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A REGRESSION TECHNIQUE FOR OBTAINING FORECAST SPECIFIC MINIMUM TEMPERATURES AT AGRICULTURAL STATIONS USING NEARBY LFM MOS FORECAST MINIMUM TEMPERATURES

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1. Introduction

Early spring minimum temperatures are of critical importance to Michigan fruit growers. Fruit growing sites are located primarily near the shores of the Great Lakes surrounding the lower Michigan peninsula. The nighttime water surface temperatures of the Great Lakes are generally warmer than the nearby land surface temperatures, and thereby greatly influence daily minimum observed temperatures.

On occasions when cold synoptic and mesoscale weather patterns overwhelm the natural warming effect of nearby waters, resulting in below freezing temperatures, fruit growers need site specific temperature forecasts. The weather forecaster can easily describe the overall weather picture, highlighting important scenarios such as a strong cold air advection event with high winds, or a short term radiational cooling event with light winds. These descriptions aid the grower for choosing the method of crop protection.

Of all the elements of the weather forecast, it is the expected minimum temperature that the grower will use to determine the necessity of crop protection. Since the methods of protection can be costly to the grower, the task of providing a specific minimum temperature forecast for an agricultural site is economically crucial and meteorologically challenging.

This paper describes the development and use of a statistical regression technique for forecasting specific minimum temperatures. The technique links selected climatological site specific observed minimum temperatures and Model Output Statistics (MOS), Limited Fine Mesh (LFM) forecast minimum temperatures for nearby stations. The resulting regression equations allows site specific minimum temperature forecasts to be made with a remarkably high degree of accuracy as the verification statistics indicate.

2. Background

The National Weather Service Forecast Office at Ann Arbor, Michigan supports the fruit growing industry of Michigan by providing a specific minimum temperature forecast for 34 agricultural sites in the lower Michigan peninsula, (Figure 1). This forecast is issued daily, between April 1 and May 15. The guidance for preparation of this forecast had been heretofore limited.

In 1978, the Techniques Development Laboratory (TDL) developed a specialized agricultural forecast guidance (TDL Office Note 78-9) for 27 Michigan stations. The 132 hour forecast was based on the six layer Primitive Equation (PE) and its barotropic extension. The PE forecast was then interpolated from the model's grid points to the location of each station. This forecast guidance has not been updated since its inception in 1978.

The Ann Arbor forecasters also used temperature forecast aids based on two studies completed by Soderberg (1969), and by NWS staff (1970). These aids used climate conditions, (i.e., sky cover, winds, etc.) as predictors. The two studies were designed so that additional (new) data and sites could not be incorporated into their scheme.

Many of the sites listed in the TDL Office Note 78-9 and the previous two studies have since either moved, or are no longer forecasted for, and new sites have been added to the forecast. The studies acting as guidance, were not sophisticated when compared to present "state of the art" forecast schemes, and did not allow direct input from available computer driven models, i.e. MOS LFM. Therefore, a new approach to provide guidance in preparing the specialized forecast was needed. The features of the new guidance were to be versatile enough to incorporate additional data and stations, and to offer a degree of flexibility in recalculation of guidance value temperatures.

The technique to regress local weather observations to MOS is not new, i.e., Annett et al. (1972), Walts (1977), Mollner and Olsen (1978), Stone (1985), and Weiland and Mentzer (1990). However, Runyan and Defever chose a simple approach for multivariate linear and non-linear regression equation development and, in the spring of 1990, demonstrated its operational application as a forecaster's guidance tool.

