Automated Temperature Guidance Based on Three-Month Seasons

Gordon A. Hammons and J. Paul Dallavalle

Techniques Development Laboratory, Systems Development Office, National Weather Service, NOAA, Silver Spring, Md. 20910

William H. Klein

Systems Development Office, National Weather Service, NOAA, Silver Spring, Md. 20910

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ABSTRACT

For the last few years the National Weather Service has been producing centralized guidance forecasts of calendar day maximum and minimum temperatures by applying multiple regression equations derived statistically from numerical model output. At first the equations were developed from a six-month stratification of the numerical forecasts, but later we were able to stratify the dependent data into three-month seasons. At the same time we added a number of new potential predictors. These two changes increased the skill of the automated guidance. Here we discuss the dependent data statistics for the three-month season equations and compare their forecasts with those made by the older six-month equations. Finally, we present verification statistics on the objective guidance for the fall and winter seasons from August 1973 to February 1976.

1. Introduction

Since August 1973 the National Weather Service (NWS) has been preparing automated guidance forecasts of calendar day maximum and minimum temperatures (max/min) from equations derived by applying the Model Output Statistics (MOS) technique (Glahn and Lowry, 1972; Klein and Glahn, 1974). The MOS linear multiple regression equations replaced most of the "perfect prog" equations which the NWS had used operationally since 1965 (Klein and Lewis, 1970). Implementation of the MOS system resulted in more accurate temperature forecast guidance, particularly at the shorter range projections, as well as an increase in the number of stations for which forecasts are produced.

Verification of the automated guidance for 126 stations scattered across the United States is summarized in Fig. 1 for 12-month periods from 1968 to 1975. Mean absolute errors were combined for the maximum (max) and minimum (min) forecasts at 24 and 48 h. Improvement of the automated guidance is evident in the downward trend of both curves from the beginning to the end of the period. In fact, by 1975 the 48 h forecasts were as accurate as the 24 h forecasts had been in 1972.

In 1975 we made two significant changes in the development of the MOS temperature forecast equations. First, we screened an expanded list of predictors that might contribute to surface temperature. Second, we derived separate sets of equations for each of the four seasons of the year, in contrast to the previous MOS temperature equations that were based on a six-month stratification of the data. This paper describes the latest screening results and compares the performance of the six-month and three-month equations.

2. Equations based on six-month seasons

Klein and Hammons (1975) described the application of the MOS technique in deriving max/min temperature equations for a six-month season. Separate equations were developed for each of 228 stations in the conterminous United States, four forecast projections (approximately 24, 36, 48 and 60 h after the initial model time), and both 0000 GMT and 1200 GMT cycles. Only data interpolated to a point over a station were used as potential predictors in that station's equations. The predictand was the station's calendar day maximum or minimum, depending on the particular projection.

For each projection an unique set of predictors was offered to the regression program in the derivation of the equations. In the six-month equations, we used 15 forecast fields from the trajectory model (Reap, 1972) and 31 forecast fields from the primitive equation (PE) model (Shuman and Hovermale, 1968). Not all of these fields were of different types; we often tried model output predictors that were valid at one or two times near the max (or min) valid time. Moreover, some predictors were filtered by a 5-point or 9-point

