Improved Automated Surface Temperature Guidance

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ABSTRACT

Currently, two sets of automated numerical-statistical forecasts of maximum/minimum (max/min) temperatures for calendar day periods are produced in the day-to-day operations of the National Weather Service. The "early" guidance forecasts are based on output from the Limited-area Fine Mesh (LFM) model, while the "final" guidance relies primarily on predictions from the hemispheric Primitive Equation (PE) model. This paper describes recent improvements to the early guidance surface temperature prediction system.

The Techniques Development Laboratory recently developed new early guidance equations to forecast calendar day max/min temperatures for projections out to approximately 60 h and hourly temperatures at 3 h intervals out to 51 h for approximately 230 stations in the conterminous United States. A combination of LFM model output, surface weather observations and climatic factors were used in this development. We derived three sets of temperature prediction equations for both the 0000 and 1200 GMT forecast cycles as follows: 1) max/min equations for the first (24 h) period and 3 h equations for projections of 6 to 27 h; 2) max/min equations for the second (36 h) period and 3 h equations for projections of 27 to 39 h; and 3) max/min equations for the third (48 h) period and 3 h equations for projections of 39 to 51 h. To enhance consistency among the various max (or min) and 3 h forecasts, all the equations within each set are comprised of the same 10 predictors. We also derived a separate set of 60 h max/min equations.

Comparative verification indicates that, in sharp contrast to past results, max/min forecasts from the new early guidance system are now better than those from the final guidance system. In addition, the automated 3 h temperature predictions are superior to persistence forecasts based on 3 to 6 h old temperature observations, as well as to persistence forecasts based on reports taken 24 h earlier.

1. Introduction

The National Weather Service has been providing its field forecasters with objective maximum and minimum surface temperature guidance since 1965. Until August 1973, the automated forecasts were based exclusively on the "perfect prog" approach (Klein and Lewis, 1970). Since that time, however, most of the max/min guidance has been generated by use of the Model Output Statistics (MOS) technique (Glahn and Lowry, 1972).

The initial MOS equations were valid for warm and cool seasons of 6 months duration (Klein and Hammons, 1975). In July 1975, equations for 3-month seasons were put into operation (Hammons *et al.*, 1976). These equations were developed primarily on surface weather observations, forecast output from the coarse mesh version of the National Meteorological Center's PE model (Shuman and Hovermale, 1968), and PE-dependent trajectory (TJ) model output (Reap, 1972). In August 1976, they were applied to output from the LFM model (Gerrity, 1977) and an LFM-dependent TJ model to obtain the early max/min temperature guidance; the purpose of this forecast package was to provide guidance to the field forecasters as soon as possible. The final MOS guidance remained dependent on forecasts from the PE and TJ models, plus weather elements from the latest surface observations.

In September 1977, with the advent of the high-resolution LFM-II model (Brown, 1977a), the early temperature guidance began to be generated from LFM-II output. In January 1978, a new fine-mesh hemispherical model, called the seven-layer PE (7LPE), was put into operation by the National Meteorological Center (Brown, 1977b). The final

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temperature guidance is now based primarily on output of the 7LPE model.

Comparative verification indicated that the early max/min guidance was from 0.2 to 0.5°F less accurate than the final guidance in terms of mean absolute errors (Dallavalle *et al.*, 1977). This difference appeared to be related to the lack of surface observations as input to the early guidance and its use of LFM model forecasts in PE-derived equations.

The Techniques Development Laboratory recently derived a new set of multiple-regression equations for the early temperature forecast system. The major improvements associated with this development included the use (as predictors) of archived output from the LFM model and observed weather elements from surface reports. Also, for the first time, equations to predict 3-hourly surface temperatures (Grayson and Dallavalle, 1977) were derived simultaneously with those for max/min temperatures. This procedure should provide for greater consistency among the objective forecasts of these variables. The new early guidance system went into operation on 1 June 1978.

Comparative verification indicates the early guidance max/min forecasts are now more accurate than those from the final guidance system. We will present these results and describe key aspects regarding the development of the new equations. Using this information, operational forecasters should be able to take full advantage of the improved early temperature guidance.

2. Highlights of the development

This particular application of the MOS technique involves matching surface temperature observations (predictand data) with various combinations of numerical model forecasts, observed weather elements and climatic factors (predictor data). We use a forward stepwise screening regression procedure to derive linear-regression equations to predict the surface temperature $\hat{T}$. Each equation is of the form

$$\hat{T} = a_0 + a_1X_1 + a_2X_2 + \ldots + a_kX_k,$$

where the caret indicates an estimate, a_0 is the regression constant, the a_i's ($i = 1, 2, \ldots, k$) are multiple-regression coefficients, and the X_i's are predictors selected by the screening procedure. Since we simultaneously derive equations to predict a particular max or min and certain temperatures at 3 h intervals, the X_i's are identical for all of the equations for a particular station and equation set, but the a_i's are unique to each individual equation. The screening technique selects the predictor which yields the highest reduction of variance for any one of the predictands when combined with the other terms in a multiple-regression equation. In this particular application, the same procedure was followed until 10 predictors had been selected. Previous research (Bocchieri and Glahn, 1972) indicated that 10 is reasonably close to the optimum number of predictors for the developmental sample that was available.

a. Predictands and predictors

The predictands for the max/min equations are maxima and minima reported for local calendar days. In contrast, the 3-hourly temperature predictand data consist of surface temperature observations for specific times throughout each day (i.e., 0000, 0300, 0600, . . . , 2100 GMT). Both max/min and 3-hourly temperature observations are available in our developmental data archive from October 1972 through the present.

The potential predictors consist of various archived forecast fields from the LFM model, meteorological parameters derived from LFM output, weather elements observed as much as 3 h after the LFM's normal input data time (i.e., reports taken at 0300 and 1500 GMT), and several climatic factors. LFM forecasts for projections of 6, 12, 18 and 24 h are available in the MOS data archive from October of 1972 through the present. Forecasts for longer projections of 30 and 36 h are available from April 1975 to the present; 42 and 48 h fields are available from February 1976 to the present.

Table 1 shows the various LFM model predictors we screened in developing the temperature prediction equations. These included heights, temperatures, potential temperatures, horizontal wind components, vertical wind velocities, relative humidities, dew-point temperatures and precipitable water at various projections and levels throughout the lower and middle troposphere. In addition, we computed horizontal wind speed and divergence, relative vorticity, temperature and vorticity advection, thickness and stability (the temperature difference between two levels). As indicated in Table 1, some of these fields were space-smoothed over 5, 9 or 25 model grid points in order to reduce the amount of small-scale noise inherent in the numerical output. The LFM forecasts were then interpolated from grid points to the location of each of the stations in the predictand data sample.

