NOAA TM NWS TDL-45

UNITED STATES DEPARTMENT OF COMMERCE PUBLICATION

NOAA Technical Memorandum NWS TDL-45

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

The Use of Model Output Statistics (MOS) To Estimate Daily Maximum Temperatures

LT. (jg) JOHN R. ANNETT, NOAA,
HARRY R. GLAHN, AND
DALE A. LOWRY

Systems Development Office

SILVER SPRING, MD.

March 1972

NOAA TECHNICAL MEMORANDA

National Weather Service, Techniques Development Laboratory Series

The primary purpose of the Techniques Development Laboratory of the Office of Systems Development is to translate increases of basic knowledge in meteorology and allied disciplines into improved operating techniques and procedures. To achieve this goal, the Laboratory conducts and sponsors applied research and development aimed at the improvement of diagnostic and prognostic methods for producing weather information. The Laboratory performs studies both for the general improvement of prediction methodology used in the National Meteorological Service System and for the more effective utilization of weather forecasts by the ultimate user.

NOAA Technical Memoranda in the National Weather Service Techniques Development Laboratory series facilitate rapid distribution of material which may be preliminary in nature and which may be published formally elsewhere at a later date. Publications 1 to 5 are in the former series, Weather Bureau Technical Notes (TD), Techniques Development Laboratory (TDL) Reports; publications 6 to 36 are in the former series, ESSA Technical Memoranda, Weather Bureau Technical Memoranda (WBTM). Beginning with TDL 37, publications are now part of the series NOAA Technical Memoranda, National Weather Service (NWS).

Publications listed below are available from the National Technical Information Service, U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, Va. 22151. Price: $3.00 paper copy; $0.95 microfiche. Order by accession number shown in parentheses at end of each entry.

ESSA Technical Memoranda

WBTM TDL 12 Charts Giving Station Precipitation in the Plateau States from 700-Mb. Lows During Winter. D. L. Jorgensen, A. F. Korte, and J. A. Bunce, Jr., October 1967. (PB-176 742)

WBTM TDL 13 Interim Report on Sea and Swell Forecasting. N. A. Pore and W. S. Richardson, December 1967. (PB-177 038)

WBTM TDL 14 Meteorological Analysis of 1964-65 ICAO Turbulence Data. DeVer Colson, September 1968. (PB-180 268)

WBTM TDL 15 Prediction of Temperature and Dew Point by Three-Dimensional Trajectories. Ronald M. Reap, September 1968. (PB-180 727)

WBTM TDL 16 Objective Visibility Forecasting Techniques Based on Surface and Tower Observations. Donald M. Gales, October 1968. (PB-180 479)

WBTM TDL 17 Second Interim Report on Sea and Swell Forecasting. N. A. Pore and Lt. W. S. Richardson, USESSA, January 1969. (PB-182 273)

WBTM TDL 18 Conditional Probabilities of Precipitation Amounts in the Conterminous United States. Donald L. Jorgensen, William H. Klein, and Charles F. Roberts, March 1969. (PB-183 144)

WBTM TDL 19 An Operationally Oriented Small-Scale 500-Millibar Height Analysis. Harry R. Glahn and George W. Hollenbaugh, March 1969. (PB-184 111)

WBTM TDL 20 A Comparison of Two Methods of Reducing Truncation Error. Robert J. Bermowitz, May 1969. (PB-184 741)

WBTM TDL 21 Automatic Decoding of Hourly Weather Reports. George W. Hollenbaugh, Harry R. Glahn, and Dale A. Lowry, July 1969. (PB-185 806)

WBTM TDL 22 An Operationally Oriented Objective Analysis Program. Harry R. Glahn, George W. Hollenbaugh, and Dale A. Lowry, July 1969. (PB-186 129)

WBTM TDL 23 An Operational Subsynoptic Advection Model. Harry R. Glahn, Dale A. Lowry, and George W. Hollenbaugh, July 1969. (PB-186 389)

WBTM TDL 24 A Lake Erie Storm Surge Forecasting Technique. William S. Richardson and N. Arthur Pore, August 1969. (PB-185 778)

WBTM TDL 25 Charts Giving Station Precipitation in the Plateau States From 850- and 500-Millibar Lows During Winter. August F. Korte, Donald L. Jorgensen, and William H. Klein, September 1969. (PB-187 476)

WBTM TDL 26 Computer Forecasts of Maximum and Minimum Surface Temperatures. William H. Klein, Frank Lewis, and George P. Casely, October 1969. (PB-189 105)

(Continued inside back cover)