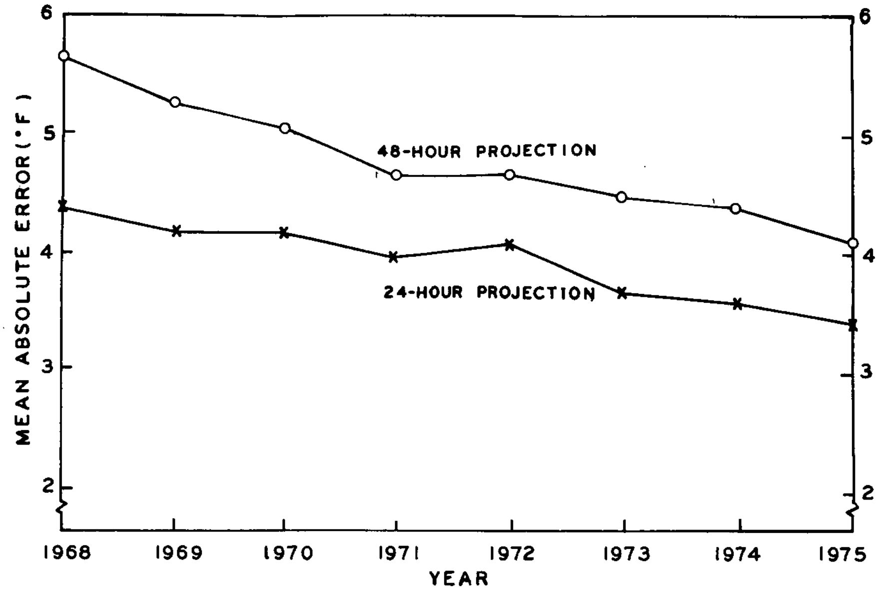

FIG. 1. Verification of automated forecasts of maximum and minimum surface temperatures produced as nationwide guidance on an operational basis in the National Meteorological Center. Errors are averaged for max and min combined at 126 cities in the conterminous United States over 12 months of each year from 1968 through 1975.

space smoother, according to the particular parameter, level and projection. As potential predictors we also included the sine and cosine of the day of the year to aid in capturing seasonal trends (Glahn and Lowry, 1972). Finally, station observations of surface conditions reported 6 h after the initial cycle time (including the max/min for the previous day) were offered as predictors in the first projection (today's maximum from 0000 GMT or tonight's minimum from 1200 GMT).

Using this procedure, we derived equations for both the warm (April–September) and cool (October–March) seasons. From August 1973 to August 1975 NWS based its objective temperature guidance on these six-month equations. On the basis of mean absolute error, the MOS forecasts were equal or superior to the perfect prog forecasts (run as a control) for all projections, types and seasons, except for the 60 h min during the cool season. The overall improvement with the MOS forecasts was 0.2–0.5°F at the 126 stations common to both systems.

Although the MOS verifications showed improvement over the perfect prog, the forecasts at some stations tended to deteriorate near the beginning and end of the six-month season. After some investigation, we concluded that the terms with sine and cosine of the day of the year could cause the forecasts at certain locations to vary by 20–30°F over the six-month season under similar atmospheric conditions.

3. Development of three-month season equations

Because of the above problems, we divided the year into four three-month seasons; namely, spring (March to May), summer (June to August), fall (September to November) and winter (December to February). By 1975 we had archived sufficient data for a stable dependent sample. For the fall and winter equations we had six years of data (1969–75), providing over 410 cases per season. For spring and summer, five years of developmental data were available (1970–74); this generally meant that over 370 cases were used in deriving these seasonal equations. As with the six-month seasons, we developed MOS 10-term equations for both 0000 and 1200 GMT cycles, for each of the 228 max/min stations, and for four projections, valid approximately 24, 36, 48 and 60 h after the initial cycle time. The predictand in the development was the calendar day maximum or minimum, depending on the particular projection.

When we changed to three-month seasons, we also increased the number of predictors offered to the screening regression program for any one projection. Table 1 lists the potential predictors used in the 0000 GMT cycle. The list for the 1200 GMT cycle is identical except that 1) the projections are tonight's min, tomorrow's max, tomorrow night's min and day after tomorrow's max; 2) the surface synoptic observations are obtained from the 1800 (instead of the 0600) GMT reports; and 3) the valid times of the predictors are in hours after 1200 (instead of 0000) GMT.

Table 1 incorporates several changes made to our former six-month predictor list. For example, in the first and second projections we increased the number of valid times of the PE temperature and moisture forecasts. Many of the model predictors underwent additional space smoothing at all projections, while in the

TABLE 1. Potential predictors of maximum and minimum surface temperatures for three-month MOS screening regression. Numbers indicate valid time of predictors in hours after 0000 GMT. Stars indicate the predictor was smoothed by 5 points (*), 9 points (**) or 25 points (***).