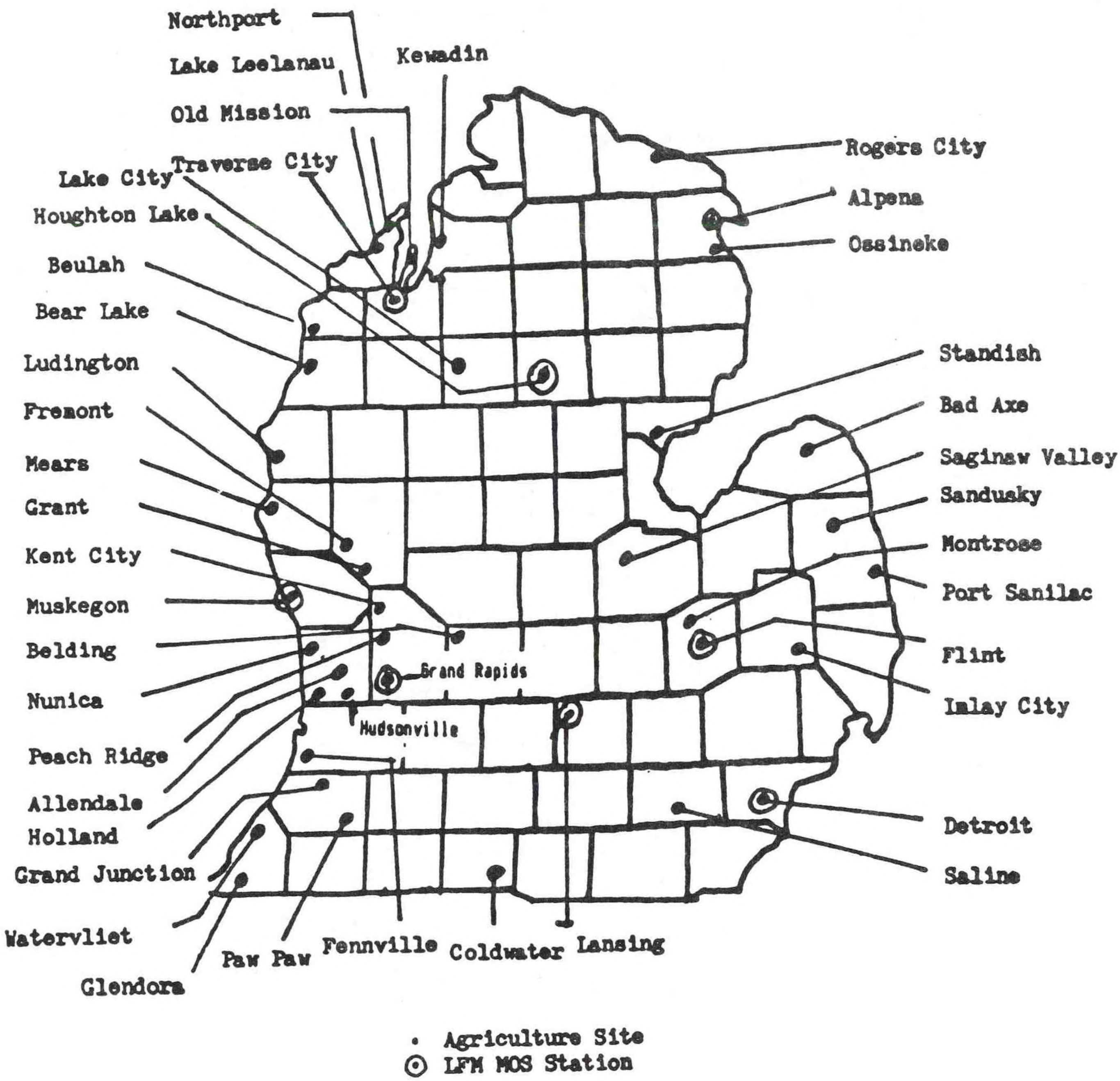
3. Fundamental Approach

Model Output Statistics (MOS), initialized on the Limited Fine Mesh (LFM) parameters provides a minimum temperature forecast. MOS stations are limited in number, and most are not strategically located for regional representation of critical temperatures vital to agricultural operations. The more numerous National Weather Service Cooperative Agriculture Stations augment the observation network, but lack forecast computer model support (i.e., MOS). If forecasters used the LFM MOS as a guidance to prepare the specific minimum temperature forecast for certain agricultural sites, they must interpolate between MOS stations, and perhaps intuitively gauge the forecast on known or perceived seasonal climatic variations of each agricultural site. Success of such forecasts vary greatly due in large part to each forecaster's skill.

This study uses the concept of grouping specific agriculture forecast sites to nearby LFM MOS stations. An assumption was made that similar climate conditions were experienced at both the LFM MOS station and the specific agriculture

Lower Michigan Peninsula

Figure 1.



site for each individual event. Distance between the LFM MOS station and the agriculture site were subjectively considered with an eye towards similar topographical characteristics.

Proximity to Lake Michigan and Lake Huron was a chief factor of consideration. Lake shoreline agriculture sites were grouped with nearby shoreline LFM MOS stations, while inland sites were set with inland LFM MOS stations at similar latitudes.

