NOAA Technical Memorandum NWS WR-113

A WINTER SEASON MINIMUM TEMPERATURE FORMULA FOR BAKERSFIELD, CALIFORNIA, USING MULTIPLE REGRESSION

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February 1977

UNITED STATES
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ATMOSPHERIC ADMINISTRATION
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I. INTRODUCTION

Multiple regression is a statistical technique where independent variables most correlated with some dependent variable (like minimum temperature) are selected in order of importance. This is done in a stepwise manner in which, at each step, the best variable is added from a large pool of remaining variables forming a new equation with all the previously selected variables. This method has been known for many years and has been used during the past 10 years by the National Meteorological Center (NMC) with increasing effectiveness. Operational prediction equations for numerous weather parameters using output from numerical models is now an important part of the daily NMC routine. Details of this so-called Model Output Statistics (MOS) program are given in numerous Technical Procedures Bulletins and papers in Monthly Weather Review, Journal of Applied Meteorology, and the Bulletin of the American Meteorological Society, e.g., Technical Procedures Bulletin No. 94 (1973); Klein and Hammons (1975); Klein and Glahn (1974).

This Technical Memorandum describes the results of using stepwise multiple regression to form a short-term (≤12 hr.) minimum temperature prediction equation for the winter fruit-frost program at Bakersfield (BFL), California. Local data available the evening before are used. Two local objective aids for minimum temperature have been operational at Bakersfield for about 10 years. They give good guidance most of the time, but objectionably large errors occur on occasion. Also, NMC provides guidance in the form of MOS 24-hour minimum temperature estimates. Because of the relatively large lag time needed to compute the necessary input data and MOS results, 24 hours is the shortest time period available. Since a high degree of accuracy in predicting temperatures below 35°F. is essential in fruit-frost forecasting, a more reliable objective aid was needed. It was assumed that use of local data and a short time period in a stepwise regression program would provide better minimum temperature guidance. The results given below show that the temperature forecast aid developed was better than MOS and the two older aids.

II. PROCEDURE

Ten years of observational data from winter frost seasons were used. This data consists of many meteorological parameters related to minimum temperature. The data were divided into three groups using as a guide the procedure suggested in Panofsky and Brier (1958). The first group consisted of five winter seasons from 1970-71 to 1974-75. This was used as the developmental data set to generate the multiple regression equations. The second group consisted of three winter seasons from 1967-68 to 1969-70.

This was used as the independent sample to evaluate the derived equations. In addition, it was used to determine the optimum number of variables to retain in the generated equations. The results of the evaluation were compared with the minimum temperature forecasts given by the two older objective aids and the final man-made forecasts. The third group consisted of 1965-66 and 1966-67 seasons. This was used as another independent sample to further test the stability of the best regression equation. The computations resulting in the final regression equation were performed on the CDC 3300 computer at California State College, Bakersfield. The UCLA Health Sciences stepwise regression program BMD02R was used.

The final regression equation was used operationally as guidance this past winter (1975-76) season. At the end of the season a comparison of the regression equation predictions was made with the older objective aids, the official forecast minimum, and the 24-hour MOS minimum temperature forecast.

The two older objective aids used in the comparisons are modifications of the so-called hygrometric formula (Ellison, 1928; Tuft, 1975). They are applicable on clear nights only. The first one (called Formula 1) uses relative humidity to obtain an empirical correction factor, which when added to the 0040Z Bakersfield dew point gives the minimum temperature forecast for the next morning. The second objective aid (called Formula 2) uses the dry-bulb, wet-bulb, and dew-point temperatures taken at 0400Z. These are added together and, from a table, the next morning's minimum temperature forecast is obtained. The standard error of estimate for these two aids is given in Tables 3 and 4.

Since cold temperatures in the Bakersfield area occur mostly on clear or partly cloudy nights, and since the effects of clouds would be very difficult to take into account, only clear nights were used in the regression program. A clear observation was defined as 0-2 tenths cloud cover, high clouds excluded, and visibility greater than 1 mile. A partly cloudy observation was defined as sky cover being 3-5 tenths. A night was defined as clear if the observations at 00Z, 06Z, and 12Z were either all clear or 2 clear and 1 partly cloudy. A partly cloudy night was similarly defined as when 2 of the 3 observations were partly cloudy. These definitions are, of course, arbitrary but considered realistic for our purposes. Initial missing data in the development data sample, i.e., Group 1, was all obtained so possible biases would not be introduced into the equations. However, for Groups 2 and 3, nights with any missing data were discarded. For the first data group 170 clear nights were used, 104 for the second group, and 62 for the third group. In the operational phase partly cloudy nights were combined with clear nights, since it was found from verification of Groups 2 and 3 that minimum temperatures on these nights did not differ appreciably from clear-night minima.

