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

TDL OFFICE NOTE 79-4

AN OBJECTIVE SCHEME FOR INCLUDING OBSERVED SNOW COVER IN THE MOS TEMPERATURE GUIDANCE

J. Paul Dallavalle and Gary M. Carter

March 1979

AN OBJECTIVE SCHEME FOR INCLUDING OBSERVED SNOW COVER IN THE MOS TEMPERATURE GUIDANCE

J. Paul Dallavalle and Gary M. Carter

I. INTRODUCTION

Since August 1973, the Techniques Development Laboratory (TDL) has produced objective forecasts of the calendar day maximum/minimum temperatures (see Klein and Hammons, 1975) based on application of the Model Output Statistics (MOS) technique (Glahn and Lowry, 1972). These calendar day max/min forecasts are prepared twice daily and are valid approximately 24, 36, 48, and 60 hours after both 0000 GMT and 1200 GMT. Since the first winter of MOS temperature forecasts, studies have shown that the automated guidance for the maximum exhibits a pronounced warm bias when snow is on the ground.[1] This bias is particularly evident at stations where a sporadic snow cover occurs during the winter. Curran and Ostby (1974) studied the bias in the first, second, and third period objective maximum forecasts at four stations in Nebraska and one in South Dakota. They found that the warm bias in the maximum forecasts under snow cover conditions increased as the magnitude of the forecast increased. Thus, the warmer the forecast temperature the greater the average warm bias. Curran and Ostby developed a correction curve that could be applied to the maximum temperature forecasts to improve the bias when snow was on the ground. Dewey (1977) documented a case where a large warm bias was observed in the first period objective maximum and minimum temperature forecasts for an area covering South Dakota, Minnesota, and Wisconsin. This case occurred during March of 1977 when there was extensive snow on the ground in the northern Great Plains and a large anticyclone dominated the region's weather.

The two studies mentioned above concern specific geographical areas. However, the warm bias could readily occur at other locations where snow cover is an intermittent feature during the winter season. Reasoning from principles of physical meteorology, we believe that a maximum over snow would be colder than otherwise expected because of the increased albedo, and because some of the absorbed solar energy is consumed by melting or sublimating snow. Likewise, the minimum over a snow cover might be lower than expected because of the snow's black body radiating properties in the infrared region of the spectrum. This reasoning can, however, be too simplistic if cloud cover or strong winds are involved. For instance, Hughes (1975) studied observed maximum temperatures at Cheyenne, Wyoming when snow cover was present. He found many cases with extremely warm temperatures, due presumably to downslope winds.

---

[1] Bias is defined here as forecast minus observed temperature.

From a statistical point of view, we believe that a warm bias in the objective forecasts would be minimal in a region where snow cover is persistent throughout the winter season. Thus, to correct occasional warm biases in the forecasts, we need to account for the observed snow cover at stations where it is not an everyday feature.

Klein and Marshall (1973) tried screening observed snow cover as a binary predictor in the older perfect prog (Klein and Lewis, 1970) equations. The results, however, were not encouraging. Later, a simple correction involving the observed snow cover at 1200 GMT the previous day and the initial MOS maximum temperature forecast was tested. Correction regression equations for the MOS forecasts of today's maximum from 0000 GMT were developed for seven geographical regions. Only in the central Great Plains was this correction even remotely successful. For this region, the use of snow cover increased the reduction of variance by about 1% for a November to February season. However, correction to the initial MOS forecast was small compared to those proposed by Curran and Ostby (1974). Again, the results were not promising. With the implementation of 3-month winter equations in December 1975 (Hammons et al., 1976), we also thought that the shorter stratification for new equations would overcome the warm bias. Thus, observed snow cover was not used in these MOS temperature prediction equations.

Dallavalle and Hammons (1977) tried to incorporate snow cover into the winter season (December-February) MOS maximum temperature forecasting equations by screening snow cover as a potential binary predictor with cutoff limits of 0, 1, 2, and 5 inches. Equations were developed for 49 stations in the conterminous United States. We tested these on independent data, but again we could find no indication that the use of snow cover improved the forecasts.

