. The predictors are listed in Table 4 in the order they were selected by the regression procedure. The column labeled TYPE indicates whether the predictor is a continuous (C), a point binary (PB), or a grid binary (GB) variable. The cutoffs for point-binary and grid-binary predictors are indicated in the predictor description. The TAU column indicates the projection of the predictors in hours after the forecast cycle. In Table 5, the seven columns listed under CEILING HEIGHT CATEGORY provide the regression constant and the coefficient of the predictor in the seven regression equations. As mentioned in Section 3.f, the predictors in these ceiling height category equations are the same, but the coefficients differ. The probability threshold values for these equations are listed in Table 6.

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.

## 4. VERIFICATION OF CATEGORICAL CEILING HEIGHT FORECASTS

Prior to implementation of the NGM MOS categorical ceiling height forecast system, we developed a set of test equations based on four warm seasons (April-September) and on five cool seasons (October-March) of dependent data. We then verified forecasts from these equations on a season of independent data and compared the results to MOS categorical ceiling height forecasts based upon Limited-area Fine Mesh Model (LFM) output (Hebenstreit 1981). Table 7 lists the six LFM MOS ceiling height categories. Since the NGM MOS ceiling height categories (Table 1) differ from those of the LFM MOS in the upper categories, we collapsed the three upper NGM MOS categories and the two upper LFM MOS categories into one for comparison. We also could only compare the two MOS systems at the 6-, 12-, 18-, ..., 42-, and 48-h projections since the LFM MOS system only forecasts at these 6-h intervals. In general, the NGM MOS forecasts were more skillful than the LFM MOS forecasts (not shown).

Table 4. Predictors used to compute the probabilities of the seven ceiling height categories for cool season (October-March) region 16 (Fig. 1b). The values of these predictors are used to generate forecasts valid 12 hours after 0000 UTC. Predictors for which no units are provided are unitless.

| TERM | PREDICTOR | | | |
|---|---|---|---|---|
| | NAME | TYPE | UNITS | TAU |
| 1 | Surface-490 mb Mean Rel. Humidity * 500 mb ω | C | % µb/s | 12 |
| 2 | 850 mb Rel. Humidity (90% cutoff) | GB | | 12 |
| 3 | Height of 2 K Dew Point Depression | C | ft | 12 |
| 4 | Observed Ceiling (900 ft cutoff) | PB | | 2 |
| 5 | 1000 mb Mean Rel. Humidity | C | % | 12 |
| 6 | 950 mb Mixing Ratio | C | g/kg | 12 |
| 7 | Observed Ceiling (100 ft cutoff) | PB | | 2 |
| 8 | 900-800 mb Mean Rel. Humidity | C | % | 12 |
| 9 | 700-850 mb Thickness | C | m | 12 |
| 10 | Surface-490 mb Mean Rel. Humidity (90% cutoff) | GB | | 12 |
| 11 | Observed Ceiling (6500 ft cutoff) | PB | | 2 |
| 12 | 950 mb Earth-Oriented V-Component of the Wind | C | m/s | 12 |
| 13 | 700 mb Earth-Oriented U-Component of the Wind | C | m/s | 12 |
| 14 | 10 m Earth-Oriented U-Component of the Wind | C | m/s | 12 |
| 15 | 1000-900 mb Mean Rel. Humidity | C | % | 12 |

Table 5. The regression constants and 15 predictor coefficients for the seven regression equations to compute the probabilities of the seven ceiling height categories for cool season (October-March) region 16 (Fig. 1b). The predictor coefficients correspond to the 15 predictors as they are listed in Table 4. The constants and coefficients are used to generate forecasts valid 12 hours after 0000 UTC.

| TERM | CEILING HEIGHT CATEGORY | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| CONSTANT | 0.246 | -0.008 | -0.787 | -1.164 | -0.505 | -0.428 | 3.646 |
| 1 | -0.000001 | -0.000003 | 0.000004 | 0.000013 | 0.000003 | 0.000086 | -0.000102 |
| 2 | -0.022412 | 0.064505 | 0.109240 | 0.126540 | -0.185050 | -0.187090 | 0.094267 |
| 3 | 0.000033 | 0.000058 | 0.000186 | -0.000203 | -0.000889 | -0.000494 | 0.001309 |
| 4 | 0.040136 | 0.106220 | 0.066531 | -0.049125 | -0.087833 | -0.034952 | -0.040977 |
| 5 | 0.008270 | 0.047715 | 0.131990 | 0.035442 | -0.193200 | -0.116330 | 0.086113 |
| 6 | 0.000860 | 0.000310 | -0.000969 | -0.001549 | -0.001725 | 0.000973 | 0.002100 |
| 7 | 0.183520 | 0.010142 | -0.026211 | -0.029294 | -0.050712 | -0.025625 | -0.061820 |
| 8 | 0.000084 | -0.000060 | 0.000085 | 0.000341 | 0.002973 | -0.001380 | -0.002043 |
| 9 | -0.000165 | -0.000013 | 0.000451 | 0.000749 | 0.000483 | 0.000319 | -0.001824 |
| 10 | -0.002843 | 0.039699 | 0.110860 | -0.096460 | -0.031939 | -0.264350 | 0.245033 |
| 11 | 0.004081 | 0.021262 | 0.029522 | 0.051712 | 0.038043 | -0.063119 | -0.081501 |
| 12 | 0.000933 | 0.002806 | 0.003225 | 0.002125 | -0.000258 | -0.004668 | -0.004163 |
| 13 | -0.000284 | 0.000720 | 0.000402 | -0.001287 | -0.000246 | 0.003822 | -0.003127 |
| 14 | -0.002260 | -0.005594 | -0.007622 | -0.005110 | 0.000525 | 0.000045 | 0.020016 |
| 15 | -0.000138 | 0.000266 | 0.000823 | 0.001644 | 0.000470 | -0.002994 | -0.000071 |