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

NOAA Technical Memorandum NWS TDL-45

The Use of Model Output Statistics (MOS) To Estimate Daily Maximum Temperatures

LT. (jg) John R. Annett, NOAA, Harry R. Glahn, and Dale A. Lowry

Systems Development Office
Techniques Development Laboratory

SILVER SPRING, MD.
March 1972

UDC 551.509.314:551.524.36:519.241

551.5	Meteorology
.509.314	Objective forecasting
.524.36	Maximum temperature
519.241	Statistical methods

CONTENTS

THE USE OF MODEL OUTPUT STATISTICS (MOS) TO ESTIMATE DAILY MAXIMUM TEMPERATURES

LT. (jg) John R. Annett, NOAA, Harry R. Glahn, and Dale A. Lowry
Techniques Development Laboratory

ABSTRACT. A statistical method for objectively producing forecasts of daily maximum temperatures from numerical model output has been developed within the Techniques Development Laboratory (TDL). The screening-regression technique is used to relate maximum temperature observations to variables forecast by two existing numerical models, the TDL Subsynoptic Advection Model (SAM) and the National Meteorological Center (NMC) Primitive Equation (PE) Model. Conclusions are drawn as to the optimum number of predictors to include in the regression equations to minimize the mean absolute error (MAE) of the forecasts. Inclusion of the sine and cosine of the day of the year as variables in the screening procedure is shown to be an effective method for reducing forecast bias and for improving the accuracy of forecasts. Monthly verification figures covering a 2 1/2-year period for 16 stations in the eastern portion of the United States show that the MAE of the forecasts is about 3.0° to 4.0°F. This score indicates that maximum temperature forecasts made by regression equations developed from numerical model output can be useful as guidance to local forecast offices.

INTRODUCTION

A statistical method for objectively producing daily maximum (max) temperature forecasts has been developed. The method is based on a procedure called Model Output Statistics (MOS). In this method, a predictand (in this case, the first day max temperature) is related to variables forecast by numerical models. Two numerical models have been used in this developmental effort--the Subsynoptic Advection Model (SAM), developed by the Techniques Development Laboratory (TDL) (Glahn, Lowry, and Hollenbaugh 1969), and the Primitive Equation (PE) Model, developed by the National Meteorological Center (NMC) (Shuman and Hovermale 1968).

Equations for two 6-month seasons (summer and winter) have been developed for 16 stations included within the SAM grid area (the eastern portion of the United States). Since the development of the first summer-season equations in April 1969, improvements have been made to the equations, increasing the skill of the max temperature forecasts. A study to determine the optimum number of predictors to include in the regression equations led to an increase in the number of predictors from six to 10. The addition of the sine and cosine of the day of the year as predictors to be screened proved to be a significant step in reducing forecast error. Monthly verification scores of mean absolute error (MAE), bias, and number of errors greater than or equal to 10° were computed. These scores were then compared with corresponding scores for the local forecasts made at the National Weather Service (NWS) offices and with scores for centrally-produced NWS objective forecasts disseminated over teletypewriter and facsimile (Klein and Lewis 1970).

DEVELOPMENT OF EQUATIONS

The screening-regression procedure (see Glahn and Lowry 1969, pp. 3-5) was used to develop the max temperature equations. An equation was developed for each station from data gathered only at that station. The data sample was divided into winter (October to March) and summer (April to September) seasons, and a distinct set of equations was developed for each subsample.

The predictand was the daily (24-hr) observed max temperature. The predictors included forecasts made from the SAM and PE model valid between 1200 and 2400 Greenwich Mean Time (GMT) and "initial" weather observations made at 0700 GMT. The predictand lead time was such that a forecast of max temperature for "today" could be made at about 0900 GMT (0400 Eastern Standard Time--EST).

Initial (0700 GMT) data included dew point, weather, cloud cover, temperature, and surface wind components. The initial saturation deficit (the moisture parameter in SAM) was also considered. Variables from the PE model output included the following at 6-hour intervals: mean relative humidity in the column from the surface to approximately 400 mb, temperature at 1000 mb, precipitation amounts, and 500-mb heights. Forecast variables from SAM were the 3-hourly saturation deficits (see Glahn, Lowry, and Hollenbaugh 1969, pp. 8 and 16), sea-level pressure, and 1000-mb geostrophic wind components. Both continuous and binary forms of predictors were included in the screening-regression procedure.

The screening technique chooses a number of significant variables to be included in each regression equation. In order, those selected most often were: the PE 1000-mb temperature, the observed surface temperature, the observed cloud cover, the PE 500-mb height, the SAM 3-hourly saturation deficit, the observed surface-wind components, and the SAM 1000-mb geostrophic wind components. Because the equation for each station is unique, the order of these predictors and their respective contributions to the total reduction of variance differ for each station.

