U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
SYSTEMS DEVELOPMENT OFFICE
TECHNIQUES DEVELOPMENT LABORATORY

TDL Office Note 73-3

USE OF MODEL OUTPUT STATISTICS FOR AUTOMATED PREDICTION OF MAX/MIN TEMPERATURES

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August 1973

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Automated Prediction of Max/Min Temperatures*

INTRODUCTION

For the past eight years, automated forecasts of maximum and minimun surface temperature in the conterminous United States have been produced twice daily in the National Weather Service (Klein and Lewis, 1970) by applying the "perfect prog" method (Klein, 1970). Recently, the Model Output Statistics (MOS) approach has been applied successfully in the Techniques Development Laboratory to forecast surface wind, cloudiness, and probability of precipitation (Glahn and Lowry, 1972). This technique statistically relates weather elements to the output of operational numerical models. In this Note we present the results of applying the MOS technique to max/min temperature forecasting.

PROCEDURE

Screening experiments were conducted at 49 stations. Fig. 1 shows the set of cities for which equations were developed and tested; they were widely distributed in order to test the system on a variety of conditions.

Table 1 shows the list of potential predictors which were offered to our screening regression program. They were carefully selected to include all available factors which might contribute to surface temperature. The table illustrates some important features of the MOS technique: first, a separate equation is derived for each projection, e.g. today's max, tonight's min, etc.; second, model output at or near the max/min valid time is used as a predictor; third, some of the predictors are space smoothed by five (*) or nine (**) points to eliminate small scale noise. Note that smoothing is generally a function of element, level, and projection.

The predictors total 49 per projection (Table 1). From the Trajectory model (Reap, 1972), for which only 24-hr forecasts are available, we used temperature, moisture, and vertical displacement at selected levels. From the Primitive Equation (PE) model (Shuman and Hovermale, 1968), we selected height and thickness parameters similar to those found important in the perfect prog system; we added temperatures, wind components, and vertical velocities at various levels, 400-1000 mb mean relative humidity, and precipitable water, all at varying projections from 12 to 48 hours. Each of these predictors was interpolated to a point directly above the station, and only data at a given station were used for that station (This differs from the perfect prog system which utilizes a field of grid points.)

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*Paper presented at 54th Annual Meeting of the American Geophysical Union, Washington, D.C., April 16-20, 1973.

Part (c) shows other variables we added to the model output: first, the sine and cosine of the day of the year to capture the seasonal trend of temperature; second, the max and min temperature forecasts produced by the perfect prog system which have been our best estimate to date; third, seven surface synoptic reports to give the latest observed conditions at the station. These are at 06Z, 6 hours after the initial time of the numerical models, but early enough to be used operationally. Of these variables, only the last two (previous max and min) were used in our previous work.

RESULTS

Table 2 gives results of screening regressions on two years (1970 and 1971) of summer data (April-September) at 00 GMT. All equations have 10 terms, since previous research has indicated this is the optimum number of predictors (Glahn and Lowry, 1972; Bocchieri and Glahn, 1972). The results are divided into four "experiments," which consist of different combinations of the PEATMOS (PM), Perfect Prog (PP), and Surface Synoptic (SS) predictors.

The main points to notice here are : (1) the reduction of variance decreases and the standard error of estimate increases with increasing forecast projection; (2) the addition of surface synoptic reports helps mainly in the first period; (3) addition of the perfect prog forecasts helps only slightly; and (4) the combination of all three types of predictors was best on this developmental sample.

Some sample equations are shown in Table 3, where the last two columns show how the reduction of variance gradually rises and the standard error gradually falls as additional terms are added up to 10. The first equation, for today's max at Minneapolis, was derived from PM and SS predictors. Note that it contains three variables of each type--Trajectory model, PE model, and surface synoptic. The second equations, for tonight's min at Salt Lake City, was based on PM variables only. It contains five PE and four trajectory predictors.

Similar equations were derived separately for each of the 49 stations of Fig. 1. Their characteristics are summarized in Table 4 which shows the importance of predictors based on the frequency of selection in ten-term PM equations. Here today's and tomorrow's max are combined, as are tonight's and tomorrow night's min. The important predictors in forecasting the max are the temperature forecasts from the numerical models, mean relative humidity, cosine of the day of the year, and wind components. Additional predictors influence the min, including 1000-500 mb thickness, surface dew point, and precipitable water.