We now have completed another test on the snow cover predictor for 20 stations in the Great Plains (Fig. 1). Our primary concern was the forecast of today's max from 0000 GMT for a winter season of January to March. Snow cover was screened as a potential predictor both in binary and "interactive" form. The latter consisted of a combination of snow cover observations and Limited-area Fine Mesh (LFM) model (Gerrity, 1977) forecasts of the boundary layer potential temperature. We experimented with LFM output because we were developing new temperature equations (Carter et al., 1978). This time, our results indicated that observed snow cover, screened as a binary predictor, helped in reducing the warm bias in the temperature forecasts.

II. APPROACH

In our latest derivation of early guidance temperature equations (Carter et al., 1978), we stratified the first period (today's calendar day maximum from 0000 GMT) developmental data into 3-month seasons--winter, spring, summer, and fall. The winter season was defined as January-March, the spring as April-June, and so forth. For the snow cover experiment, we considered only the winter season. There were 6 years (January 1973-March 1978) of developmental data. All model output was taken from the LFM. For the 20 stations shown in Fig. 1, we derived 10-term regression equations through an application of the MOS approach. Briefly, the MOS technique (Glahn and Lowry, 1972) consists of correlating a particular meteorological variable observed at the station of interest with model forecasts interpolated to a station, climatic terms, and station observations. Linear regression equations are obtained via a forward, stepwise screening technique. In our experiments, the predictand was normally the calendar day maximum (today's max) valid approximately 24 hours after 0000 GMT. In one experiment, though, we used nine predictands, namely, the calendar day maximum and the surface temperature observed every 3 hours from 6 to 27 hours after 0000 GMT. We will return to this point later. As our basic set of predictors, we screened a variety of forecast fields from the LFM, four climatic terms, and station observations taken at 0300 GMT. The model fields were interpolated to the individual stations. By screening the predictors shown in Table 1, we obtained a control set of prediction equations. For this set, observed snow cover was not included as a predictor.

Besides the 0000 GMT cycle control equation set, we derived two other types of equations. For the first of these, we screened the snow cover observed at 1200 GMT of the previous morning as a binary predictor, in addition to the predictors given in Table 1. When the snow cover was less than or equal to a specified cutoff value (binary limit), the predictor was given a value of one. When the snow cover exceeded the cutoff value, the predictor was given a value of zero. We experimented with several combinations of binary limits (see Table 2). Snow cover observations at 1200 GMT of the previous day were used as potential predictors because the 1200 GMT snow cover observation is mandated in the synoptic code if snow is on the ground. On the other hand, snow cover observations at 0000 GMT are very sporadic.

For the other equation type, we added an "interactive" quantity as a potential predictor to those shown in Table 1. This term was a function of the observed snow cover at 1200 GMT of the previous day and the 18-h (from 0000 GMT) LFM boundary layer potential temperature forecast. We defined the interactive predictor I as:

$$I = S \times \left[T_1 - \text{minimum}\,(T_1, T_c)\right] , \qquad (1)$$

where S (defined in Table 2) was a function of the observed snow cover, T_1 was the 18-h LFM boundary layer potential temperature forecast (K), and T_c was some cutoff value of the boundary layer potential temperature forecast (for example, 268 K). The "minimum" term was equal to T_1 or T_c, according to which quantity was less. Thus, if T_c exceeded T_1, the quantity in brackets equaled zero. Accordingly, the predictor I was always a nonnegative quantity. Note that either S or T_c could be altered in an experiment. Table 2 summarizes the interactive predictors that we tested. In general, as the snow depth increased, the predictor I also increased. Likewise, as forecasts in the boundary layer exceeded T_c by a larger amount, the interactive term increased. In this manner, we wanted to increase the correction to the objective maximum temperature forecast as either the boundary layer warmed or the snow deepened. Fig. 2 shows the value of I for interactive tests D, E, and F (Table 2). The S quantity in Table 2 may seem arbitrary; the functional values were actually derived from the snow cover code that TDL uses in its operational work. Table 3 lists these particular codes and the corresponding snow cover amounts.

