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AN INVESTIGATION OF MOS MINIMUM TEMPERATURE ERRORS IN NORTH AND SOUTH DAKOTA DURING DECEMBER 1982

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1. INTRODUCTION

The winter (December-February) of 1982-83 was unusually mild, ranking as the fifth warmest over the entire United States, and the warmest of all winters in North and South Dakota since 1931 (Quiroz, 1983). Correspondingly, during the 1982-83 cool season (October-March), the forecasts of minimum temperature from the Model Output Statistics (MOS) guidance had unusually large errors (Carter et al., 1983) over portions of the United States. To investigate the cause of these errors, we examined the objective minimum temperature forecasts generated during December 1982 for five selected stations in North and South Dakota. Additionally, because we noticed especially large errors in early December, we investigated some of the minimum temperature forecasts made on December 5-8, 1982, for the Dakota sites.

In this report, we present a brief summary of the 1982-83 cool season verifications, verifications for December 1982, and the results of our study of the MOS minimum temperature forecasts produced during December 5-8, 1982. MOS errors during anomalous temperature regimes, the influence of the Limited-area Fine Mesh (LFM) model on the MOS forecasts, the inherent limitations of the minimum temperature forecasts, and the importance of soil temperature and moisture are also discussed.

2. BACKGROUND

Field forecasters of the National Weather Service routinely receive automated public weather guidance developed by the Techniques Development Laboratory. The linear regression equations used to generate the forecasts were derived by applying the MOS technique (Glahn and Lowry, 1972) to output from the National Meteorological Center's LFM model (Gerrity, 1977; Newell and Deaven, 1981; National Weather Service, 1981). The MOS approach relates a surface weather element (predictand) to LFM forecast fields, LFM analyzed fields, and surface weather observations (predictors). Objective forecasts of the maximum and minimum temperature (max and min) are among the weather elements forecast by the MOS equations (Dallavalle et al., 1980). Forecasts of the Day 1 and Day 2 max and the Day 2 and Day 3 min are available from 0000 GMT LFM model output. Likewise, forecasts of the Day 2 and Day 3 min and max are available from 1200 GMT LFM model output. Day 1 is defined to be the day on which the forecast was made. The max/min forecasts are valid for the local calendar day. For example, the Day 1 max forecast from 0000 GMT on December 7, 1982, is valid for the calendar day beginning locally at midnight, December 7, 1982.

3. 1982-83 COOL SEASON TEMPERATURE VERIFICATION RESULTS

During the 1982-83 cool season, some of the smallest errors ever were recorded for the max guidance (Carter et al., 1983). The min forecasts, however, had large errors, with a pronounced cold bias (forecast minus

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observed is negative) in all regions and at all projections. The mean absolute errors of the min guidance were also greater than those of the max guidance for corresponding projections (Table 1). This tendency has been noted in previous cool season verifications (Carter et al., 1983), and seems to be the effect of microscale and mesoscale processes on the min. Factors such as snow cover, soil moisture, drainage winds, and stratus clouds, for example, can radically affect the cool season min. Unfortunately, the MOS forecasts often do not account for these processes, since the LFM model lacks the vertical and horizontal resolution to predict features such as drainage winds or stratus. Moreover, even though snow amount is used as a predictor, soil temperature and moisture are not explicitly included in the MOS forecast equations. Though it is not shown here, the largest forecast errors were found in the Montana-Dakota region, an area which also had the greatest temperature anomalies during the 1982-83 winter.

4. DAY 2 MIN FORECAST ERRORS IN NORTH AND SOUTH DAKOTA FOR DECEMBER 1982

Because of the large errors mentioned in the previous section, we examined the Day 2 min forecasts generated from 0000 GMT data during December 1982. This projection was selected to represent all the min forecasts. We were particularly interested in the guidance for five stations in North and South Dakota (Fig. 1).