Predictor	Today's max	Tonight's min	Tomorrow's max	Tomorrow night's min
		a. PE model		
850 mb height	12, 24	24, 36	36, 48	48, 48*
500 mb height	12, 24	24, 36	36, 48	36*, 48, 48*
500–1000 mb thickness	12, 24	24, 36	36, 48	48, 48*
850–1000 mb thickness	12, 24	24, 36	36, 48	48, 48*
500–850 mb thickness	12, 24	24, 36	36, 48	48, 48*
1000 mb temperature	12, 24, 24*, 36*	24*, 36, 36*, 48*	36*, 48, 48*, 48**	48*, 48**, 48***
850 mb temperature	12, 24, 24*, 36*	24*, 36, 36*, 48*	36*, 48, 48*, 48**	48*, 48**, 48***
700 mb temperature	24	24*	24**	
Boundary layer pot temp	12, 24, 24*, 36*	24*, 36*, 48*	36*, 48*, 48**	48*, 48**, 48***
Boundary layer U wind	12, 24*	24*, 36*	36*, 48*	48*, 48**, 48***
Boundary layer V wind	12, 24*	24*, 36*	36*, 48*	48*, 48**, 48***
Boundary layer wind speed	24	36	48	48*, 48**
850 mb U wind	24	24*	24**	24***
850 mb V wind	24	24*	24**	24***
700 mb U wind	24	24*	24**	24***
700 mb V wind	24	24*	24**	24***
1000 mb relative vorticity	24*	36*	48**	48***
850 mb relative vorticity	24*	36*	48*	48**
500 mb relative vorticity	24*	36*	48*	48**, 48***
850 mb vertical velocity	24	24*	24**	—
650 mb vertical velocity	24	24*	24**	—
Stability (700–1000 mb temp)	24	24*	24**	—
Stability (500–850 mb temp)	24	24*	24**	—
400–1000 mb mean rel hum	12*, 24*, 36*	24*, 36*, 48*	36**, 48**	48**, 48***
Precipitable water	18*, 30*	30*, 42*	42*, 42**	42**, 42***
Boundary layer wind divergence	24*	36*	48*	48**, 48***
		b. Trajectory model		
Surface temperature	24, 24*	24*, 24**	24*, 24**	24**, 24***
850 mb temperature	24, 24*	24*, 24**	24*, 24**	24**, 24***
700 mb temperature	24	24*	24**	24**, 24***
Surface dew point	24, 24*	24*, 24**	24*, 24**	24***
850 mb dew point	24*	24*	24**	24***
700 mb dew point	24	24*	24**	24***
700 mb—surface mean rel hum	24	24*	24**	24***
850 mb 12 h net vert displ	24	24*	24**	24***
850 mb 24 h net vert displ	24	24*	24**	24***
700 mb 12 h net vert displ	24	24*	24**	24***
700 mb 24 h net vert displ	24	24*	24**	24***
Surface 12 h horiz conv	24, 24*	24*, 24**	24*, 24**	24***
850 mb 12 h horiz conv	24	24*	24**	24***
George's *K* index	24	24*	24**	24***
		c. Other variables		
Sine day of year	00	00	00	00
Cosine day of year	00	00	00	00
Sine of twice day	00	00	00	00
Cosine of twice day	00	00	00	00
Latest surface temperature	06	06	—	—
Latest surface dew point	06	06	—	—
Latest cloud cover	06	06	—	—
Latest surface U wind	06	06	—	—
Latest surface V wind	06	06	—	—
Latest surface wind speed	06	06	—	—
Latest ceiling	06	06	—	—
Previous maximum	06	—	—	—
Previous minimum	—	06	—	—

TABLE 2. List of changes in potential predictors of maximum and minimum surface temperature for MOS screening regression; changes are relative to the predictor list used in developing equations based on six-month seasons (Table 3, Klein and Glahn, 1974).

Predictors added	Predictors dropped
a. PE model	
500–850 mb thickness	1000 mb height
Boundary layer wind speed	
Boundary layer wind divergence	
1000 mb relative vorticity	
850 mb relative vorticity	
500 mb relative vorticity	
700 mb temperature minus 1000 mb temperature	
500 mb temperature minus 850 mb temperature	
b. Trajectory model	
850 mb dew point	850 mb relative humidity
700 mb dew point	700 mb relative humidity
850 mb 12 h horizontal convergence	
George's K index	
c. Other variables	
Sine twice day of year	None dropped from previous list
Cosine twice day of year	
Latest observed ceiling	

last projection some data were filtered by a 25-point space smoother. We also added surface observations as predictors in the second projection. Though we had earlier found that the effect of surface observations was relatively small in this particular forecast period, we later discovered that their importance depended strongly on the season of the year. Finally, we selected a number of new predictors, such as vorticity, stability and divergence, and dropped some of the older ones that were either unimportant in temperature prediction or redundant. These latter changes are summarized in Table 2. In all, the number of possible predictors was increased by 15–20 per projection over the older six-month equations.