As shown in Table 2, we also screened surface temperature, dew point, wind, cloud amount, ceiling height, snow amount (during the cool season), and max and min temperatures for the previous calendar day from synoptic and hourly observations. We used only the previous min for the 0000 GMT cycle equations because, in day-to-day operations, the max for the previous calendar day is not available from the 0000 GMT synoptic reports.

TABLE 1. Potential numerical model predictors used to derive the early guidance temperature prediction equations. The asterisks indicate the field was smoothed by 5 (*), 9 (**) or 25 points (***).

LFM output field	Forecast projections (hours from 0000 GMT or 1200 GMT)
1000 mb height	12*,24*,30*,36*,36**,42**,48**,48***
850 mb height	12,24,30,36,42,48,48*,48**
500 mb height	12,24,30,36,36*,42,48,48*
500–1000 mb thickness	0,6,12,18,24,30,36,42,48,48*
850–1000 mb thickness	0,6,12,18,24,30,36,42,48*,48**
500–850 mb thickness	0,6,12,18,24,30,36,42,48*
1000 mb temperature	0,12*,24*,36*,36**,48**,48***
850 mb temperature	0,6,12,18,24,24*,30*,36*,42*,48*,48**
700 mb temperature	0,12,24,30,36,36*,42*,48*,48**
Boundary-layer potential temperature	6,12,18,24,24*,30*,36*,42*,48*,48**
Boundary-layer U component	6,12,18*,24*,30*,36*,42*,48*,48**
Boundary-layer V component	6,12,18*,24*,30*,36*,42*,48*,48**
Boundary layer wind speed	6,12,18*,24*,30*,36*,42*,48*,48**
850 mb U component	6,12,18*,24*,30*,36*,42*,48*,48**
850 mb V component	6,12,18*,24*,30*,36*,42*,48*,48**
700 mb U component	12,24*,36*,48*,48**
700 mb V component	12,24*,36*,48*,48**
850 mb relative vorticity	6*,12*,18*,24*,30**,36**,42**,48**
500 mb relative vorticity	12*,24*,30**,36**,42**,48**
850 mb vertical velocity	12*,24*,36*,48**,48***
700 mb vertical velocity	12*,24*,30*,36*,42**,48**,48***
700–1000 mb temperature difference	12,24,36*,48*,48**
500–850 mb temperature difference	12,24,30*,36*,42*,48*,48**
Boundary-layer relative humidity	0*,6*,12*,18*,24*,30*,36*,36**,42**,48**,48***
Mean relative humidity (sfc to 490 mb)	6*,12*,18*,24*,30*,36*,36**,42**,48**,48***
Precipitable water	6*,12*,18*,24*,30*,36*,42**,48**,48***
1000 mb dew-point temperature	6*,12*,18*,24*,30*,36*,42*,48*,48**,48***
850 mb dew-point temperature	12*,24*,30*,36*,42*,48*,48**
700 mb dew-point temperature	12*,24*,30*,36*,42*,48*,48**
Boundary-layer wind divergence	6*,12*,18*,24*,30*,36*,42**,48**,48***
850 mb temperature advection	12*,24*,30*,36*,42**,48**,48***
500 mb vorticity advection	12*,24*,30*,36*,42**,48***

Analogously, since the calendar day min is not available operationally at 1200 GMT, we screened only the previous max for the 1200 GMT cycle equations. To partially compensate for this deficiency, we screened temperature observations at three different times (2100, 0000 and 0300 GMT) for the 0000 GMT cycle and at two times (1200 and 1500 GMT) for the 1200 GMT cycle. For example, 2100 GMT reports were used because the temperature at this time is closely related to the observed daily max for stations in the eastern and central United States.

Additionally, we screened the first and second harmonics of the day of the year as potential predictors for all the equations. This was done in an attempt to simulate the normal seasonal trend of temperature.

b. Forecast projections and seasonal stratifications

We derived the max/min and 3-hourly temperature prediction equations for a number of different forecast projections. The 0000 GMT cycle max/min equations are for projections of approximately 24 (today's max), 36 (tomorrow's min), 48 (tomorrow's max), and 60 (day after tomorrow's min) hours from 0000 GMT. Analogously, the 1200 GMT cycle max/min projections are approximately 24 (tomorrow's min), 36 (tomorrow's max), 48 (day after tomorrow's min) and 60 (day after tomorrow's max) hours from 1200 GMT. For both forecast cycles, the 3-

TABLE 2. Potential observed predictors, in addition to the LFM fields in Table 1, used to derive the early guidance temperature equations.

Element	0000 GMT cycle	1200 GMT cycle
	0300	1500
Sfc temperature	0000	1200
	2100 (yesterday)	
Sfc dew point temp	0300	1500
Cloud cover	0300	1500
Sfc U wind	0300	1500
Sfc V wind	0300	1500
Sfc wind speed	0300	1500
Ceiling height	0300	1500
Previous maximum temp		1200
Previous minimum temp	0000	
Snow cover	1200 (yesterday)	1200

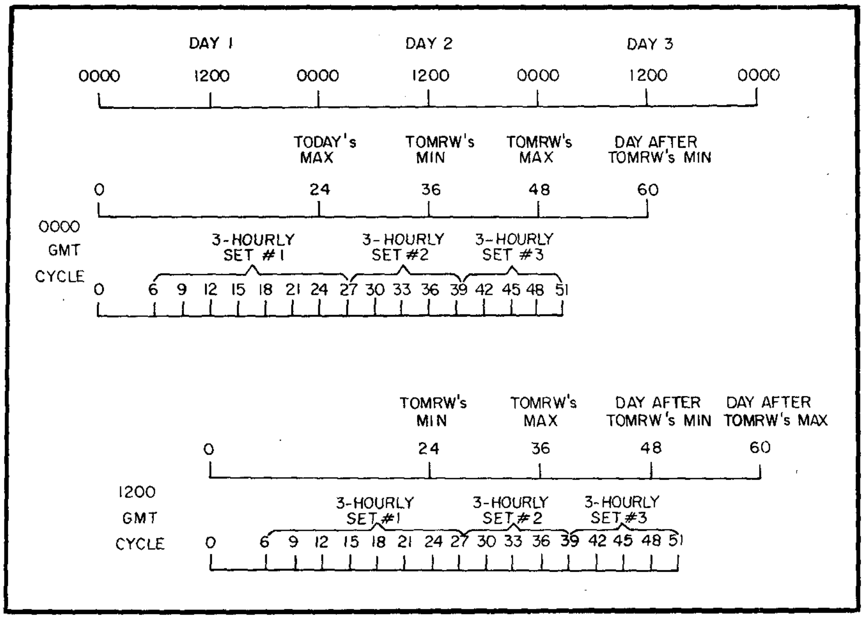

FIG. 1. Forecast periods associated with the early guidance temperature prediction equations.

hourly temperature guidance is for projections with valid times every 3 h from 6 to 51 h inclusive.