Table 2 shows the mean algebraic, mean absolute, and root mean square errors for the December 1982 Day 2 min forecasts at these stations. The standard errors of estimate on the developmental sample (December 1975-February 1980) and the standard deviation of the daily min during December 1975-79 are also given. In addition, we computed the mean min for each of the Decembers in the developmental sample and then calculated the standard deviation of these values. Finally, Table 2 includes the departures of the December 1982 mean min from the developmental normal. Note that the min forecasts at all stations had a cold bias of at least 2°F. The mean absolute errors were somewhat high, but were, at least partially, due to the large variability of the winter min in North and South Dakota. The large standard deviation given in Table 2 for the December daily min indicates this variability. The deviations over the entire winter season (not shown) were somewhat larger. The inherent difficulty of forecasting such a highly variable weather element can be seen in the standard error of estimate (SE) of the Day 2 min forecast equations. The SE's are the root mean square errors of the forecasts made from the developmental sample. Large SE's imply large errors in forecasts made on independent data. In fact, the forecasts made in December 1982 had root mean square errors somewhat higher than the SE's.

The SE also gives information about the distribution of algebraic errors associated with the min forecast equations. If we assume the algebraic errors of the regression equation are normally distributed about the mean of zero, then the SE of the forecast equation equals the standard deviation of the algebraic errors. With the assumption of normality and the SE's in Table 2, the absolute errors at ABR, FSD, and BIS exceeded 7.3°F 32% of the time, and 14.6°F 5% of the time on the dependent data. Likewise, the absolute errors at Huron exceeded 6.9°F 32% of the time and 13.8°F 5% of the time. At RAP, errors exceeded 5.9°F 32% of the time and 11.8°F 5% of the time. Thus, on independent data, we expect to see errors that exceed 11.8°F at least 5% of the time, if the characteristics of the independent and dependent data are similar.

The differences in mean min temperatures between December 1982 and the developmental sample, however, were also quite large. The mean December 1982 min was more than one standard deviation above the mean of the developmental sample at FSD and HON, and at least two standard deviations above the mean of the developmental sample at ABR and BIS. The latter two stations also had the largest mean absolute errors in December 1982 (Table 2).

5. GUIDANCE PRODUCED DURING DECEMBER 5-8, 1982, FOR NORTH AND SOUTH DAKOTA

To see if we could determine precisely why the MOS guidance had gone awry during December, we examined the Day 2 min forecasts made from 0000 GMT data on December 5-8, 1982. The verifying observations and algebraic errors for the five Dakota stations are given in Table 3. The magnitude of the absolute errors ranged from 4°F to 20°F, and nearly all of the forecasts were too cold.

During the previous week, the min temperatures at each station were 10°F to 20°F above the corresponding mean December min of the developmental sample. As of Monday, December 6, 1982, the warm temperatures had melted most of the snow cover and warmed much of the surface. Of the five stations used in this study, only BIS still reported a trace of snow. On late Monday and early Tuesday, a cold front moved southward through the Dakotas accompanied by light snow. A trace of snow fell at BIS, FSD had one inch of snow, and RAP accumulated three inches of new snow. Surface winds were light and from the southwest, shifting to northwest behind the front. By Wednesday, December 8, a ridge of high pressure had intensified and was centered over North Dakota. Surface winds were from the north at 5 to 15 knots. On Thursday, December 9, a warm front moved through the Dakotas causing cloudy conditions and light precipitation in southern South Dakota.

After verifying that the operational MOS forecasts were calculated correctly, we recomputed the MOS guidance by substituting, where possible, "perfect model" predictions into the forecast equations. In other words, if the MOS equation used the 36-h LFM forecast of 1000-850 mb thickness from 0000 GMT on December 5, 1982, as a predictor, we substituted the observed 1000-850 mb thickness from the LFM analysis at 1200 GMT on December 6, 1982, and recalculated the MOS forecast. This allowed us to evaluate the accuracy of the MOS forecasts if perfect LFM forecasts were made. Since the verifying analyses for every LFM field used as a predictor were not archived in December 1982, we could not substitute for all predictors. As an example of this approach, the equation used to forecast the Day 2 min at BIS on December 5 is shown in Table 4. Notice that the improvement in the forecast made from substituting perfect model fields was about 3°F.