Table 6. Probability threshold values to transform the seven probability forecasts computed using the equations given in Tables 4 and 5 into categorical ceiling height forecasts for cool season (October-March) region 16 (Fig. 1b). There is no probability threshold value for ceiling height category 7. The probability thresholds are used to generate forecasts valid 12 hours after 0000 UTC.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 0.0935 | 0.2363 | 0.3698 | 0.3861 | 0.4216 | 0.4491 | --- |

After implementation of the NGM MOS ceiling height forecast system, we verified forecasts from the operational NGM MOS guidance and again compared the results to the LFM MOS guidance. Figures 2a and 2b show Heidke skill scores (Dagostaro 1985) for the LFM MOS and the operational NGM MOS guidance for the 1993-1994 cool season and the 1994 warm season, respectively. The Heidke skill score eliminates the influence of forecasts that would have been correct by chance. Higher Heidke skill scores indicate greater skill. Note that the NGM MOS forecasts were more skillful at every 6-h projection for both seasons and both cycles. Figures 3a and 3b compare threat scores[1] for categories 1 and 2 combined for both systems. The NGM MOS generally had higher scores than the LFM MOS. We believe the rarity of observed ceilings less than 500 feet combined with the lack of vertical resolution of the MOS predictors in the lower troposphere hindered development of an NGM-based system which consistently improved over the LFM-based system.

Table 7. LFM MOS ceiling height categories.

| | |
|---|---|
| 1 | < 200 ft |
| 2 | 200 - 400 ft |
| 3 | 500 - 900 ft |
| 4 | 1000 - 2900 ft |
| 5 | 3000 - 7500 ft |
| 6 | > 7500 ft |

Since more forecast projections are available in the NGM MOS ceiling height system, we also verified the skill of just the NGM MOS guidance at all projections. These skill scores were compared with the skill of persistence forecasts, defined as the ceiling height observed at 0300 (1500) UTC for the 0000 (1200) UTC forecast cycle. Figures 4a and 4b indicate the Heidke skill scores of the NGM MOS categorical ceiling height forecasts and the persistence forecasts at all projections, both cycles, and both seasons. At the 6-h projection, the persistence forecasts were more skillful than the NGM MOS forecasts. However, at the 9-h projection and all subsequent projections, the NGM MOS categorical ceiling height forecasts were more skillful than persistence forecasts. This inability of the guidance to improve relative to persistence at the earliest projection is not unusual (see, for example, Dallavalle and Dagostaro 1995).

## 5. ALPHANUMERIC AND GRAPHICAL PRODUCTS

Categorical ceiling height forecasts are part of the FOUS14 KWBC NGM-based MOS guidance message described in Technical Procedures Bulletin (TPB) No. 408 (Dallavalle et al. 1992). The forecasts are also part of the NGM-based MOS guidance messages produced for stations supported by the United States Air Force (USAF). These stations are listed in Appendix D of TPB No. 399 (Miller 1993). The NGM MOS guidance is produced twice daily around 0400 and 1600 UTC. AFOS users may obtain the guidance through the FWC**xxx** message, where **xxx** are the call letters of the station requested. The guidance is also available through the NWS Family of Services and the FAA's Weather Message Switching Center as the FOUS14 product. A sample of the FOUS14 message is shown in Fig. 5. The forecast values correspond to the definitions of the NGM MOS ceiling height categories given in Table 1. For a complete explanation of the FWC/FOUS14 KWBC message, refer to TPB No. 408 referenced above. USAF-supported sites receive the guidance through 33 individual messages, arranged generally by geographical areas. These bulletins are transmitted to the USAF's Automated Weather Network and are then routed to appropriate base weather stations.

Note that the NGM MOS ceiling height probability forecasts are unavailable in the messages. In order to conserve space and accommodate the increased number of forecast projections, only the categorical

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[1] Threat score is defined as H/(F+O-H) where H is the number of correct forecasts of the event category, F is the number of forecasts for the category, and O is the number of observations for the category.

ceiling height forecasts appear. Note, too, that the NGM MOS categorical ceiling height guidance is available in the FOUS14 at 3-h intervals from 6 to 36 hours and at the 42-h and 48-h projections. In the USAF bulletins, the guidance is available at 3-h intervals from 6 to 36 hours and at 6-h intervals from 42 to 60 hours.