NWS Cooperative Agriculture Stations reset their minimum temperature thermometers daily at 7:00 a.m. local time. This created a problem of reconciling the true calendar day minimum temperature with the nearby LFM MOS station forecast minimum temperature. The problem was solved by comparing the thermograph trace charts recorded at each agriculture site with the observed 24 hour minimum temperatures.

The LFM MOS has a seasonal stratification for the formulated minimum temperature forecast. Care was taken to ensure that the period of data for the development of the regression equations did not overlap such seasonal stratification.

4. Data, Statistics, and Equations

The correctness of the LFM MOS 24 hour minimum temperature forecasts (12Z data base) were first determined. This task was accomplished by comparing observed minimum temperatures to forecast temperatures at only the LFM MOS station. If the error was greater than + or - $3^{o}F$, then the LFM MOS forecast was not correct, and it was not used in the development of the regression equation.

As testing of data proceeded, first order standard deviation of the mean differences between the LFM MOS forecast and the observed minimum temperature at the LFM MOS station proved that the threshold of + or - $3^{o}F$ to be within reason. Refer to Table 1 for the LFM MOS station's standard deviation (SD).

A simple mean difference value between the LFM MOS 24 hour forecast minimum temperature and the observed minimum temperature at the specific agriculture forecast site was computed. A sample standard deviation of the differences was used to aid identification of improper grouping of sites to nearby LFM MOS stations. A standard deviation of less than 8^{o} was considered to within operational range of the forecast. The sample standard deviation equal to or greater than 8^{o} indicated that the nearby LFM MOS station may not have been the best choice, and regrouping of stations were made and again tested.

Using the "Least Squares" theory, multivariate linear regression coefficients were computed for the regression equation,

$$Y = A + BX.$$

The regression coefficients A and B were determined by,

$$B = \frac{(N * \Sigma (XY)) - ((\Sigma X) * (\Sigma Y))}{N * \Sigma X^2 - (\Sigma X)^2}$$

$$A = \text{Mean } Y - (B * \text{Mean } X)$$

where N = number of population sample
X = LFM MOS 24 Hour Forecast Minimum Temperature
Y = Specific Site Observed Minimum Temperature

The statistical results were then summarized in tabular format; mean difference, standard deviation of mean difference, and linear regression coefficients. Manual computation of each regression equation was found to be tedious, therefore a computer program was designed for operational daily forecast construction.

As testing of the linear regression equations proceeded, it became apparent that at the extremes of the minimum temperature ranges an argument could be made for using a non-linear approach to finding the line of best fit. One site, Rogers City, was then recalculated using a "Least Square Parabola" non-linear regression equation. A simple scatter diagram plot of observed minimum temperatures with both the linear and non-linear lines of best fit (Figure 2) demonstrates the improved non-linear approach.

