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DEVELOPMENT AND OPERATIONAL USE OF 3-HOUR TEMPERATURE GUIDANCE

J. Paul Dallavalle and Thomas H. Grayson

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Development and Operational Use of 3-hour MOS Temperature Guidance

J. Paul Dallavalle and Thomas H. Grayson*

1. INTRODUCTION

Since August 1973 the Techniques Development Laboratory of the National Weather Service (NWS) has been using the Model Output Statistics (MOS) approach to derive linear regression equations for the prediction of maximum/minimum temperatures valid for calendar day periods (Hammons, et al., 1976). However, in recent years it has become clear that there is also a need for temperature forecasts verifying at specific times. An objective prediction of the diurnal temperature curve can be used by NWS forecasters to estimate fire weather potential during the dry season, evapotranspiration during the growing season, energy requirements for heating or cooling, and flood potential from snow melt. Additionally, a reliable forecast of the diurnal temperature curve can lead to more accurate computer-worded objective forecasts (Glahn, 1976). While the National Weather Service does transmit twice daily Limited Area Fine Mesh (LFM) model (Howcroft, 1971 and Gerrity, 1977) forecasts of the boundary layer potential temperature valid every 6 h from 12 to 48 h after the initial model time, these predictions are not always useful in determining the diurnal temperature variation. To establish a diurnal curve from the model parameters, we developed regression equations that forecast the temperature at 3-h intervals.

2. GENERAL CONCEPT

The MOS technique (Glahn and Lowry, 1972), statistically relates specific meteorological parameters to output from numerical prediction models. In this development, we used forecasts from the 0000 GMT LFM model, interpolated them to the station of interest, and then screened those data in a stepwise fashion against the station's surface temperature observed at 3 h intervals from 6 to 24 h after 0000 GMT. The result was a single station, multiple linear regression temperature equation for a particular projection. Surface parameters observed at the station 3 h after initial model time were also screened as potential predictors for some of the equations. The developmental data were stratified into 3-month seasons, though in this particular test, we worked exclusively with the winter (December-February) period. There were four (1972-76) seasons of data (approximately 313 cases) in the dependent sample.

3. DEVELOPMENT OF THE EQUATIONS

We approached the development of the temperature equations in a number of ways. Five distinct sets of equations were derived for each station and each projection:

(a) Station observations and LFM forecasts were used as possible predictors in 10-term equations--different combinations of fields were screened in each projection (OBS);

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*Currently Principal Assistant at the NWS WSFO in Reno, Nevada.

(b) LFM forecasts were used as possible predictors in 10-term equations--different combinations of fields were screened in each projection (NOOBS);

(c) LFM forecasts were used as potential predictors--each predictor chosen in an equation had to contribute at least 0.75% to the reduction in variance--consequently, most equations contained fewer than 10 terms (CUTOFF);

(d) Station observations, LFM forecasts, and the first and second harmonics of the day of the year were used as possible predictors in 10-term equations--the same set of fields were used as predictors for all projections, and for any station all the equations for the various projections had to use the same 10 predictors, but had different coefficients (IDOBS);

(e) The same set of LFM fields and harmonics of the day of the year were used as potential predictors for all projections--for any station all the equations for the various projections used the same 10 predictors, but with different coefficients (IDNOOBS).

These five groups are schematically summarized in Figure 1.

The types of predictors that were used in various screenings are listed in Tables 1 and 2. Table 1 contains the predictors for the first three equation sets. For any one projection the predictors screened were a subset of the entire list. Identical predictor sets were used for the 6-, 9-, and 12-h projections; the 15- and 18-h projections; and the 21- and 24-h projections. Some of the model fields were smoothed by a five-point space filter at the earlier projection times.

The potential predictors for the last two equation sets are given in Table 2. For IDOBS, we screened all of these fields for every projection. To improve consistency among the forecasts at 3-h intervals, we derived simultaneously all of a station's equations for all projections. Thus, the equations for one station had the same 10 predictors, regardless of the projection. The coefficients, however, varied from one projection to the next. For IDNOOBS, the same predictors in Table 2 less observations were used. For both IDOBS and IDNOOBS, we also added the first and second harmonics of the day of the year. Note that many more predictors were used in deriving the last two sets of equations compared to the first three. In fact, in deriving IDOBS and IDNOOBS, we screened twice as many predictors for the projections from 6 to 18 h and over three times as many predictors for the 21- and 24-h projections relative to OBS, NOOBS and CUTOFF.

The average standard errors of estimate and reduction of variance for the dependent sample are given in Figure 2. For the first two projections, the forecast equations with observations had much lower standard errors of estimate than those without observations. However, for the projections from 12 to 21 h, the standard errors of all sets tended to converge. This was most noticeable in IDOBS and IDNOOBS. The difference in the standard errors between OBS and IDOBS was small --0.1°F or less for all projections but the last. Intuitively, one expects that deriving the equations simultaneously for all projections would give larger standard errors because the predictors are not all chosen for one specific period. Perhaps, the larger predictor set compensated for the difference in method. Set IDNOOBS had smaller standard errors of estimate than NOOBS at all projections. Presumably, this was due to the added predictors in INDOOBS, particularly the 0000 GMT LFM analyzed surface temperature. Set CUTOFF, where the equations averaged four terms or less, had the largest standard error. For all equation sets, the standard error generally increased with increasing projection, although not monotonically.

The most important predictors are given in Table 3. When observations were screened as possible predictors (OBS, IDOBS), the observed 0300 GMT surface temperature was one of the most important predictors at all projections. This is because persistence is generally a reliable "first guess" for these 3-h forecasts. Regardless of the use of observations, LFM forecasts of the boundary layer potential temperature and the 850-1000-mb thickness were important in all projections of all equation sets. The forecast boundary layer relative humidity and the 1000-mb dew point were also significant predictors in equation sets NOOBS and CUTOFF. In IDNOOBS, the LFM analyzed surface temperature at 0000 GMT was often chosen as a predictor. This field also represents a forecast of persistence.

4. TESTS ON INDEPENDENT DATA

In December 1976, we began using these equations to make forecasts in real time from 0000 GMT LFM data. On a daily basis, we subjectively evaluated the forecasts at a selected group of 20 stations (Figure 3) by using the computer to plot the temperature forecasts at each station as a function of time. As part of this graph, we interpolated the LFM boundary layer potential temperature forecasts to the station of interest. These latter forecasts were not reduced to the surface, but they did indicate what the model was forecasting. The verifying surface observations were also plotted on each graph. We quickly learned that a subjective evaluation was difficult because any one forecast type might be good one day and poor the next. Moreover, the "best" forecast type varied from one station to another on the same day. Nevertheless, we did obtain a feel for the general accuracy of the forecasts.

A series of surface weather maps every 24 h from 1200 GMT on December 12, 1976 through 1200 GMT on December 14, 1976 is shown in Figures 4a, 4b, and 4c. The 0000 GMT surface temperature forecasts from December 13 and verifying observations are shown in Figures 5a and 5b for Buffalo, New York (BUF) and Washington, DC (DCA). By 0000 GMT on December 13 the cold front that was located over Lake Michigan at 1200 GMT on December 12 had moved through Buffalo. Thus, any observations used in the BUF temperature forecast equation represented the new air mass. The potential temperature forecast from the LFM (Figure 5a) indicated the temperature would fall rapidly throughout most of the day. On the other hand, the MOS forecasts realistically predicted that the temperature would decrease rapidly at first before remaining nearly constant most of the day. In this paritcular case, there were only small differences between the various types of MOS forecasts. For station DCA the

LFM output also forecast colder temperatures with time (Figure 5b). The MOS forecasts, however, predicted the observed temperature curve rather well. The best MOS forecast was one produced by set NOOBS which did not have any surface observations as predictors. The forecasts that used the observed surface temperature at 0300 GMT as a predictor were initially too cold and then too warm for the later projections. The IDNOOBS forecasts were similar. The equations that produced these latter forecasts used the analyzed LFM surface temperature at 0000 GMT as a predictor. This is comparable to having the actual station observations.

The December 14 forecasts for BUF and DCA are shown in Figure 6. By this time, the cold front had passed through both stations and the high pressure system behind it moved rapidly offshore. The warming that occurred at BUF (Figure 6a) was accurately forecast by both the LFM model and the MOS guidance. However, the MOS forecasts that used observations were too cold for the first three projections. The MOS guidance for DCA (Figure 6b) reflected the diurnal trend, although the eventual warming was overforecast.

After this experiment ended in early February, we objectively verified all the MOS forecasts. The mean absolute errors for all projections and forecast types are plotted in Figure 7. In addition, the mean algebraic errors and the root mean square errors are summarized in Table 4. On the basis of mean absolute errors, forecast accuracy generally decreased with time, although there was a slight improvement in going from 12 to 15 h and from 21 to 24 h. Set IDOBS was slightly worse than OBS in the projections up to and including 12 h after 0000 GMT. After that time, IDOBS was 0.1° to 0.2°F better in mean absolute error. This improvement was probably due to the additional predictors that were screened for IDOBS. Set OBS had smaller mean absolute errors than NOOBS for all projections. The differences ranged from 0.3°F at 18 h to 1.1°F at 6 h. Station observations, particularly the surface temperature, appeared to be important in producing accurate objective guidance when the model-analyzed surface temperature was not used as a predictor.