Table 1 lists 37 variables that went into the stepwise multiple regression program and their individual correlation coefficients with minimum temperature. Other variables could have been added, but they were either unavailable or not considered related close enough to minimum temperature to be included. Table 1 shows that both the maximum temperatures on the previous day and the temperature at 0040Z at Bakersfield correlated highest (0.75) with the next morning's minimum. Actually the temperature at 0040Z was the first variable chosen in the regression program and accounted for the most variance in minimum temperature. Vector 1 and Vector 2 are surface pressure-gradient vectors through BFL, and Vector 3 is the height-gradient vector on the 700-mb surface, all described by Riddiough (1972; 1965). The difference between Vector 1 and Vector 2 is that the former is on a broader scale. Of particular interest is that the magnitude of these vectors is negatively correlated with minimum temperature, which means that the stronger the pressure gradient, the colder the next morning's minimum. This is just the opposite of what normally occurs at other stations. A likely explanation for this anomaly is terrain effect. Bakersfield is almost completely surrounded by mountains. When strong pressure gradients exist in the area, colder air is usually advected into the area, settles near the ground at night, thereby insulating the surface from higher winds aloft.

The stepwise regression program was allowed to run through 10 steps (Panofsky and Brier, 1958). Table 2 is a summary of the 10 steps, including the multiple correlation coefficient of all entered variables with minimum temperature, the reduction of variance or the variance accounted for by the entered variables, the increase in the reduction of variance, the standard error of estimate and the decrease in the standard error of estimate accounted for by the added variable. The standard error of estimate is similar to the standard deviation but applies to the scatter about a regression line. Therefore, it means that 68% of the scatter should be within that number of degrees. Each step produces a separate equation for minimum temperature using only those variables already chosen. From Table 2 it is seen that the addition of variables improves the minimum temperature estimate rapidly with the first 2 variables, but then tapers off significantly with the addition of more variables. Since the later steps improve the standard error of estimate only slightly, one might question whether they really represent an improvement in the forecast of the dependent variable. For example, the relation with minimum temperature, in this case, could be due to small-scale random fluctuations in the developmental data set. Consequently, the first independent data set, Group 2, was used to help determine how many variables or steps are really significant (Panofsky and Brier, 1958). Then the second independent data set, Group 3, was used to test the stability of the equation from using data Groups 1 and 2. Table 3 gives the standard error of estimate for each of the 10 regression equations using Group 2 data and comparative standard errors for the two objective aids and the man-made forecasts. It can be seen that regression Step 4 with 4 variables is the best. The standard error increases sharply at Step 5 and oscillates from then on. This indicates that after Step 4 there is no significant improvement in the minimum temperature estimate. Table 4 is a comparison using only Group 3 data.

In the verification procedure a problem was encountered in deriving a comparative man-made forecast for the Bakersfield airport instrument shelter. No man-made fruit-frost forecast is made for this shelter, yet the two objective aids and the regression equation apply to shelter temperatures. The key station for which a fruit-frost temperature forecast is issued is a shelter located in an orange grove 3 miles northwest of the airport (called NW BFL). Therefore, the man-made forecasts are modified NW BFL forecasts using normal differences observed between shelter and NW BFL minimum temperatures.

In Table 3 it is seen that the lowest standard error was achieved by the man-made forecasts while regression equation 4 came in second. In Table 4 regression equation 4 was the best, being more than .63 of a degree better than the man-made forecasts. Table 5 is a summary of the verification adding groups 2 and 3 together. A bias factor is included, which is simply the average deviation. The important feature to notice is that the regression equation for this 5-year period (166 clear night cases) has a little better standard error of estimate than the man-made forecasts and overestimates the minimum temperature by about a degree while the forecaster underestimates the minimum temperature. Formula 1 is the best objective aid, Formula 2 being quite poor.