Categorical ceiling height forecasts are combined with NGM MOS categorical visibility forecasts to produce the three-category flight weather forecasts plotted on the computer produced four-panel chart D072 (D229) available around 0415 (1600) UTC for the 0000 (1200) UTC forecast cycle on the Digital Facsimile (DIFAX) circuit. The flight weather forecasts are given by a category number: 1, LIFR and IFR conditions (ceiling less than 1000 ft and/or visibility less than 1 mi); 2, MVFR conditions (ceiling 1000 to 3000 feet and/or visibility 3 to 5 mi); or 3, VFR conditions (ceiling greater than 3000 ft and visibility greater than 5 miles). These category numbers are plotted underneath the station circle wherever possible. Forecasts are depicted for 131 terminals in the contiguous United States for projections of 12, 18, 24, and 30 hours after 0000 or 1200 UTC. NGM MOS forecasts of cloud amount, a four-category (clear, scattered, broken, overcast) forecast of opaque sky cover, and surface wind are also plotted on these four-panel charts.

Forecasts for 256 terminals are depicted on a similar set of graphics available in the AFOS system. Four separate displays, corresponding to the four panels on the facsimile chart, are available at approximately 0400 (1600) UTC each day. AFOS users may access the charts by plotting the products NMCPLTPxW, where **x** is either 2, 3, 4, or 5 for the 12-, 18-, 24-, and 30-hour forecast panels, respectively.

## 6. OPERATIONAL CONSIDERATIONS

The MOS categorical ceiling height forecasts are based on the NGM output. If a forecaster suspects that the NGM output contains errors, he/she should qualitatively adjust the MOS forecasts accordingly. The multiple linear regression technique can account for some systematic biases in the NGM, but regression cannot correct bad model forecasts.

Although the NGM MOS categorical ceiling height forecasts are generally more skillful than the LFM MOS forecasts, the rare events (categories 1 and 2) still pose problems for the NGM-based MOS system. This was evident in the threat scores for categories 1 and 2 combined shown in Figs. 3a and 3b. Stations along the West Coast will experience high false alarm rates for the rare events due to lack of NGM predictor information in the lower layers of the atmosphere. Indeed, for West Coast stations, the relative frequency of ceilings below 1000 ft (that is, a climatic predictor) was often chosen second or third in the regression procedure. Midwest and East Coast stations did not indicate this tendency to the same degree.

For stations that reliably report hourly conditions, the NGM MOS categorical ceiling height forecasts for the 6-, 9-, and 12-h projections will be more dependent on the 0200 and 1400 UTC observations. This indicates the importance of persistence during the first 12 hours after model cycle time. Indeed, since implementation, we have noticed that low ceiling categories will often be forecast (categories 1, 2, or 3) for the first three projections when low ceilings are observed at 0200 or 1400 UTC, and that dramatic improvement in the ceiling heights will then be forecast at the 15-h projection. This situation seems to occur more often during a stratus or fog event when no major storm system is affecting the sites' ceiling heights. In reality, however, conditions may take longer to improve than the forecasts indicate. During synoptic-scale events with large precipitation and cloud shields, the ceiling height will usually be forecast to remain low beyond the 12-h projection.

Although the ceiling heights were not simultaneously developed with the NGM-based MOS cloud amount guidance, which forecasts opaque sky cover, the two seem remarkably consistent with one another.

There may, however, be some timing differences, but usually when the ceiling height is predicted to lower, the cloud amount forecasts go from clear or scattered to broken or overcast. An exception appears to be during fog or low stratus forecasts. In these cases, the cloud amount category may indicate clear or scattered even though ceiling height category 1 or 2 is forecast, probably because the cloud amount forecasts rely more on the NGM forecast of the mean relative humidity between the surface and approximately 500 mb.

As a final note, some regions will not have forecasts for categories 1 or 2 at some projections. Observations of these categories were so rare that the 5- and 6-year developmental data sets did not contain enough cases to develop an equation. The lack of these observations was more common in the afternoon projections, in the warm season, and in regions west of the Front Range of the Rocky Mountains.

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## 8. ACKNOWLEDGMENTS


After writing the first two drafts of this TPB, Major Miller was assigned to another USAF position. Captain Frederick G. Meyer of the USAF later resumed preparation of this document. We are deeply grateful to Captain Meyer who prepared the verifications presented in this TPB and modified the TPB in response to some of the concerns of the reviewers.