4. Results of screening regression on three-month seasons

Fig. 2 indicates the average standard error of estimate at 0000 GMT for all 228 stations for the four sets of seasonal equations. The smallest standard errors occurred during the summer, while winter had the largest errors. The errors during spring and fall were about the same in magnitude and intermediate between those of summer and winter. These results were expected since the standard errors tend to increase as the variability of the predictand increases from summer to winter.

Because of operational requirements, we developed backup equations for the first two projections that use model output but no surface observations. A plot of the standard errors in the first and second projections, both with and without surface observations (Fig. 2), indicates the importance of these observations as predictors. In the first projection during the winter season, the use of surface data reduced the average standard error by 0.5°F. This decrease was greater than any that we had previously obtained. For the second projection in winter, the inclusion of surface reports improved the standard error by 0.2°F. This change is about the same as that shown for the other three seasons during the first period. Use of surface observations in the second projection during spring, summer and fall reduced the standard error by only small amounts.

The shapes of the curves indicate a general decrease in skill with increasing projection, as one would expect; however, the standard errors for the 60 h min were actually less than those for the 48 h max in the spring and summer seasons. This reflects the difficulty of forecasting the max during the warm part of the year. In the warmer months, because of the presence of small-scale convective clouds, the max is usually more variable than the min. In contrast, during the winter months the minimum seems harder to forecast because local effects, such as drainage winds and low-level cloudiness, tend to dominate nighttime cooling, while the daytime max is more subject to large-scale synoptic conditions.

Table 3 presents the relative importance of the predictors in the 10-term equations for spring (0000 GMT cycle). This tabulation is based on both the frequency and order of selection. If a predictor was picked as the

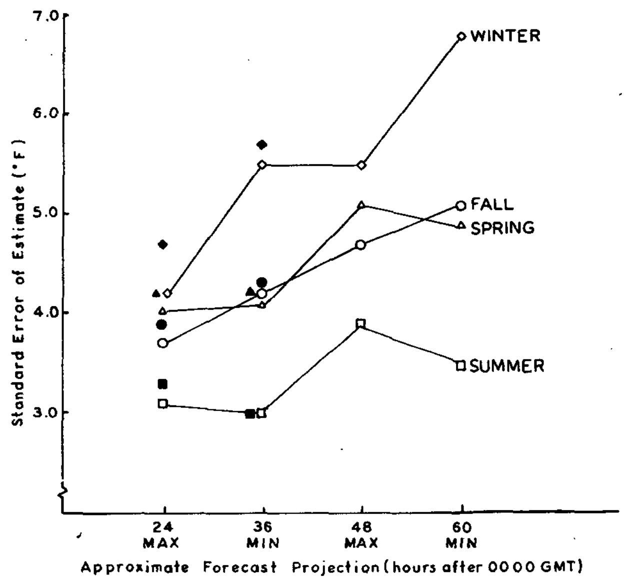

FIG. 2. Standard errors of estimate averaged at 228 stations in the conterminous United States for the three-month MOS equations from the 0000 GMT cycle for spring, summer, fall and winter. The 24 and 36 h backup equations do not use observations, but only model output as predictors. The standard errors for these equations are shown by the appropriate, solid geometrical figure.

TABLE 3. Importance of primitive equation (PE) and trajectory model (TM) predictors on basis of frequency and order of selection in 10-term equations for maximum and minimum spring (March–May) temperatures at 228 stations (0000 GMT data). Surface synoptic (SS) reports at 0600 GMT were included as predictors for today's maximum and tonight's minimum.

Rank	Today's maximum	Tonight's minimum	Tomorrow's maximum	Tomorrow night's minimum
1.	SS previous max	PE 850 mb temperature	PE boundary layer pot temp	PE 850 mb temperature
2.	PE boundary layer pot temp	Cosine day of year	PE 850 mb temp	Cosine day of year
3.	PE 1000 mb temperature	PE precipitable water	Sine twice day of year	PE boundary layer *V* wind
4.	TM surface temperature	PE 1000 mb temperature	PE boundary layer *U* wind	PE 1000 mb relative vorticity
5.	PE mean relative humidity	PE boundary layer pot temp	PE mean relative humidity	PE boundary layer pot temp
6.	Sine twice day of year	SS latest temperature	Cosine day of year	PE 500–1000 mb thickness
7.	SS latest temperature	PE 500–1000 mb thickness	PE 500 mb height	PE 1000 mb temperature
8.	PE 850–1000 mb thickness	PE mean relative humidity	PE 1000 mb temperature	Sine twice day of year
9.	PE 850 mb temperature	SS previous min	TM surface temperature	PE mean relative humidity
10.	PE 500 mb height	TM surface dew point	PE boundary layer *V* wind	TM 850 mb convergence