The operational MOS forecasts, the recalculated perfect model guidance, and the verifying observations are shown in Table 5 for the Day 2 min on December 5-8. Little or no decrease occured in the temperature errors at ABR, FSD, BIS, and HON; at RAP, however, a slight improvement in the forecasts was evident. Overall, the improvement due to the substitution of perfect model forecasts was relatively small compared to the size of the MOS errors.

We next put the coefficient of each model predictor in a standard form to show the relative importance of that predictor, and, perhaps, to indicate which model fields were responsible for the erroneous forecasts. The standardized regression coefficients (Neter and Wasserman, 1974) were calculated for the forecast equation at each station. A standardized regression coefficient indicates how much the predictand changes in response to changes in a given predictor. Predictors with large standardized coefficients tend to have more influence on the predictand than those with small standardized coefficients. The four predictors with the largest coefficients at each of the five stations are given in Table 6. Notice that thickness forecasts were most important at all stations. Although we were able to substitute a perfect model forecast at each station for the appropriate thickness, the MOS forecasts were not improved significantly (Table 5).

Finally, we checked the top four predictors at each station for large deviations from the appropriate mean values. Extreme variations from the mean could partially explain why the MOS guidance did poorly, since MOS forecasts can deteriorate when conditions deviate greatly from those of the developmental sample. We found that most of the predictors were within one standard deviation of their mean. However, the 1000-850 mb thickness field was forecast more than one standard deviation below the mean on December 7 at BIS and RAP. At ABR, the 1000-500 mb thickness field was also forecast more than one standard deviation below the mean on December 7. In all of these cases, the thickness forecasts were too cold.

6. DISCUSSION

As shown in the previous section, we attempted to modify the MOS Day 2 min guidance by substituting, where possible, observed model quantities (perfect forecasts) for actual forecasts. The results (Table 5) were mixed. At all stations, substituting perfect thickness forecasts raised (lowered) the MOS min guidance when the thickness forecasts were too cold (warm). Only at RAP, however, were the MOS forecasts consistently improved. When the MOS guidance improved at other stations, the increase in accuracy was small compared to the original size of the error. Several factors may explain these results. As discussed earlier, we were unable to substitute analyzed quantities for all predictors. Based on previous experience, however, we don't think that our results would have been significantly altered even if all analyzed fields had been available. In fact, Hlywiak and Dallavalle (1984) showed that complete substitution did not improve the MOS forecasts consistently. Perhaps, in our study, the improvements at RAP were a matter of chance. Since the MOS technique accounts for systematic errors or inherent biases in the LFM forecast fields, substituting a perfect LFM forecast may not always be helpful. We can not tell, of course, which biases, if any, are compensated for by each MOS equation. Moreover, when more than one model forecast is replaced by a perfect value, the contributions to improving the MOS forecast may enhance, or cancel, each other. Finally, even with perfect LFM model forecasts, the MOS guidance in any given situation might become more accurate, but not necessarily perfect. Under these circumstances, the forecasts can only improve to the extent that the MOS regression equations explain actual physical relationships among the predictors and the predictand. Inherent inaccuracy exists in the MOS equations because not every surface and atmospheric condition which affects the min is included (Dallavalle, 1984). As explained earlier, a standard error of estimate is also associated with every forecast equation. Because of these complications, we think that modifying the MOS guidance by altering the original model fields in the regression equation is a useless effort. If a forecaster suspects the LFM model fields have a cold bias, for example, he or she would be better off subjectively adjusting the min forecast itself rather than trying to recalculate the forecast from the original MOS regression equation.

In many instances, erroneous LFM model forecasts are the primary cause of inaccurate MOS forecasts. Since the model forecasts were reasonably accurate during the December 5-8 period, we think other factors contributed to the large errors in the min guidance. A weather element as highly variable as the winter min in the Dakotas is inherently difficult to forecast. If the observed min takes on a wide range of values even when given the same LFM-predicted 1000-850 mb thickness, the spread about the regression line, or, equivalently, the standard error of estimate, increases. Recall the large standard deviation and standard errors of estimate at the five Dakota stations in Table 2. As we have shown, forecast errors exceeding 11°F are not unexpected in North and South Dakota.