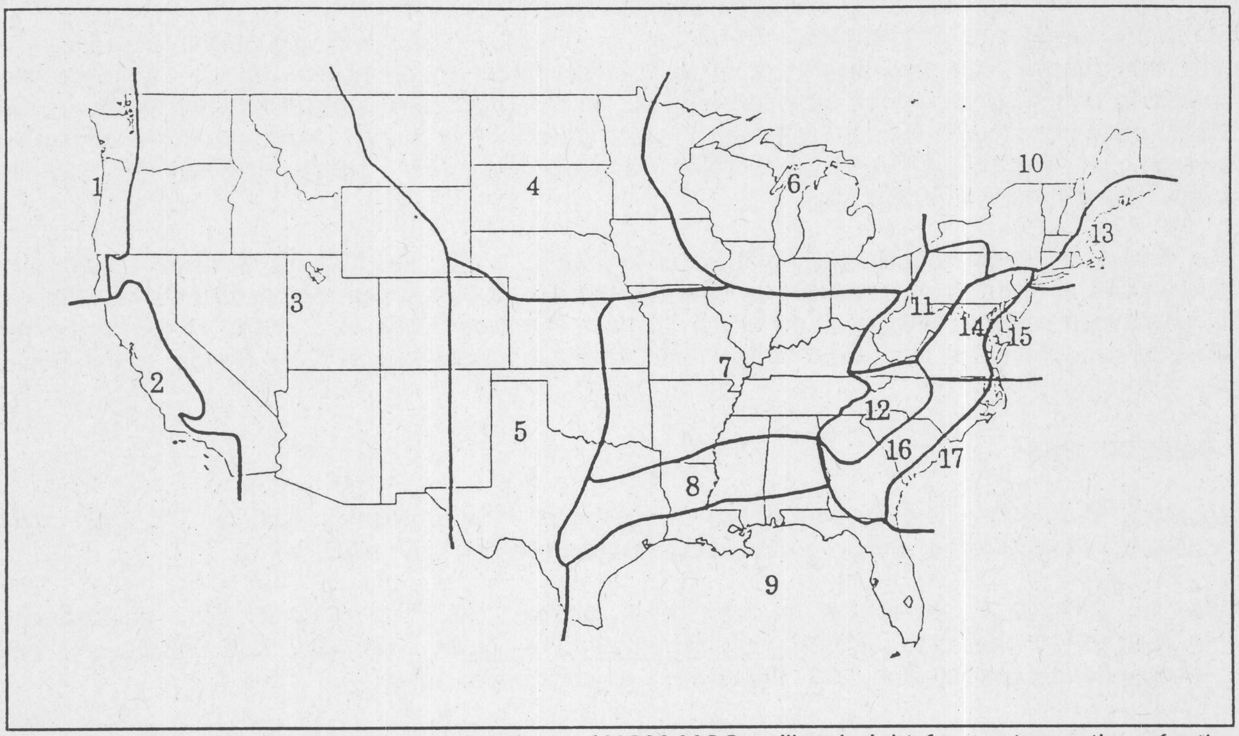

Figure 1a. Regions used in the development of NGM MOS ceiling height forecast equations for the warm season (April-September).

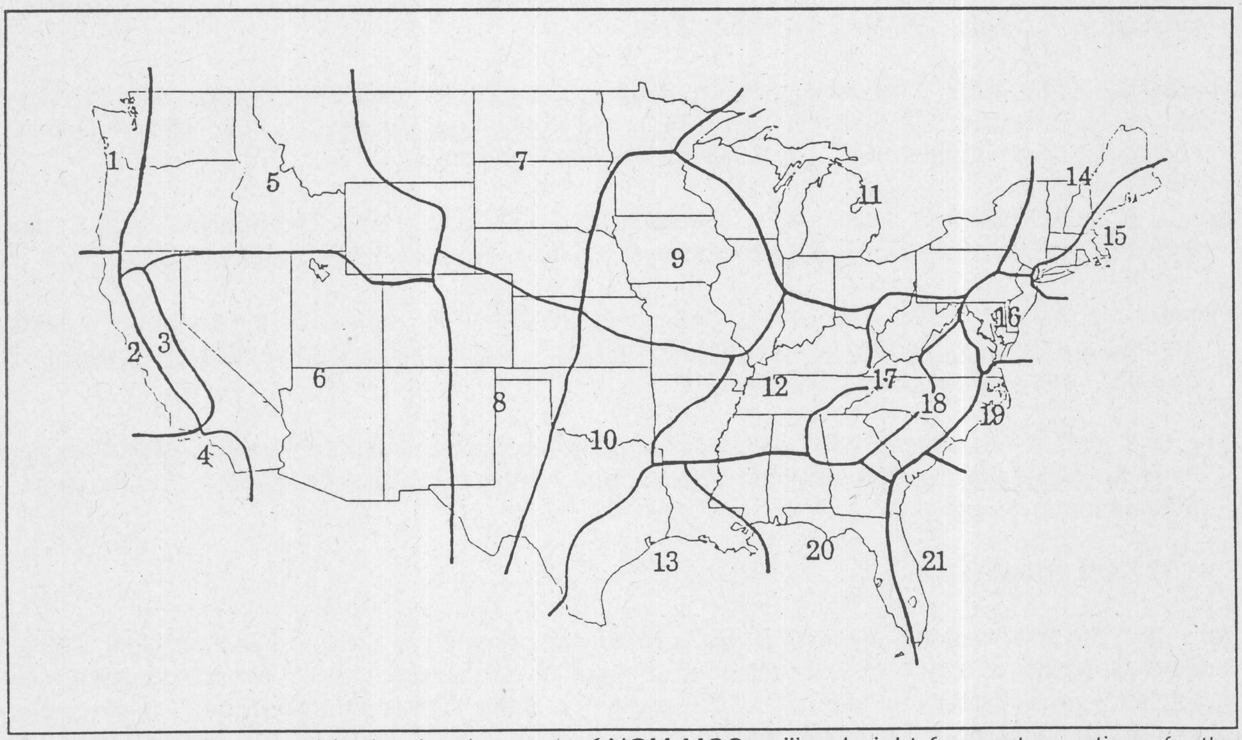

Figure 1b. Regions used in the development of NGM MOS ceiling height forecast equations for the cool season (October-March).