The MOS max temperature equations were derived every 6 months beginning in April 1969 for the forthcoming summer or winter season. Each new set of summer equations was developed on a dependent data sample which included the available data from all the previous summers combined. The same procedure was followed for the winter-season equations.

Equations developed for use during the summer of 1969 were developed on a dependent data sample consisting of 203 days. This sample consisted of the 6-month periods from April through September of 1967 and 1968. Equations used during the following summer (1970) were developed on a data sample of 340 days which consisted of 137 additional days from April through September of 1969. A total of 85 predictors were screened for the summer-season equations. For the summer-season equations used during 1969, screening continued until a total of six predictors had been chosen for each station; for the equations used during 1970, screening was allowed to continue until 10 predictors had been chosen for each station.

For the winter equations in use during the 1969-70 season, a dependent data sample of 308 days was used. It consisted of 6-month periods from October through March of 1967-68 and 1968-69. For the following winter, equations used during the 1970-71 season were developed on a data sample of 455 days which included 147 additional days from October 1969 through March 1970. Again, 85 predictors were screened for the two winter seasons, and screening continued until 10 predictors had been chosen for each station. Examples of the summer 1970 and winter 1970-71 equations are given in table 1.

DETERMINATION OF THE OPTIMUM NUMBER OF PREDICTORS

A considerable amount of effort has gone into determining the optimum number of predictors to include in these and similar regression equations. Even though a predictand may be correlated with hundreds of variables, a regression equation containing only a very few of them usually explains nearly as much of the variance as an equation containing many. This is the result of high intercorrelations among the variables. Also, if many predictors are included, the predictand may be estimated extremely well in the dependent data sample, but the equation may be showing not only the real physical relations but also the chance relations in the dependent data that will not be present in other samples. Therefore, the equation with many terms may perform more poorly on independent data than the one with fewer terms.

We have found through verification of max temperature forecasts, based on equations containing two, four, six, eight, and 10 predictors, respectively, that although the ninth and 10th predictors added very little in the way of reduction of variance (0.10 to 0.30 percent), the 10-predictor equation gave significantly better results on independent data than the equations with two, four, or six predictors. The superiority of the 10- over the eight-predictor equation is of lesser importance, although improvement in the forecasts is noted for the MAE and for the bias (see table 2).

Development of equations containing more than 10 predictors would probably not, in the case of max temperature, improve the forecasts to a significant degree. This fact is indicated by the only slight improvement of the 10-predictor equation over the eight-predictor equation and by the slight increase in the number of "busts" (absolute error $\geq 10°$) as shown in table 2. With 10 predictors, we have likely reached the "noise level;" that is, we have reached the point where the small additional reductions of variance are due mainly to chance relationships between the predictors and predictand, and these same relationships do not exist in other data samples.

Table 1.--Equations for estimating maximum temperature at Washington, D.C.

Predictor	Coefficient	Cumulative reduction of variance
SUMMER 1970		
Constant	-30.830	--
1000-mb temperature (°C) at 1800Z	.693	0.822
Saturation deficit (m) at 2400Z	.012	.838
Observed surface temperature (°F) at 0700Z	.228	.856
U-component 1000-mb wind (kt) at 2400Z	.120	.869
Observed cloud cover at 0700Z*	-.611	.876
500-mb height (m) at 1800Z	.013	.880
V-component 1000-mb wind (kt) at 2400Z	-.074	.885
Saturation deficit ≤ 50 (m) at 1800Z (binary)	-1.580	.887
Precipitation amount ≤ 0.30 in. at 1800Z (binary)	-3.126	.888
Observed dew point (°F) at 0700Z	.095	.890
WINTER 1970-71		
Constant	21.620	--
1000-mb temperature (°C) at 1200Z	.310	0.742
Mean relative humidity (%) at 1200Z	-.032	.796
Observed surface temperature (°F) at 0700Z	.570	.839
Observed cloud cover at 0700Z*	-1.093	.855
U-component 1000-mb wind (kt) at 1200Z	.084	.865
Saturation deficit (m) at 1500Z	.014	.873
1000-mb temperature (°C) at 1800Z	.488	.876
V-component 1000-mb wind (kt) at 2400Z	-.044	.880
Observed weather at 0700Z**	2.776	.883
Precipitation amount ≤ 0.10 in. at 2400Z (binary)	1.999	.885

*Observed total cloud cover in coded form: 0 = none or partial obscuration; 1 = scattered; 2 = broken; 3 = overcast; and 4 = obscured.

**Observed weather at 0700Z in coded form: 0 = none of the following; 1 = frozen precipitation; 2 = drizzle or freezing drizzle; and 3 = rain or freezing rain.