VERIFICATION

We will now look at the errors of forecasts made on independent data during April, May, and June of 1972 (83 days) and compare them to the operational perfect prog system. The first two columns of Table 5 show that for the test period, the PEATMOS forecasts were consistently 0.5 degrees better than the perfect prog forecasts. This is about the same amount by which official forecasts now issued to the public at local weather offices improve over their automated guidance (Derouin and Cobb, 1972). Adding the perfect prog forecasts to the PEATMOS predictors improves results very little (0.1 deg. at 48 hr). This agrees with the results from the dependent data (Table 2). Adding surface synoptic reports reduces the error in the first projection, but combination of all three types of predictors does not produce any improvement.

Table 6 shows the improvement of PEATMOS only forecasts over the current system by month for the spring months of 1972. The improvement was consistent for all projections in each month. When temperatures were most variable (or harder to forecast)--in April--we made the most improvement (0.7°), and when temperatures were least variable (June), we made the least improvement (0.3°). Although we have no results yet for the winter season, we believe we can do as well or better in that period.

CONCLUSION

In summary, we have found that equations derived by the MOS system are superior to the operational perfect prog system; addition of surface synoptic reports as predictors is beneficial in the first period; and use of perfect prog forecasts as predictors does not significantly improve the basic PEATMOS forecasts.

Therefore, we plan to implement the new equations around August 8, 1973, including surface data in the first projection, and PEATMOS only for the others. We will have the capability of adding almost 100 stations to our current set of 131, giving us both expanded coverage and increased accuracy in automated temperature forecast guidance for the National Weather Service.

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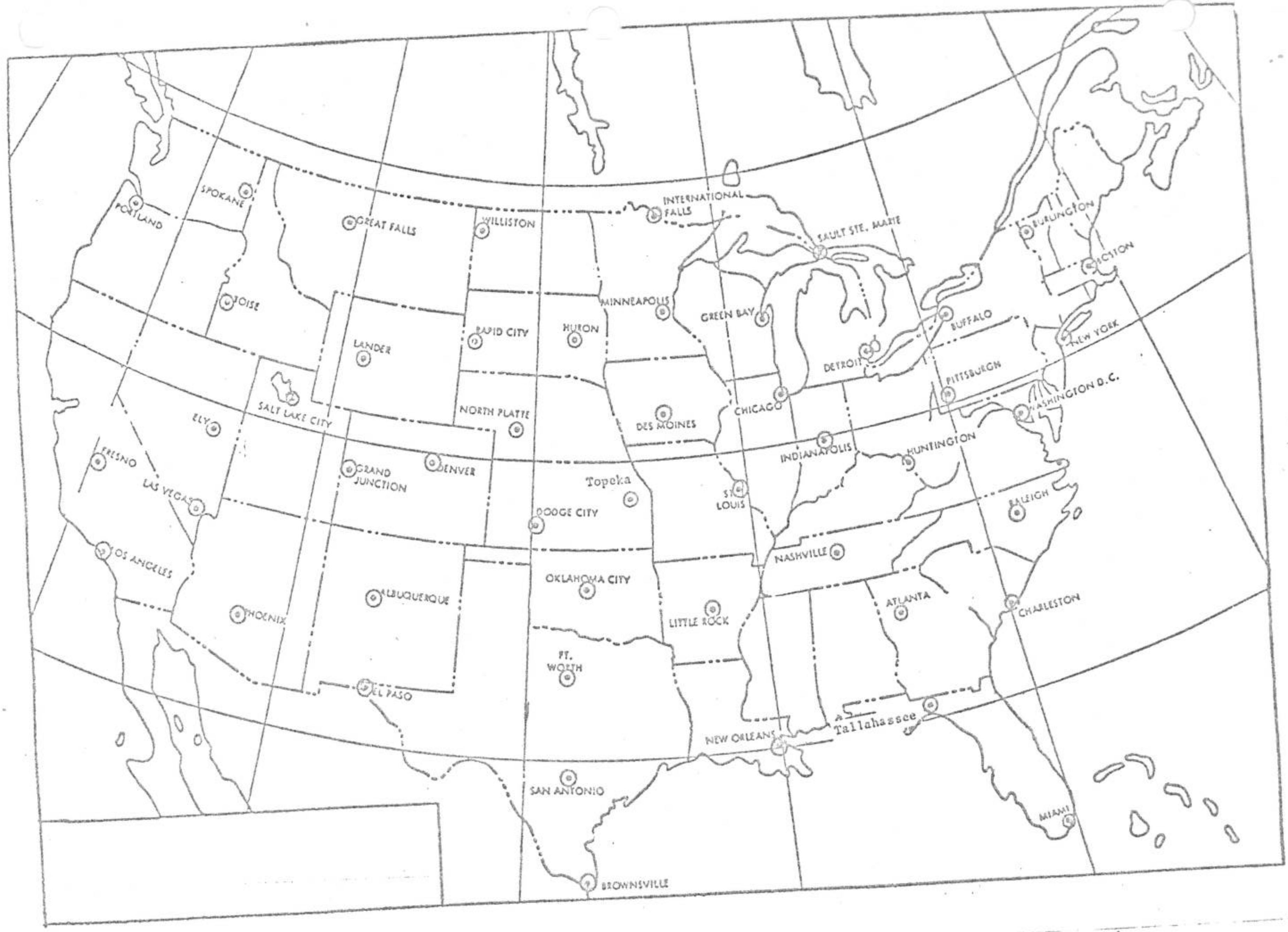