After the various sets of equations were developed, we used them to make forecasts on the developmental sample. We then examined the algebraic errors (forecast-observed), according to categories of observed snow cover amount, to determine if the forecast bias had improved when snow cover was used in the prediction equations. Due to the relative scarcity of snow cover reports even in the developmental sample, we did not attempt to conduct tests on independent data.

III. RESULTS

For each of the various tests and the control set, the average standard error of estimate, the average reduction of variance, and the number of stations containing a snow cover term are shown in Table 4. We also included the average standard error of estimate and reduction of variance for an additional equation set. This set of equations was derived by screening simultaneously nine predictands: the surface temperatures valid every 3 hours from 6 to 27 hours after 0000 GMT and the first day's calendar-day max. This was identical to the procedure for deriving the new max/min guidance. In this way, we could determine whether our test results were representative. As Table 4 indicates, there was little difference in the standard errors among the various sets of equations. In fact, the improvement from using a snow cover predictor did not exceed 0.13°F when equations for only one predictand were derived. The variation among the different forms of snow cover predictors was extremely small, though binary predictor type A gave the smallest standard error of estimate. If these small variations permit generalizations about the interactive predictor, it appears that varying the snow cover function caused little or no change in the standard error. However, modifying the cutoff value of the boundary layer potential temperature seemed to affect the standard error somewhat. The lowest cutoff value (268.15 K) gave the best results. Note that the simultaneous derivation added about 0.22°F to the standard error of estimate--an indication that equations with more than 10 terms might be necessary.

Examining individual equations, we found that the binary snow cover term was occasionally picked as the second predictor. The interactive snow cover was never picked higher than third by the screening procedure. In the simultaneous derivation, the binary snow cover predictor decreased in importance, never being picked higher than sixth in any equation.

After deriving these various types of equations, we used them to make forecasts on the developmental sample. Algebraic errors, categorized by snow cover amounts, were considered. Naturally, the algebraic error over the entire sample was 0.0°F, but in any one category of snow cover there were substantial biases. In Table 5, the algebraic errors are listed as a function of observed snow cover for several of the equation sets: the control set which does not use snow cover as a predictor, the type C binary, the type D interactive, and the simultaneously derived group. Though we have not listed the contingency tables for the other equation sets, they were quite similar to the binary or interactive counterpart shown here.

When snow cover observations were not used as predictors, note that there were more large positive errors ($\geq$6°F) than large negative errors ($\leq$-6°F) if the snow cover exceeded 1 inch. In short, there was a distinct warm bias when snow cover was observed. Likewise, there were more large negative errors than large positive ones when no snow cover or only a trace was observed at 1200 GMT. Table 6 is an abbreviated version of Table 5 that clearly illustrates this point.

When we used snow cover as a binary predictor, the error distributions (Table 5) were better balanced between cold and warm biases for snow cover and no snow cover observations. The interactive snow cover predictor gave a similar redistribution of the errors although the overall effect was not as great as with the binary snow cover predictor. Note that using the snow cover observations as a binary predictor for the nine predictand screening also improved the warm bias when there was a snow cover. The results, however, were not quite as dramatic as for the single predictand case. Again, Table 6 gives a succinct summary of these results. It should be noted that the developmental sample was marginally different for the various derivations, usually differing by no more than five or six cases.

These tables refer, of course, to the 20 station sample. A look at contingency tables for individual stations (not shown) indicated that these corrections to the error distributions occurred at all the stations where snow cover was chosen as a predictor. In other words, when no snow or a trace was observed, the snow cover predictor increased the number of forecasts with a warm bias. When snow cover of an inch or more was reported, fewer forecasts with a warm bias were observed in the developmental sample. Thus, the error distribution became more symmetrical.

The equation to predict the 24-h max from 0000 GMT for Omaha, Nebraska is shown in Table 7. This equation was derived simultaneously with the 3-h temperature forecast equations valid every 3 hours from 6 to 27 hours after 0000 GMT. Snow cover was chosen as a binary predictor. In this instance, if the snow cover was zero or a trace, the binary predictor was given the value of one. Then, the regression coefficient effectively added about $4^{\circ}F$ to the forecast. On the other hand, if the snow cover was equal to 1 inch or more, the binary predictor equaled zero and the regression coefficient added nothing to the forecast. In essence, however, this was equivalent to subtracting about $4^{\circ}F$ from a forecast that would be obtained under identical model conditions when no snow cover was reported. For all stations in this test, the effect was similar whenever the binary snow cover predictor was chosen as a term in the regression equation; the regression coefficient was always positive. Thus, when the snow depth exceeded a certain cutoff value, a few degrees were effectively subtracted from the max forecast.

