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OPERATIONAL TEMPERATURE FORECASTING BY MEANS OF MODEL OUTPUT STATISTICS

Gordon A. Hammons and William H. Klein

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Operational Temperature Forecasting
by Means of Model Output Statistics*

by Gordon A. Hammons and William H. Klein

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

ABSTRACT

A new automated system of forecasting maximum and minimum surface temperatures in the contiguous United States, based on the Model Output Statistics (MOS) approach, is discussed. This system replaced the "perfect prog" technique in the operations of the National Weather Service in August, 1973. Derivation of the MOS equations is described, and sample equations are presented. Verification results, comparing the MOS and "perfect prog" systems, are summarized. Operational aspects, such as facsimile and teletype transmissions, are discussed.

INTRODUCTION

At last year's annual meeting of the AGU, a series of screening experiments was described for predicting maximum and minimum surface temperatures for periods 24 to 60 hours in advance at 49 cities in the conterminous United States from PEATMOS (Primitive Equation And Trajectory Model Output Statistics) data for the warm seasons of 1970-72 (Klein and Hammons, 1973). Briefly, the results showed that:

a) The PEATMOS forecasts were 0.5 degrees Fahrenheit better, on the

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average, than the then-operational "perfect prog" forecasts, for all projections;

b) Use of surface synoptic data observed six hours after the initial time of the numerical models as predictors improved the forecasts only in the first projection;

c) Use of the "perfect prog" forecasts as predictors did not improve the forecasts significantly.

As a result of these experiments, an automated system of forecasting max/min temperatures, based on the MOS approach, was made operational in August, 1973, replacing the "perfect prog" technique in the operations of the National Weather Service.

DESCRIPTION OF FORECAST SYSTEM

Table 1 shows the list of potential predictors offered to our screening regression program; note the following characteristics of this predictor list:

a) A separate equation is derived for each projection (today's max tonight's min, etc.);

b) Projections from the model output increase with increasing forecast projection, except for the trajectory model predictors, for which only 24-hr forecasts are available;

c) Space smoothing (denoted by the star) is generally a function of projection and elevation, as well as of predictor, with heavier smoothing at the longer projections and for smaller scale predictors.

d) We have included surface observations, taken six hours after the initial time of the numerical models, only in the first projection.

Now, looking at the types of predictors, found in the left-hand column:

e) Group (a) shows 15 variables from the three-dimensional trajectory model (Reap, 1972); the predictors include temperature, moisture, and vertical displacements at selected levels.

f) Group (b) contains 33 variables from the Primitive Equation model (Shuman and Hovermale, 1968); including height and thickness parameters, temperatures, wind components, vertical velocities, mean relative humidity, and precipitable water.

g) Group (c) contains the sine and cosine of the day of year, to reduce the seasonal bias of the equations, and surface synoptic data, to give the initial conditions at the station. The 06Z (18Z) surface predictors include cloud cover, temperature, dew point, wind speed and direction, and latest maximum (or minimum) temperature.

It should be noted that all data are interpolated to a point directly above a station, and only data at a given station are used for that station's forecast. Separate equations are derived for each station (228), projection (4), run time (2), and season (2) for a total of 3648 equations. This is called the Single Station approach.

FORECAST EQUATIONS

The relative importance of the predictors, based on frequency of selection in ten-term multiple regression equations, is shown in Table 2. The most important predictors for the maximum forecast are the temperature forecasts from the models, mean relative humidity, cosine of the day of the year, and wind components. For forecasting the minimum, additional predictors are important, including the 1000-500 mb thickness, surface dew point, and precipitable water. Notice the surface reports in the first projection.

Table 3 gives sample PEATMOS temperature forecast equations for Washington, D.C. from 00 and 06Z data for: (a) Today's maximum, and (b) Tonight's minimum. This example serves to show that the standard error decreases and the reduction of variance increases as terms are added up to ten, with a final reduction of variance of 85 to 90 percent and standard error of 4 1/2 degrees. Note the similarity of the predictors in the sample equation to those in Table 2, the list of the most important predictors, including selection of dew point for the minimum, but not for the maximum, temperature. Note also that terms 3 and 5 in today's max are the same except for projection, while terms 3 and 7 in tonight's min are the same except for smoothing.