Fig. 1 shows the combination of forecast projections used to develop the max/min and 3-hourly equations. The three basic sets of equations are 1) max/min equations for the first (~24 h) period and 3-hourly equations for projections of 6, 9, 12, 15, 18, 21, 24 and 27 h; 2) max/min equations for the second (~36 h) period and 3-hourly equations for projections of 27, 30, 33, 36 and 39 h; and 3) max/min equations for the third (~48 h) period and 3-hourly equations for projections of 39, 42, 45, 48 and 51 h. We also derived separately a set of max/min equations valid approximately 60 h after 0000 and 1200 GMT.

As mentioned before, the period of record in our developmental data archive was somewhat limited in regard to 30–48 h output from the LFM model. In order to obtain a large enough sample to develop stable regression equations, we tried pooling the data and deriving all the equations through the use of a regional generalized operator technique (Glahn and Lowry, 1972). Then we conducted a test to determine if a regionalized system could produce max/min forecasts of the same skill and accuracy as those from our traditional single-station system.

Our experiment consisted of deriving max/min prediction equations for stations grouped in 22 climatologically homogeneous regions (Fig. 2) by screening LFM output, climatic factors, station constants and observed weather elements. We also derived a similar set of single-station equations for each of 50 test stations depicted by circles in Fig. 2. Forecasts for both sets of equations were then generated and verified on independent data. The results (not shown) indicated that the forecasts from the single-station equations were slightly better than those from the regional equations. These findings, in conjunction with the regionalized system's inability to adequately differentiate between urban and rural temperatures within a metropolitan area, convinced us to stay with the traditional single-station approach.

We derived the first set of 24 h max/min and 6–27 h 3-hourly equations by stratifying the data into 3-month seasons, similar to the approach used by Hammons *et al.* (1976). However, due to the scarcity of developmental data from the LFM model for projections beyond 24 h, we used a 6-month stratification for the other sets of prediction equations (all projections beyond 27 h). Table 3 shows the particular seasons that were selected, as well as the years for which archived data were available. It should be noted that, starting with September 1977, all data in our archive are from the LFM-II model. Thus, the cool season, fall and winter of 1977–78 are comprised entirely of output from the new model. In contrast, the warm season and summer of 1977 both contain only one month of LFM-II data.

c. *Screening regression results*

We derived separate sets of 10-term regression equations for each station and forecast cycle. We screened observed weather elements as potential predictors—in addition to the forecast output from the LFM model and the first and second harmonics

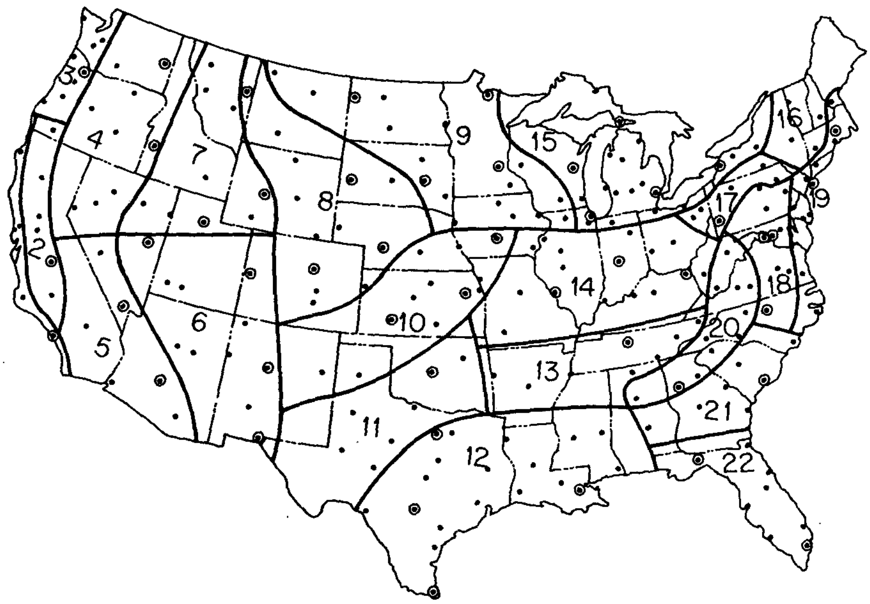

FIG. 2. Twenty-two regions used to test the regional generalized operator concept in temperature forecasting. The dots locate stations whose data were pooled to derive max/min equations for each region. The circles represent 50 stations where forecasts made from the regional equations on independent data were compared to forecasts made by single-station equations.

of the day of the year—when we developed the first two sets of max/min and 3-hourly temperature equations shown in Fig. 1. We also derived backup equations for these two sets by not including surface observations as potential predictors. The backup equations are used to generate forecasts in day-to-day operations when surface observations are missing and the primary equations cannot be applied.

Sets of prediction equations valid for the six seasons shown in Table 3 are now available for approximately 230 stations throughout the conterminous United States. Due to the various forecast projections and the corresponding primary and backup equations, most stations have 55 separate equations for each forecast cycle and each of the 6-month warm and cool seasons.

Table 4 shows the predictors selected for the 0000 GMT cycle 24 h max and 6–27 h 3-hourly temperature prediction equations valid during January through March for Omaha, Nebraska. All nine equations contain these same 10 predictors, but the individual regression coefficients and constants differ from equation to equation. For this particular set of equations, the surface temperature at 0300 GMT and the 24 h LFM model forecast of the thickness between 850 and 1000 mb, taken together, accounted for 81–95% of the reduction in variance of the various surface temperature predictands. Six other fields from the LFM model, plus the cosine of the day of the year and the observed snow cover at 1200 GMT, added from 1 to 9% to the cumulative reductions of variance. Note that Omaha's observation of snow cover is treated as a binary predictor which is given a value of 1 if less than 1 inch of snow is reported; otherwise, the value of this predictor is set to zero. Equations for the other stations have similar characteristics.