Despite the fact that the CUTOFF equations had only four terms or less, the verification scores revealed that there were only small differences (0.1°F or less) in the accuracy of the forecasts made from this set and from the 10-term equations (NOOBS). Apparently the extra predictors in the equations contributed very little to the accuracy of these 3-h temperature forecasts.

Set IDOBS had smaller absolute errors at all projections than IDNOOBS. However, the differences between the two sets became small after the 12-h projection. Note, also, that IDNOOBS provided more accurate guidance than NOOBS at all projections. In addition to the greater number of predictors screened for IDNOOBS, we suspect that by using the analyzed 0000 GMT LFM surface temperature as a predictor in many of the IDNOOBS equations, we may have found an adequate substitution for the surface observation. The analyzed temperature gave a good "first guess" of the observed temperature field.

Since the objective of this experimentation was to obtain an accurate forecast of the diurnal temperature variation, we looked for a verification statistic that might indicate how well we were forecasting temperature change. For each station we computed a type of S1 score (Teweles and Wobus, 1954) that was defined to be $\frac{\sum_{i=1}^{N} |e_{\Delta t}|_i}{\sum_{i=1}^{N} |E_{\Delta t}|_i}$ where $e_{\Delta t}$ is the error in the forecast temperature change between projections, $E_{\Delta t}$ is the maximum of the observed or forecast temperature change between hours, and N is the number of days for which forecasts were made. If we consider time t and time $t + \Delta t$ where $F_t, F_{t+\Delta t}$ are the forecast temperatures at those times, respectively, and O_t, $O_{t+\Delta t}$ are the observed temperatures at the same times, then the S1 score for that one period only is:

$$\frac{|(F_{t+\Delta t} - F_t) - (O_{t+\Delta t} - O_t)|}{\text{maximum } [\,|F_{t+\Delta t} - F_t|\,,\ |O_{t+\Delta t} - O_t|\,]}$$

This score can range from 0 to 2.0 where the lower scores indicate better forecasts of the trend. However, since we conceivably could have a perfect trend score (0) and yet be degrees off in absolute error at both times, a low S1 score by itself is not indicative of a good forecast.

We computed S1 scores for both 3-h (6-9, 9-12, ...) and 6 h (6-12, 9-15,...) periods. The results for all forecast types and periods are given in Table 5. In general, the lowest 3-h S1 scores were obtained in the middle of the day 15-18 h) while the highest scores occurred during the night and around sunrise (6-9, 9-12 h). During the winter it was much more difficult to forecast nighttime temperature trends than daytime variations. The 6-h scores indicated a similar pattern.

In general, those forecasts that used observations (OBS, IDOBS) provided better estimates of temperature trends than corresponding forecasts without observations. Set IDOBS, in which all the forecasts for one station were derived simultaneously, had lower S1 scores at almost all of the 3-h periods than OBS. However, for the 6-h periods, the differences between the two sets were small. While IDOBS also had lower S1 scores than set IDNOOBS, the differences were not large, particularly as the forecast projection increased. These S1 scores seemed to corroborate what we had seen before, namely, that the forecast equations that were derived simultaneously produced as accurate 3-h forecasts as the equations derived individually.

5. USE OF THE 3-HOUR TEMPERATURE FORECASTS

Because of an urgent request from the Eastern Region of the National Weather Service to produce 3-h temperature guidance for help in predicting runoff and potential flooding from snow-melt, we also derived spring (March-May) equations (IDOBS only). From February through May we provided 3-h temperature guidance for 16 stations in the northeastern Unived States. The message containing the forecasts for 12 to 24 h after 0000 GMT was sent to the Boston Weather Service Forecast Office. A sample is shown in Figure 8. Forecasters at the Boston WSFO added forecasts for the 30- and 36-h projections before relaying the revised forecast to the Hartford River Forecast Center.

6. SUMMARY

We derived 3-h temperature forecast equations from 0000 GMT LFM data and tested them on a real-time operational basis from December 1976 to February 1977.

Generally, there were only minor differences in the mean absolute errors when we derived equations with observations either independently from one projection to the next, or simultaneously for all projections. An S1 score for temperature tendency seemed to indicate, however, that the equations developed simultaneously were slightly better for predicting changes in temperatures. Part of this improvement is likely due to the larger predictor list that was screened in the simultaneous development.

The simultaneously derived equations that did not use surface observations had much smaller mean absolute errors than analagous equations derived independently. Again, there were many added predictors in the simultaneous derivations, and we suspect that the 0000 GMT analyzed LFM surface temperature was an important contributor to the overall accuracy of the forecasts. These latter equations also had slightly better S1 scores than the equations developed independently.

7. ACKNOWLEDGMENTS

Many people in the Techniques Development Laboratory contributed to the work described in this paper. We are grateful for their help. We especially thank Mr. Gary Carter and Mr. John Jensenius for their assistance in reviewing the paper and getting it into an acceptable form, Mrs. Anna Booth for drafting the figures, Miss Nancy Harrison for typing the many revisions of the paper, and Miss Barbara Howerton for typing the final manuscript.

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Table 1. Predictors screened for equation sets OBS, NOOBS and CUTOFF. The star (*) indicates the field was smoothed by a five-point filter.

Field	Projection (hours after 0000 GMT)
a) LFM Model Output	
Precipitable water	6,6*,12,12*,18,24
Mean rel hum (1000-490 mb)	6*,12*,18*,24*
Boundary layer potential temp	6,6*,12,12*,18,24
Boundary layer U wind	6,6*,12,12*,18,24
Boundary layer V wind	6,6*,12,12*,18,24
850 mb temperature	6,6*,12,12*,18,24
850 mb U wind	6,6*,12,12*,18,24
850 mb V wind	6,6*,12,12*,18,24
1000 mb dew point	6,6*,12,12*,18,24
Boundary layer rel hum	6*,12*,18*,24*
Layer 1 (1000 mb-720 mb) rel hum	6*,12*,18*,24*
Layer 2 (720 mb-490 mb) rel hum	6*,12*,18*,24*
500-1000 mb thickness	6,6*,12,12*,18,24
500-850 mb thickness	6,6*,12,12*,18,24
850-1000 mb thickness	6,6*,12,12*,18,24
700-1000 mb thickness	6,6*,12,12*,18,24
700-850 mb thickness	6,6*,12,12*,18,24
500-700 mb thickness	6,6*,12,12*,18,24
b) Observations	
Sky Cover	3
Dew Point	3
Temperature	3

Table 2. Predictors screened for equation sets IDOBS and IDNOOBS. All fields were smoothed by a five-point filter.

Field	Projection (hours after 0000 GMT)
a) LFM Model Output	
700 mb height	0,6,12,18,24
850 mb height	0,6,12,18,24
500 mb height	0,6,12,18,24
500-1000 mb thickness	0,6,12,18,24
850-1000 mb thickness	0,6,12,18,24
500-850 mb thickness	0,6,12,18,24
1000 mb rel vort	0,6,12,18,24
850 mb rel vort	0,6,12,18,24
500 mb rel vort	0,6,12,18,24
Precipitable water	6,12,18,24
Surface temperature	0
1000 mb temperature	12,24
850 mb temperature	0,6,12,18,24
700 mb temperature	0,12,24
1000 mb dew point	6,12,18,24
850 mb dew point	12,24
700 mb dew point	12,24
Boundary layer rel hum	0,6,12,18,24
Layer 1 (1000 mb-720 mb) rel hum	0,6,12,18,24
Layer 2 (720 mb-490 mb) rel hum	0,6,12,18,24
Boundary layer pot temp	6,12,18,24
Boundary layer U wind	6,12,18,24
Boundary layer V wind	6,12,18,24
Boundary layer wind speed	6,12,18,24
850 mb U wind	6,12,18,24
850 mb V wind	6,12,18,24
700 mb U wind	12,24
700 mb V wind	12,24
850 mb vertical velocity	12,24
700 mb vertical velocity	6,12,18,24
700-1000 mb temperature	12,24
Mean rel hum (1000-490 mb)	6,12,18,24
Boundary layer wind div	6,12,18,24
b) Trigonometric Terms	
Sine day of year	0
Cosine day of year	0
Sine 2* day of year	0
Cosine 2* day of year	0

Table 2 (continued)

Field	Projection (hours after 0000 GMT)
c) Station Observations	
Ceiling	3
Sky Cover	3
Dew Point	3
Wind Speed	3
U Wind	3
V Wind	3
Temperature	3

Table 3. The three most important predictors used in each of the equation derivations. The ranking is based on both the number of times a predictor was chosen and the order in which it appeared in the equation. The equation sets are identified in Figure 1.