VERIFICATION

Shown in Table 4 are verification statistics averaged at 126 U.S. cities for the period September 1-December 31, 1973, for forecasts made operationally twice daily by both MOS and perfect prog systems. On the left it can be seen that the MOS forecasts were 0.2 to 0.7 degrees Fahrenheit (°F) lower in mean absolute error than the perfect prog forecasts. On the right, the table shows that MOS forecasts also had higher correlation coefficients, on the average, at all projections except the last.

TELETYPE OUTPUT

The format of the max/min message transmitted on teletypewriter has been somewhat changed in the past year, mostly to save increasingly scarce circuit time. At present, 228 stations, plotted in Figure 1, are sent to the FAA's Kansas City switch, where all reports are immediately available via request/reply on dedicated circuits at Weather Service Offices. 135 of these stations are divided (with some overlapping) into six regional bulletins and are sent as scheduled transmissions on Service "C". Figure 2 shows the scheduled transmission received on the East coast, for example. The "M"s printed after certain station call letters are provided to indicate to users that a required surface observation(s) was not available, and a "backup" equation, with only PE and Trajectory model data as input, was used to make the forecast for the first projection. We have found that the "backup" forecast averages 0.1-0.2°F worse than the forecast including surface observations.

The message at the bottom refers to the restriction of forecasts for 126 stations to climatological limits. Whenever a MOS forecast exceeds these limits, it is "truncated" to a climatological value near the extreme for that particular station and time of year (Klein et al., 1971). Verification results show that the mean absolute error of the truncated forecasts is 1.3°F less than the corresponding raw MOS forecasts.

FACSIMILE OUTPUT

The facsimile output (Figure 3) contains a mixture of MOS and perfect prog forecasts. This system was adapted because NWS field offices required forecasts for some stations for which no MOS equations were derived, and also, the existing facsimile program could be used.

The map displays plotted MOS forecasts at 126 stations, and perfect prog forecasts at 5 U.S. and 12 Canadian stations. The computer-drawn isotherms are based on all 143 reports and analyzed with Cressman's successive approximation technique on a grid 1/2 the mesh length of the PE model (Figure 4).

In the future, we plan to use a better facsimile map (Figure 5) background designed for other MOS products. When the new background is implemented, we will use forecasts at 228 MOS stations and 16 perfect prog stations to compute the grid values for contouring. Due to lack of space, we will plot only 135 of the MOS stations plus 16 perfect prog cities for a total of 151 stations, 8 more than on the current map (Figure 3). As a further benefit, we will eliminate the insertion of Maine into the Gulf of Mexico required by the present chart (see Figure 3).

CONCLUDING REMARKS

Implementation of the MOS system has resulted in increased accuracy in National Weather Service temperature forecast guidance and an increase in coverage, from 131 to 228 U.S. stations.

We plan to further improve the MOS forecasts by screening an additional two years of data, making a total of five years, to generate new equations for implementation this October.

In addition, we plan experiments to determine the effect of snow cover on the forecasts since large errors this past winter have been attributed to this effect in the Central Plains (Curran and Ostby, 1974). If the snow cover experiments are successful, we plan to implement a correction term in our equations next winter.

REFERENCES

Curran, J. T. and F. P. Ostby, 1974: "Bias of NMC Objective Surface Temperature Forecasts," Technical Attachment 74-1, National Weather Service, Central Region, News and Views, Feb. 1, 1974, 4 pp.

Klein, W. H. and G. A. Hammons, 1973: "Use of Model Output Statistics for Automated Prediction of Max/Min Temperatures," TDL Office Note 73-3, 10 pp.

_____, Frank Lewis, and Gordon A. Hammons, 1971: "Recent Developments in Automated Max/Min Temperature Forecasting," J. Appl. Meteor., 5, 916-920.

Reap, R. M., 1972: "An Operational Three-Dimensional Trajectory Model," J. Appl. Meteor., 11, 1193-1202.

Shuman, F. G., and J. G. Hovermale, 1968: "An Operational Six-Layer Primitive Equation Model," J. Appl. Meteor., 7, 525-547.

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
Latest surface temperature	06	--	--	--
Latest surface dew point	06	--	--	--
Latest cloud cover	06	--	--	--
Latest surface U wind	06	--	--	--
Latest surface V wind	06	--	--	--
Latest surface wind speed	06	--	--	--
Previous min	00	--	--	--
Previous max	00	--	--	--

Table 2

Importance of Primitive Equation (PE) and Trajectory Model (TM) predictors on basis of frequency of selection in 10-term equations for maximum and minimum winter temperatures at 228 cities (00GMT data). Surface Synoptic (SS) reports at 06GMT were included as predictors for Today's Max.