TABLE 3. Number of seasons of archived forecasts from the LFM model available for the development of the early guidance temperature prediction equations.

Season	24 h max/min 3-hourly set #1	36 h max/min 3-hourly set #2	48 and 60 h max/min 3-hourly set #3
Spring (April–June)	5 (1973–77)	—	—
Summer (July–September)	5 (1973–77)	—	—
Warm (April–September)	—	3 (1975–77)	2 (1976–77)
Fall (October–December)	6 (1972–77)	—	—
Winter (January–March)	6 (1973–78)	—	—
Cool (October–March)	—	3 (1975–78)	2 (1976–78)

TABLE 4. Predictors used in the equations to predict today's calendar day maximum and 3-hourly temperatures valid 6–27 h from 0000 GMT for Omaha, Nebraska (OMA). Cumulative reductions of variance and standard errors of estimate are also shown for each equation. The developmental data were from January, February and March of 1973–78 (415 days).

Predictor (units)	Smoothing (points)	Cumulative reduction of variance: max 24	3-hourly temperatures: 6	9	12	15	18	21	24	27
0300 GMT observed surface temp (°F)	—	0.625	0.947	0.867	0.794	0.770	0.645	0.545	0.552	0.532
24 h LFM 850–1000 mb thickness (m)	0	0.836	0.948	0.876	0.813	0.844	0.862	0.841	0.844	0.830
12 h LFM 850–1000 mb thickness (m)	0	0.848	0.956	0.901	0.862	0.877	0.875	0.843	0.844	0.831
Cosine day of year	—	0.862	0.956	0.901	0.862	0.888	0.889	0.859	0.885	0.854
12 h LFM mean relative humidity (%)	5	0.866	0.961	0.918	0.888	0.898	0.889	0.861	0.885	0.855
Yesterday's 1200 GMT observed snow cover (binary predictor: 1 if <1 inch; zero otherwise)	—	0.877	0.961	0.918	0.889	0.901	0.895	0.873	0.892	0.856
24 h LFM boundary-layer rel humidity (%)	5	0.889	0.962	0.919	0.889	0.901	0.898	0.881	0.896	0.857
12 h LFM boundary-layer wind speed (m s^{-1})	0	0.890	0.962	0.923	0.897	0.903	0.898	0.881	0.896	0.858
18 h LFM 1000-mb dew point (K)	5	0.891	0.964	0.927	0.904	0.909	0.904	0.883	0.898	0.859
18 h LFM boundary-layer V wind (m s^{-1})	5	0.893	0.964	0.927	0.905	0.912	0.906	0.884	0.900	0.865
Standard error of estimate (°F)		5.06	2.76	3.92	4.55	4.46	4.70	5.37	4.94	5.25

Prior to deriving prediction equations for the cool season, we conducted an experiment to determine the best way to include the observed snow cover as a potential predictor. We compared several binary snow cover predictors (with threshold values of a trace, 1 inch, 2 inches and 5 inches) against various "interactive" predictors which combined 18 h LFM boundary-layer potential temperature forecasts with each station's observation of snow cover. Our test results (not shown) for 20 stations in the central Great Plains showed that the binary snow cover predictors were more effective than the interactive predictors in removing a warm bias in the maximum temperature forecasts when snow was on the ground. Therefore, we screened snow cover as a binary predictor for the first two sets of max/min and 3-hourly equations valid during the cool season.

Nearly all the potential predictors we offered were selected by the screening regression procedure for one station or another. However, these selections were not distributed uniformly and a few predictors predominated. For the primary equations, observed temperatures and low-level temperature, dew point and thickness forecasts from the LFM model were frequently selected. In addition, during the cool season, observed snow cover often appeared in the equations for stations throughout the Midwest, the northern and central Great Plains, and the Rocky Mountains. For backup equations, the LFM surface temperature analyzed from initial data also was an important predictor. In essence, this field served as a substitute for the station's surface temperature observation. The cosine of the day of the year was selected quite often for the equations valid for the longer projections.

Fig. 3a shows the average standard errors of estimate for all stations combined for the warm season max/min equations. The standard errors for the 24 h max from 0000 GMT and the 24 h min from 1200 GMT were obtained by averaging the values for the spring (April–June) and summer (July–September) seasons. The errors were smaller in summer than in spring and increased almost linearly with projection for both the max and the min.

The comparative magnitudes of the errors in Fig. 3a indicate that the max is more difficult to predict than the min during the warmer part of the year. In the warmer months, because of the presence of small-scale convective clouds, the max is usually more variable and localized than the min. Fig. 3a also shows that the use of observed predictors by the primary equations reduced the standard errors by about 0.1°F on the average. These findings are consistent with those of Hammons *et al.* (1976).

Similar max/min developmental standard errors for the cool season are indicated in Fig. 3b. During the colder months, the standard errors of estimate for the min temperature prediction equations are higher than those for the max. This is because local effects, such as drainage winds and low-level cloudiness, tend to dominate nighttime cooling. In contrast, the max during the cool season is more strongly influenced by synoptic-scale weather patterns. Once again, we averaged the values for the 24 h max and min equations for the fall (October–December) and winter (January–March) equations. As before, the use of observed predictors reduced the average errors by about 0.1°F.