Table 2.--Maximum temperature verification statistics for 16 eastern U.S. stations during the summer of 1971. Equations with two, four, six, eight, and 10 predictors were verified.

Months	Predictors 2	4	6	8	10	No. of Cases
			Mean absolute error (°F)			
April	4.79	4.49	4.49	4.45	4.43	303
May	3.92	3.77	3.71	3.59	3.49	320
June	3.63	3.05	2.78	2.70	2.59	395
July	3.30	2.91	2.65	2.59	2.51	369
August	3.23	2.84	2.63	2.60	2.66	303
September	3.71	3.49	3.29	3.15	3.14	371
Average	3.74	3.40	3.22	3.14	3.10	(2,061)
			Bias (°F)			
April	-0.29	-0.45	-0.29	-0.14	0.02	303
May	-1.72	-1.56	-1.33	-1.22	-0.96	320
June	-2.88	-2.14	-1.56	-1.45	-1.20	395
July	-2.19	-1.51	-1.03	-0.95	-0.80	369
August	-2.18	-1.66	-1.40	-1.33	-1.36	303
September	-1.13	-0.70	-0.49	-0.61	-0.61	371
Average	-1.78	-1.36	-1.03	-0.96	-0.83	(2,061)
			Absolute error $\geq$ 10°F (No.)			
April	29	32	32	32	30	303
May	14	18	22	12	18	320
June	10	8	3	4	2	395
July	11	8	6	7	6	369
August	11	6	5	6	7	303
September	17	14	12	9	8	371
Total	92	86	80	70	71	(2,061)

THE SINE AND COSINE AS PREDICTORS

The regression equations were developed on a seasonal basis with 6-month periods of dependent data. When these equations are applied to independent data, there should be little or no overall bias in the forecasts, unless there exists a substantial difference between the dependent and independent data samples. This difference may occur if the dependent data sample upon which the equations were developed consists of seasons which were exceptionally warmer or cooler than the season to which the equations are applied. However, it may be that there is a monthly bias even in the dependent data.

The bias computed for each month during the 1970-71 winter season (shown in fig. 1) revealed that there was a monthly bias; the forecasts were slightly too low at the beginning (Oct.) and the end (Mar.) of the period and too high during the other months (Nov., Dec., Jan., and Feb.). In an attempt to correct this periodic bias, the sine and cosine of the day of the year were included as possible predictors to be screened.

Each of the 16 single-station equations, which were rederived, contained the cosine of the day of the year as one of the 10 predictors chosen by the screening procedure. In addition, four equations also used the sine as a predictor. Figure 1 indicates that by using the sine and cosine terms, the periodic bias was reduced but not entirely removed. This could be because the inclusion of the sine and cosine as only linear terms is not sufficient to remove the periodic bias, or it could be because systematic differences exist between the dependent and independent samples. The fact that the overall (seasonal) bias in the independent data forecasts was large, indicating a difference in relation between max temperature and certain predictors in the two samples (dependent and independent), was probably the result of changes made in the PE model. The reduction in the overall bias when the sine and cosine terms were used (from 1.10° to 0.88°F) occurs because some of the effect of those PE predictors is taken over by the trignometric terms.

Table 3 gives verification scores for the two sets of equations. The MOS equations containing the sine and cosine show a marked improvement as compared to the equations not containing these predictors. The rederived equations show a 20-percent decrease in bias and a 6.7-percent reduction in MAE and in the number of large errors.

The success of the MOS equations containing the sine and cosine for the 1970-71 winter season resulted in development of summer-season (1971) equations with these predictors included. These equations were developed on a data sample of 501 days, including the 6-month periods from April through September of 1967, 1968, 1969, and 1970. Examples of the winter- (1970-71) and summer- (1971) season equations are given in table 4.

COMPARATIVE VERIFICATION

A verification program was initiated in April 1969 to compare the MOS max temperature forecasts with those of certain local forecast offices (see table 5) and the Klein-Lewis "perfect prog" (Klein and Lewis 1970) max temperature forecasts. Comparative verification figures for a 30-month period (Apr. 1969