IV. CONCLUSIONS

Our snow cover predictor tests showed that the standard errors of estimate varied little among the various equation sets. However, the binary snow cover predictor gave the best error distribution when the equations were used to make forecasts on the developmental sample. For this reason, we decided to use snow cover as a binary predictor (type C in Table 2) in the derivation of the new LFM-based cool season max/min forecast equations. We are, however, somewhat concerned since the equations in our experiment were never tested on independent data. There is the possibility that if the winter were abnormally cold and dry we could have a large warm bias since the equations would constantly add a fixed amount to the forecast. Alternately, if the winter were unusually warm (but below $32^{\circ}F$) and wet, we might exhibit a large cold bias because the equations would consistently subtract a fixed amount from the forecast. Naturally, we'll closely monitor the operational forecasts during the coming winter.

We were, of course, somewhat disappointed by the failure of the interactive predictor to give better results. It is certainly more appealing from a scientific viewpoint to change the correction term as the general temperature conditions in the boundary layer change. Additionally, the radiative effects of snow cover vary as the cloud cover ranges from clear to overcast. The binary predictor is limited in operations since it does not account for these changes. In the future, we plan to experiment with a snow cover predictor that will be a function of observed snow cover and the model forecasts of relative humidity and temperature.

ACKNOWLEDGMENTS

Many people are involved in making the MOS system work. We are grateful for their efforts. In addition, we want to thank Mrs. Elizabeth Booth for her assistance in drafting the diagrams and Ms. Nancy Harrison for typing the manuscript.

REFERENCES

Carter, G. M., A. L. Forst, W. H. Klein, and J. P. Dallavalle, 1978: Improved automated forecasts of maximum/minimum and 3-hourly temperatures. Preprints Conference on Weather Forecasting and Analysis and Aviation Meteorology, October 1978, Silver Spring, Md., Amer. Meteor. Soc., 171-178.

Curran, J. T., and F. P. Ostby, 1974: Bias of NMC objective surface temperature forecasts. Central Region Tech. Attachment 74-1, National Weather Service, Kansas City, Mo., 4 pp.

Dallavalle, J. P., and G. A. Hammons, 1977: Tests on various predictor lists used in development of maximum/minimum forecast equations. TDL Office Note 77-19, National Weather Service, NOAA, U.S. Department of Commerce, 16 pp.

Dewey, K. F., 1977: Daily maximum and minimum temperature forecasts and the influence of snow cover. Mon. Wea. Rev., 105, 1594-1597.

Gerrity, J. F., 1977: The LFM model-1976: A documentation. NOAA Technical Memorandum NWS NMC 60, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 68 pp.

Glahn, H. R., and D. A. Lowry, 1972: The use of Model Output Statistics (MOS) in objective weather forecasting. J. Appl. Meteor., 11, 1203-1211.

Hammons, G. A., J. P. Dallavalle, and W. H. Klein, 1976: Automated temperature guidance based on three-month seasons. Mon. Wea. Rev., 104, 1557-1564.

Hughes, L. A., 1975: Maximum temperature over snow - Cheyenne. Central Region Tech. Attachment 75-5, National Weather Service, Kansas City, Mo., 2 pp.

Klein, W. H., and F. Lewis, 1970: Computer forecasts of maximum and minimum temperatures. J. Appl. Meteor., 9, 350-359.

_____, and F. Marshall, 1973: Screening improved predictors for automated max/min temperature forecasting. Preprints Third Conference on Probability and Statistics, Boulder, Co., Amer. Meteor. Soc., 36-43.

_____, and G. A. Hammons, 1975: Maximum/minimum temperature forecasts based on model output statistics. Mon. Wea. Rev., 103, 796-806.