The extended period of anomalously warm temperatures also added to the difficulty of the December forecast situation. As we have shown, the min for December 1982 averaged 3°F to 10°F above the mean December min of the developmental sample. The MOS technique can not always forecast such wide deviations from normal accurately. In this case, the winters used to develop the MOS equations for the min were generally colder than the winter of 1982-83. The relationship among the LFM model fields and the min may not be valid for such a warm pattern. Though the MOS equations can predict individual record events, we think that the average errors for all stations combined will increase with a corresponding increase in the departure from normal.

Finally, the unusual soil conditions may have contributed to the forecast errors. As was mentioned in our overview of the weather situation, the week previous to our case study was extremely warm. This left much of the Dakotas without a snow cover and probably warmed much of the surface. It's possible that this residual heat and lack of snow cover set up a feedback mechanism which led to the high min temperatures. If the daytime temperature is above freezing, for example, the snow cover melts and/or the surface soil warms considerably. With no snow cover, the albedo and the emissivity of the surface are diminished. After the sun sets, the surface begins cooling. However, it starts cooling from a warmer temperature, and at a slower rate since its nocturnal radiating ability has been decreased. The nighttime min is not as cool as before, and this in turn allows higher daytime temperatures again, especially if no snow is available for melting. Similar cases of a trace or no snow cover in the Dakotas did occur during the developmental period, but a snow cover of an inch or more was found at least 55% of the time at all stations except Huron. Unfortunately, measurements of soil moisture and temperature are not currently available, and, therefore, can not be used explicitly in the MOS equations.

7. CONCLUSION

We looked at the MOS Day 2 minimum temperature guidance from the 0000 GMT LFM model for the month of December 1982, and for the period of December 5-8 only, at five stations in North and South Dakota. Over the entire month of December, we found the mean forecast errors to be higher than usual. The anomalously warm temperatures in the Dakotas seemed to contribute to these errors. When such an extreme temperature regime is not represented in the developmental sample, MOS equations are likely to account for unusual conditions only to the extent that the temperature relationships are linear. While on some occasions the MOS temperatures may accurately predict record-breaking events, we think the average errors increase with increasing deviations from sample means.

From the study of the December 5-8 period, we found the LFM model forecasts did not seem to be the primary cause of the inaccurate MOS forecasts. Substitution of subsequently analyzed LFM fields ("perfect" model forecasts) into the MOS relationships did not improve the guidance substantially. The large forecast errors were probably due, in part, to the lack of information about soil temperature and moisture.

It is important to recognize that a statistical technique such as MOS has limitations, especially in forecasting situations which deviate greatly from normal. While the average forecast errors in the Dakotas during December 1982 were large, they reflect the current limitations of the MOS technique in such an anomalous temperature regime.

8. ACKNOWLEDGMENTS

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Table 1. Verification of the MOS maximum and minimum temperature forecasts for 87 stations in the conterminous United States during the 1982-83 cool season. The approximate verifying time (in hours after model run time) of each forecast is given in parentheses.

Model Run Time (GMT)	Forecast Projection	Mean Algebraic Error (°F)	Mean Absolute Error (°F)	Number(%) of Absolute Errors $\geq$10°F	Number of Cases
0000	Day 1 Max (24)	0.7	3.2	515 (3.3)	15628
	Day 2 Min (36)	-1.3	4.2	1206 (7.7)	15623
	Day 2 Max (48)	-0.2	4.3	1402 (9.0)	15541
	Day 3 Min (60)	-2.2	5.4	2450 (15.8)	15536
1200	Day 2 Min (24)	-1.1	3.8	849 (5.5)	15449
	Day 2 Max (36)	0.2	3.9	1058 (6.8)	15454
	Day 3 Min (48)	-1.9	4.9	1919 (12.4)	15449
	Day 3 Max (60)	-0.3	4.9	2024 (13.1)	15454

Table 2. Mean algebraic, mean absolute, and root mean square errors at five Dakota stations for the Day 2 min forecasts from 0000 GMT during December 1982. The standard error of estimate for the developmental sample, the standard deviation (SD) of the daily min temperature during December 1975-1979, the standard deviation of the mean min temperature during the same period, and the departure from the developmental normal of the mean min temperature in December 1982, are also given. All values are in ^{o}F.