first term in an equation, it was assigned a value of ten points. If it was the second predictor in that equation, it was given nine points, and so on. Summing these points for the predictors in all the equations for one projection illustrates the most important types of predictors chosen in the MOS equations. The relative order varied, of course, from season to season, but the majority of the predictors shown in Table 3 were important in all seasons.

Generally, for both max and min forecasts, the model forecasts of low-level temperatures, boundary layer winds and mean relative humidity, as well as the sine and cosine terms, were frequently selected predictors. For today's max, the previous day's max, the latest (0600 GMT) surface temperature, and some measure of the station cloudiness (either ceiling or cloud cover at 0600 GMT) were usually important predictors in all seasons. For tonight's min, surface observations were somewhat less important than in the first projection, although the latest observed temperature and the previous min were often picked in the spring and fall for the 36 h forecast. Table 3 indicates that of the new predictors added to the three-month screenings, the sine twice day of the year, surface observations for the second projection and the PE 1000 mb geostrophic relative vorticity were important factors in the spring equations.

For each season and projection, we summarized the three predictors that occurred most frequently in the leading three terms of the 0000 GMT equations (Table 4). In the forecast equations, the first three terms normally account for most of the reduction in variance of the temperature. For the 24 h max, the previous max and the PE boundary layer potential temperature were extremely important in all four seasons. Similarly, the PE 850 mb temperature was a very important predictor in nearly all seasons for the 36 h minimum, the 48 h maximum and the 60 h minimum.

TABLE 4. List of predictors that are used most often in the first three terms of the 0000 GMT equations for the three-month seasons. The frequency is computed by summing over all 228 stations. The first three terms of the equations explain most of the forecast variance. (PE, primitive equation model output; TM, trajectory model output; SS, surface synoptic reports.)

Spring	Summer	Fall	Winter
24 h maximum	24 h maximum	24 h maximum	24 h maximum
SS obs max temp	SS obs max temp	SS obs max temp	SS obs max temp
PE boundary layer pot temp	PE 850 mb temp	PE boundary layer pot temp	PE 850–1000 mb thickness
PE 1000 mb temp	PE boundary layer pot temp	Cos day of year	PE boundary layer pot temp
36 h minimum	36 h minimum	36 h minimum	36 h minimum
Cos day of year	PE precip water	PE precip water	PE 850 mb temp
PE 850 mb temp	PE 850 mb temp	PE 850 mb temp	SS latest obs temp
PE precip water	SS latest obs temp	Cos day of year	PE boundary layer pot temp
48 h maximum	48 h maximum	48 h maximum	48 h maximum
Sin twice day of year	PE 850 mb temp	Cos day of year	PE 850 mb temp
PE boundary layer pot temp	PE boundary layer *U* wind	PE boundary layer pot temp	PE boundary layer pot temp
Cos day of year	PE boundary layer pot temp	PE 850 mb temp	TM surface temp
60 h minimum	60 h minimum	60 h minimum	60 h minimum
PE 850 mb temp	PE 500–1000 mb thickness	Cos day of year	PE 850 mb temp
Cos day of year	PE 500–850 mb thickness	PE 850 mb temp	PE 1000 mb rel vort
PE boundary layer pot temp	PE boundary layer *V* wind	PE precip water	PE boundary layer pot temp

In addition, the PE precipitable water was frequently selected for forecasting the min, but not the max. The table reaffirms the importance of the latest surface temperature (0600 GMT) in the second projection during both winter and summer. This shows the 36 h minimum forecast tends toward persistence in those seasons. That tendency was not as strong in the transitional (spring or fall) seasons. The sine and cosine terms were most important in spring and fall when they could account for the more pronounced seasonal temperature trend. Of the new predictors used in the three-month season development, the sine twice day of the year, the latest observed surface temperature (second projection), the PE 500–850 mb thickness and the PE 1000 mb geostrophic relative vorticity were important in the first three terms of the equations.