Table 1. Predictors used in deriving the control equations for the snow cover test. When observed snow cover was used as a predictor, it was added to this basic list. All model output was taken from the LFM. The * indicates that the model output field was smoothed by a five-point filter. The projection refers to hours after 0000 GMT.

Predictor Type	Projection
Model Forecasts	
1000-mb height	12*,24*
850-mb height	12,24
500-mb height	12,24
500-1000 mb thickness	12,18,24
850-1000 mb thickness	12,18,24
500-850 mb thickness	12,18,24
1000-mb temperature	12*,24*
850-mb temperature	12,18,24
700-mb temperature	12,24
Boundary layer potential temperature[1]	12,18 ,24
Boundary layer u wind	12,18*,24*
Boundary layer v wind	12,18*,24*
Boundary layer wind speed	12,18*,24*
850-mb u wind	12,18*,24*
850-mb v wind	12,18*,24*
700-mb u wind	12,24*
700-mb v wind	12,24*
850-mb relative vorticity	12*,18*,24*
500-mb relative vorticity	12*,24*
850-mb vertical velocity	12*,24*
700-mb vertical velocity	12*,24*
Stability (700-1000 mb temperature)	12,24
Stability (500-850 mb temperature)	12,24
Boundary layer relative humidity	12*,18*,24*
Mean relative humidity (490-1000 mb)	12*,18*,24*
Precipitable water	12*,18*,24*
1000-mb dew point	12*,18*,24*
850-mb dew point	12*,24*
700-mb dew point	12*,24*
Boundary layer wind divergence	12*,18*,24*
850-mb temperature advection	12*,24*
500-mb vorticity advection	12*,24*
Climatic Terms	
Sine day of year	0
Cosine day of year	0
Sine twice day of year	0
Cosine twice day of year	0
Station Observations	
Surface temperature	0,3
Ceiling (binary cutoff of 10000 ft)	3
Sky cover	3
Surface dew point	3
Surface wind speed	3
Surface u wind	3
Surface v wind	3

[1]Because of programming considerations, when we included snow cover as an interactive predictor, we screened the five-point smoothed, 18-h projection of the boundary layer potential temperature rather than the unsmoothed value.

Table 2. Summary of experiments for screening snow cover as a predictor in forecasting the calendar day maximum valid approximately 24 hours after 0000 GMT. See equation 1 in the text for the definition of the binary and interactive predictors.

	Predictor Type	Snow Cover Amounts (Limits if Binary Predictor)	Snow Cover Function S for Interactive Predictor
A)	Binary	Trace, 1 inch, 2 inches	-
B)	Binary	1 inch, 5 inches	-
C)	Binary	Trace, 1 inch, 2 inches, 5 inches	-
D)	Interactive (T_c=268.15 K	None or trace 1 inch 2 inches or more	0 1 2
E)	Interactive (T_c=273.15 K)	None or trace 1 inch 2 inches or more	0 1 2
F)	Interactive (T_c=278.15 K)	None or trace 1 inch 2 inches or more	0 1 2
G)	Interactive (T_c=273.15 K)	None or trace Between 1 and 4 inches 5 inches or more	0 $(\text{snow cover})^{1/2}$ 2
H)	Interactive (T_c=273.15 K)	None or trace Between 1 and 5 inches 6-10 inches 11-20 inches 21 inches or more	0 $(\text{snow cover})^{1/2}$ $(6)^{1/2}$ $(7)^{1/2}$ $(8)^{1/2}$
I)	Interactive (T_c=278.15 K)	None or trace Between 1 and 5 inches 6-10 inches 11-20 inches 21 inches or more	0 $(\text{snow cover})^{1/2}$ $(6)^{1/2}$ $(7)^{1/2}$ $(8)^{1/2}$

Table 3. Observed snow cover amounts and the corresponding TDL code.

Snow Cover Amount	TDL Code
None	0
Trace	1
1 inch	2
2 inches	3
3 inches	4
4 inches	5
5 inches	6
6-10 inches	7
11-20 inches	8
Greater than 20 inches	9

Table 4. Average standard error of estimate and reduction of variance of the developmental sample for the 20 stations used in the snow cover experiment. The number of stations that picked snow cover as a predictor is also included.