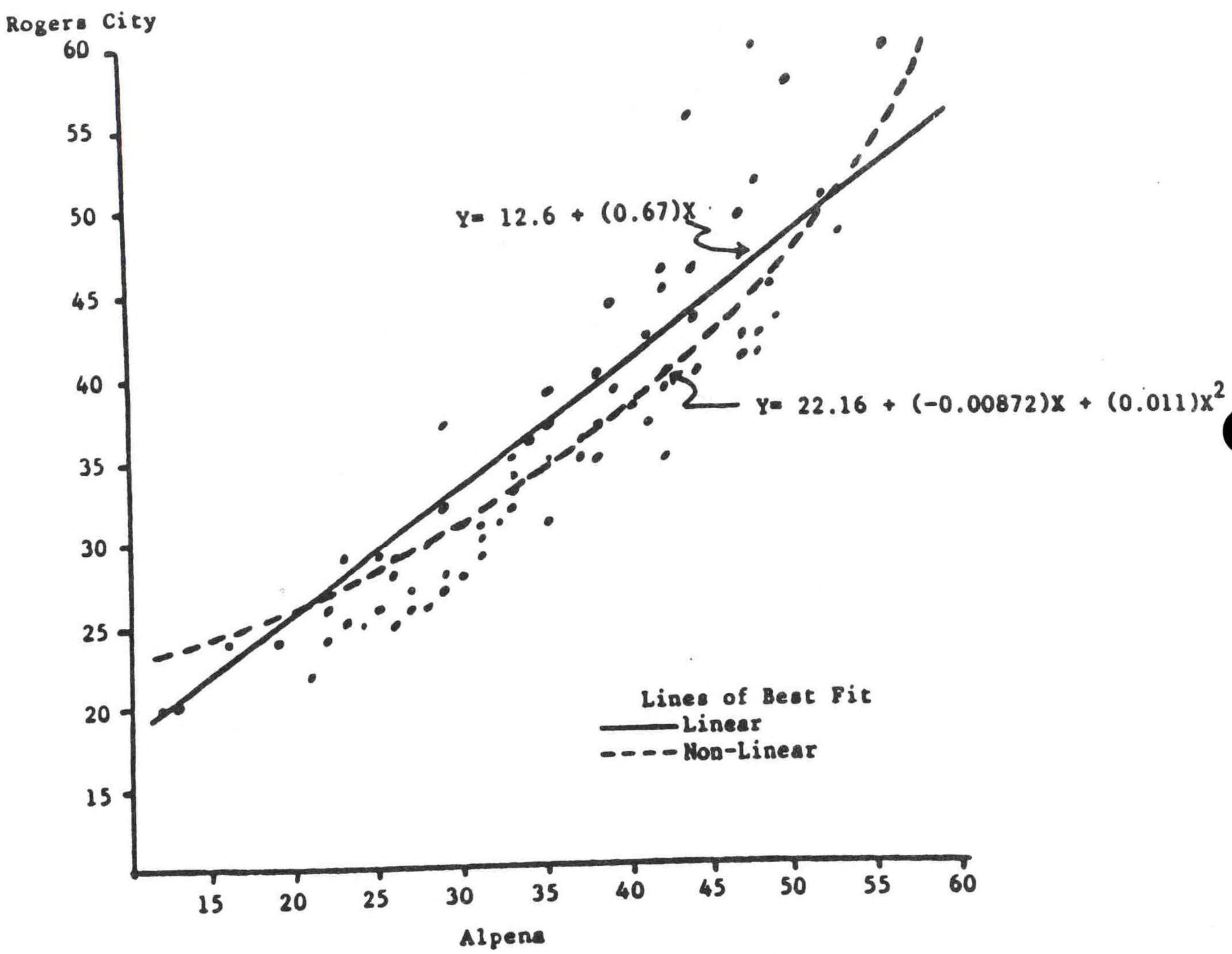
The non-linear relationship, and regression equation took the form of,

$$Y = A + BX + CX^2$$

The regression coefficients A, B, and C were determined by solving simultaneously the normal equations:

$$\begin{aligned}
\Sigma Y &= (A*N) + B*(\Sigma X) + C*(\Sigma X^2) \\
\Sigma(X*Y) &= A*(\Sigma X) + B*(\Sigma X^2) + C*(\Sigma X^3) \\
\Sigma(X^2*Y) &= A*(\Sigma X^2) + B*(\Sigma X^3) + C*(\Sigma X^4)
\end{aligned}$$

Linear versus Non-Linear Regression Lines of Best Fit
Figure 2.



Observed minimum temperatures at agriculture station - Rogers City and LFM MOS Station. Period of record April 1 through May 15, 1985-88.

LINEAR REGRESSION STATISTICS

TABLE 1

LFM MOS STATION	Specific Site	#OBS	Rounded Mean Diff	SD	Regression Coefficients A	B
Muskegon	Fennville	97	-1	3.59	-1.65	1.03
MD 3.91	Holland	97	-3	4.16	-7.54	1.12
SD 5.35	Nunica	97	-3	4.70	-5.64	1.06
	Mears	97	-2	7.57	-2.85	1.05
	Ludington	97	0	3.18	-2.83	1.05
Grand Rapids	Freemont	100	-1	2.80	0.43	0.96
MD 4.48	Grant	100	-3	3.82	-2.75	0.98
SD 4.44	Kent City	100	-1	2.64	2.02	0.92
	Peach Ridge	100	0	3.08	3.78	0.91
	Allendale	100	+1	3.22	3.73	0.92
	Hudsonville	100	-1	4.15	-0.31	0.96
	Belding	100	-1	3.45	1.23	0.95
Traverse City	Bear Lake	88	+5	5.51	7.36	0.92
MD 3.08	Beulah	88	+4	4.29	4.07	0.99
SD 5.53	Lake Leelanau	88	+2	3.91	7.33	0.85
	Old Mission	88	0	3.19	2.78	0.92
	Kewadin	88	+3	6.67	5.09	0.92
	Northport*	19	0	3.78	10.50	0.70
Lansing MD 3.44 SD 4.78	Coldwater	101	0	3.53	3.87	0.91
Houghton Lake MD 4.25 SD 4.52	Lake City	89	-2	3.24	-0.24	0.94
Alpena	Rogers City	106	+1	3.74	12.6	0.67
MD 2.13	Ossineke	106	+1	3.12	8.99	0.78
SD 4.68						
Flint	Standish	100	-5	3.86	1.88	0.83
MD 3.26	Saginaw Valley	100	-2	3.97	2.40	0.90
SD 5.12	Montrose	100	-1	3.42	-1.47	1.01
	Bad Axe	100	-3	3.73	5.22	0.80
	Sandusky	100	-2	4.07	5.58	0.82
	Port Sanilac	100	-3	4.11	6.74	0.76
	Imlay City	100	-3	3.40	2.38	0.86
Detroit MD 2.15 SD 4.33	Saline	101	0	3.77	2.02	0.94
South Bend	Glendora	101	-2	3.24	-3.36	1.03
MD 3.64	Watervliet	101	-4	4.27	-2.72	0.97
SD 4.34	Paw Paw	101	-3	3.45	-4.45	1.04
	Grand Junction	101	-4	4.98	-1.87	0.95