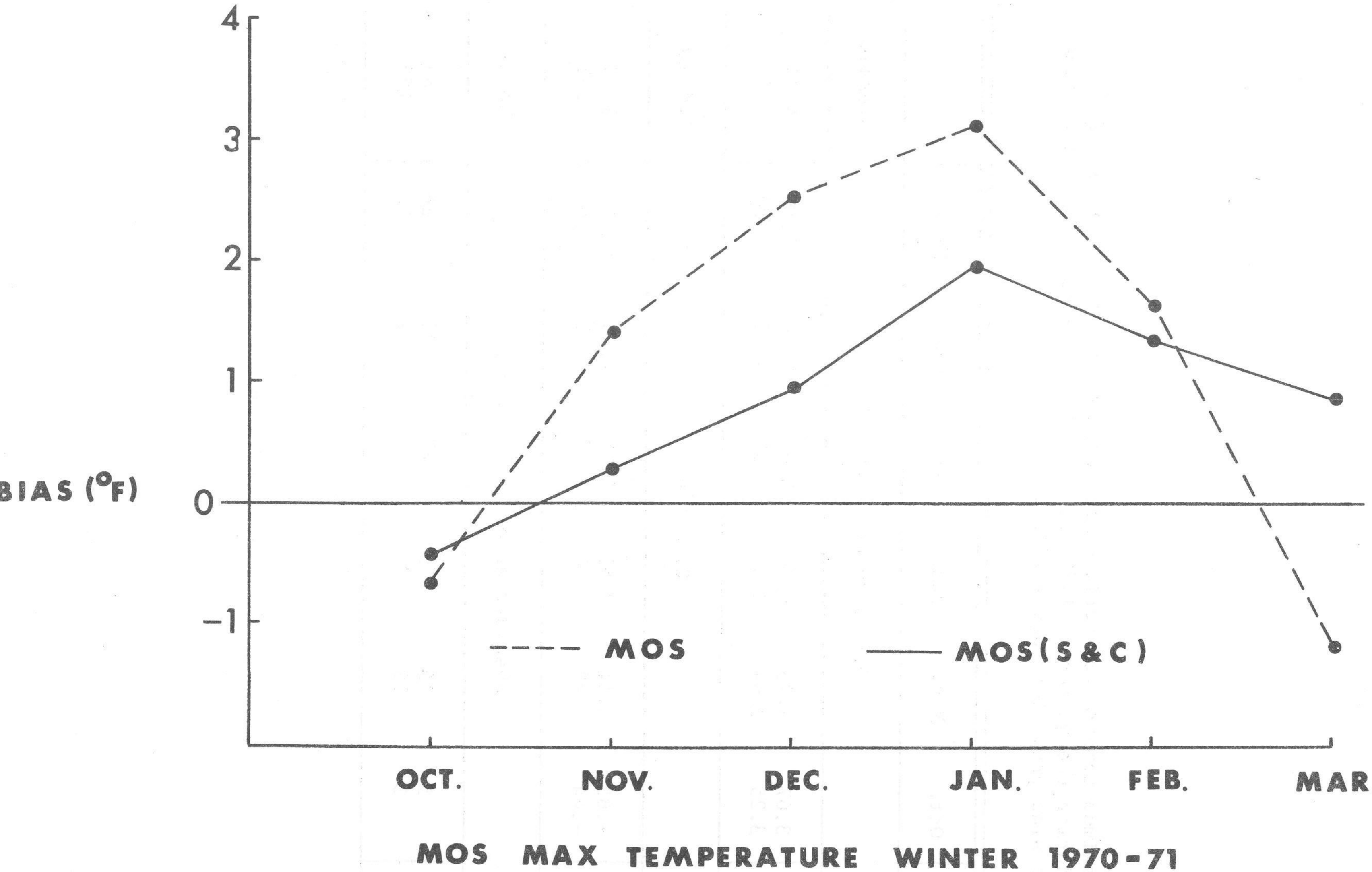

Figure 1.--Graph showing 6-months of forecast biases for 16 eastern U.S. stations during the winter of 1970-71. The dotted line represents MOS equations without sine and cosine predictors, while the solid line represents MOS equations including the sine and cosine as predictors.

Table 3.--Maximum temperature verification statistics for 16 eastern U.S. stations during the winter of 1970-71. The MOS equations with and without sine and cosine predictors are verified.

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	
			Mean absolute error (°F)				Average
MOS	3.67	3.73	4.36	5.03	4.73	4.19	4.36
MOS(S&C)	3.25	3.64	3.86	4.56	4.53	4.00	4.06
			Bias (°F)				Average
MOS	-.65	1.41	2.53	3.12	1.35	-1.18	1.10
MOS(S&C)	-.44	.28	95	1.98	1.63	.85	.88
			Absolute error $\leq$ 10°F (No.)				Total
MOS	5	15	33	47	38	26	164
MOS(S&C)	3	19	20	40	39	32	153

Table 4.--Equations containing sine and cosine predictors for estimating maximum temperature at Washington, D.C.