Station	Mean Algebraic Error	Mean Absolute Error	Root Mean Square Error	Standard Error of Estimate	SD of Daily Min	SD of Mean Min	Departure from Normal
RAP	-2.8	5.6	7.1	5.9	11.7	4.9	3.2
FSD	-2.1	5.7	6.9	7.3	13.1	5.7	6.1
HON	-4.4	5.9	7.3	6.9	12.9	5.5	7.6
ABR	-7.0	7.5	9.3	7.3	13.1	4.9	9.8
BIS	-6.1	7.2	8.8	7.3	12.6	3.8	8.9

Table 3. Verifying observations and algebraic errors for the Day 2 min (calendar day) temperature forecasts made from 0000 GMT data on December 5-8, 1982. All values are in ^{o}F. Observations were taken from the appropriate 0600 GMT synoptic report of the min temperature.

Station	Date of Forecast	Forecast	Observation	Algebraic Error
RAP	5	10	19	-9
	6	7	-1	8
	7	-6	7	-13
	8	13	7	6
FSD	5	10	20	-10
	6	4	9	-5
	7	-3	1	-4
	8	-4	2	-6
HON	5	11	21	-10
	6	1	13	-12
	7	-3	9	-12
	8	1	9	-8
ABR	5	5	18	-13
	6	-3	17	-20
	7	-10	3	-13
	8	-1	9	-10
BIS	5	5	17	-12
	6	-2	6	-8
	7	-13	-2	-11
	8	2	12	-10

Table 4. The MOS regression equation used to produce the Day 2 min temperature forecast at Bismarck, North Dakota from 0000 GMT data on December 5, 1982. All predictors, except for the observed temperature at 0000 GMT and the observed wind speed at 0300 GMT, were from the LFM model. The LFM forecast values and corresponding contributions to the MOS guidance were from the actual model output. The perfect model values were taken, when possible, from the verifying LFM analyses. An asterisk indicates that the verifying observed fields were unavailable and that forecast values were used. The verifying min temperature was 17°F.

Predictors	Units	Projection	Coefficient	Forecast		Perfect Model	
				Value	Contribution	Value	Contribution
Constant = -351.45							
1000-mb dew point	K	24	-0.0654	269.80	-17.64	269.80*	-17.64*
1000-850 mb thickness	m	36	0.1900	1260	239.40	1273	241.87
Observed surface temperature	F	0	0.2717	37	10.05	37	10.05
Sfc-490 mb mean relative humidity	%	36	0.2329	45.76	10.66	45.76*	10.66*
850-mb wind speed	ms^{-1}	36	0.4725	13.82	6.53	13.82*	6.53*
1000-850 mb thickness	m	24	0.0438	1286	56.33	1295	56.72
500-mb height	m	36	0.0088	5390	47.43	5364	47.20
700-mb dew point depression	K	36	0.4828	11.99	5.79	11.99*	5.79*
850-mb wind speed	ms^{-1}	24	0.4699	12.44	5.85	12.44*	5.85*
Observed surface wind speed	kt	3	-0.2419	14	-3.38	14	-3.38
700-mb u wind component	ms^{-1}	24	-0.2863	4.00	-1.15	4.00*	-1.15*
700-mb dew point depression	K	24	-0.3189	10.15	-3.24	10.15*	-3.24*
				Forecast:	5.17°F		7.81°F

Table 5. Operational MOS forecasts of the Day 2 min (calendar day) temperature made from 0000 GMT data on December 5-8, 1982, at five Dakota stations. Recalculated MOS forecasts and the verifying observations are also given. All values are in °F. Observations were obtained from the appropriate 0600 GMT synoptic report of the min temperature.