Rank	Today's Max	Tonight's Min	Tomorrow's Max	Tomorrow Night's Min
1	Cosine day of year	PE 850-mb temp	TM surface temp	PE 850-mb temp
2	SS latest temp	Cosine day of year	Cosine day of year	Cosine day of year
3	SS previous max	TM sfc dew point	PE 850-mb temp	PE bound layer V wind
4	TM surface temp	PE bound layer V wind	PE bound layer temp	TM sfc dew point
5	SS cloud cover	PE mean rel hum	PE bound layer U wind	Sine day of year
6	PE mean rel hum	Sine day of year	Sine day of year	PE 500-mb height
7	PE bound layer temp	TM surface temp	PE bound layer V wind	PE 1000-500 mb thick
8	PE 850-mb temp	PE precipitable water	TM surface convergence	PE mean rel hum
9	PE 1000-mb temp	PE bound layer temp	PE mean rel hum	TM surface temp
10	PE bound layer U wind	PE 1000-mb temp	PE 1000-mb temp	PE bound layer U wind*
				PE 850-mb height*

*Tied for 10th place.

Table 3

Sample MOS temperature forecast equations for first two periods during cool season (Oct.-Mar.) at Washington, D.C. (from 0000 GMT data):

Term	Predictor	tau	Cumulative RV(%)	Cumulative S.E.(°F)
	(a) Today's Max			
1	1000-mb temperature (PE)	12	77.1	6.33
2	Yesterday's observed max temp (SS)	--	81.7	5.66
3	1000-mb temperature (PE)	24*	83.9	5.30
4	Boundary layer U wind (PE)	12	85.7	5.01
5	Cosine (day of year)	--	87.1	4.74
6	400-1000 mb mean relative humidity (PE)	24*	87.8	4.63
7	Latest surface V wind (SS)	--	88.4	4.50
8	850-mb temperature (PE)	24	89.3	4.32
9	Latest surface temperature (SS)	--	89.8	4.23
10	Latest cloud cover (SS)	--	90.2	4.14
	(b) Tonight's Min			
1	Boundary layer potential temperature (PE)	24*	70.0	6.58
2	Cosine (day of year)	--	74.8	6.03
3	850-mb temperature (PE)	36*	79.6	5.42
4	Sine (day of year)	--	82.2	5.06
5	Surface dew point (TM)	24*	83.6	4.87
6	1000-mb temperature (PE)	24*	84.4	4.75
7	850-mb temperature (PE)	36	85.2	4.63
8	Precipitable water (PE)	30*	85.4	4.60
9	850-mb vertical velocity (PE)	24*	85.8	4.52
10	Boundary layer potential temperature (PE)	36*	86.1	4.48

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

Table 4

Verification of objective maximum/minimum temperature forecasts, averaged at 126 cities for the period 1 Sept.-31 Dec. 1973, made twice a day from NMC prognostic data by MOS and Perfect Prog (PP) Systems.

Projection	Mean Absolute Error (°F)		Correlation of Forecast vs Observed Temperature	
	MOS	PP	MOS	PP
		Minimum		
24-hr	3.9	4.3	.78	.74
36-hr	4.4	4.7	.74	.69
48-hr	4.6	4.9	.71	.69
60-hr	5.1	5.3	.65	.63
		Maximum		
24-hr	3.3	4.0	.85	.80
36-hr	4.0	4.3	.80	.78
48-hr	4.2	4.7	.77	.75
60-hr	4.7	5.0	.73	.73
		Combined		
24-hr	3.6	4.2	.82	.77
36-hr	4.2	4.5	.77	.74
48-hr	4.4	4.8	.74	.72
60-hr	4.9	5.2	.69	.68