Figure 1. Names and locations of 49 weather stations used for testing MOS equations.

Table 1

Potential predictors of maximum and minimum surface temperature for screening regression. Numbers indicate valid time of predictors in hours after 0000 GMT. Stars indicate the predictor was smoothed by 5 points (*) or 9 points (**).

Predictor	Today Max	Tonight Min	Tomorrow Max	Tomorrow Night Min
	a) Trajectory Model			
Surface temperature	24, 24*	24, 24*	24, 24*	24*, 24**
Surface dew point	24*	24*	24*	24**
850-mb temperature	24, 24*	24, 24*	24, 24*	24*, 24**
700-mb temperature	24, 24*	24, 24*	24, 24*	24*, 24**
700-mb 12 hr net vert displ	24*	24*	24**	24**
700-mb 24 hr net vert displ	24*	24*	24**	24**
850-mb 12 hr net vert displ	24*	24*	24**	24**
850-mb 24 hr net vert displ	24*	24*	24**	24**
700-mb relative humidity	24*	24*	24**	24**
850-mb relative humidity	24*	24*	24**	24**
700-mb-surface mean rel hum	24*	24*	24**	24**
Surface 12 hr horiz conv	24*	24*	24**	24**
	b) PE Model			
1000-mb height	24	36	48	48*
850-mb height	24	36	48	48*
500-mb height	12, 24	24, 36	36, 48	48, 48*
1000-500 mb thickness	12, 24	24, 36	36, 48	48, 48*
1000-850 mb thickness	12, 24	24,	36, 48	48, 48*
1000-mb temperature	12, 24, 24*	24*, 36, 36*	36*, 48, 48*	48, 48*, 48**
850-mb temperature	12, 24, 24*	24*, 36, 36*	36*, 48, 48*	48, 48*, 48**
700-mb temperature	24	24	24*	24*
Boundary layer potential temp	12, 24, 24*	24*, 36, 36*	36*, 48, 48*	48, 48*, 48**
Boundary layer U wind	12, 24*	24*, 36*	36*, 48*	48*, 48**
Boundary layer V wind	12, 24*	24*, 36*	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*
400-1000 mb mean rel hum	12*, 24*	24*, 36*	36**, 48**	48*, 48**
Precipitable water	18*	30*	42**	42**
Precipitation amount	24	36*	48*	48**
850-mb vertical velocity	24*	24*	24**	24**
650-mb vertical velocity	24*	24*	24**	24**
	c) Other Variables			
Sine day of year	00	00	00	00
Cosine day of year	00	00	00	00
Min forecast	12	36	36	60
Max forecast	24	24	48	48
Latest surface temperature	06	06	06	06
Latest surface dew point	06	06	06	06
Latest cloud cover	06	06	06	06
Latest surface U wind	06	06	06	06
Latest surface V wind	06	06	06	06
Previous min	00	00	00	00
Previous max	00	00	00	00

Table 2

Results obtained by screening maximum and minimum temperatures at 49 cities during summer (April-Sept) of 1970-71 (293 days at 00GMT). Forecasts were made from 10-term equations containing different combinations of PEATMOS (PM), Perfect Prog (PP), and 06GMT Surface Synoptic (SS) predictors.