Predictor	Coefficient	Cumulative reduction of variance
	WINTER 1970-71	
Constant	-22.650	--
1000-mb temperature (°C) at 1200Z	.491	0.742
Cosine of the day of the year	-8.233	.813
Saturation deficit (m) at 1500Z	.016	.846
Observed surface temperature (°F) at 0700Z	.383	.869
U-component 1000-mb wind (kt) at 1800Z	.107	.887
Precipitation amount ≤ 0.01 in. at 1200Z (binary)	2.665	.893
Observed cloud cover at 0700Z*	-.858	.897
1000-mb temperature (°C) at 1800Z	.270	.899
V-component 1000-mb wind (kt) at 2400Z	-.069	.903
500-mb height (m) at 1800Z	.010	.906
	SUMMER 1971	
Constant	67.240	--
1000-mb temperature (°C) at 1800Z	.367	0.749
500-mb height (m) at 1800Z	.033	.784
Observed surface temperature (°F) at 0700Z	.344	.805
Mean relative humidity (%) at 1800Z	-.035	.832
U-component 1000-mb wind (kt) at 1800Z	.177	.856
V-component 1000-mb wind (kt) at 1200Z	-.092	.866
Sea-level pressure (mb) at 1800Z	-.203	.869
Observed cloud cover at 0700Z*	-.638	.872
Saturation deficit ≤ 50 (m) at 2400Z (binary)	-1.593	.875
Cosine of the day of the year	-1.666	.877

*Observed total cloud cover at 0700Z in coded form: 0 = none or partial obscuration; 1 = scattered; 2 = broken; 3 = overcast; and 4 = obscured.

Table 5.--List of cities for which max temperature forecasts were verified

1) Atlanta, Ga.	10) Greensboro, N.C.
2) Burlington, Vt.	11) Indianapolis, Ind.
3) Buffalo, N.Y.	12) Jackson, Miss.
4) Nashville, Tenn.	13) Jacksonville, Fla.
5) Boston, Mass.	14) New Orleans, La.
6) Columbia, Mo.*	15) Miami, Fla.
7) Cleveland, Ohio	16) Pittsburgh, Pa.
8) Charleston, W.Va.	17) Tampa, Fla.
9) Washington, D.C.	

*Verification for Columbia was discontinued on October 1, 1969, because the station was relocated.

to Sept. 1971) indicate that the max temperature forecasts developed from SAM and PE variables have considerable skill (see table 6). In fact, the monthly MAE's of the local forecasts were for the most part only 0.5° to 1.0°F less than those of the MOS forecasts. Although no objective forecast system has equaled the skill of the local forecast offices, it must be kept in mind that objective forecasts such as the Klein-Lewis max temperature forecasts are used as guidance at the local level and are improved upon by whatever later data the forecasters may have available.

The results of our studies concerning the optimum number of predictors to include in the regression equations indicated that 10-predictor equations should be used instead of six-predictor equations. Therefore, the MOS scores shown in table 6 are for 10-predictor equations after September 1969. The MAE of the MOS forecasts for the period during which the six-predictor equations were verified was about 0.5°F less than the MAE of the Klein-Lewis forecasts and about 0.5°F more than the MAE of the local forecasts. For the following 6-month period (Oct. 1969 to Mar. 1970), the MAE of the MOS forecasts made from 10-predictor equations continued to be less than the MAE of the Klein-Lewis forecasts and was about 1.0°F greater than the MAE of the local forecasts.

In April 1970, the Klein-Lewis (barotropic) max temperature forecasts were replaced by improved Klein-Lewis (PE) max temperature forecasts (Klein, Lewis, and Hammons 1971). Verification scores show that the MAE of the Klein-Lewis (PE) forecasts was less than the MAE of the MOS forecasts for the period April through September 1970. The MOS forecasts continued to have a MAE about 1.0°F greater than that of the local forecasts.

The development of MOS equations containing the sine and cosine as predictors (Oct. 1970) reduced the MAE of MOS forecasts below that of Klein-Lewis forecasts during the winter of 1970-71. The scores for the following summer season (1971) showed that the MAE of the Klein-Lewis forecasts was now about equal to that of the MOS forecasts, which now had a MAE about 0.5°F greater than that of the local forecasts.

APPLICATIONS AND PLANS

The MOS max temperature forecasts for four cities (Atlanta, Ga., St. Louis, Mo., New York City, N.Y., and Washington, D.C.) have been made on a semi-operational basis as part of the computer-produced worded forecasts (Glahn 1970) since early 1970. The max temperature forecasts for Atlanta and Washington are among those included in the 16-station verification program. Forecasts for New York City and St. Louis have not been verified because the regression equations for these stations were developed at a later date.