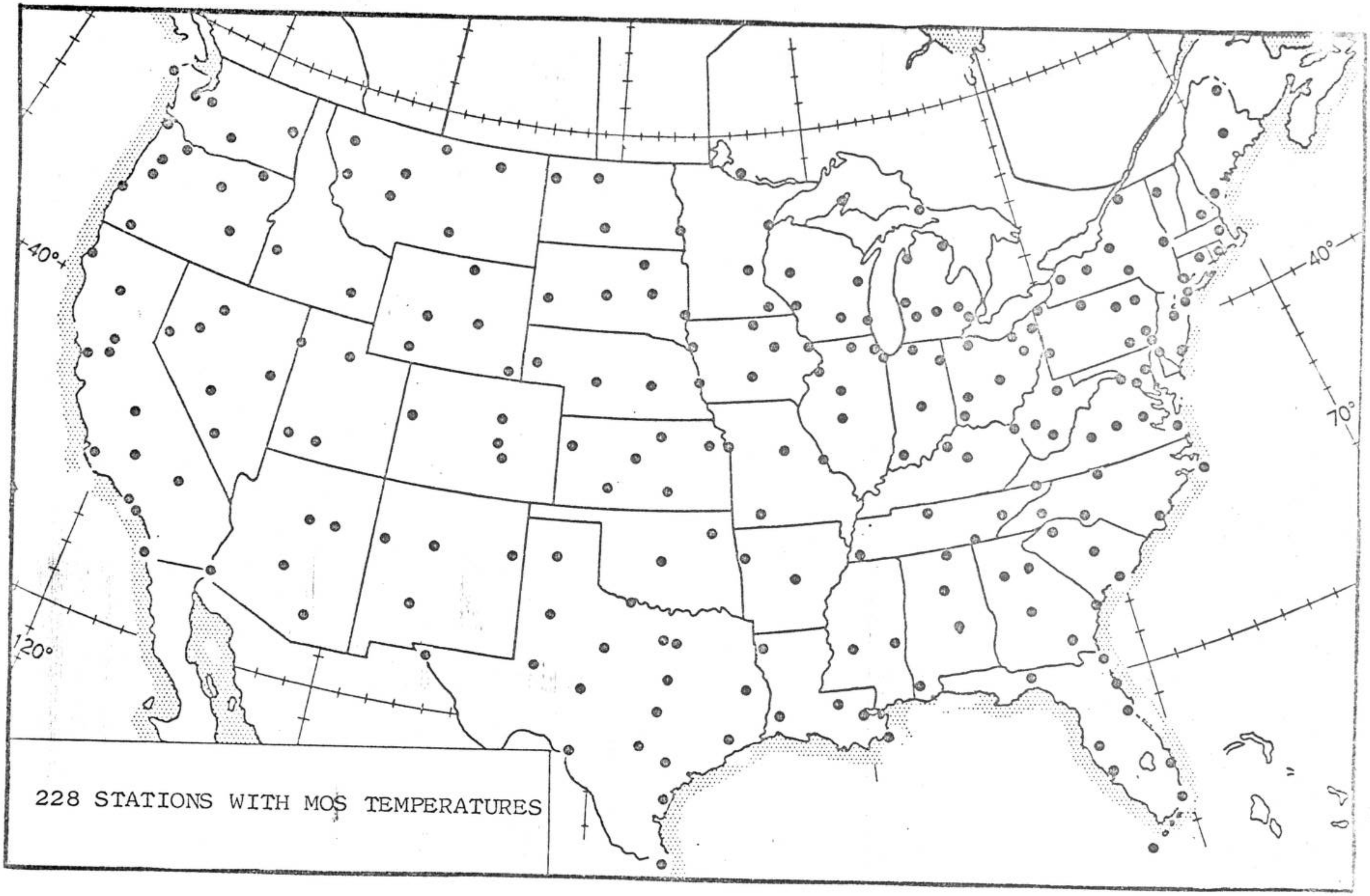

Figure 1

```
FXUS1Ø KWBC Ø3Ø8Ø1
MXMN MAX MIN TEMP FCST  Ø3ØØØØ
HRS     24 36 48 6Ø 72
SIA     MX MN MX MN MX
PWM     55 43 57 43 58
CRW     82 58 83 46 64
PIT     73 5Ø 77 42 61
LGA     65 53 71 49 68
ROA M   78 56 79 51 67
BOS     6Ø 49 66 48S65
CAR     4Ø 29 49 34 47
HTS     82 59S82 44 64
PHL     71S54 76 49 72
RIC     79 59 83 55 76
SYR     62 45 68 42 64
BDL     62 5Ø 68 49 62
BTV     53 43 63 41 61
DCA     73 58 79 5Ø 7Ø
ORF     78 57 79 57 79
IPT M   67 5Ø 69 44 67
BUF     63 46 66 38 58
ALB     64 5Ø 7Ø 45 63
PVD     6Ø 5Ø 7Ø 48 //
TRUN LIMITS APPLIED TO EXTREXE FORECASTS AT
EYW 2↙HRⒹ ORL 24HRⒹ TPAS24HRⒹ MSY 24HRⒹ JAN 24HRⒹSLCH 24HRⒹ
SHV 24HRⒹ CRP 24HRⒹ SAT 24HR→ HAT 24HRⒹ MEM 24HRⒹ MIA 36HRⒹ
DCA 36HRⒹ PHL 36HRⒹ HTS 36YR→ BDL 36HRⒹ ALB 36HRⒹ PWM 36HRⒹ
BTV 36HRⒹ EYW 48HRⒹ ORL 48HRⒹ HAT 48HRⒹ CRW 48HRⒹ PIT 48HRⒹ
IAH 6ØHRⒹ SAT 6ØHR→ EYW 72HRⒹ
```