Equation Type	Standard Error Of Estimate (°F)	Reduction Of Variance (%)	Number of Stations Using Snow Cover
Control Set (no snow cover)	4.72	90.6	--
Binary Set A (Table 2)	4.59	91.1	19
Binary Set B (Table 2)	4.62	91.0	19
Binary Set C (Table 2)	4.60	91.1	19
Interactive Set D (Table 2)	4.61	91.0	18
Interactive Set E (Table 2)	4.63	91.0	16
Interactive Set F (Table 2)	4.65	90.9	13
Interactive Set G (Table 2)	4.63	91.0	17
Interactive Set H (Table 2)	4.62	91.0	17
Interactive Set I (Table 2)	4.65	90.9	15
Simultaneous derivation for 9 predictands; otherwise, same as set C	4.82	90.2	15

Table 5. Contingency tables of algebraic errors (forecast-observed) for today's max temperature forecast from 0000 GMT model data versus the 1200 GMT snow cover observation from the previous day. Forecasts were made for 20 stations on the developmental winter sample of January 1973 through March 1978. The equation types are described in the text and in Table 2.

Errors (°F)	OBS SNOW COVER			Errors (°F)	OBS SNOW COVER		
	< 1 inch	1 to 5 inches	≥ 5 inches		< 1 inch	1 to 5 inches	≥ 5 inches
Control Set				Set C			
< -15	13	8	0	< -15	11	7	2
-6 to -15	817	174	46	-6 to -15	679	249	58
-1 to -5	2083	761	262	-1 to -5	1977	872	346
0	527	245	108	0	497	265	114
1 to 5	1673	1039	507	1 to 5	1835	931	468
6 to 15	504	320	146	6 to 15	618	223	81
≥ 15	16	6	0	≥ 15	16	6	0
Set D				Simlt. Derv.			
< -15	9	9	0	< -15	14	9	3
-6 to -15	709	235	45	-6 to -15	749	252	59
-1 to -5	2050	875	290	-1 to -5	1940	845	309
0	474	239	105	0	485	232	102
1 to 5	1808	962	516	1 to 5	1737	957	478
6 to 15	562	231	112	6 to 15	625	251	117
≥ 15	21	2	1	≥ 15	29	4	1

Table 6. Abbreviated contingency table from the same data given in Table 5. The equation types are described in the text and in Table 2.

Errors (^oF)	OBS SNOW COVER		Errors (^oF)	OBS SNOW COVER	
	$<$ 1 inch	$\geq$1 inch		$<$1 inch	$\geq$1 inch
Control Set			Set C		
$\leq$ -6	830	228	$\leq$ -6	690	316
-5 to +5	4283	2922	-5 to +5	4309	2996
$\geq$ 6	520	472	$\geq$ 6	634	310
Set D			Simlt. Derv.		
$\leq$ -6	718	289	$\leq$ -6	763	323
-5 to +5	4332	2987	-5 to +5	4162	2923
$\geq$ 6	583	346	$\geq$ 6	654	373

Table 7. Sample equation to predict today's max (^{o}F) at Omaha, Nebraska from 0000 GMT model data. Development of this winter season (January-March) equation was based on 6 years of data (1973-78). The equation was derived simultaneously with expressions to forecast the hourly temperature every 3 hours from 6 to 27 hours after 0000 GMT.

Predictor	Regression Coefficient	Cumulative Reduction Of Variance
0300 GMT Observed surface temp (^{o}F)	0.142	0.625
24-hour LFM 850-1000 mb thickness (m)	0.049	0.836
12-hour LFM 850-1000 mb thickness (m)	0.178	0.848
Cosine day of year	-7.409	0.862
12-hour LFM mean rel humidity (%)	0.005	0.866
Yesterday's 1200 GMT observed snow cover (binary predictor: 1 if $<$ 1 inch; zero otherwise)	4.042	0.877
24-hour LFM bndry layer rel humidity (%)	-0.127	0.889
12-hour LFM bndry layer wind speed (m sec^{-1})	0.091	0.890
18-hour LFM 1000-mb dew point (^{o}K)	0.101	0.891
18-hour LFM bndry layer v wind (m sec^{-1})	0.141	0.893