EQUATION SET Proj (h)	OBS	NOOBS	CUTOFF	IDOBS	IDNOOBS
6	Obs Temperature LFM 1000 mb Dew Pt LFM BL Pot Temp	LFM BL Pot Temp LFM 1000 mb Dew Pt LFM 850-1000 mb Th	LFM BL Pot Temp LFM 1000 mb Dew Pt LFM 850-1000 mb Th	Obs Temperature LFM 850-1000 mb Th LFM BL Pot Temp	LFM 850-1000 mb Th LFM BL Pot Temp LFM Sfc Temp
9	Obs Temperature LFM 1000 mb Dew Pt LFM BL Pot Temp	LFM BL Pot Temp LFM 1000 mb Dew Pt LFM 850-1000 mb Th	LFM BL Pot Temp LFM 1000 mb Dew Pt LFM 850-1000 mb Th	Obs Temperature LFM 850-1000 mb Th LFM BL Pot Temp	LFM 850-1000 mb Th LFM BL Pot Temp LFM Sfc Temp
12	Obs Temperature LFM BL Pot Temp LFM 1000 mb Dew Pt	LFM BL Pot Temp LFM 1000 mb Dew Pt LFM 850-1000 mb Th	LFM BL Pot Temp LFM 1000 mb Dew Pt LFM 850-1000 mb Th	Obs Temperature LFM 850-1000 mb Th LFM BL Pot Temp	LFM 850-1000 mb Th LFM BL Pot Temp LFM Sfc Temp
15	LFM BL Pot Temp Obs Temperature LFM 850-1000 mb Th	LFM BL Pot Temp LFM 850-1000 mb Th LFM 1000 mb Dew Pt	LFM BL Pot Temp LFM 850-1000 mb Th LFM 1000 mb Dew Pt	Obs Temperature LFM 850-1000 mb Th LFM BL Pot Temp	LFM 850-1000 mb Th LFM BL Pot Temp LFM Sfc Temp
18	LFM 850-1000 mb Th LFM BL Pot Temp Obs Temperature	LFM 850-1000 mb Th LFM BL Pot Temp LFM BL Rel Hum	LFM 850-1000 mb Th LFM BL Pot Temp LFM BL Rel Hum	Obs Temperature LFM 850-1000 mb Th LFM BL Pot Temp	LFM 850-1000 mb Th LFM BL Pot Temp LFM Sfc Temp
21	Obs Temperature LFM 850-1000 mb Th LFM BL Pot Temp	LFM 850-1000 mb Th LFM BL Pot Temp LFM BL Rel Hum	LFM 850-1000 mb Th LFM BL Pot Temp LFM BL Rel Hum	Obs Temperature LFM 850-1000 mb Th LFM BL Pot Temp	LFM 850-1000 mb Th LFM BL Pot Temp LFM Sfc Temp
24	LFM 850-1000 mb Th Obs Temperature LFM BL Pot Temp	LFM 850-1000 mb Th LFM BL Pot Temp LFM 850 U Wind	LFM 850-1000 mb Th LFM BL Pot Temp LFM 850 mb Temp	Obs Temperature LFM 850-1000 mb Th LFM BL Pot Temp	LFM 850-1000 mb Th LFM BL Pot Temp LFM Sfc Temp

Table 4. Mean absolute errors, mean algebraic errors, and the root mean square errors (all in °F) for the December 1976 - February 1977 test for the five types of temperature forecasts defined in Tables 1 and 2. The forecast projections are hours after 0000 GMT.

Proj (h)	Fcst Type	OBS	NOOBS	CUTOFF	IDOBS	IDNOOBS
6	Mean Abs Error	2.7	3.8	3.9	2.8	3.5
9	Mean Abs Error	3.4	4.1	4.1	3.5	3.9
12	Mean Abs Error	3.8	4.3	4.4	3.9	4.2
15	Mean Abs Error	3.8	4.3	4.3	3.8	3.9
18	Mean Abs Error	3.9	4.2	4.3	3.8	3.8
21	Mean Abs Error	4.1	4.6	4.7	4.0	4.1
24	Mean Abs Error	4.1	4.7	4.7	3.9	4.0
6	Mean Alg Error	1.2	1.5	1.6	1.2	0.8
9	Mean Alg Error	1.3	1.6	1.7	1.3	1.0
12	Mean Alg Error	1.4	1.7	1.8	1.5	1.2
15	Mean Alg Error	1.9	2.3	2.3	1.6	1.4
18	Mean Alg Error	1.6	1.8	1.8	1.0	0.9
21	Mean Alg Error	1.2	1.6	1.6	0.6	0.5
24	Mean Alg Error	1.6	2.1	2.1	0.9	0.9
6	Root Mean Sq Er	3.9	5.1	5.2	3.9	4.7
9	Root Mean Sq Er	4.6	5.3	5.4	4.6	5.1
12	Root Mean Sq Er	5.1	5.7	5.8	5.2	5.5
15	Root Mean Sq Er	5.0	5.6	5.7	4.9	5.1
18	Root Mean Sq Er	5.3	5.6	5.7	5.0	5.1
21	Root Mean Sq Er	5.5	6.2	6.2	5.4	5.5
24	Root Mean Sq Er	5.6	6.3	6.4	5.4	5.5

Table 5. S1 scores for the December 1976-- February 1977 test for the five types of temperature forecasts. The forecast types are defined in Tables 1 and 2. The forecast periods are hours after 0000 GMT.

Type Period (h)	OBS	NOOBS	CUTOFF	IDOBS	IDNOOBS
6 - 9	0.68	0.71	0.74	0.67	0.69
9 - 12	0.74	0.76	0.78	0.72	0.75
12 - 15	0.58	0.60	0.62	0.56	0.57
15 - 18	0.37	0.38	0.39	0.37	0.37
18 - 21	0.52	0.54	0.52	0.47	0.47
21 - 24	0.53	0.54	0.55	0.50	0.51
6 - 12	0.59	0.62	0.64	0.59	0.62
9 - 15	0.58	0.61	0.62	0.58	0.61
12 - 18	0.36	0.38	0.39	0.37	0.37
15 - 21	0.33	0.36	0.36	0.34	0.35
18 - 24	0.58	0.60	0.59	0.56	0.56

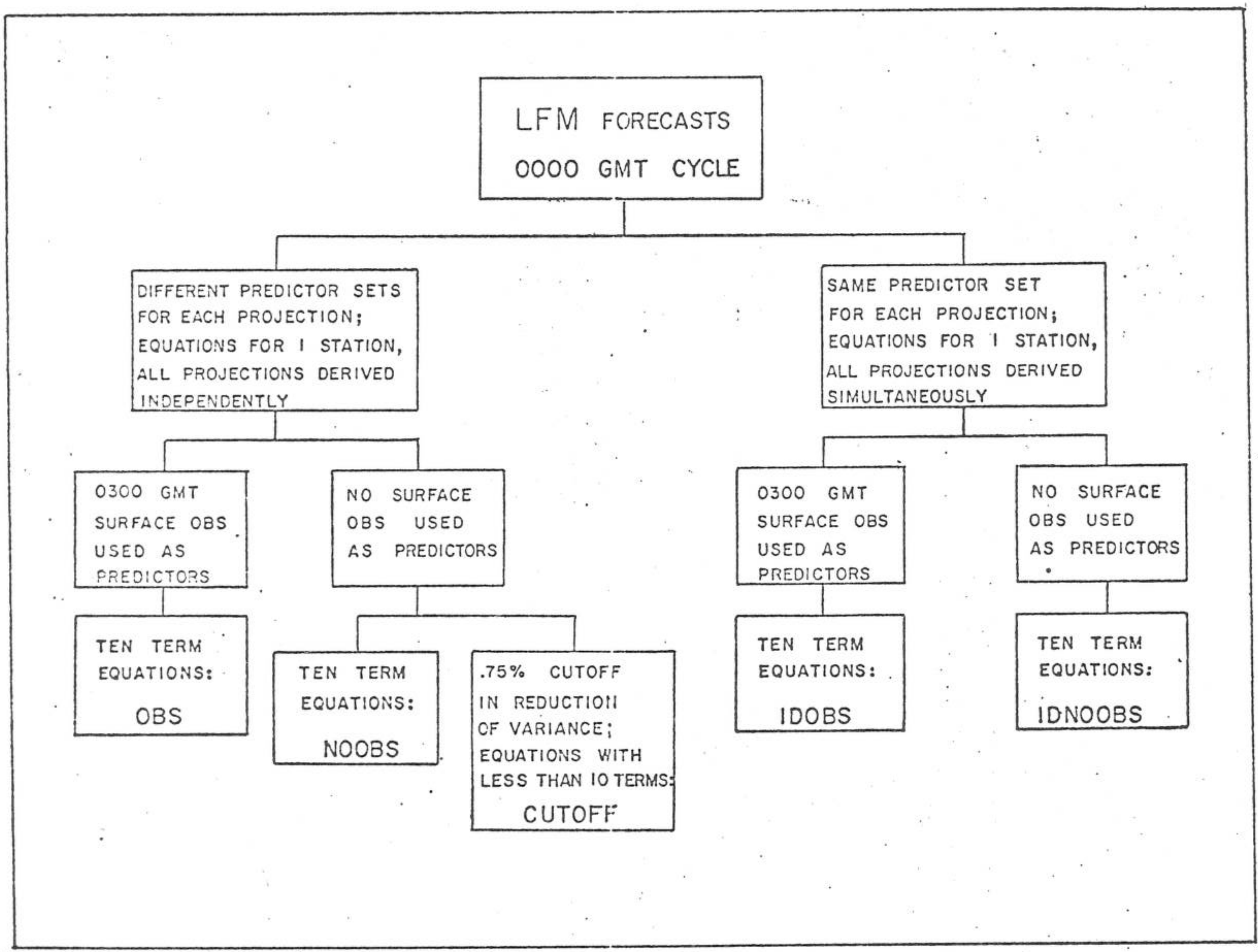


Figure 1. Various experimental equation sets for forecasting surface temperature every 3 h from 6 to 24 h after 0000 GMT.