The average developmental standard errors for the warm season 3-hourly temperature equations are given in Fig. 4a. Unlike the previous figures, these results apply to the 0000 GMT cycle equations only. We averaged the 6–27 h values for the spring and summer, and the values for the two sets of equations

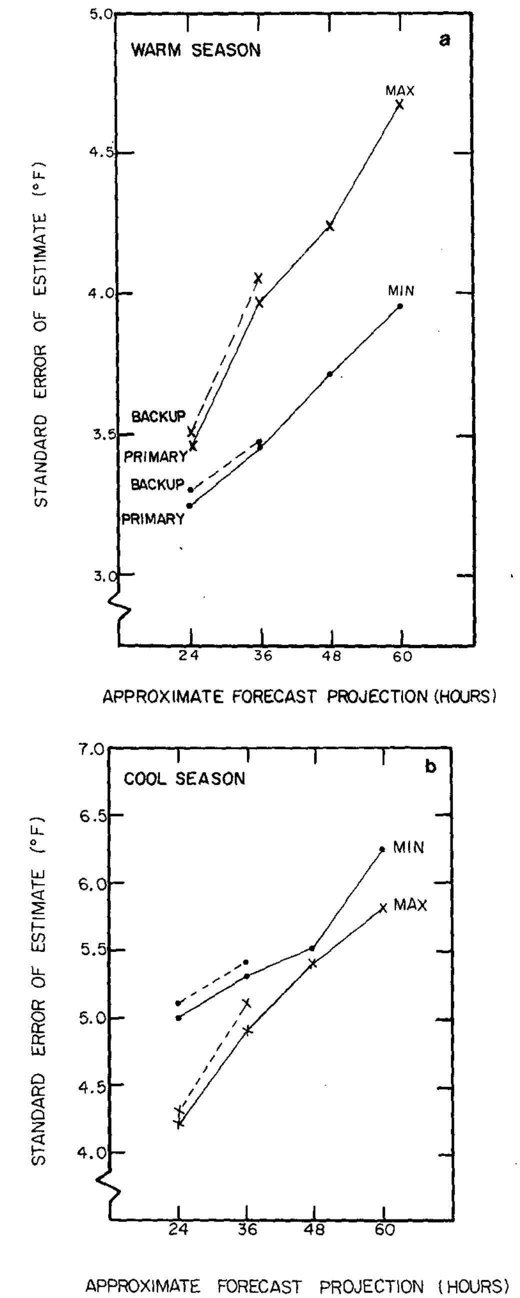

FIG. 3. Developmental standard errors of estimate averaged at approximately 230 stations for the early guidance max and min temperature equations valid during the warm (a) and cool (b) seasons. The standard errors for the primary equations are indicated by a solid line; those for the backup equations, by a dashed line.

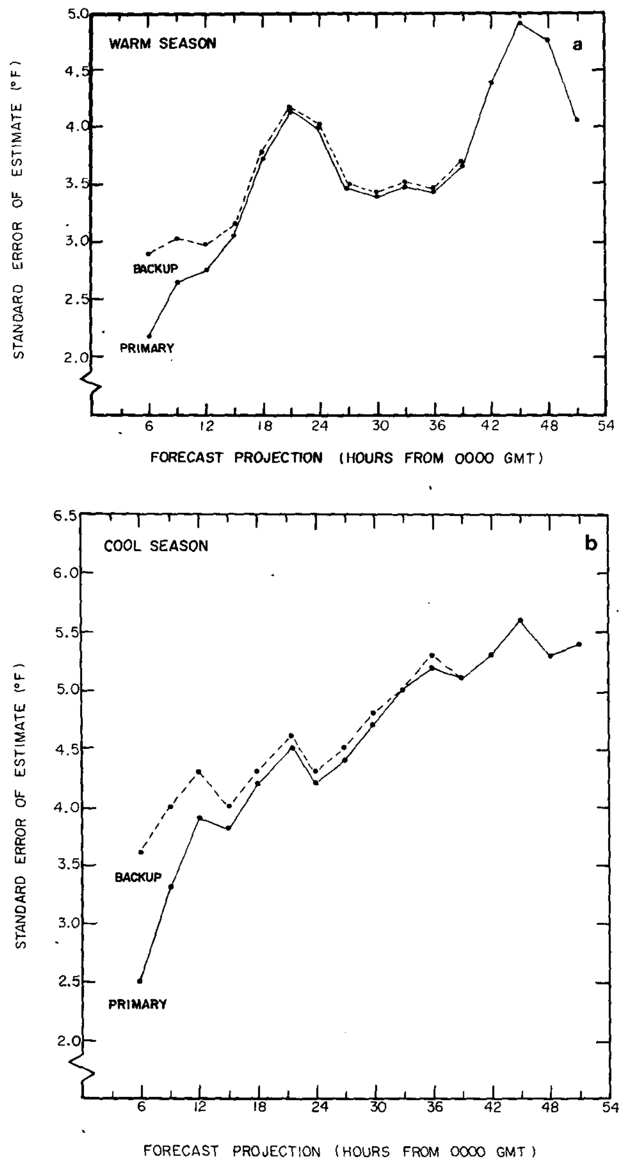

FIG. 4. Developmental standard errors of estimate averaged at approximately 230 stations for the 0000 GMT cycle early guidance 3-hourly temperature equations valid during the warm (a) and cool (b) seasons. The standard errors for the primary equations are indicated by a solid line; those for the backup equations, by a dashed line.

valid for projections of 27 and 39 h from 0000 GMT. Generally, the standard errors increased with increasing forecast projection, although not monotonically. The curves peak at 2100 GMT each day. As was noted for the max, this characteristic appears to be related to the presence of small-scale convective cloudiness in the mid to late afternoon. Also of interest is the manner in which the observed predictors substantially reduce the standard errors of the primary equations for projections out to about 15 h.

Fig. 4b shows developmental standard errors for 3-hourly equations valid during the cool season; 6–27 h fall and winter values were averaged, as were the errors from the two sets of equations valid for the 27 and 39 h projections. Here, the curves tend to peak around 1200 and 2100 GMT each day. The peak at 1200 GMT most likely is associated with local drainage winds and low-level cloudiness during the early morning hours, while the 2100 GMT max may be related to the variability of surface temperature in the late afternoon. The warm and cool season standard errors for the 1200 GMT cycle 3-hourly temperature prediction equations (not shown) are generally like those in Fig. 4 except the patterns are offset by 12 h.

3. The operational system

Both max/min and 3-hourly temperature forecasts generated from the new equations have been available for use as guidance by NWS forecasters since 1 June 1978. These forecasts for approximately 230 stations are distributed twice daily through the Federal Aviation Administration's Weather Message Switching Center at Kansas City. Calendar day max/min forecasts for the first three periods (projections of ~24, 36 and 48 h) are now presented in the EARLY FOUS12 teletype message along with the 3-hourly forecasts for projections of 6 through 51 h.

As mentioned before, the max/min and 3-hourly temperature prediction equations were developed simultaneously in three sets. Although this approach tends to provide a degree of consistency among the operational forecasts, complete agreement is not guaranteed. In order to enhance consistency among the various 3-hourly forecasts, we developed two sets of equations for the 27 and 39 h projections (see Fig. 1). In day-to-day operations, both sets of equations are used to obtain the forecasts for these two projections. First, we generate all the 3-hourly forecasts independently. Next, the two forecasts for the 27 h projection are averaged to give a single representative prognosis. We use the same technique to determine the value of the operational forecast for the 39 h projection.