5. Tests of three-month equations on independent data

Before we implemented our new three-month equations, we tested them on independent data for two weeks in July 1975 to have a comparison with the then-operational six-month warm season equations. Table 5 gives the verification results for 126 stations for both sets of equations. The forecasts based on the three-month sample were better than the operational forecasts by about 0.2°F in mean absolute error. We began using the three-month equations to produce the operational temperature forecasts on 30 July 1975.

A second comparison between the two MOS systems was made from 27 October to 26 November, 1975. The fall (September–November) three-month equations were fully operational during this period. Forecasts based on the older six-month cool season equations were made from the same PE and trajectory models and the same surface data used as input to the operational predictions. We verified forecasts for the same 126 stations used in the July test; these stations are common to the MOS and perfect prog systems. The perfect prog forecasts (Klein and Lewis, 1970) serve as a control since the perfect prog system has been competitive with other temperature forecast methods for several years. Results are presented in Table 6. Clearly, during this test the three-month MOS equations were superior to the older six-month equations and to the perfect prog equations for both the max and the min and for all projections. In contrast, the six-month equation forecasts were actually inferior to the perfect prog forecasts for the 48 and 60 h projections. This failure of the six-month MOS equations to improve over the perfect prog equations at longer projections was noticed during the past two cool seasons, especially for the 60 h forecast of the minimum. Although the three-month equations were superior to the perfect prog, the improvement decreased with increasing projection.

A third test was made during the winter season from 4 January through 3 February, 1976. The results are shown in Table 7. As before, the three-month MOS equations improved the six-month equations by 0.3°F mean absolute error, averaged over all projections for both the max and the min. This improvement was most dramatic for the min forecasts. In comparison to perfect prog, the three-month season forecasts had smaller mean absolute errors for both the max and the min during the initial three projections. For the 60 h projection, however, the three-month MOS forecasts of the max were 0.1°F worse than the perfect prog.

During this last test, the overall deterioration of the six-month MOS equations in comparison to perfect prog disturbed us. We investigated this problem and found that during January of 1974 and 1975, the six-month equations performed poorly relative to the perfect prog, particularly in forecasting the min and at projections greater than 24 h. Overall, the three-month

TABLE 5. Verification of objective maximum/minimum temperature forecasts, averaged at 126 cities for the period 16–29 July 1975, made twice a day from operational prognostic data by test (three-month equations) and operational (six-month equations) MOS systems. (Approximately 1340 forecasts from 0000 GMT and 730 from 1200 GMT.)

		Mean absolute error (°F)		Correlation of forecast with observed temperatures	
Projection	Type	Operational	Test	Operational	Test
24 h	Min	2.5	2.5	0.53	0.57
36 h	Min	2.9	2.6	0.52	0.55
48 h	Min	2.8	2.7	0.51	0.55
60 h	Min	3.2	3.0	0.46	0.47
24 h	Max	2.8	2.5	0.67	0.66
36 h	Max	3.2	3.0	0.63	0.65
48 h	Max	3.1	3.0	0.60	0.60
60 h	Max	4.0	3.9	0.39	0.35

TABLE 6. Verification of objective maximum/minimum temperature forecasts averaged at 126 cities for the period 27 October–26 November, 1975, made twice a day from operational prognostic data by perfect prog (PP), and MOS systems. MOS (6) denotes MOS forecasts based on six-month equations, and MOS (3) denotes MOS forecasts based on three-month equations.

		Mean absolute error (°F)			Correlation of forecast with observed temperatures		
Projection	Type	PP	MOS (6)	MOS (3)	PP	MOS (6)	MOS (3)
24 h	Min	4.5	4.4	3.8	0.83	0.86	0.87
36 h	Min	5.0	5.0	4.4	0.79	0.83	0.84
48 h	Min	5.1	5.2	4.8	0.78	0.81	0.82
60 h	Min	5.6	5.7	5.3	0.76	0.78	0.79
24 h	Max	3.8	3.4	3.3	0.90	0.86	0.93
36 h	Max	4.1	4.1	3.7	0.89	0.83	0.91
48 h	Max	4.5	4.7	4.3	0.87	0.81	0.90
60 h	Max	4.9	5.3	4.7	0.85	0.78	0.87

TABLE 7. Verification of objective maximum/minimum temperature forecasts averaged at 126 cities for the period 4 January–3 February, 1976, made twice a day from operational prognostic data by perfect prog (PP) and MOS systems. MOS (6) denotes MOS forecasts based on six-month equations, and MOS (3) denotes MOS forecasts based on three-month equations.