Figure 2

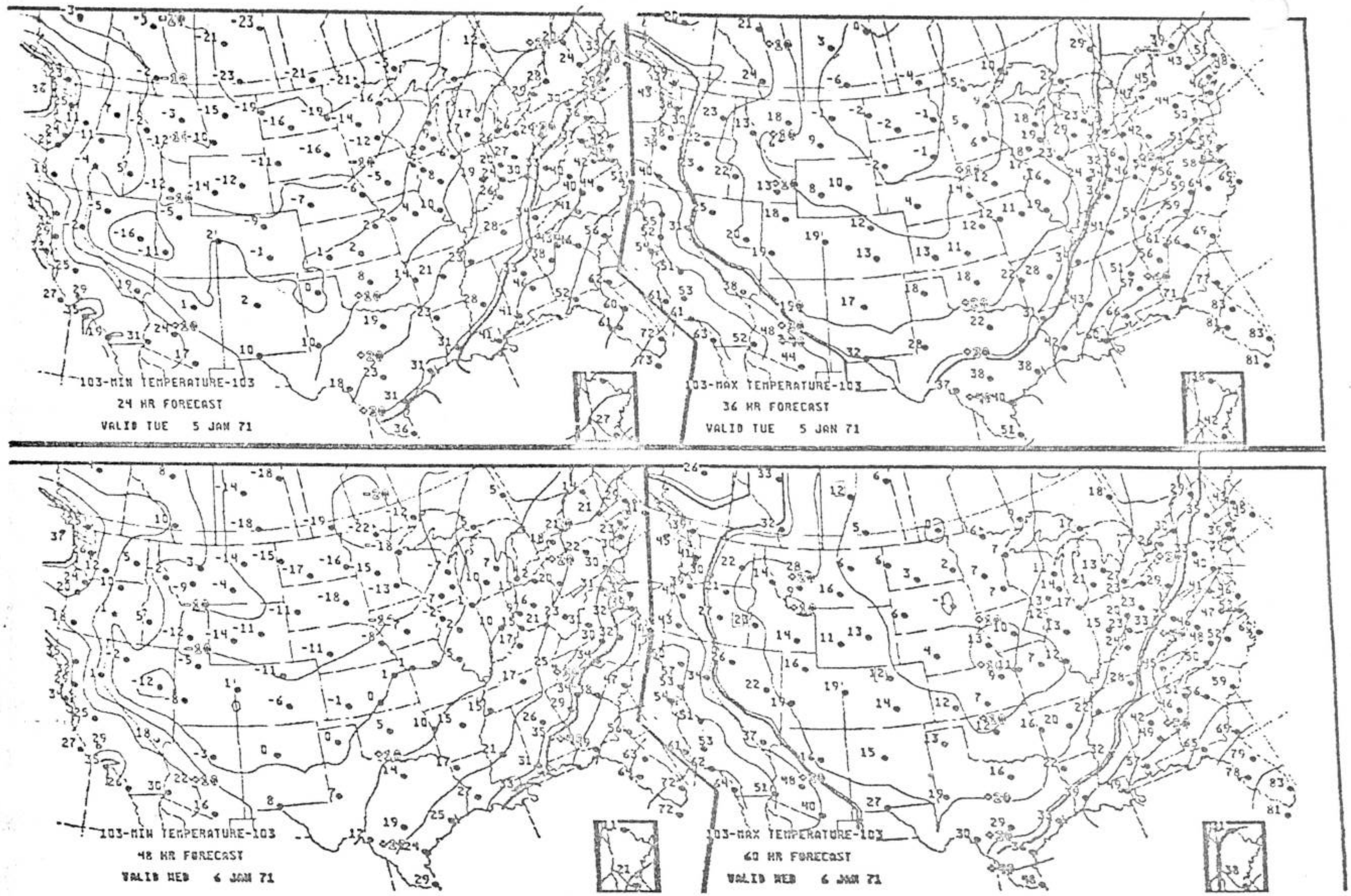
103-MIN TEMPERATURE-103
24 HR FORECAST
VALID TUE 5 JAN 71
103-MAX TEMPERATURE-103
36 HR FORECAST
VALID TUE 5 JAN 71
103-MIN TEMPERATURE-103
48 HR FORECAST
VALID WED 6 JAN 71
103-MAX TEMPERATURE-103
60 HR FORECAST
VALID WED 6 JAN 71