Early guidance max/min temperature forecasts are also available to NWS forecasters, private meteorologists and universities via teletype (Service C) and facsimile (NAFAX and NAMFAX). Calendar day max/min forecasts for projections of approximately 24, 36, 48 and 60 h are given in both the EARLY FOUS22 bulletin and the TDLFM four-panel facsimile chart.

These forecasts are strongly dependent on the accuracy of the LFM-II model predictions used as input. For example, if a trough or front has intensified or accelerated, corresponding adjustments to the forecast temperature patterns should be considered. Specific localized conditions and mesoscale features should also be taken into account by the forecaster. In addition, the prediction equations were developed primarily from output of the original LFM model. However, since the equations are now being applied to output from the LFM-II, they do not account for any characteristic differences between the old and new version of the model.

When we derived the new prediction equations, we tried to minimize inconsistencies among the resulting max (or min) and 3-hourly forecasts. However, as we mentioned before, complete consistency is not guaranteed. During situations where the temperature is changing rapidly, the calendar day max (or min) and certain 3-hourly forecasts may differ considerably. In fact, Fig. 5 shows an example of a recent forecast for Washington, DC, where the prediction for tomorrow's max (26°F) is less than the 3-hourly temperature guidance (31°F) valid at 0900 GMT for that same day.

4. Verification results

a. Max/min temperature forecasts

Comparative verification between the early and final max/min guidance has been carried out on a monthly basis since September 1976. Fig. 6a shows the mean absolute errors (MAE's) associated with 24 and 48 h max temperature forecasts from these two systems for each month of 1978.[1] The scores are average values for 224 stations common to both systems throughout the year. As mentioned before, the final guidance was based primarily on 7LPE model output and observed data, while the early guidance relied on LFM-II model forecasts input to PE-derived equations prior to June, and a combination of LFM-II and observed data input to LFM-derived equations, thereafter.

As indicated in Fig. 6a, the final guidance MAE's for the max forecasts ranged from 0.1 to 0.8°F lower than those for the early guidance during the period January–May 1978. The greatest differences were associated with forecasts for the 24 h projection. This is not surprising, since the final guidance equations had the advantage of using observed predictors which improve the accuracy of the shorter range predictions. However, in June, when the early guidance equations went into operation, the comparative skill between the two systems reversed, and the early guidance held an advantage of from 0.1 to 0.5°F throughout the rest of the year.

Similar comparative scores for the 24 and 48 h min forecasts are presented in Fig. 6b. As before, the final guidance had lower MAE's prior to June, with the early guidance being as good as, or considerably better than, the final guidance thereafter. Furthermore, this marked improvement in the early

[1] All the verification statistics in this section will be presented in terms of MAE's. Similar comparative results would be obtained if only large discrepancies were considered because the automated temperature forecast errors follow the normal distribution very closely (Dallavalle *et al.*, 1977).

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                         TDL AUTOMATED FORECASTS   USING EARLY GUIDANCE
                         TUESDAY 2 JAN 1979

WASHINGTON, DC                                               VALID TIME
                         ELEMENT    UNITS      12Z   18Z   00Z   06Z   12Z   18Z   00Z
                                               (---TODAY---)(--TONIGHT--)(--TOMORROW--)

                         TEMP M/M   DEG F            59          22          26
                         TEMP       DEG F     56 56 55 55 50 45 41 36 31 27 29 23 24 21


WASHINGTON, DC           RAIN, HEAVY AT TIMES, TODAY.  EARLY MORNING HIGH IN THE MID 50S.
                         NORTHWESTERLY WINDS 10 TO 15 MPH IN THE AFTERNOON.  TONIGHT--CLOUDY
                         WITH SLEET OR FREEZING RAIN TURNING TO SNOW LIKELY IN THE EARLY
                         EVENING, CLEARING BY MIDNIGHT.  LOW IN THE LOWER 20S.  NORTHWESTERLY
                         WINDS 15 TO 20 MPH.  WEDNESDAY--CLEAR AND MUCH COLDER, HIGH IN THE
                         MID 20S.  WINDY IN THE MORNING.  PROBABILITY OF PRECIPITATION NEAR
                         100 PERCENT TODAY, 70 PERCENT TONIGHT, AND NEAR 0 PERCENT TOMORROW.
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FIG. 5. Automated max/min and 3-hourly temperature guidance, and the corresponding computer worded objective forecast for Washington, DC (DCA) based on data from 0000 GMT 2 January 1979. The first 3-hourly temperature forecast is 56°F valid 0900 GMT Tuesday 2 January; the second is 56°F at 1200 GMT; the third is 55°F at 1500 GMT, etc.; and the last is 21°F at 0000 GMT on Thursday 4 January. The max/min temperatures are valid as follows: 59°F for Tuesday 2 January; 22°F for Wednesday 3 January; and 26°F for Wednesday 3 January. Several other automated MOS forecast variables (not shown) also went into the composition of the computer worded message.

guidance after the new equations were introduced in June occurred uniformly for most of the United States. This is in sharp contrast to the old early guidance system which was particularly poor in comparison with the final guidance throughout the Southwest (Dallavalle *et al.*, 1977).

Fig. 7a shows the 24 to 60 h max and min forecast MAE's for the period June–September 1978. As before, these scores are average values for 224 stations. Here we see an indication of the clear superiority of the early max temperature guidance for all projections. The early min guidance also was substantially better than the final guidance, but the margin of improvement was less for all but the 48 h projection. This may be related to the fact that both types of guidance do relatively well in regard to predicting min temperatures during the warm season. Thus, the major differences were associated with the max temperature forecasts where the finer scale information contained in the LFM output appeared to enhance the early guidance.

The corresponding MAE's for the period October through December of 1978 are given in Fig. 7b. For the max temperature forecasts, the early guidance was superior to the final guidance for all four projections. This also was the case for all of the min temperature forecasts except those for the 60 h projection. For that particular forecast period, the final guidance was based on 3-month equations developed from six seasons of data. In contrast, the early guidance equations for the 60 h projection were derived from a 6-month stratification with two years of data. These developmental differences may have affected the MAE's.