		Mean absolute error (°F)			Correlation of forecast with observed temperatures		
Projection	Type	PP	MOS (6)	MOS (3)	PP	MOS (6)	MOS (3)
24 h	Min	5.0	5.2	4.7	0.72	0.73	0.75
36 h	Min	5.3	5.1	4.8	0.71	0.75	0.77
48 h	Min	5.5	5.6	5.3	0.69	0.72	0.71
60 h	Min	6.0	6.4	5.9	0.63	0.59	0.64
24 h	Max	4.2	3.9	3.8	0.83	0.86	0.86
36 h	Max	4.8	4.9	4.5	0.79	0.81	0.82
48 h	Max	5.1	5.1	4.8	0.76	0.79	0.81
60 h	Max	5.6	6.0	5.7	0.72	0.71	0.73

MOS equations are a definite improvement over both the six-month MOS equations and the perfect prog equations.

6. Verifications of operational forecasts

The MOS max/min temperature equations based on three-month seasons have been used for objective guidance by the National Weather Service since July 1975. To compare further the performance of our current forecast system with that of past years, we verified MOS guidance forecasts made over several years in late summer and fall and in the winter season. Again, the perfect prog forecasts served as a control. In 1973 and 1974, warm season (six-month) equations were used during August and September, while cool season (six-month) equations were operational during the October through February (1973–74, 1974–75) period. The new three-month equations were used last August (1975), September–November (1975), and December 1975 through February 1976.

The verification statistics for late summer and fall (August–November) are given in Table 8 for the years 1973 to 1975. During all three years, the mean absolute errors at any one projection in the perfect prog forecast of the min varied by no more than 0.3°F. The MOS and perfect prog forecasts were about equally skillful in 1974; however, MOS was better in both 1973 and 1975. The improvement in 1975, when the new three-month MOS equations were operational, was approximately twice that in 1973.

For the max, the perfect prog errors for a given projection varied by no more than 0.1°F during all three years. The MOS forecasts of the max were consistently better than the perfect prog forecasts for all projections except in 1974, when the errors were equal for the 60 h max.

The summary for three winter seasons is given in Table 9. Again the perfect prog mean absolute errors for the min varied no more than 0.3°F for any one projection during the three seasons. In the first season, the perfect prog minimum forecast had smaller mean absolute errors than the MOS prognosis at all projections except 24 h. Even in the second season, the perfect prog was 0.2°F better than MOS for the 60 h min. This trend was reversed during the latest winter season when the new MOS three-month equations averaged almost 0.4°F better than perfect prog at all projections of the min. For the max temperature forecast, the MOS system was consistently better than perfect prog at all projections during each of the three seasons.

In terms of the correlation coefficient between observed and forecast temperature, the new three-month MOS forecasts (Tables 8c and 9c) were better for all projections (both max and min) than either perfect prog or the older MOS equations in any previous year.

TABLE 8. Verification of objective maximum/minimum temperature forecasts, averaged at 126 stations for the period 1 August–30 November, made twice a day from operational prognostic data by MOS and perfect prog (PP) systems.

		Mean absolute error (°F)		Correlation of forecast with observed temperature	
Projection	Type	MOS	PP	MOS	PP
a. August 1973–November 1973					
24 h	Min	3.5	3.8	0.76	0.71
36 h	Min	3.9	4.2	0.72	0.64
48 h	Min	4.1	4.4	0.69	0.64
60 h	Min	4.5	4.7	0.62	0.57
24 h	Max	3.0	3.6	0.83	0.77
36 h	Max	3.7	4.0	0.78	0.74
48 h	Max	3.9	4.3	0.75	0.70
60 h	Max	4.3	4.5	0.70	0.68
b. August 1974–November 1974					
24 h	Min	3.7	3.7	0.71	0.68
36 h	Min	3.9	4.0	0.70	0.62
48 h	Min	4.3	4.2	0.66	0.60
60 h	Min	4.6	4.4	0.59	0.57
24 h	Max	3.2	3.7	0.80	0.76
36 h	Max	3.8	4.0	0.73	0.71
48 h	Max	4.0	4.3	0.72	0.68
60 h	Max	4.5	4.5	0.65	0.65
c. August 1975–November 1975					
24 h	Min	3.2	3.8	0.79	0.73
36 h	Min	3.5	4.2	0.77	0.69
48 h	Min	3.8	4.4	0.72	0.66
60 h	Min	4.2	4.6	0.67	0.63
24 h	Max	3.1	3.6	0.85	0.81
36 h	Max	3.7	4.1	0.80	0.76
48 h	Max	4.1	4.3	0.77	0.73
60 h	Max	4.5	4.6	0.71	0.68