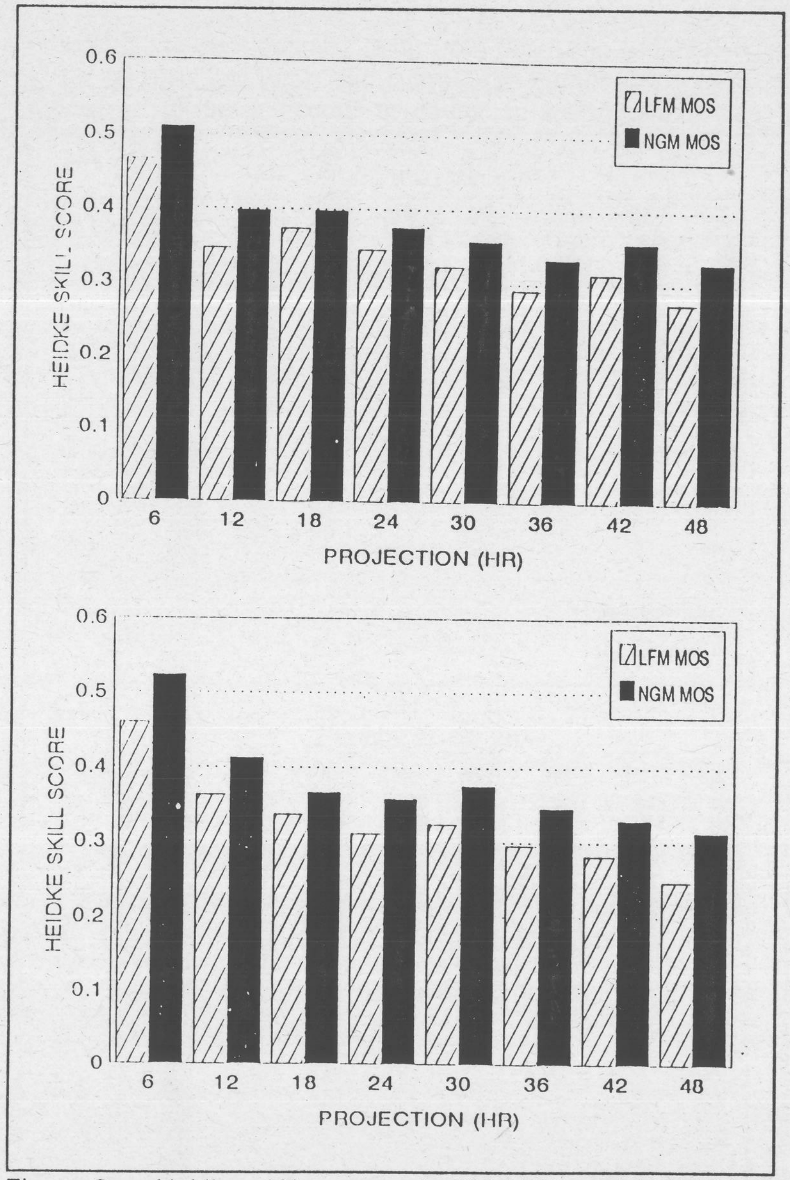


Figure 2a. Heidke skill scores of LFM MOS and NGM MOS categorical ceiling height forecasts, 1993-1994 cool season, 0000 (top) and 1200 (bottom) UTC.