Station	Date of Forecast	Operational Forecast	Recalculated Forecast	Verifying Observation	Improvement of Recalculated Forecast
RAP	5	10	14	19	+4
	6	7	5	-1	+2
	7	-6	-1	7	+5
	8	13	7	7	+6
FSD	5	10	10	20	0
	6	4	4	9	0
	7	-3	-2	1	+1
	8	-4	-3	2	+1
HON	5	11	11	21	0
	6	1	-1	13	-2
	7	-3	-2	9	+1
	8	1	-1	9	-2
ABR	5	5	7	18	+2
	6	-3	-4	17	-1
	7	-10	-8	3	+2
	8	-1	0	9	+1
BIS	5	5	8	17	+3
	6	-2	-5	6	-3
	7	-13	-9	-2	+4
	8	2	-2	12	-4

Table 6. The four predictors with the largest standardized regression coefficients in the MOS Day 2 min temperature forecast equation at each Dakota station.

Station	Predictor	Units	Projection
RAP	LFM 1000-850 mb thickness	m	36
	LFM 850-mb dew point	K	36
	LFM 700-mb u wind component	ms^{-1}	36
	LFM analyzed surface temperature	K	0
FSD	LFM 1000-850 mb thickness	m	24
	LFM 850-mb temperature advection	$10^{-5}Ks^{-1}$	36
	LFM 1000-mb geostrophic u wind	ms^{-1}	30
	LFM 700-mb u wind component	ms^{-1}	36
HON	LFM 1000-850 mb thickness	m	24
	LFM 1000-mb dew point	K	24
	Observed surface temperature	F	-3
	Observed surface snow depth	inches	-12
ABR	LFM 1000-500 mb thickness	m	36
	LFM K-index	-	36
	LFM 1000-mb dew point	K	24
	LFM analyzed surface temperature	K	0
BIS	LFM 1000-850 mb thickness	m	36
	Observed surface temperature	F	0
	LFM Sfc-490 mb mean relative humidity	%	36
	LFM 850-mb wind speed	ms^{-1}	36

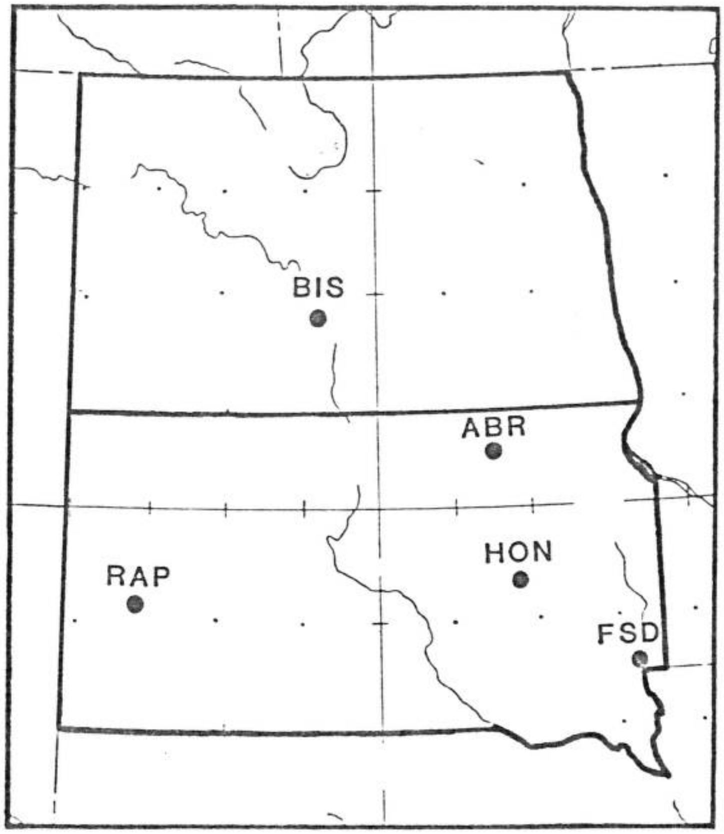

Figure 1. The five stations used in this study: Bismarck, North Dakota (BIS); Rapid City, South Dakota (RAP); Aberdeen, South Dakota (ABR); Huron, South Dakota (HON); and Sioux Falls, South Dakota (FSD).