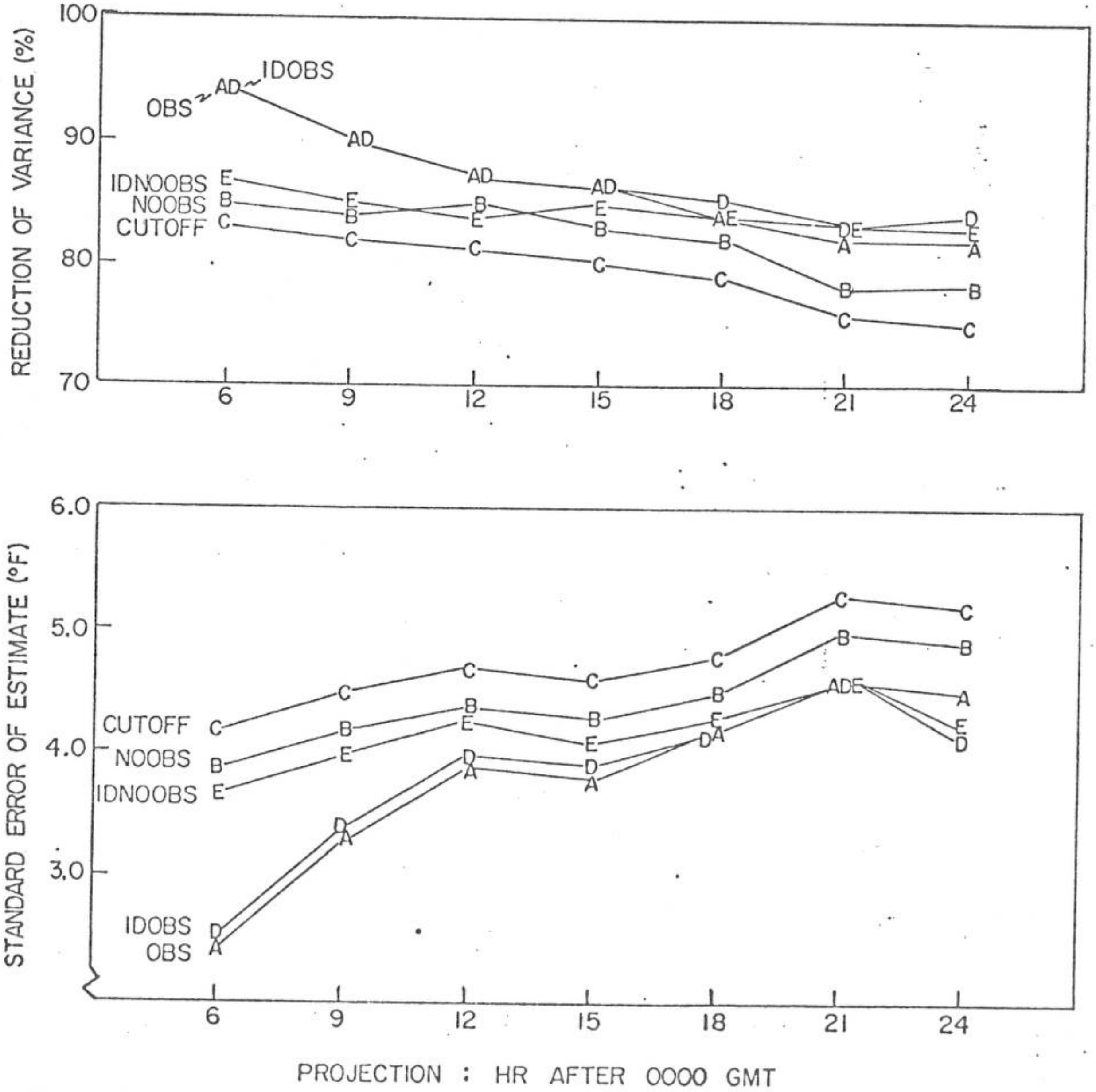


Figure 2. Average standard error of estimate (°F) and reduction of variance (%) as a function of projection for the winter season 3-h temperature equations defined in Fig. 1. The dependent sample consisted of four seasons (1973-76) of data. (Legend: A-OBS; B-NOOBS; C-CUTOFF; D-IDOBS; E-IDNOOBS.)

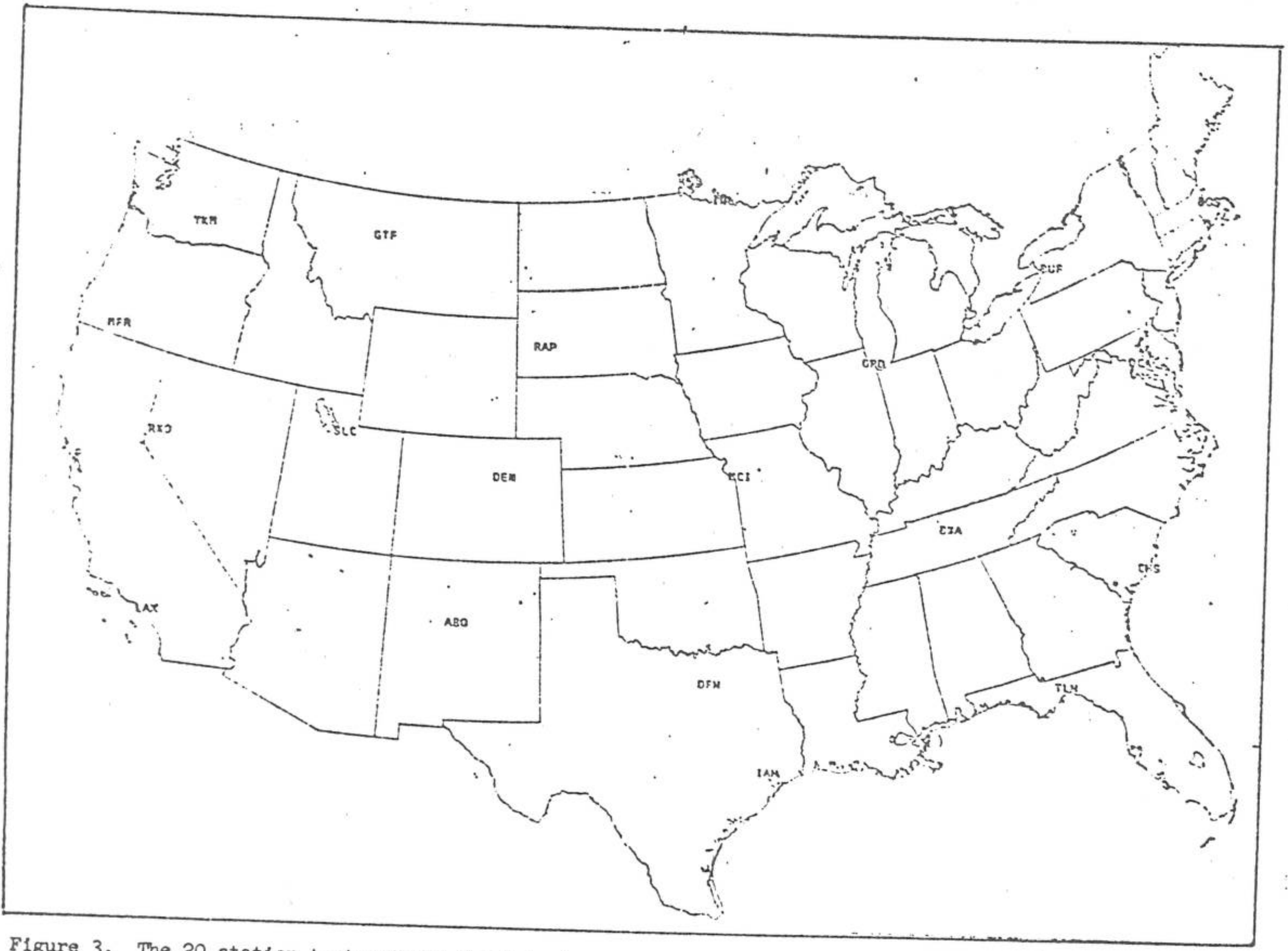


Figure 3. The 20 station test network for 3-h temperature forecast equations.