Equation (1) gives regression equation 4 which turned out to be the best.

$$\text{BFL MIN} = -3.89 + 0.43 \times \text{BFL TEMP (0040Z)} + 0.18 \times \text{BFL DP (0040Z)} + 0.27 \times \text{PREVIOUS MIN} + 0.06 \times \text{OAK DP (700 mb at 00Z)}. \tag{1}$$

From a glance at the regression coefficients, the Bakersfield temperature at 0040Z is the most important variable and the dew point at Oakland (OAK) at 700 mb is the least important. As an example of how Eq. (1) is used, let the temperature at 0040Z at the BFL shelter be 50 degrees and the dew point 28 degrees. Also let the previous minimum at BFL be 28 degrees and the OAK 700-mb dew point at 00Z be -30 degrees. Plugging these values into Eq. (1) gives:

$$\text{BFL MIN} = -3.89 + 0.43 \times 50 + 0.18 \times 28 + 0.27 \times 28 + 0.06 \times (-30)$$

$$\text{BFL MIN} = -3.89 + 21.50 + 5.04 + 7.56 - 1.80$$

$$\text{BFL MIN} = 28.4 \text{ degrees.}$$

III. OPERATIONAL RESULTS

Regression equation 4 was used operationally during the past winter frost season (1975-76) as guidance along with the 2 older objective aids and the 24-hour MOS minimum. These were verified against the final man-made forecasts. The results are given in Table 6 for 60 clear nights and 10 partly cloudy nights. It is readily seen that the forecaster this time did the best. As usual the two older objective aids verified poorly. Also in comparing the standard error of estimates in Table 6 with those in Table 5, it is seen that the standard error of estimates for the operational year were much better than the 5-year verification. This is most likely a reflection of the unusually clear frost season this past year. Radiational effects dominated over advection effects. The new regression equation was second best, about 1/4 of a degree behind the man-made forecasts. MOS came in third. Note that the regression equation was more than 1/2 of a degree better than MOS and much better than the older objective aids. This substantiates the basic idea of this research: that multiple regression applied to local data can be a valuable supplement to MOS guidance for short forecast periods.

This one season of operational experience in using the new regression equation brought out several biases that are inherent in the system. First of all, the technique doesn't pick up rapid changes associated with the advection of cold, dry air from the north or moist advection from the west during the forecast period. Second, the previous minimum temperature is weighted so heavily it produces a warm bias in the equation when meteorological conditions are changing rapidly. Third, nights classified as clear but with thick cirrus clouds existing most of the night were associated with minimum temperatures warmer than indicated. Ideally this situation should have been considered as a cloudy night in the developmental and verification stages but was not. Fortunately, the above three biases did not occur very often and when they did their effects were small. Also, the forecaster normally can foresee these situations and adjust his forecast accordingly. Regression equation 4 for both the 5-year verification period and the operational year had a bias of about 1 degree too high. This bias could be subtracted from the constant in the equation to arrive at even a better objective system. As a test, this was done on the operational year data, and the standard error of estimate was improved by .16 of a degree. This change in the equation will be made for the next frost season.

Five percent and one percent significance levels were not calculated in this study because of the problem of independence in weather events (Panofsky and Brier, 1958). However, it is assumed that enough observations were included in each group to make the results significant.

Ideally, it would be desirable to use MOS predictions as variables in a multiple regression program, especially since they have shown considerable skill. One approach considered during this study was to use the MOS minimum temperature forecast as one of the dependent variables. Presumably this would be the first variable picked by the multiple regression program. Other variables, selected from then on, would represent an improvement over MOS. Unfortunately, this couldn't be done because NMC has incorporated so many changes into MOS during the past 5 years. Hopefully, MOS equations might remain constant enough in the future for us to include them in short period regression equations.

IV. CONCLUSIONS

Conceivably, the method outline in this memorandum, where local data are used in a short-period multiple-regression equation, can also be applied to other forecast problems. It seems to be tailor-made for short-period forecasting in not only the fruit-frost program, but also in the fire weather and aviation programs. It can be used at other weather service offices to either update existing objective aids by adding additional variables or to more easily produce new objective aids. When Automation of Field Operations and Services (AFOS) becomes a reality, minicomputers will hopefully be available to make it convenient to perform the computations.

ACKNOWLEDGMENTS

I would like to express my appreciation to Earl Riddiough, Meteorologist in Charge at Bakersfield Weather Service Office, for his valuable suggestions and guidance and to the rest of the staff at Bakersfield for their encouragement. Appreciation is expressed for the help received by Tenneco Oil Company and the Scientific Services Division, Western Region Headquarters staff; especially Sandy MacDonald for his advice in the computing phase. And lastly thanks go to Fresno, Stockton, and Red Bluff Weather Service Offices for filling in missing data.

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TABLE 1

Variables Used in Multiple Regression and Their Individual Correlation Coefficient With Bakersfield Minimum Temperature. Five Years of Data or 170 Clear Night Cases.