TABLE 9. Verification of objective maximum/minimum temperature forecasts, averaged at 126 stations for the period 1 December–28 February, made twice a day from operational prognostic data by MOS and perfect prog (PP) systems.

		Mean absolute error (°F)		Correlation of forecast with observed temperature	
Projection	Type	MOS	PP	MOS	PP
a. December 1973–February 1974					
24 h	Min	4.6	4.8	0.79	0.78
36 h	Min	5.5	5.3	0.77	0.73
48 h	Min	5.6	5.3	0.73	0.74
60 h	Min	6.2	5.9	0.68	0.71
24 h	Max	3.9	4.7	0.86	0.80
36 h	Max	4.6	5.0	0.81	0.79
48 h	Max	5.3	5.7	0.79	0.78
60 h	Max	5.6	5.9	0.74	0.72
b. December 1974–February 1975					
24 h	Min	4.2	4.6	0.79	0.75
36 h	Min	4.8	5.0	0.77	0.71
48 h	Min	5.1	5.2	0.73	0.69
60 h	Min	5.8	5.6	0.67	0.66
24 h	Max	3.6	4.3	0.84	0.80
36 h	Max	4.4	4.8	0.80	0.77
48 h	Max	4.5	5.0	0.78	0.74
60 h	Max	5.2	5.6	0.71	0.68
c. December 1975–February 1976					
24 h	Min	4.4	4.8	0.81	0.79
36 h	Min	4.8	5.3	0.80	0.75
48 h	Min	5.2	5.5	0.75	0.73
60 h	Min	5.7	5.9	0.71	0.69
24 h	Max	3.8	4.5	0.88	0.85
36 h	Max	4.5	5.1	0.84	0.80
48 h	Max	5.0	5.4	0.81	0.77
60 h	Max	5.6	6.0	0.75	0.72

7. Additional research

In recent months the National Weather Service has been emphasizing the limited-area fine-mesh (LFM) model (Howcroft, 1971) which is now being run out to 48 h for operational forecasts. Accordingly, we have been testing the use of LFM prognostic fields and LFM-based trajectory forecasts as input to our operational three-month max/min equations (which were derived from PE output).

Testing on a limited sample during the spring of 1976 indicates some differences in the accuracy of the two sets of forecasts. When station observations were included as predictors, the LFM max/min temperature forecasts were only 0.1°F worse in mean absolute error than the PE forecasts. This figure was a composite of all projections for both max and min at 126 cities. During another period, we excluded station observations; that is, the backup equations only were used. In this test the PE forecasts were better than the LFM by about 0.3°F mean absolute error for all projections and max and min combined. On a geographical basis, the largest forecast degradation occurred in the southwestern United States, while the smallest changes were in the northeast. Despite this deterioration, we have decided to run our "early" max/min temperature guidance off the LFM model output, beginning in the late summer of 1976. This should make the objective forecasts available to field forecasters at least an hour earlier than at present.

The above procedure has been necessitated by lack of sufficient LFM data to derive new equations. We plan to develop such equations in phases over the next two years. We also intend to do additional research in the area of extended range forecasts since about four years of PE forecasts for 60 to 84 h projections have now been archived. From these data we hope to derive MOS equations for making 72 to 96 h max/min forecasts at 0000 GMT. The data will also be used to improve the 60 h temperature forecasts.

8. Conclusion

Implementation of the new three-month MOS equations that forecast maximum and minimum temperatures has improved the objective temperature guidance used by the National Weather Service in its public weather forecasts. Since we simultaneously increased the number of potential predictors and changed the seasonal stratification, we are unsure of the contribution of either factor. Because several of the new predictors were frequently selected, we suspect that both changes played a role.

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