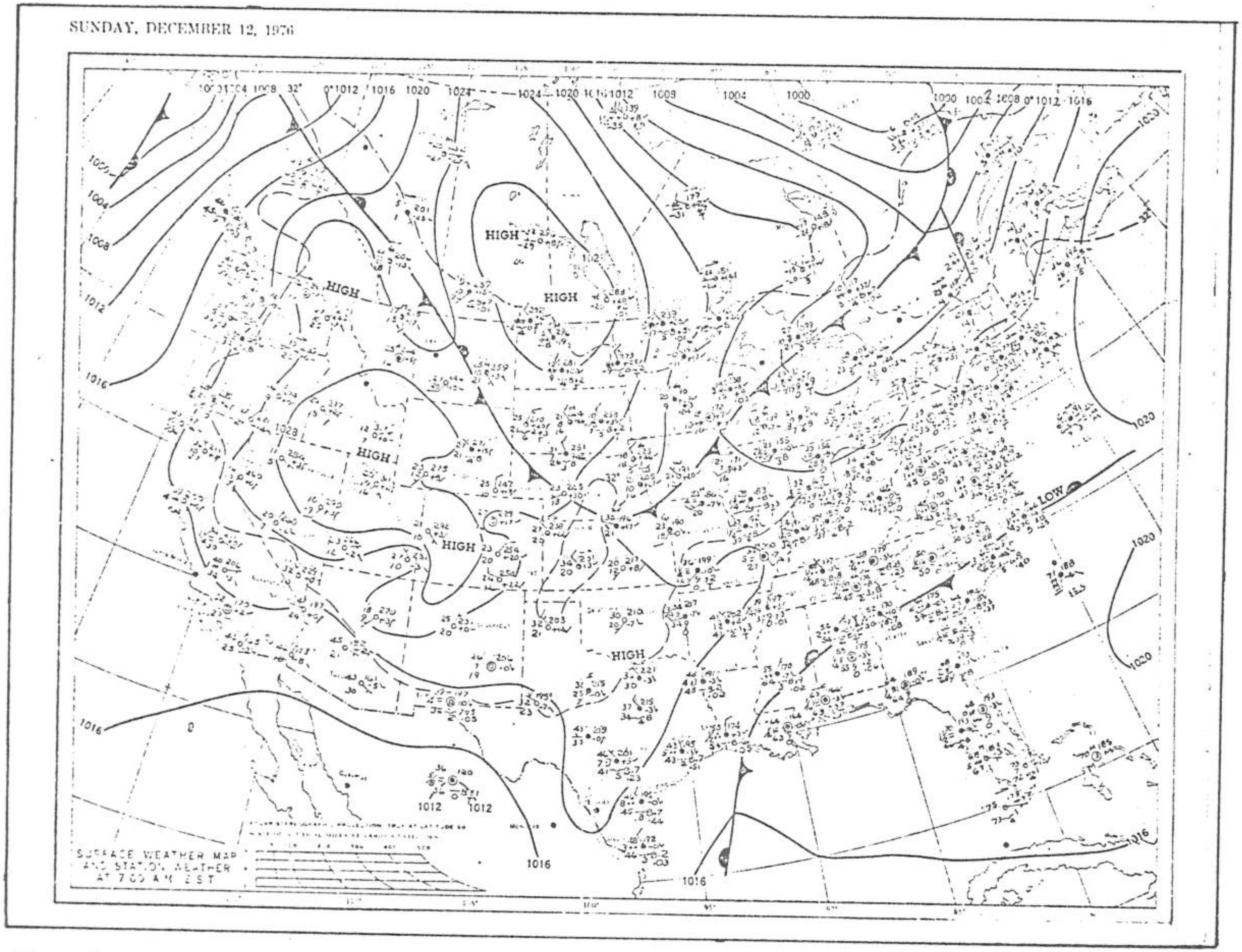


Figure 4a. Surface weather map for 1200 GMT on 12 December 1976.

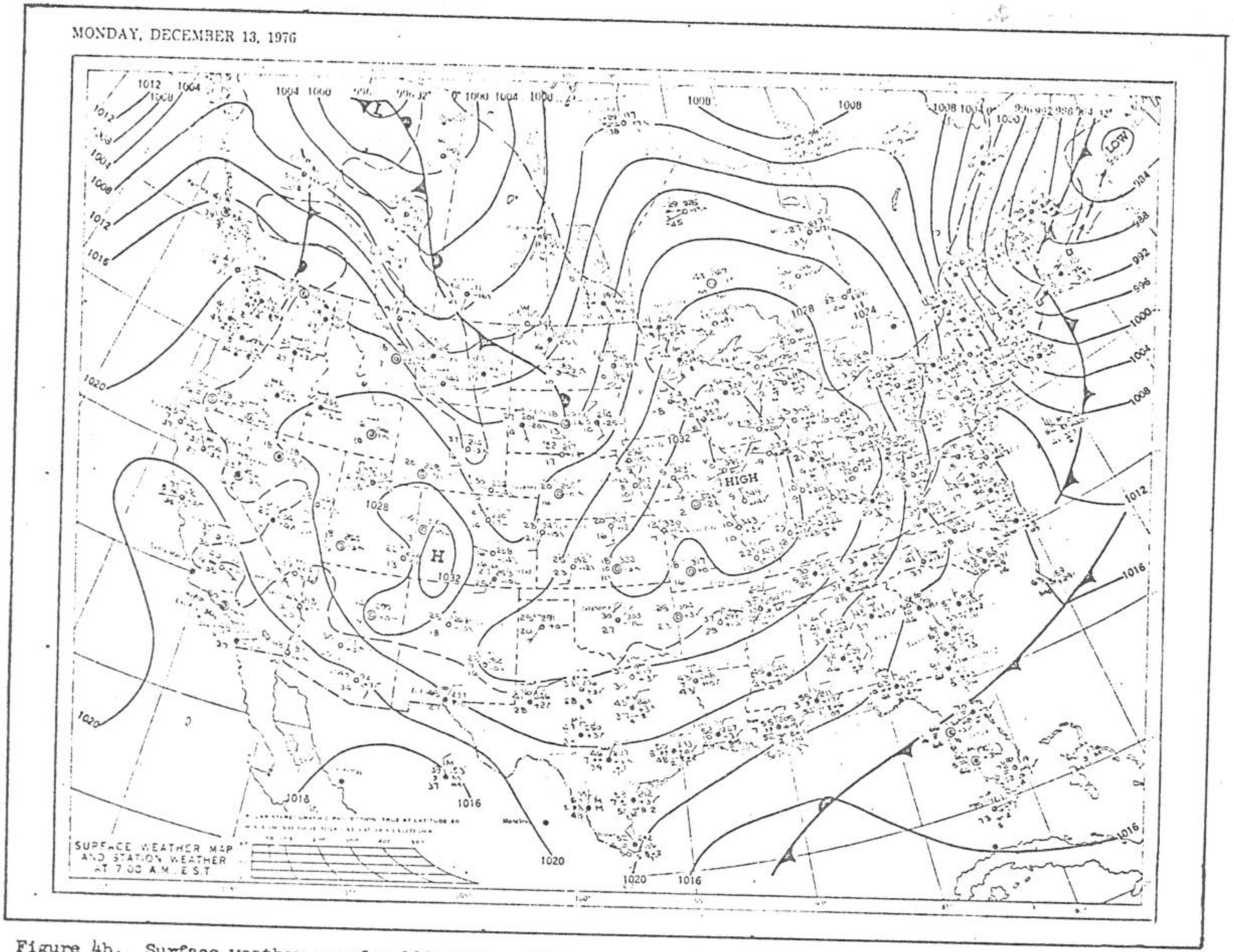


Figure 4b. Surface weather map for 1200 GMT on 13 December 1976.