We ran an experiment to determine if this improvement in the early max/min guidance was due to the introduction of the new prediction equations or the increased accuracy of the LFM-II model. In particular, during the month of July we generated a set of test forecasts based on the former early guidance system. These forecasts were then verified and the results compared with those for the operational early and final guidance. The max/min forecast MAE's averaged for 224 stations common to all three systems are shown in Fig. 8. These results for independent data indicate that the operational early guidance forecasts based on the new equations were 0.2–0.5°F more accurate than those from the old early guidance system. Also for most projections, the operational final guidance was better than the old early guidance. Thus, it appears that the improvement in the early guidance was related primarily to the introduction of the new equations.

b. Three-hourly temperature forecasts

Equations to predict specific temperatures at 3 h intervals were also put into operation on 1 June 1978. To assess the accuracy of this system, we conducted a comparative verification of 0000 GMT cycle fore-

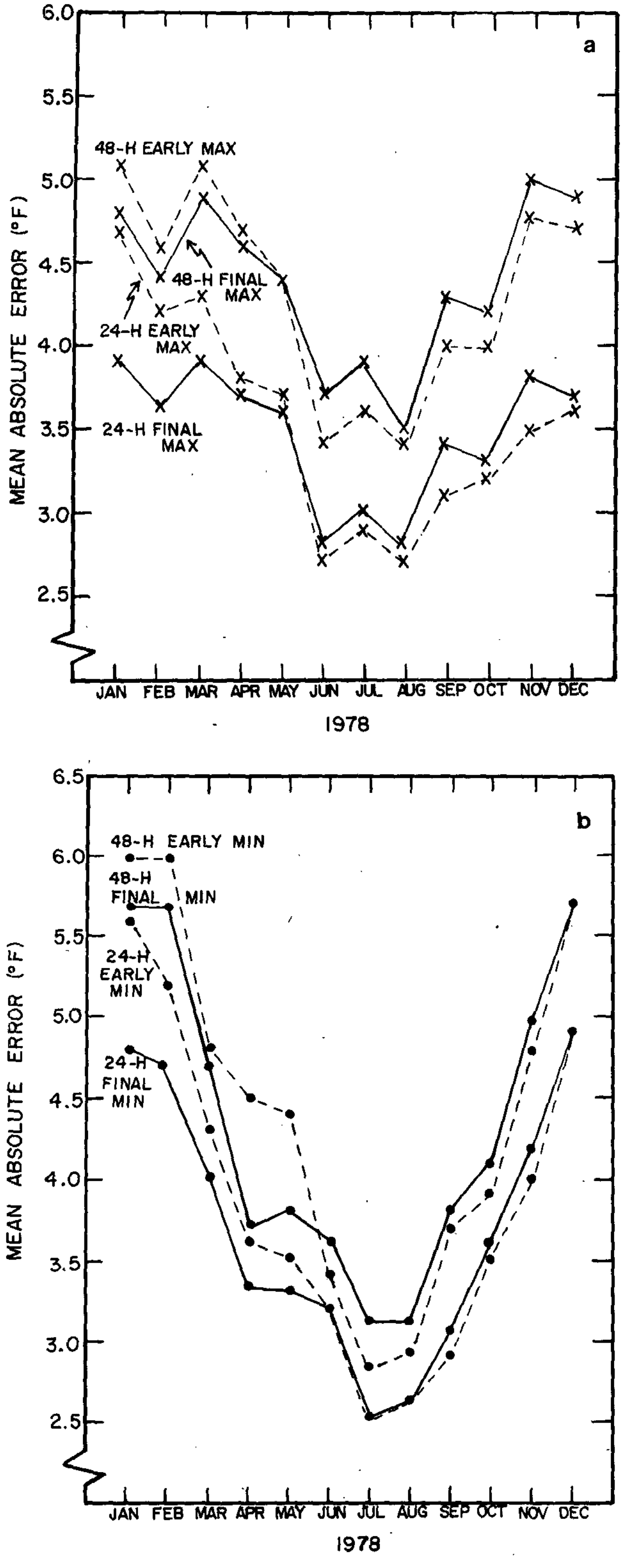

FIG. 6. Max (a) and min (b) temperature mean absolute errors for 24 and 48 h forecasts for each month of 1978. The final guidance errors are indicated by a solid line; those for the early guidance, by a dashed line. Each value is a monthly average of the forecasts for 224 stations (~6000 cases).

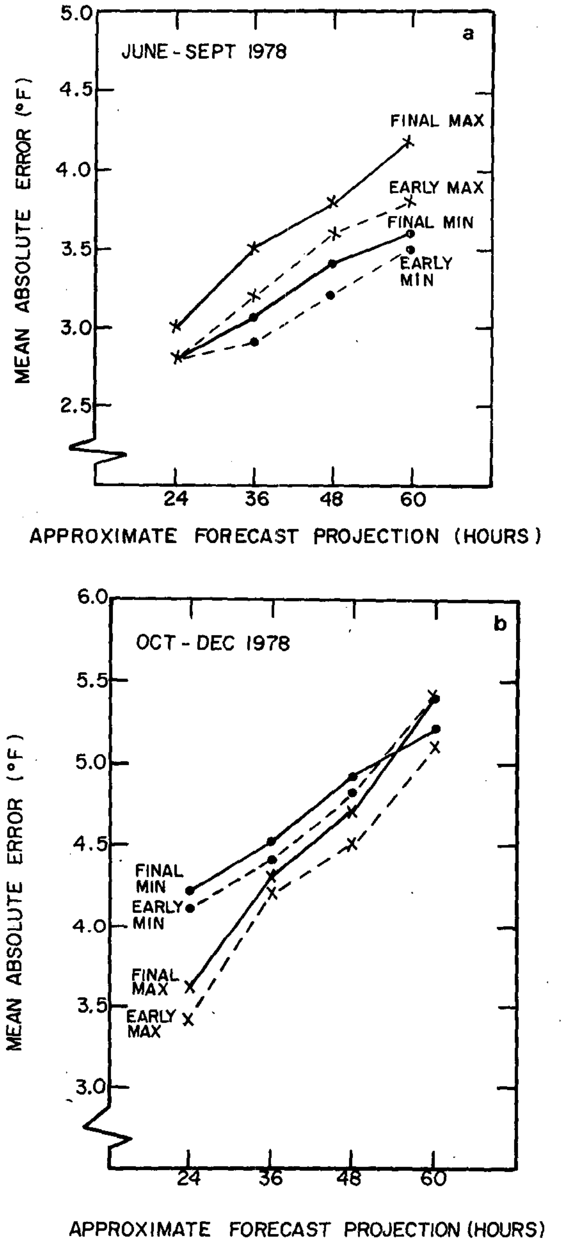

FIG. 7. Max and min temperature mean absolute errors for 24 to 60 h forecasts valid during the periods June–September (a) and October–December (b) of 1978. The final guidance errors are indicated by a solid line; those for the early guidance, by a dashed line. Each value is an average of the forecasts for 224 stations.