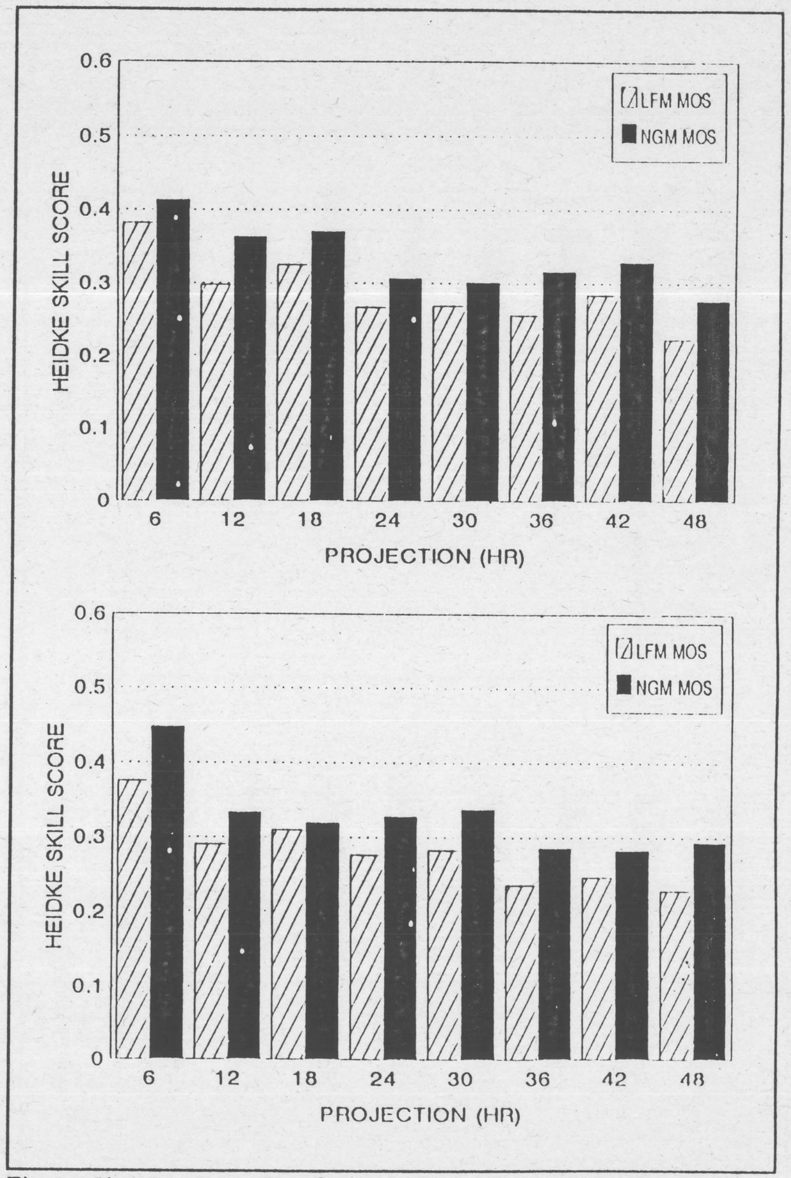


Figure 2b. Same as Fig. 2a, except for the 1994 warm season.

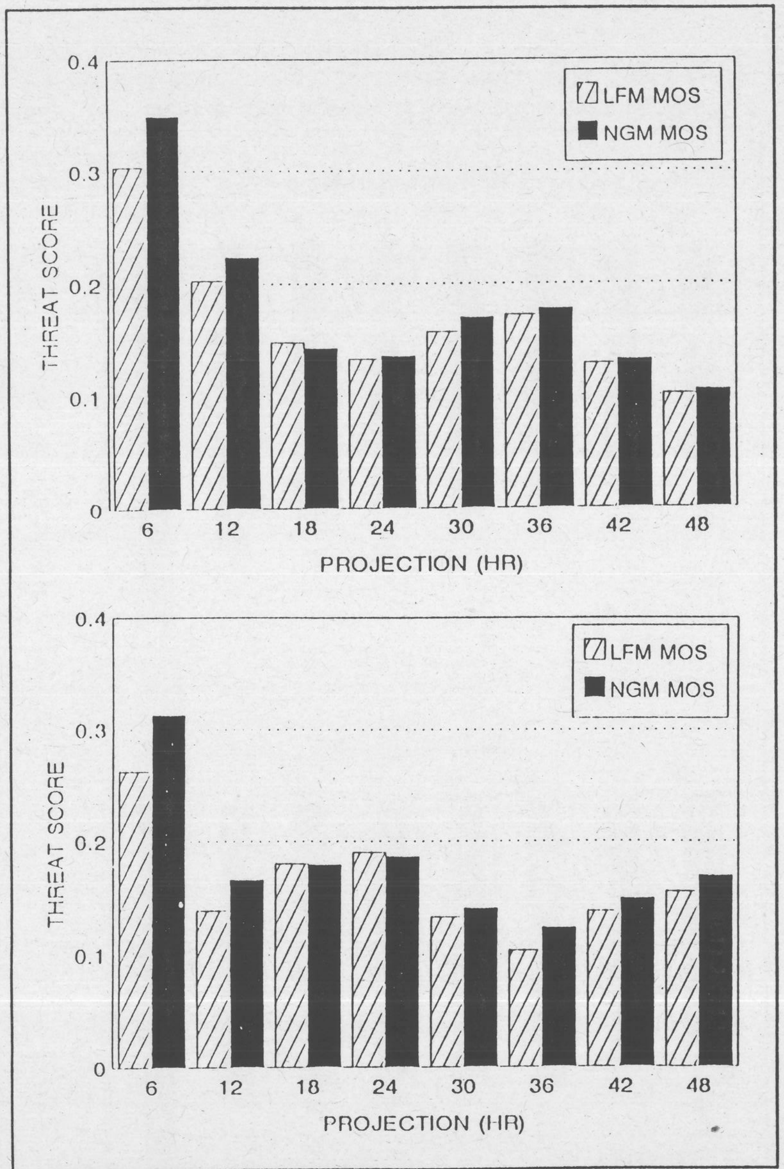


Figure 3a. Threat scores of combined categories 1 and 2 (≤ 400 ft) LFM MOS and NGM MOS categorical forecasts, 1993-1994 cool season, 0000 (top) and 1200 (bottom) UTC.