Regression equations using only PE predictors are now being derived for 20 stations in the conterminous United States. These equations will produce both maximum and minimum temperature forecasts for three forecast periods (today, tonight, and tomorrow).

Table 6.--Monthly max temperature verification scores for 16 eastern U.S. stations, April 1969--Sept. 1971. Scores for the absolute error were not computed before February 1970. K-L means the Klein-Lewis perfect prog system.

	1969									1970												1971								
	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT
MEAN ABSOLUTE ERROR (°F)																														
MOS	3.9	3.2	3.6	3.2	2.8	2.9	3.8	3.9	4.9	4.9	4.5	4.1	3.9	3.9	3.7	4.0	3.5	3.4	3.2	3.6	3.9	4.6	4.5	4.0	4.4	3.5	2.6	2.5	2.7	3.1
K-L	4.4	3.7	3.8	2.7	3.3	3.3	4.1	3.7	5.4	5.1	5.1	5.3	4.2	3.7	2.8	2.9	2.2	2.8	3.9	3.6	4.2	4.7	4.5	4.2	4.5	3.7	2.6	2.4	2.4	3.0
LOCAL	3.5	2.8	2.8	2.4	2.1	2.4	3.5	3.3	3.5	3.5	3.0	3.7	3.8	2.9	2.6	2.5	2.0	2.3	3.5	3.0	3.2	3.3	3.2	3.3	3.8	3.2	2.3	2.3	2.3	2.6
BIAS (°F)																														
MOS	-.4	-.4	-1.4	-1.4	-1.3	.2	-1.6	1.1	3.5	2.9	1.2	-.8	-.6	-1.9	-2.6	-3.2	-2.8	-2.2	-.4	.3	1.0	2.0	1.6	.9	.0	-1.0	-1.2	-.8	-1.4	-.6
K-L	.8	-.1	.0	.2	-.1	1.5	1.7	-.8	3.7	2.6	1.0	1.4	-.7	1.0	.4	.4	.3	.2	2.4	.5	1.8	2.7	.8	1.3	-.0	.6	.8	.5	.6	.4
LOCAL	.2	.3	.3	.8	.5	.6	.3	-.2	1.2	.6	-.7	-.4	.1	.8	.3	.2	.3	.3	1.9	.8	1.0	.9	.4	.3	-.5	.3	.8	.8	.8	.3
ABSOLUTE ERROR ≥ 10 °F (NO.)																														
MOS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	33	35	18	16	10	18	8	5	3	19	20	40	39	32	30	18	2	6	7	8
K-L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	48	74	30	30	10	12	3	2	8	14	27	50	32	30	32	19	9	9	7	12
LOCAL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	9	28	24	13	10	7	4	2	8	9	8	17	16	11	19	10	3	11	7	6
	MOS EQUATIONS WITH 6 PREDICTORS						MOS EQUATIONS WITH 10 PREDICTORS												MOS EQUATIONS WITH 10 PREDICTORS (SINE & COSINE)															
	17 STATIONS						16 STATIONS																							
	KLEIN-LEWIS (BAROTROPIC)												KLEIN-LEWIS (PE)																	

CONCLUSIONS

The MOS approach to developing reliable objective maximum-temperature forecasts has been shown to have considerable skill. Verification scores have shown that the forecasts are as good or better than those prepared from perfect prog techniques and are about 0.5 to 1.0°F less accurate than the local official forecasts. The addition of the sine and cosine of the day of year as predictors has been shown to be a significant step in reducing the forecast bias and in improving the accuracy of forecasts. Equations containing 10 predictors have been shown to be superior to those containing only two, four, six, or eight predictors; however, little or no advantage would be gained by using equations containing more than 10 predictors.

ACKNOWLEDGMENTS

We wish to thank those members of the Techniques Development Laboratory who contributed to the MOS maximum-temperature program in various ways, especially George Hollenbaugh, Jackie Hughes, Patricia Robinson, Dean Costantinou, and Gene Legg.

REFERENCES

Glahn, H. R., Lowry, D. A., and Hollenbaugh, G. W., "An Operational Sub-synoptic Advection Model," ESSA Technical Memorandum WBTM TDL-23, July 1969, 26 pp.

Glahn, H. R., and Lowry, D. A., "An Operational Method for Objectively Forecasting Probability of Precipitation," ESSA Technical Memorandum WBTM TDL-27, Oct. 1969, 24 pp.

Glahn, H. R., "Computer-Produced Worded Forecasts," Bulletin of the American Meteorological Society, Vol. 51, No. 12, Dec. 1970, pp. 1126-1131.