	Reductions of Variance (%)				Standard Errors (°F)			
Forecast For:	PM	PM,PP	PM,SS	PM,PP,SS	PM	PM,PP	PM,SS	PM,PP,SS
Today's Max	87.8	88.7	88.7	89.0	3.6	3.5	3.4	3.4
Tonight's Min	87.7	88.0	88.0	88.2	3.5	3.4	3.4	3.4
Tomorrow's Max	81.8	82.3	82.2	82.5	4.4	4.4	4.4	4.3
Tomorrow Night's Min	82.5	82.8	82.7	82.9	4.1	4.0	4.1	4.0

Table 3

Sample PEATMOS temperature forecast equations for first two periods (from 0000 GMT data):

Term	Predictor	tau	Cumulative RV(%)	Cumulative S.E.(°F)
	(a) Today's max - Minneapolis, Minn.			
1	Boundary layer potential temperature (PE)	24*	83.4	5.40
2	Yesterdays observed maximum temperature (SS)	---	85.1	5.10
3	700-mb-surface mean relative humidity (TM)	24*	86.4	4.88
4	Latest surface temperature (SS)	06	86.9	4.79
5	Latest cloud cover (SS)	06	87.2	4.74
6	Surface temperature (TM)	24	87.6	4.66
7	700-mb 12-hr net vert displacement (TM)	24*	88.0	4.60
8	850-mb U wind (PE)	24*	88.5	4.49
9	Sin (day of year)	---	88.8	4.43
10	Boundary layer U wind (PE)	12	89.0	4.39
	(b) Tonight's min - Salt Lake City, Utah			
1	Surface temperature (TM)	24*	84.5	4.45
2	Cos (day of year)	---	87.2	4.04
3	Precipitable water (PE)	30	88.6	3.82
4	Boundary layer potential temperature (PE)	36*	90.8	3.43
5	1000-mb temperature (PE)	36	91.3	3.34
6	700-mb relative humidity (TM)	24*	91.5	3.29
7	1000-500 mb thickness (PE)	24	91.8	3.24
8	400-1000 mb mean relative humidity (PE)	24*	91.8	3.21
9	850-mb 24-hr net vert displacement (TM)	24*	91.9	3.21
10	700-mb 24-hr net vert displacement (TM)	24*	92.1	3.17

TM-Trajectory Model; PE-Primitive Equation Model; SS-Surface Synoptic Observations; * indicates 5-point smoothing operator was applied; tau is valid time of predictors in hours after 0000 GMT; RV is reduction of variance; SE is standard error of estimate.

Table 4

Importance of Primitive Equation (PE) and Trajectory Model (TM) predictors on basis of frequency of selection in 10-term equations for maximum (today and tomorrow) and minimum (tonight and tomorrow night) summer temperatures at 49 cities.

Rank	Maximum	Minimum
1	PE bound layer temp	PE 1000-500 mb thick
2	TM surface temp	Cosine day of year
3	Cosine day of year	PE bound layer V wind
4	PE 1000-mb temp	PE 850-mb temp
5	PE mean rel hum	Sine day of year
6	PE 850-mb temp	TM surface dew point
7	PE 500-mb ht	PE bound layer U wind
8	PE bound layer V wind	PE mean rel hum
9	PE bound layer U wind	PE precipitable water
10	TM 850-mb temp	PE bound layer temp
11	PE 1000-850 mb thick	TM surface temp
12	TM 700-mb net vert disp	PE 1000-mb temp

Table 5

Mean absolute errors (°F) of objective maximum and minimum temperature forecasts at 49 cities during April, May, and June of 1972 (83 days at 00 GMT). Forecasts were made from different combinations of Perfect Prog (PP), PEATMOS (PM), and 06 GMT Surface Synoptic (SS) predictors.

Forecast For:	PP	PM	PM,PP	PM,SS*	PM,PP,SS*
Today's Max	3.9	3.4	3.4	3.3	3.3
Tonight's Min	3.9	3.4	3.4	3.4	3.4
Tomorrow's Max	4.6	4.2	4.1	4.1	4.1
Tomorrow Night's Min	4.4	3.9	3.9	4.0	3.9

* PM forecasts were used for last two columns when SS data were missing (about 12% of cases).

Table 6

Mean absolute errors (°F) of objective maximum and minimum temperature forecasts at 49 cities during spring months of 1972. Forecasts were prepared by Perfect Prog (PP) and PEATMOS (PM) techniques.

	April			May			June		
Projection:	PP	PM	PP-PM	PP	PM	PP-PM	PP	PM	PP-PM
24 hr - max	4.4	3.7	0.7	3.7	3.3	0.4	3.5	3.2	0.3
36 hr - min	4.5	3.8	0.7	3.8	3.4	0.4	3.4	3.0	0.4
48 hr - max	5.5	4.8	0.7	4.2	3.9	0.3	4.1	3.8	0.3
60 hr - min	5.2	4.7	0.5	4.1	3.7	0.4	3.8	3.4	0.4