MD, Mean Difference; SD, Standard Deviation, #OBS, Number of observations; Rounded Mean Difference, between LFM MOS Forecast and Observed Minimum Temperature.

* New site with a statistically low number of events available.

5. Validation

The regression equations, both linear and non-linear, were used in actual forecast preparation during the spring of 1990 with the following results. Of the 34 sites forecasted, 23 sites had a complete set of 44 days of observed minimum temperatures each to verify with the corresponding 44 forecasts.

The LFM MOS 24 hour forecast minimum temperature was based on the 12Z data. (A correct forecast, equal to or less than +/- 3°.) The nine LFM MOS stations averaged 27 correct forecasts out of 44 forecasts. The worst LFM MOS station, Houghton Lake, had 24 correct forecasts, and the best LFM MOS station, Flint, had 40 correct forecasts.

OPERATIONAL RESULTS OF REGRESSION FORECASTS

TABLE 2

Agriculture site	Mean Algebraic Error	SD
Fennville	+1.86	3.42
Ludington	+0.64	5.98
Holland	-0.5	4.62
Fremont	+2.07	3.91
Grant	+0.73	4.06
Kent City	+1.81	4.06
Hudsonville	-0.34	4.46
Belding	-0.16	3.77
Beulah	+3.2	4.61
Kewadin	+0.66	4.67
Coldwater	+0.18	3.67
Lake City	-0.45	3.99
Rogers City*	+2.39	2.74
Standish	+0.82	4.85
Saginaw Valley	+0.34	4.21
Bad Axe	+0.89	4.64
Sandusky	-0.5	4.39
Port Sanilac	+0.52	4.42
Imlay City	-0.36	4.21
Glendora	+0.89	3.84
Watervliet	-0.41	4.44
Paw Paw	+1.14	4.44
Grand Junction	+0.5	5.47

* A Non-linear regression equation.

Sign, "+" means a too warm forecast and "-" means a too cold forecast.

6. Conclusion

The regression of observed minimum temperatures at the agriculture sites to nearby LFM MOS, 24 hour minimum temperature forecast stations, was a successful attempt to simplify the blending of climatological observed minimum temperatures with model forecasts. The operational usage of these regression equations were relatively easy once the forecaster deemed the LFM MOS forecast to be correct. The forecasters, regardless of forecast skill, were able to issue the forecasts with a high degree of confidence.

It is possible that this technique could be adapted to other regions of the country, and even expanded to encompass other programs outside of the field of agriculture, i.e. regions where LFM MOS stations are sparse but routine valid temperature observations are taken.

Further work needs to be done concerning restriction to distance and spatial placement of the forecast site and LFM MOS station. The question of maximum distance between an LFM MOS station and a forecast site should be addressed with an eye towards the LFM grid points as an absolute extreme. The future of the LFM in the next few years appears to be in question as refinement of the Nested Grid Mesh comes to the fore as basis for MOS. The regression equation developmental process described herein can be easily adapted to the new MOS.

7. Acknowledgments

National Weather Service Technical Development Laboratory (TDL) provided four years, 1985-88, of LFM MOS 24 hour minimum temperature forecasts (based on previous day's 12Z data).

Michigan State University Agriculture Meteorologist, Dr. J. D. Carlson, provided the same four years of observed minimum temperatures at the specific agriculture sites.

8. References

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