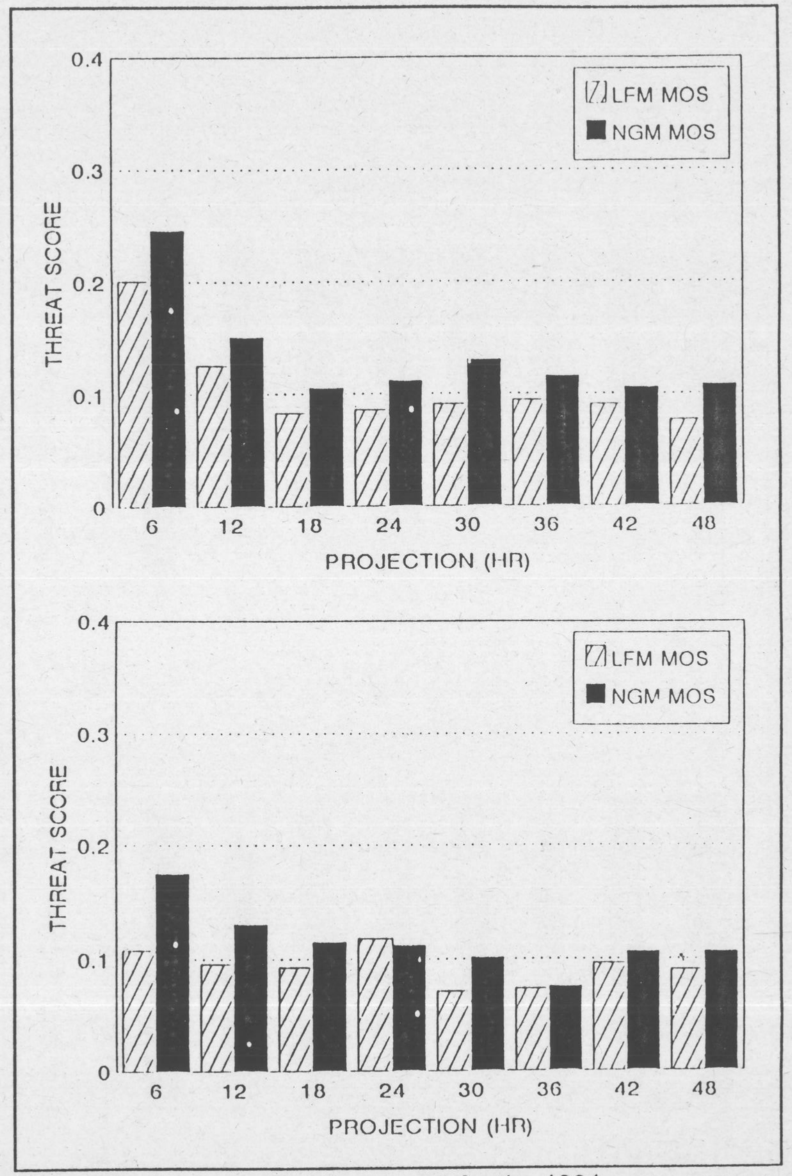


Figure 3b. Same as Fig. 3a, except for the 1994 warm season.