Initial constant = $-278.3^{o}F$

Standard error of estimate = $5.06^{o}F$

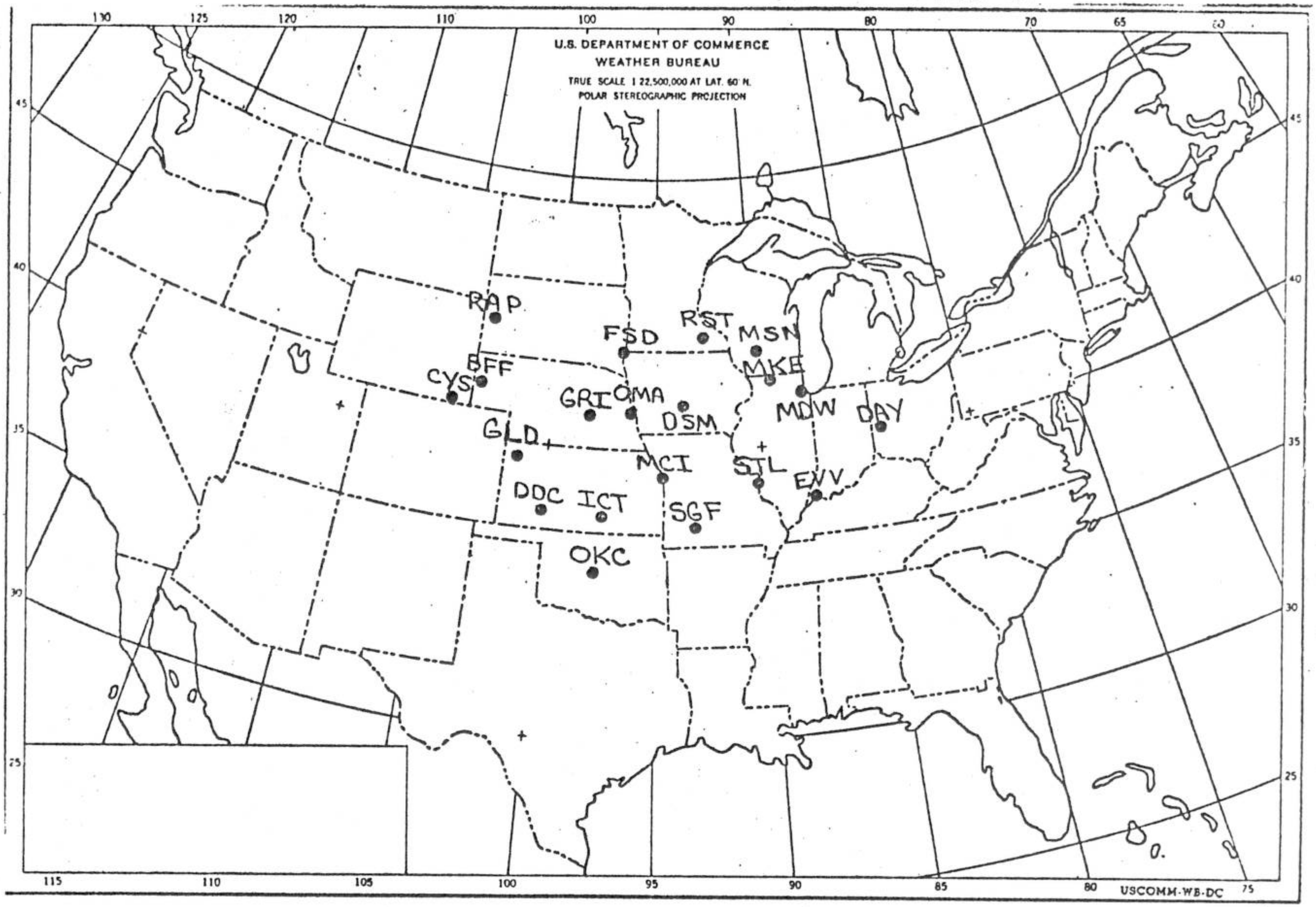

Figure 1. Twenty stations used in the snow cover test.