casts produced during June through September. MAE's averaged for approximately 230 stations are shown in Fig. 9. Since the final guidance system does not predict any temperatures valid for specific times, we compared the new 3-hourly early guidance forecasts with two types of predictions based on persistence. Specifically, the temperature observed at 0300 GMT was used as a forecast for the 6 and 9 h projections from 0000 GMT. We also estimated temperatures 6–27 h after 0000 GMT using temperatures observed 24 h earlier at each of these times. In addition, the early guidance forecasts for projections beyond 27 h were verified, but these forecasts were not compared with persistence. Other types of forecasts, such as those produced manually or based on climatology, were not available.

The scores in Fig. 9 show that the early guidance was substantially better than either short-range or 24 h persistence. Also, both the trends and absolute magnitude of the guidance MAE's were quite similar to the standard errors of estimate for the warm season developmental sample which were presented in Fig. 6a.

5. Conclusions and future plans

Implementation this past summer of a new system to predict max/min and 3-hourly temperatures—based on LFM model output, observed weather elements and various climatic factors—has enhanced the objective temperature guidance used daily by the National Weather Service in its public weather forecasts. In fact, recent verification indicates a long-term pattern has been reversed in that the early (LFM-based) max/min temperature guidance is now more accurate than the final (PE-based) guidance. This is encouraging because the early guidance is rapidly becoming the primary source of detailed surface temperature guidance to field forecasters prior to issuance of the local forecast.

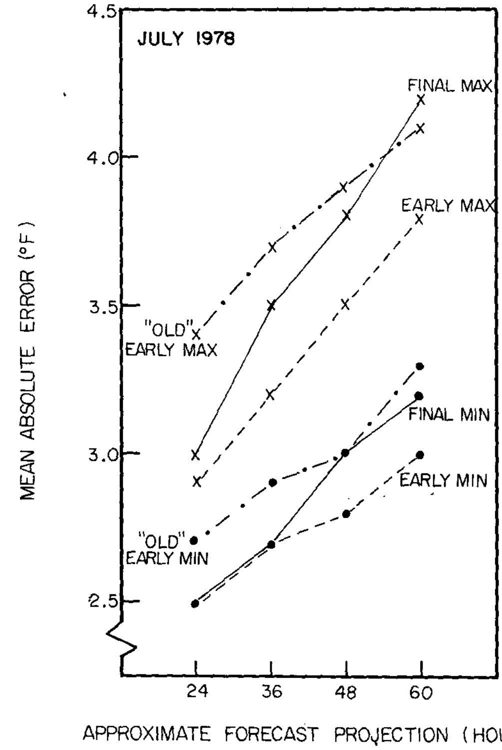

FIG. 8. Max and min temperature mean absolute errors for 24 to 60 h forecasts valid during July 1978. The operational final guidance forecasts are indicated by a solid line; the operational early guidance forecasts are indicated by a dashed line; and forecasts from the former early guidance system are indicated by a dash-dot line. Each value is an average of the forecasts for 224 stations.

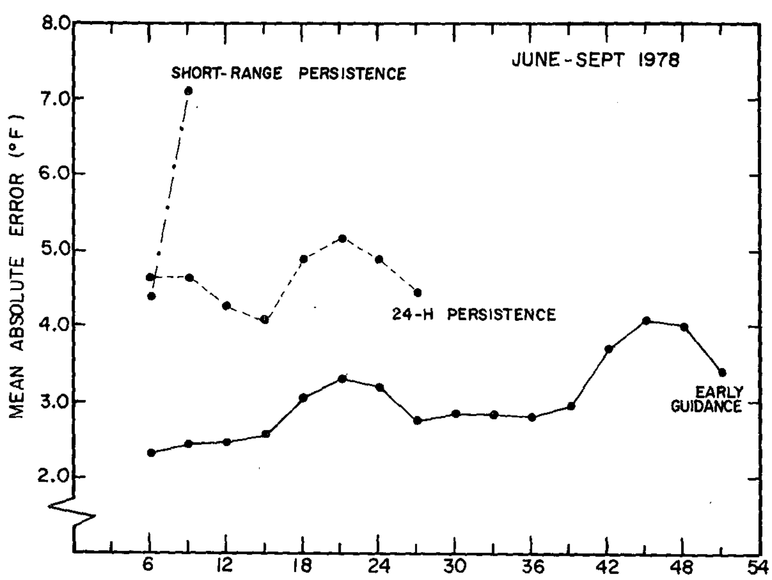

FIG. 9. Three-hourly temperature mean absolute errors for 6 to 51 h forecasts valid during the period June–September of 1978. The early guidance forecasts are indicated by a solid line; the short-range (3 to 6 h) persistence forecasts are indicated by a dash-dot line; and the 24 h persistence forecasts are indicated by a dashed line. Each value is an average of the forecasts for approximately 230 stations.

Verifications also show that the automated 3-hourly temperature guidance is more accurate than either short-range or 24 h persistence. These forecasts should be quite helpful in predicting diurnal temperature patterns that affect rates of evapotranspiration during the growing season, the potential for flooding from snow melt, and energy requirements for heating and cooling. Also, a reliable forecast of the diurnal curve can lead to more accurate computer worded objective guidance (Glahn, 1978) of the type shown in Fig. 5.

In a couple of years, when there are more LFM data in our developmental archive, we will rederive all the early guidance prediction equations using 3-month seasons and a more sophisticated form of the snow-cover predictor. We also plan to develop a technique to obtain max/min forecasts valid for 12 h periods from the 3-hourly predictions. This procedure should assure greater internal consistency among the temperature forecasts and should produce more useful guidance for Weather Service forecasters, who normally issue max/min forecasts for 12 h, rather than 24 h, periods. In addition, we hope to have the capability to update our objective temperature guidance on a real-time basis using the latest data available from surface and upper air reports.

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*Available from the National Weather Service Headquarters, Silver Spring, MD.