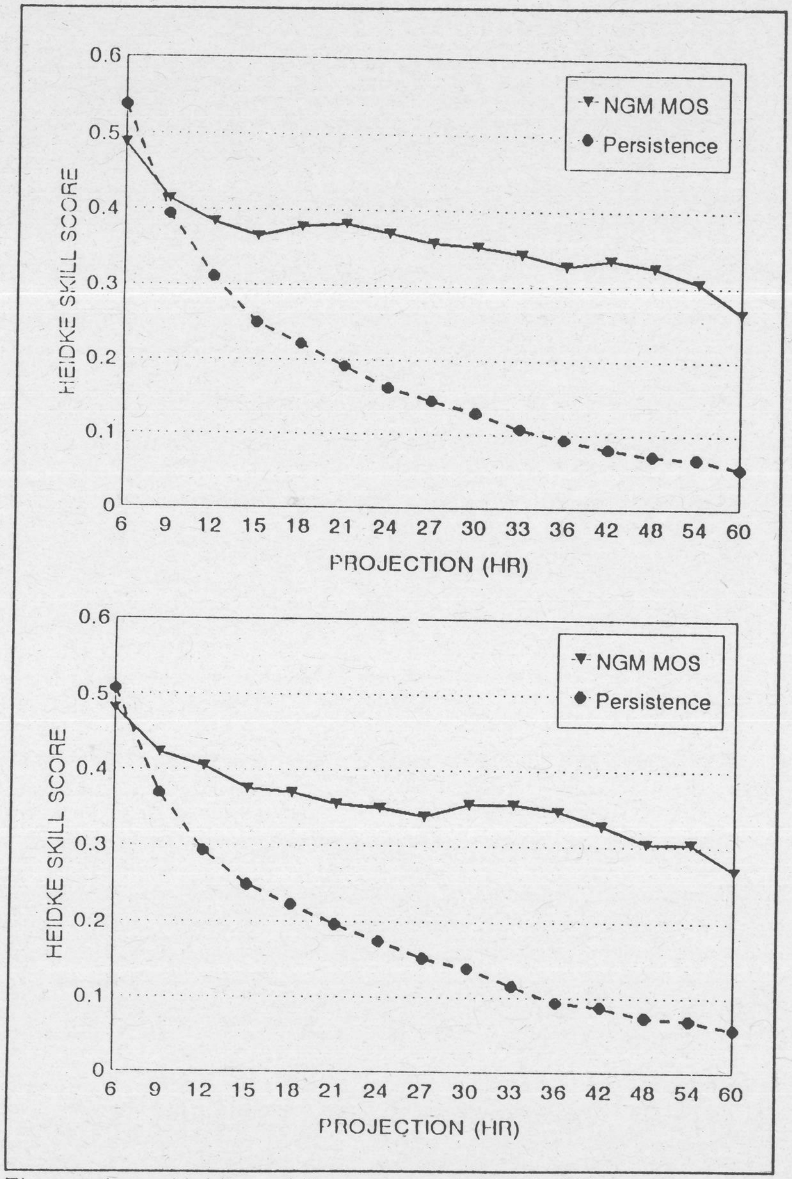


Figure 4a. Heidke skill scores of NGM MOS categorical forecasts and persistence forecasts, 1993-1994 cool season, 0000 (top) and 1200 (bottom) UTC.

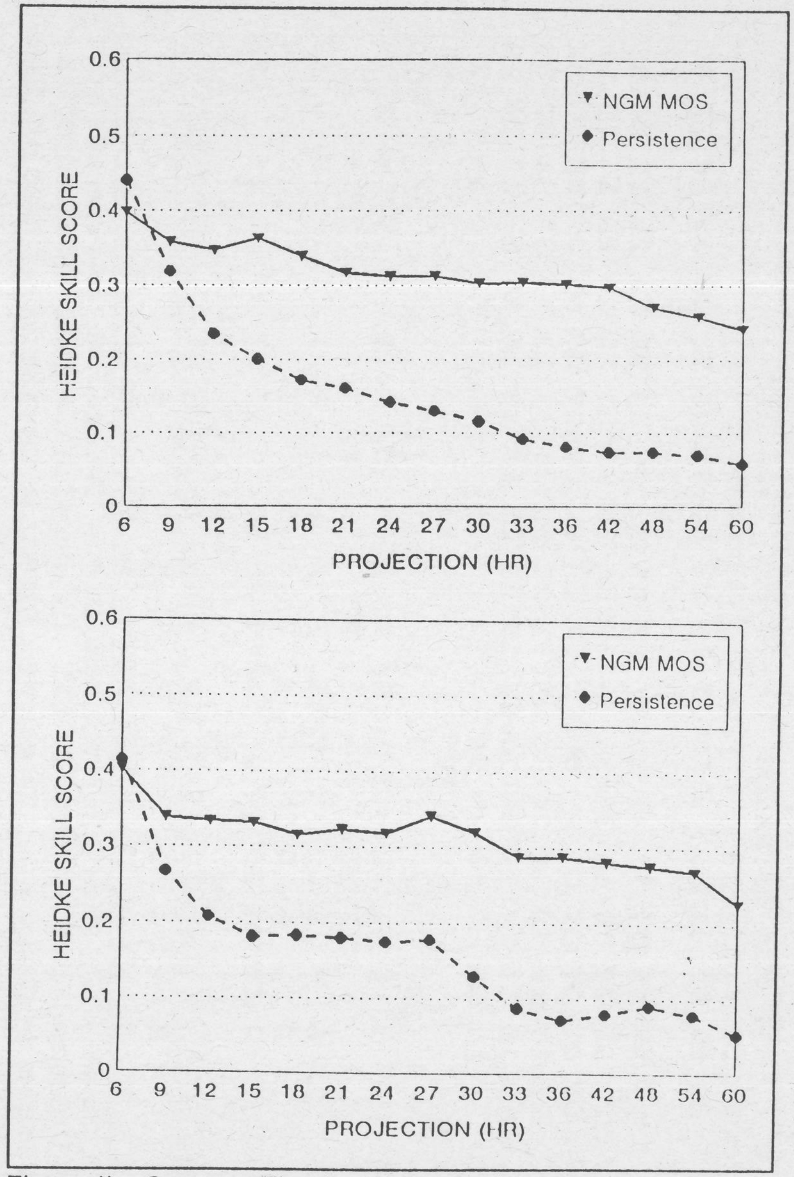


Figure 4b. Same as Fig. 4a, except for the 1994 warm season.

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 | | | | |

Figure 5. Sample FOUS14 KWBC (FWCINL) message for International Falls, Minnesota (INL) for the 1200 UTC forecast cycle on October 27, 1993. The categorical ceiling height forecasts (CIG) are highlighted in the stippled area of the message. The forecast values correspond to the definitions of the NGM MOS ceiling height categories listed in Table 1.