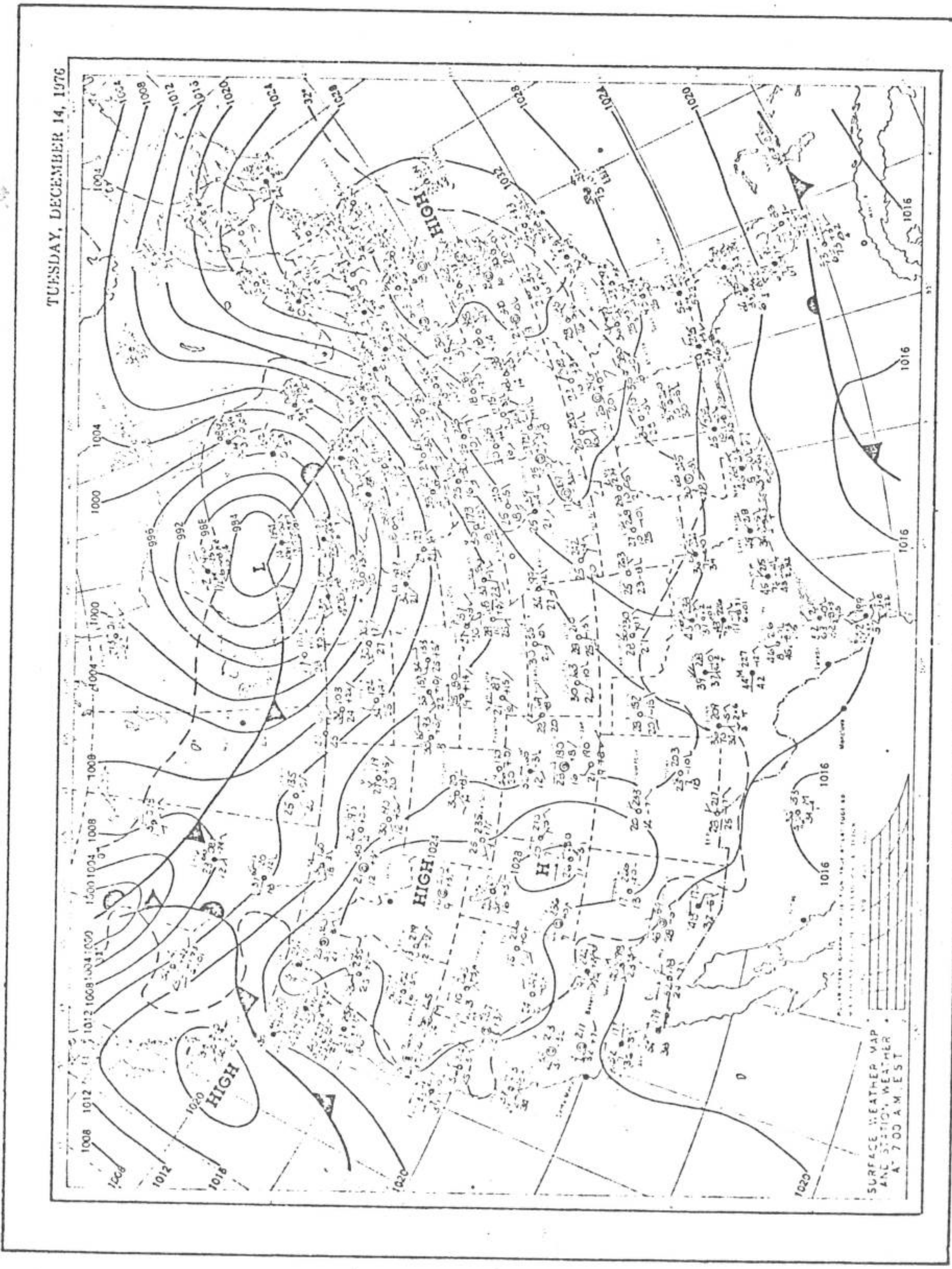


Figure 4c. Surface weather map for 1200 GMT on 14 December 1976.

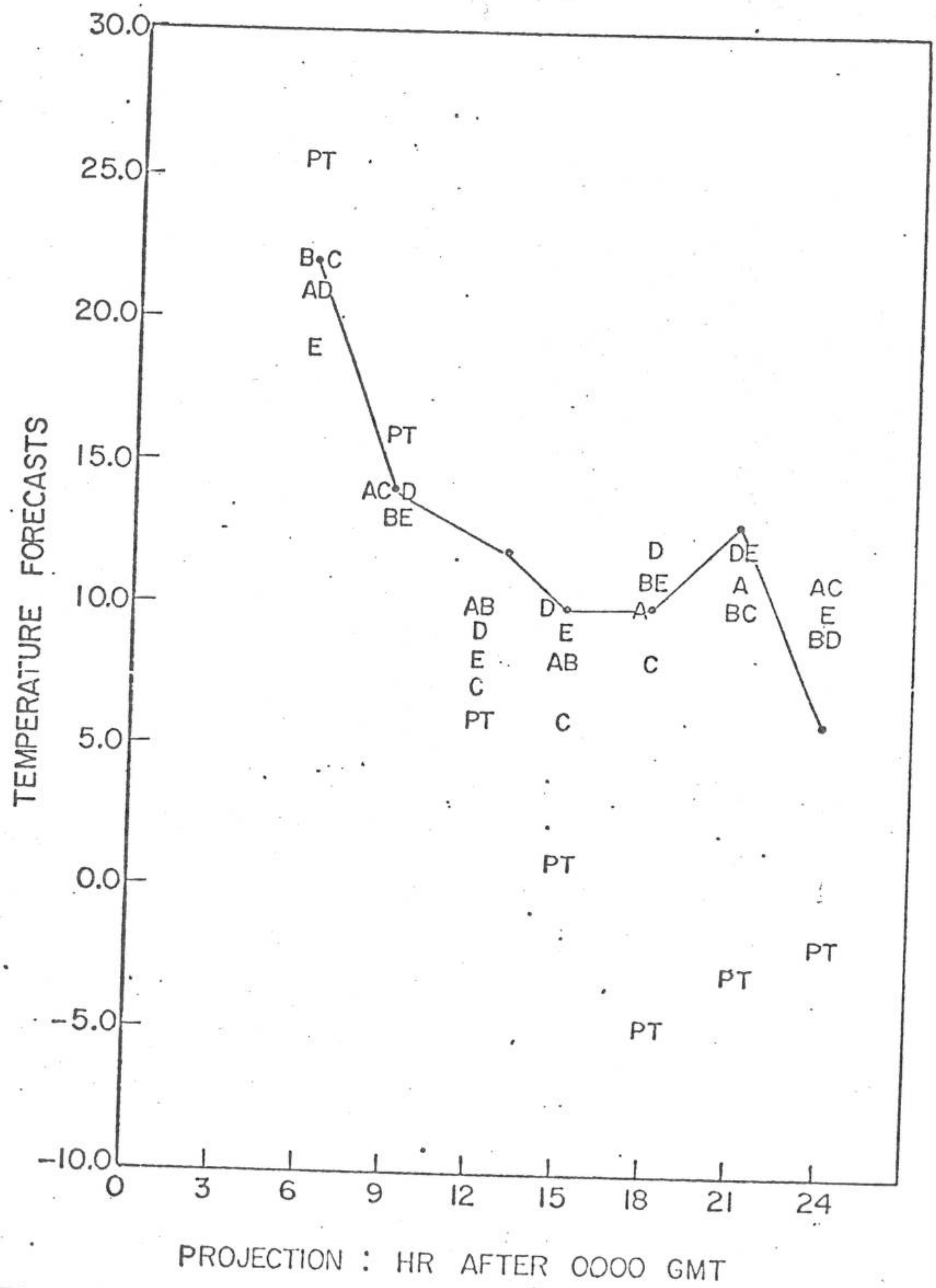


Figure 5a. Sample 3-h temperature forecasts in °F for Buffalo, New York for 13 December 1976. (Legend: A-OBS; B-NOOBS; C-CUTOFF; D-IDOBS; E-IDNOOBS; PT-LFM boundary layer potential temperature forecast; ●-observed surface temperature.)

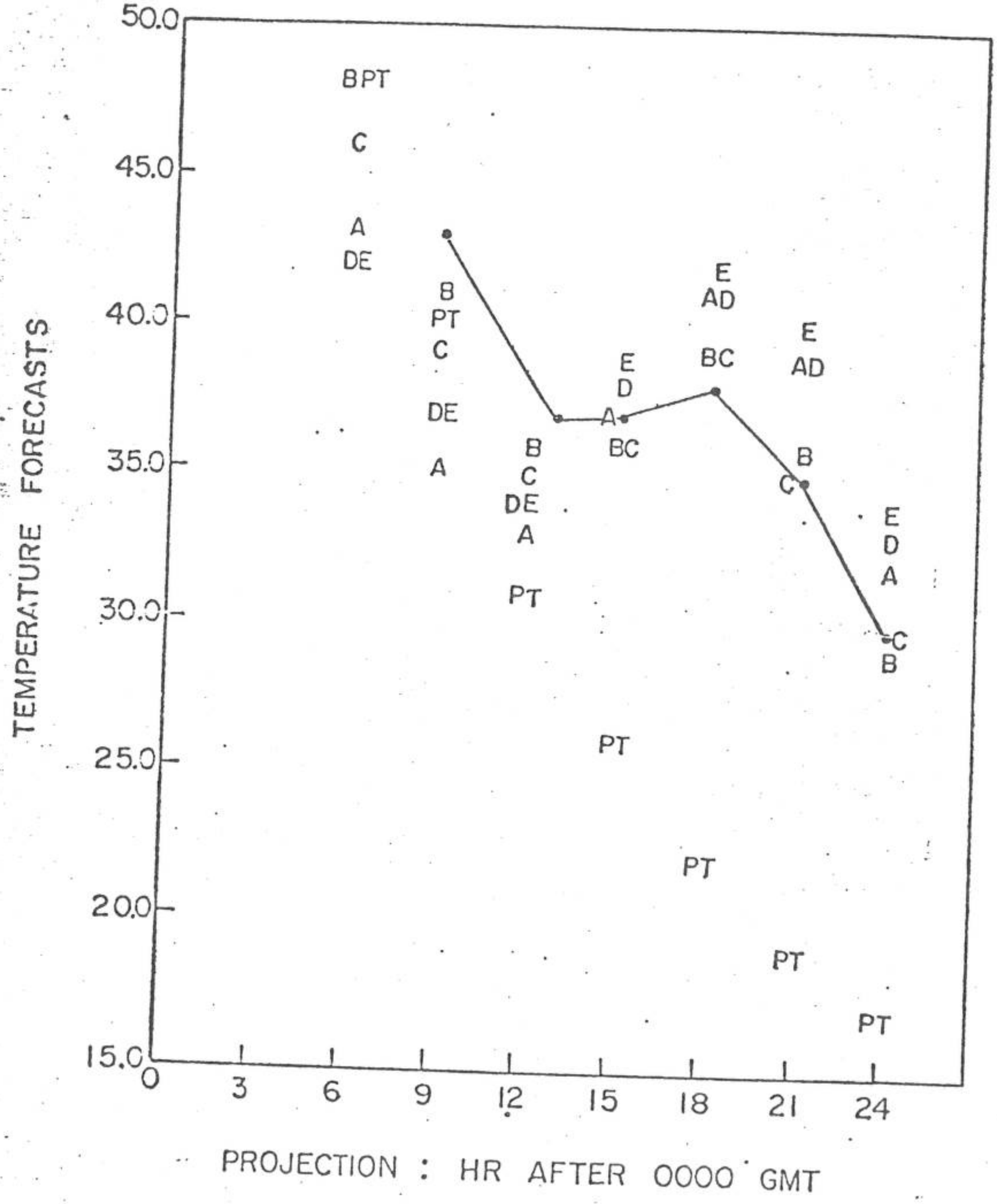


Figure 5b. Same as 5a except for Washington, D.C.