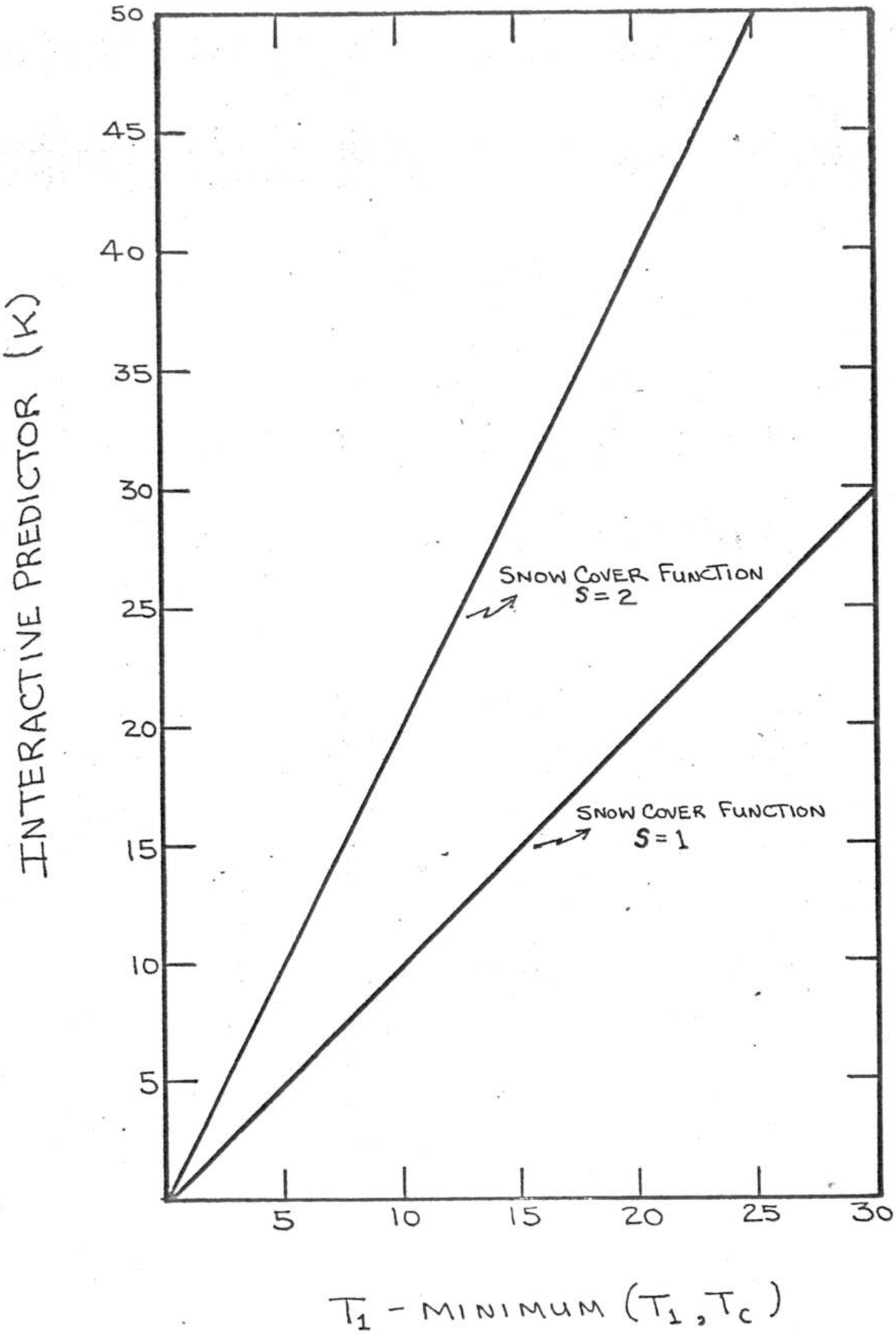

Figure 2. Interactive predictor as a function of snow cover and the LFM forecast of the boundary layer potential temperature (T_1). T_c is a cutoff value of the potential temperature forecast. The snow cover function S is described in Table 2.