Variable	Correlation Coefficient
COS (Day of Year)	-.28
COS (2 x Day of Year)	-.31
SIN (Day of Year)	-.14
SIN (2 x Day of Year)	-.13
Previous BFL MIN	.69
BFL MAX Temp	.75
BFL Temp (0040Z)	.75
SDB Temp (01Z)	.67
FAT Temp (01Z)	.72
SCK Temp (01Z)	.64
RBL Temp (01Z)	.26
BFL DP (0040Z)	.63
SDB DP (01Z)	.54
FAT DP (01Z)	.68
SCK DP (01Z)	.73
RBL DP (01Z)	.73
SDB Temp Wet Bulb (00Z)	.73
VBG 850mb Temp (00Z)	.53
VBG 850mb DP (00Z)	.48
VBG 700mb Temp (00Z)	.44
VBG 700mb DP (00Z)	.30
OAK 850mb Temp (00Z)	.39
OAK 850mb DP (00Z)	.31
OAK 700mb Temp (00Z)	.31
OAK 700mb DP (00Z)	.29
SDB Wnd Spd (01Z)	-.04
SDB U Comp. (01Z)	.10
SDB V Comp. (01Z)	.10
Vector 1 Magnitude (00Z)	-.18
Vector 1 U Comp. (00Z)	-.13
Vector 1 V Comp. (00Z)	.16
Vector 2 Magnitude (00Z)	-.21
Vector 2 U Comp. (00Z)	-.24
Vector 2 V Comp. (00Z)	.20
Vector 3 Magnitude (00Z)	-.23
Vector 3 U Comp. (00Z)	-.51
Vector 3 V Comp. (00Z)	.32

TABLE 2

Summary of Stepwise Regression With Five Years of Data or 170 Clear Night Cases

Step Number	Variable Entered	Multiple Correlation Coefficient	Reduction of Variance	Increase In Reduction Of Variance	Standard Error Of Estimate	Decrease Of S.E. Of Estimate
1	BFL Temp (0040Z)	0.7467	0.5575	0.5575	3.8368°	---
2	BFL Dp (0040Z)	0.8419	0.7087	0.1512	3.1222°	0.7146°
3	Previous BFL MIN (Persistence)	0.8592	0.7383	0.0296	2.9684°	0.1538°
4	OAK 700mb Dp (00Z)	0.8763	0.7678	0.0295	2.8043°	0.1641°
5	Vector 3 U comp (00Z)	0.8868	0.7864	0.0186	2.6983°	0.1060°
6	SCK Temp (01Z)	0.8909	0.7938	0.0074	2.6593°	0.0390°
7	RBL Temp (01Z)	0.8968	0.8043	0.0105	2.5982°	0.0611°
8	Vector 1 U comp (00Z)	0.9015	0.8126	0.0083	2.5504°	0.0478°
9	Vector 3 Magnitude (00Z)	0.9082	0.8248	0.0122	2.4742°	0.0762°
10	COS (2xDay of Year)	0.9108	0.8295	0.0047	2.4482°	0.0260°

TABLE 3

Verification on Three Years of Independent Data With 104 Clear Night Cases and Comparison With Two Objective Aids and Man-Made Forecasts.

Minimum Temperature Forecast System	Standard Error of Estimate
Regression Equation 1	3.35°
" " 2	3.11°
" " 3	3.06°
" " 4	3.05°
" " 5	3.26°
" " 6	3.31°
" " 7	3.16°
" " 8	3.19°
" " 9	3.20°
" " 10	3.17°
Man-Made Forecasts	2.74°
Formula 1	3.39°
Formula 2	4.30°

TABLE 4

Comparison on Two Years of Independent Data With 62 Clear Night Cases Between Regression Equation 4, Two Objective Aids, and the Man-Made Forecasts.

Minimum Temperature Forecast System	Standard Error of Estimate
Regression Equation 4	2.52°
Man-Made Forecasts	3.15°
Formula 1	3.31°
Formula 2	3.49°

TABLE 5

Summary of Tables 3 and 4 With 166 Total Clear Night Cases.
Bias Factor in Degrees Per Day Added.

Min. Temp. Fcst. System	Standard Error of Est.	Bias Factor
Regression Eq. 4	2.86°	0.90°/day
Man-Made Fcst.	2.90°	-0.31°/day
Formula 1	3.36°	-0.54°/day
Formula 2	4.02°	0.97°/day

TABLE 6

Comparison on 1975, 76 Winter Frost Season With
70 Cases MOS 24 MIN From 1200Z Data Added.

Min. Temp. Fcst. System	Standard Error of Est.	Bias Factor
Regression Eq. 4	2.32°	0.85°/day
Man-Made Fcst.	2.08°	-0.67°/day
Formula 1	3.27°	-0.62°/day
Formula 2	3.50°	1.53°/day
MOS	2.85°	-0.50°/day

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