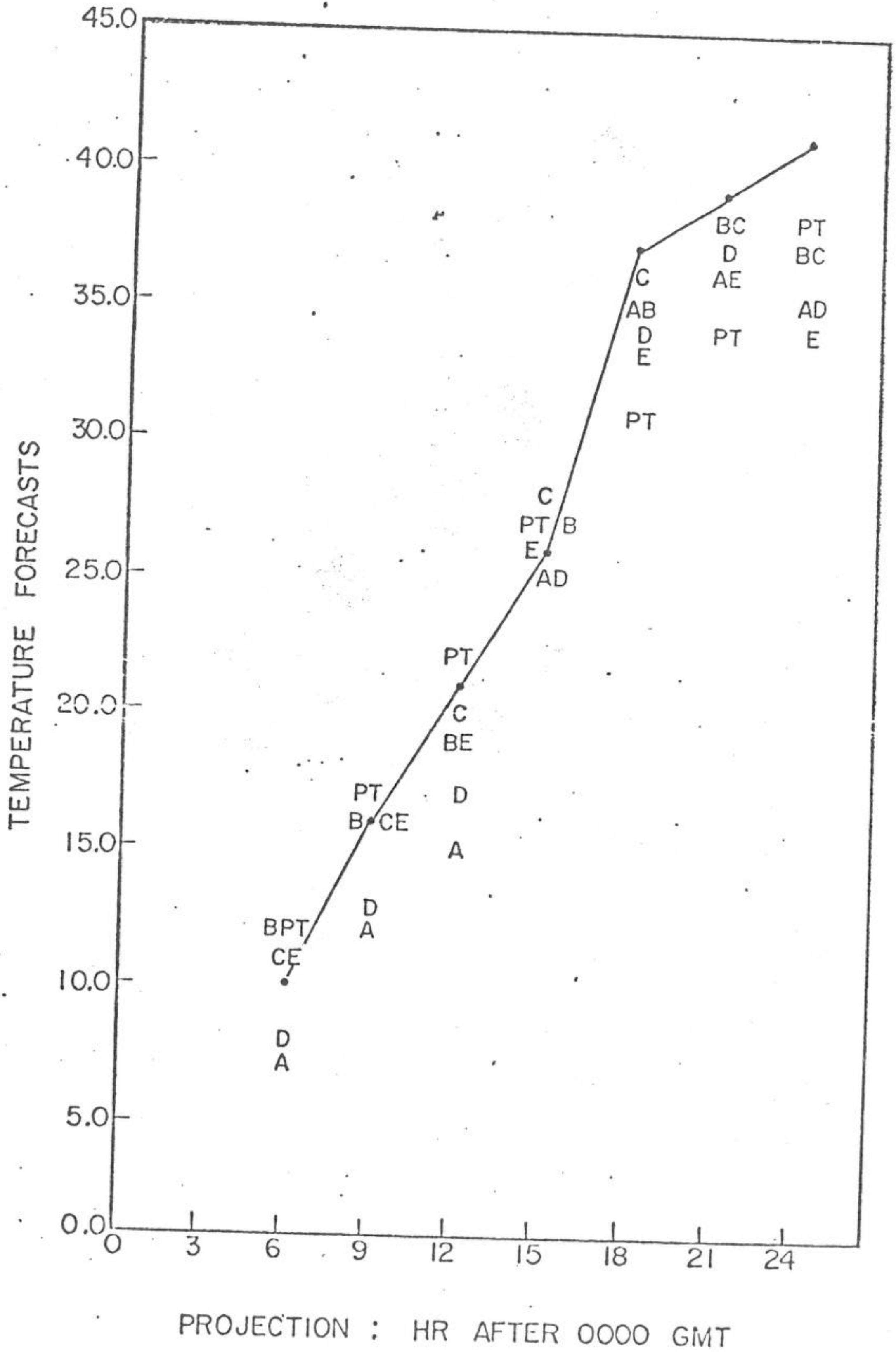


Figure 6a. Same as Fig. 5a except for 14 December 1976.

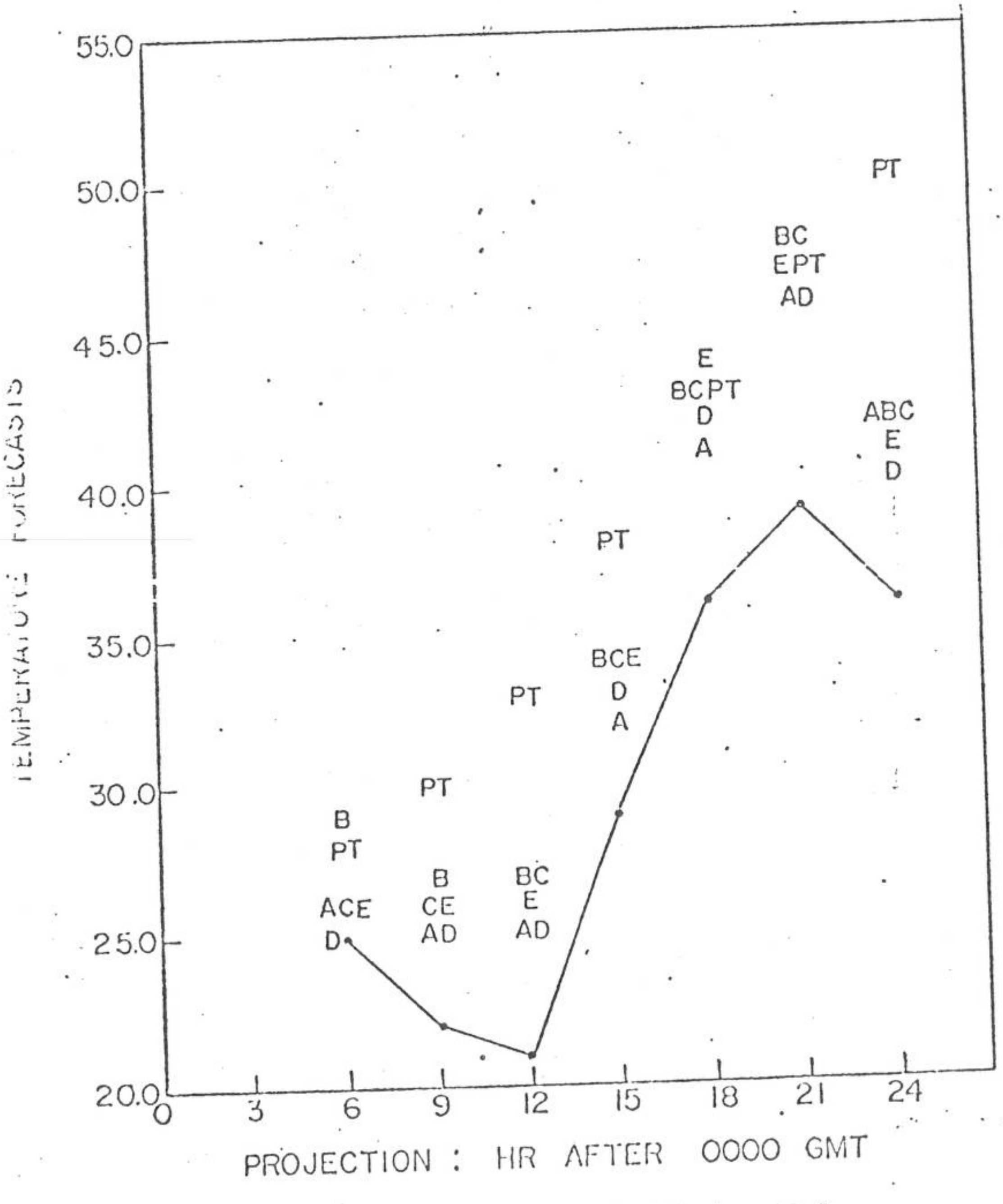


Figure 6b. Same as Fig. 6a except for Washington, D.C.