Figure 3

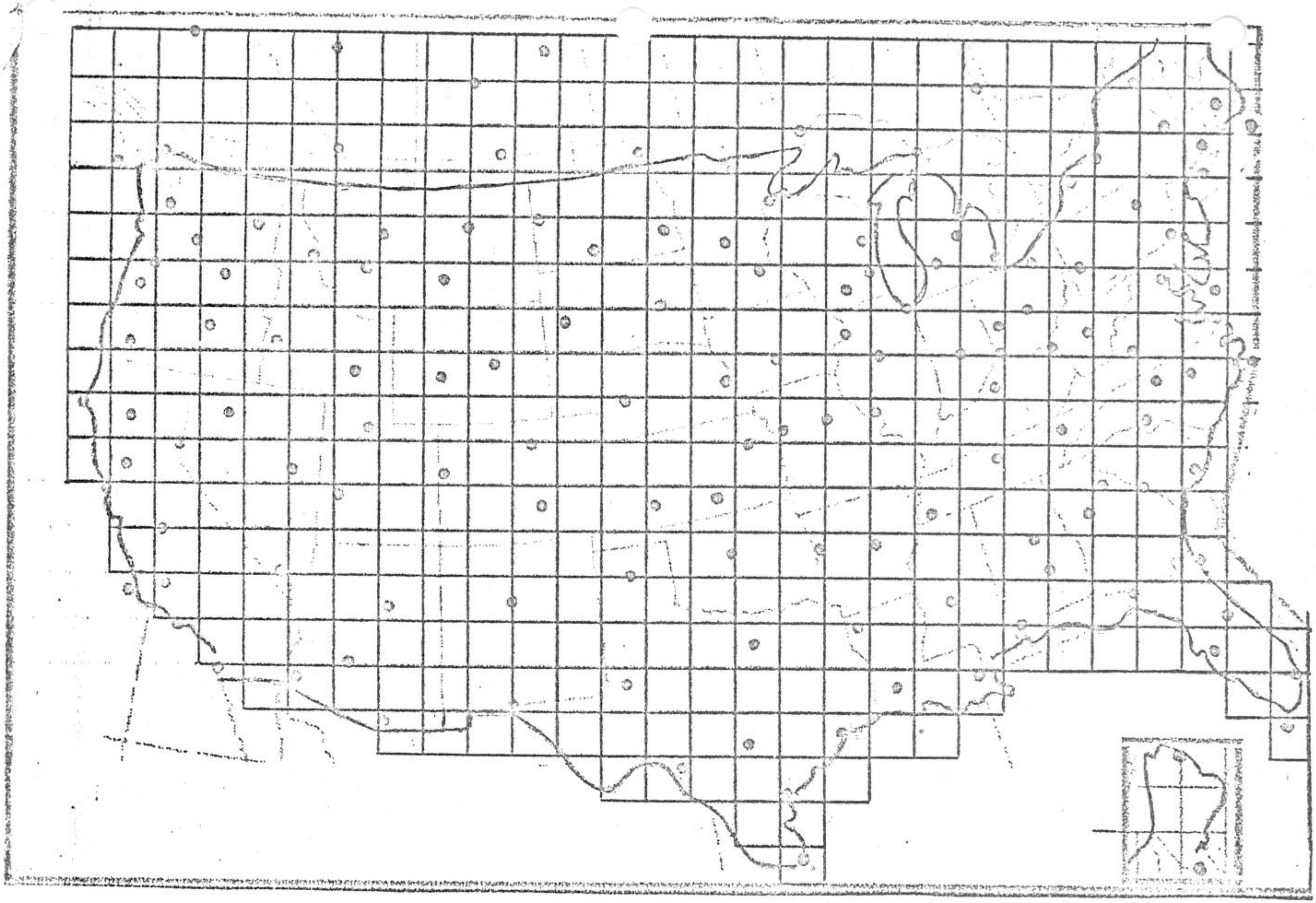

Figure 4

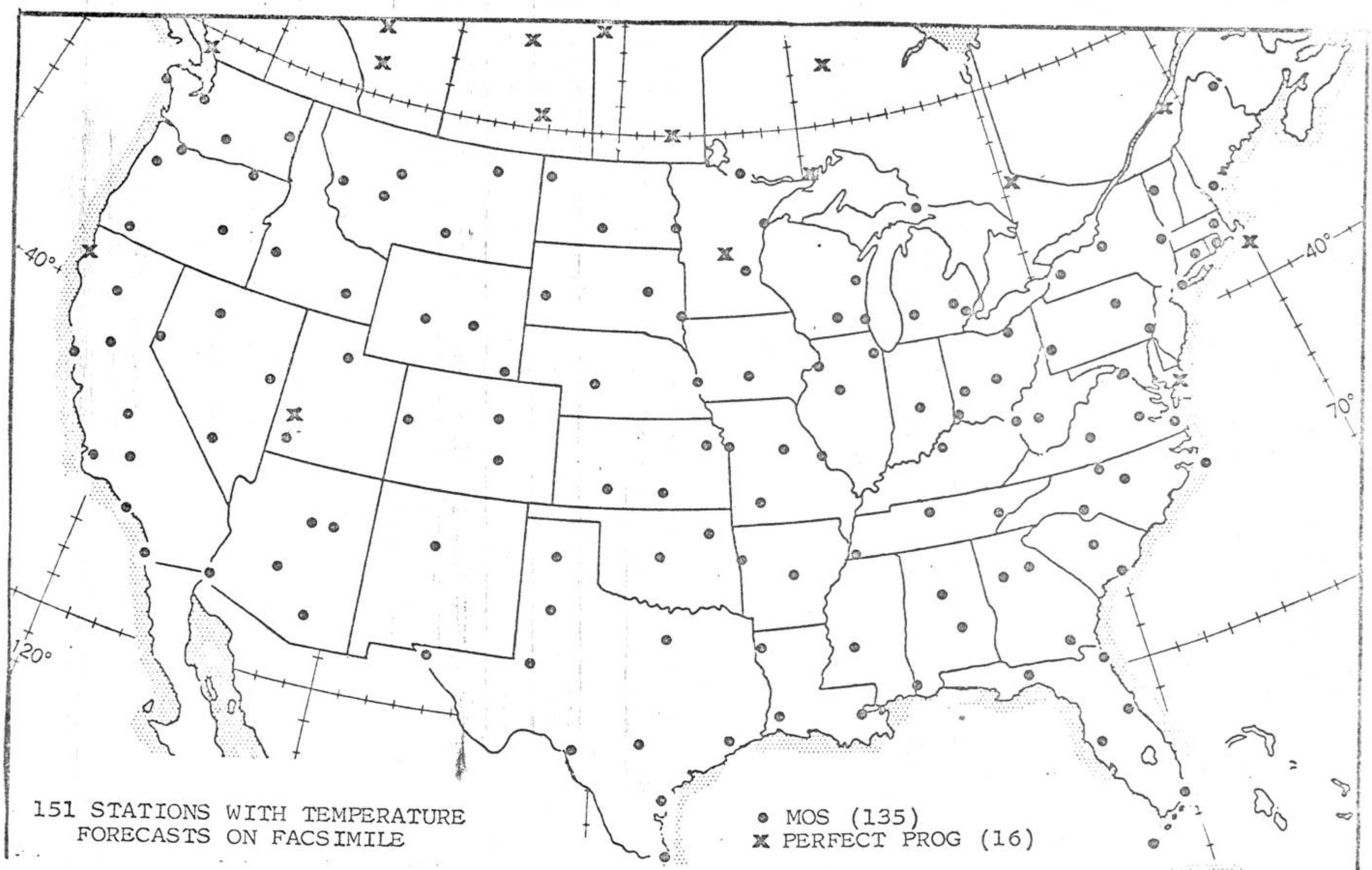
40°
40°
70°
120°
151 STATIONS WITH TEMPERATURE
FORECASTS ON FACSIMILE
MOS (135)
PERFECT PROG (16)

Figure 5