Klein, W. H., and Lewis, F., "Computer Forecasts of Maximum and Minimum Temperature," Journal of Applied Meteorology, Vol. 9, No. 3, June 1970, pp. 350-359.

Klein, W. H., Lewis, F., and Hammons, G. A., "Recent Developments in Automated Max/Min Temperature Forecasting," Journal of Applied Meteorology, Vol. 10, No. 5, Oct. 1971, pp. 916-920.

Shuman, F. G., and Hovermale, J. B., "An Operational Six-Layer Primitive Equation Model," Journal of Applied Meteorology, Vol. 7, No. 4, Aug. 1968, pp. 525-547.

(Continued from inside front cover)

WBTM TDL 21 Automatic Decoding of Hourly Weather Reports. George W. Hollenbaugh, Harry R. Glahn, and Dale A. Lowry, July 1969. (PB-185 806)

WBTM TDL 22 An Operationally Oriented Objective Analysis Program. Harry R. Glahn, George W. Hollenbaugh, and Dale A. Lowry, July 1969. (PB-186 129)

WBTM TDL 23 An Operational Subsynoptic Advection Model. Harry R. Glahn, Dale A. Lowry, and George W. Hollenbaugh, July 1969. (PB-186 389)

WBTM TDL 24 A Lake Erie Storm Surge Forecasting Technique. William S. Richardson and N. Arthur Pore, August 1969. (PB-185 778)

WBTM TDL 25 Charts Giving Station Precipitation in the Plateau States From 850- and 500-Millibar Lows During Winter. August F. Korte, Donald L. Jorgensen, and William H. Klein, September 1969. (PB-187 476)

WBTM TDL 26 Computer Forecasts of Maximum and Minimum Surface Temperatures. William H. Klein, Frank Lewis, and George P. Casely, October 1969. (PB-189 105)

WBTM TDL 27 An Operational Method for Objectively Forecasting Probability of Precipitation. Harry R. Glahn and Dale A. Lowry, October 1969. (PB-188 660)

WBTM TDL 28 Techniques for Forecasting Low Water Occurrences at Baltimore and Norfolk. Lt. (jg) James M. McClelland, USESSA, March 1970. (PB-191 744)

WBTM TDL 29 A Method for Predicting Surface Winds. Harry R. Glahn, March 1970. (PB-191 745)

WBTM TDL 30 Summary of Selected Reference Material on the Oceanographic Phenomena of Tides, Storm Surges, Waves, and Breakers. Arthur N. Pore, May 1970. (PB-193 449)

WBTM TDL 31 Persistence of Precipitation at 108 Cities in the Conterminous United States. Donald L. Jorgensen and William H. Klein, May 1970. (PB-193 599)

WBTM TDL 32 Computer-Produced Worded Forecasts. Harry R. Glahn, June 1970. (PB-194 262)

WBTM TDL 33 Calculation of Precipitable Water. L. P. Harrison, June 1970. (PB-193 600)

WBTM TDL 34 An Objective Method for Forecasting Winds Over Lake Erie and Lake Ontario. Celso S. Barrientos, August 1970. (PB-194 586)

WBTM TDL 35 A Probabilistic Prediction in Meteorology: A Bibliography. A. H. Murphy and R. A. Allen, June 1970. (PB-194 415)

WBTM TDL 36 Current High Altitude Observations--Investigation and Possible Improvement. M. A. Alaka and R. C. Elvander, July 1970. (Com-71-00003)

NOAA Technical Memoranda

NWS TDL 37 Prediction of Surface Dew Point Temperatures. R. C. Elvander, January 1971. (Com-71-00253)

NWS TDL 38 Objectively Computed Surface Diagnostic Fields. Robert J. Bermowitz, February 1971. (Com-71-00301)

NWS TDL 39 Computer Prediction of Precipitation Probability for 108 Cities in the United States. William H. Klein, February 1971. (Com-71-00249)

NWS TDL 40 Wave Climatology for the Great Lakes. N. A. Pore, J. M. McClelland, and C. S. Barrientos, February 1971. (Com-71-00368)

NWS TDL 41 Twice-Daily Mean Monthly Heights in the Troposphere Over North America and Vicinity. August F. Korte, June 1971. (Com-71-00826)

NWS TDL 42 Some Experiments With A Fine-Mesh 500-Millibar Barotropic Model. Robert J. Bermowitz, August 1971. (COM-71-00958)

NWS TDL 43 Air-Sea Energy Exchange in Lagrangian Temperature and Dew Point Forecasts. Ronald M. Reap, October 1971. (COM-71-01112)

NWS TDL 44 Use of Surface Observations in Boundary-Layer Analysis. H. Michael Mogil and William D. Bonner, March 1972.