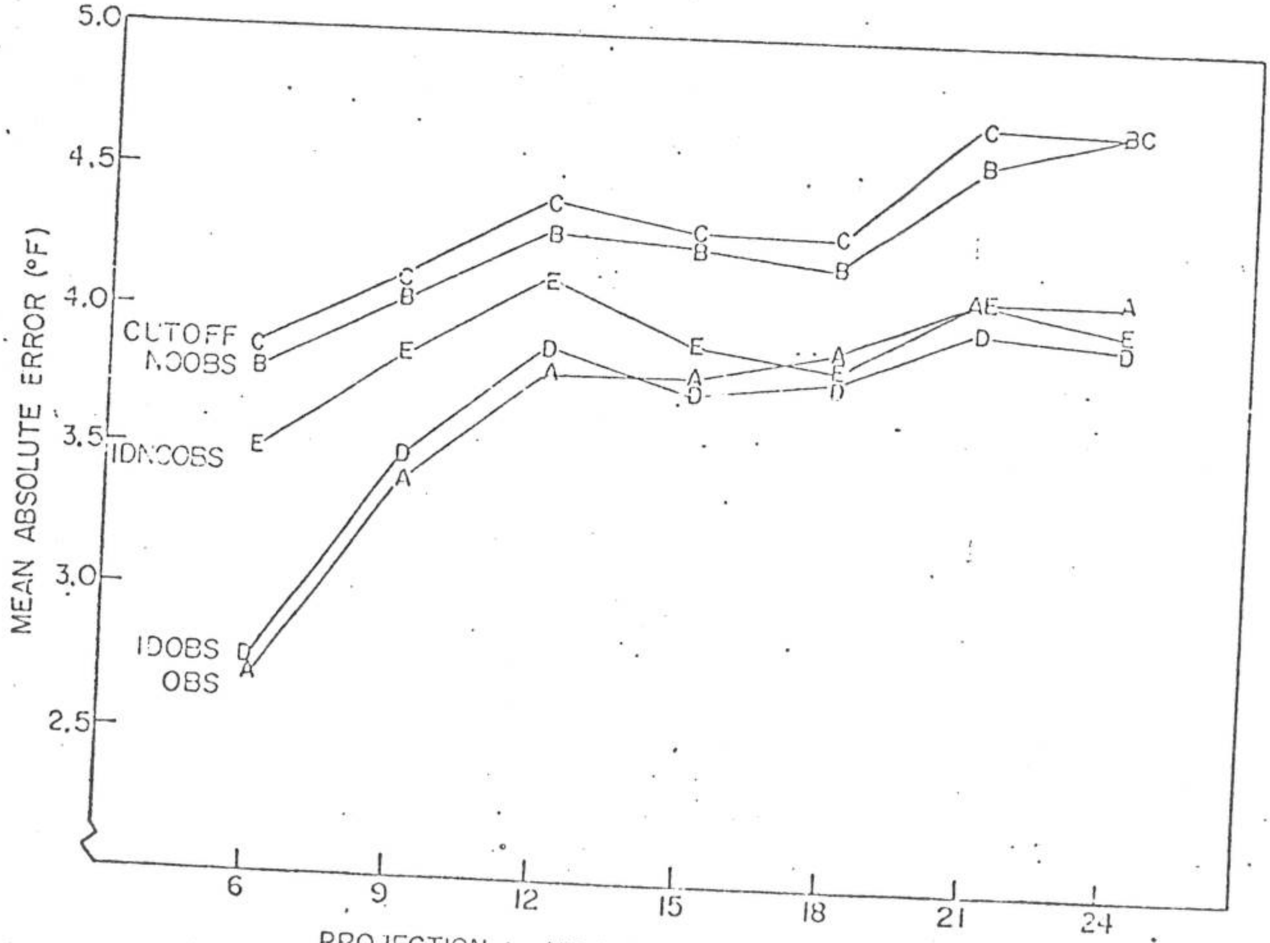
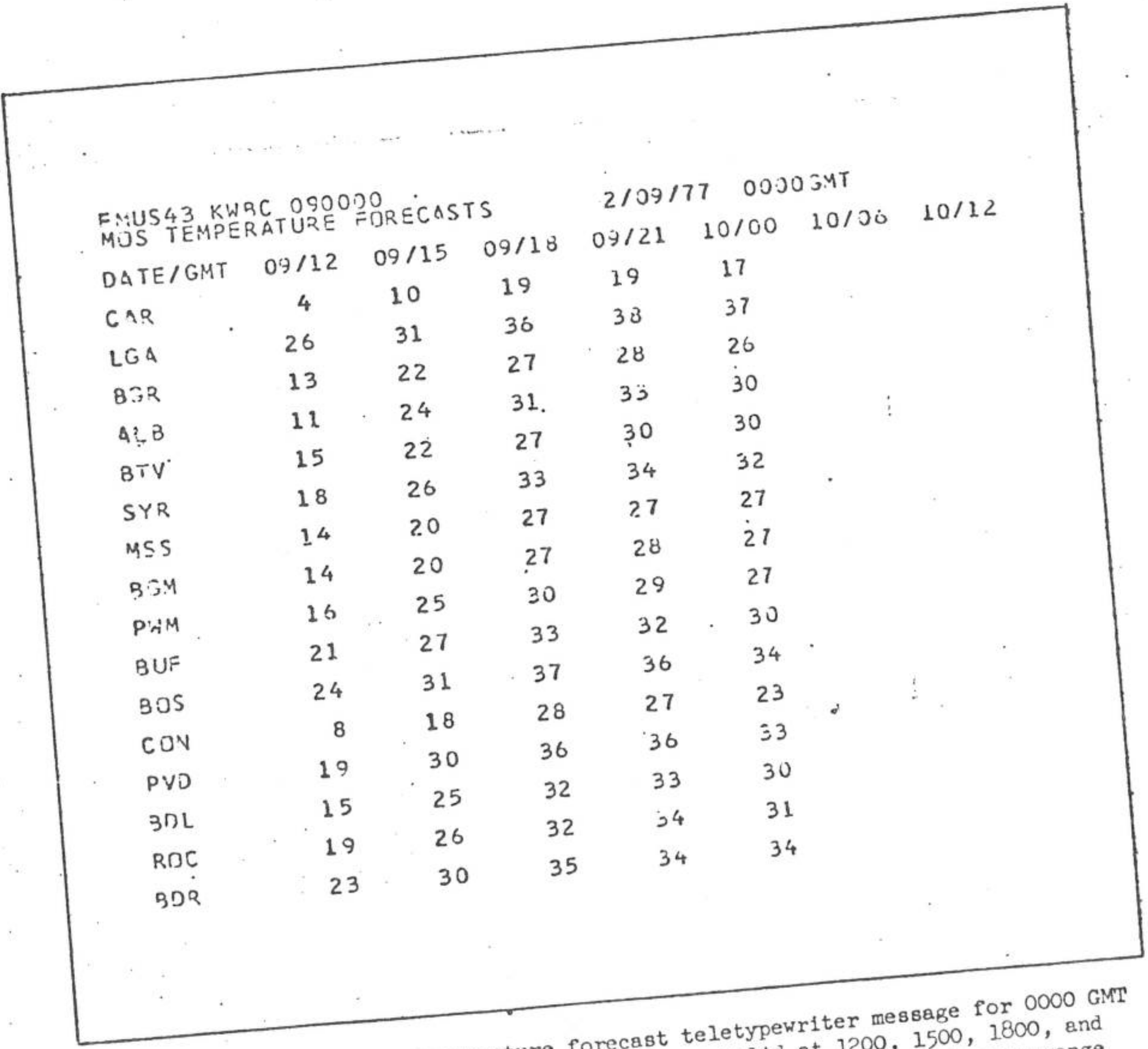


Figure 7. Mean absolute error (°F) as a function of projection for the 3-h temperature forecasts made during December 1976 through February 1977. The various equation sets are described in Fig. 1.



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FMUS43 KWBC 090000                              2/09/77  0000GMT
MOS TEMPERATURE FORECASTS
DATE/GMT  09/12  09/15  09/18  09/21  10/00  10/06  10/12
CAR          4     10     19     19     17
LGA         26     31     36     38     37
BGR         13     22     27     28     26
ALB         11     24     31     33     30
BTV         15     22     27     30     30
SYR         18     26     33     34     32
MSS         14     20     27     27     27
BGM         14     20     27     28     27
PWM         16     25     30     29     27
BUF         21     27     33     32     30
BOS         24     31     37     36     34
CON          8     18     28     27     23
PVD         19     30     36     36     33
BDL         15     25     32     33     30
ROC         19     26     32     34     31
BDR         23     30     35     34     34
```

Figure 8. Sample 3-h temperature forecast teletypewriter message for 0000 GMT on 9 February 1977. These forecasts were valid at 1200, 1500, 1800, and 2100 GMT on 9 February and at 0000 GMT on 10 February. The longer-range forecasts for 0600 GMT and 1200 GMT on 10 February were added at the Boston WSFO before the complete bulletin was relayed to the Hartford River Forecast Center.