U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

National Weather Service

TDL Office Note 74-1

Objective Forecasts of Severe Thunderstorms from Observed Surface Predictors

Jess Charba
Techniques Development Laboratory

Systems Development Office
Silver Spring, Md.
February 1974

Objective Forecasts of Severe Thunderstorms from Observed Surface Predictors

1. Introduction

An on-going effort at the Techniques Development Laboratory (TDL) aims to develop a useful scheme to forecast the probability of severe local storms 2 to 6 hrs in advance in areas of about 10,000 nm^2. On the basis of experiments to test the predictive value of meteorological parameters based almost solely on hourly surface observations, Charba and Livingston (1973) found important correlations between these parameters and reports of severe weather. The data sample available for that study was too small to support development of useful statistical forecast relationships. Subsequently, data was collected from almost the entire severe storm season of 1973. This report discusses the results found in re-developing the 2→6 hour forecasting equations on the basis of this new data sample. A test of the forecasting skill of these equations was made by applying them to the 1972 data sample.

2. Developmental Procedure

The technique used in this study is based entirely on the classical statistical method (Klein, 1970). An empirical relationship is derived between the weather element to be forecast (the predictand) and various parameters (the predictors) based on data observed at an earlier time. The predictors are extracted from objective analyses of these data. The correlation procedure is designed so that once the empirical relationship is derived, it can have real-time forecasting application given the routine measurements.

A multiple (stepwise) screening regression technique (Miller, 1958) is used to screen the predictors offered; the best predictors are selected for inclusion into the derived equation. This technique has been applied extensively at TDL in various forecasting applications (e.g. see Glahn and Lowry, 1972).

a. Predictors

The meteorological observations used to develop the predictors are surface wind, temperature, moisture, MSL pressure, and 500-mb temperature. Hourly surface observations, collected from the "Service A" teletype circuit, are objectively interpolated to the grid array shown in Fig. 1. (The grid spacing averages about 40 nm, i.e, 1/4 the spacing of the operational grid used at the National Meteorological Center, NMC). The 500-mb temperature fields were obtained from NMC's final operational upper-air objective analysis.

From these gridded fields we extracted 26 predictors (Table 1). Most of the quantities listed have previously been found to relate to severe storms (Foster, 1964; Miller, 1967; Endlich and Mancuso, 1968; Newman, 1971; David, 1973; Sasaki and Tegtmeier, 1974; and others). A few of the quantities, such as $\Theta_E|\nabla\Theta_E|$ and $\nabla^2 p$ for example, have not, to the author's knowledge been previously tested. The parameter $\Theta_E|\nabla\Theta_E|$ depicts the warm, moist side of instability lines, while $\nabla^2 p$ picks out small-scale lows and highs in the pressure field. Later in this paper we will see that, at least, $\Theta_E|\nabla\Theta_E|$ is a very useful predictor.

b. Predictand

The predictors are correlated with reports of severe weather, compiled by the National Severe Storms Forecast Center (NSSFC). A severe weather event is defined as one or a combination of the following: tornado, funnel cloud, hail $\geq$ 3/4 in. dia., or wind gust $\geq$ 50 kts. In order to get a high enough frequency of storm events, it was necessary to integrate reports over some area and over some time span. The predictand then takes on a value of one if one or more severe weather reports are found and zero otherwise.

In order for the derived relationship between the predictand and predictors to have forecasting value, the area searched and the time period spanned by the predictand was taken downstream in space and later in time from the predictor point. On the basis of many experiments Charba and Livingston (1973) found that the predictor-predictand configuration giving the highest correlations is as shown in Fig. 2.

c. Sample Generation

During the 1973 season we collected data for all days between 28 March and 15 September. Predictor-predictand data were generated at 3-hourly times except at 06 and 09 GMT (Severe weather occurrences are relatively scarce following these times of the day). The statistics within the irregular area covering much of the eastern U.S. in Fig. 1 were archived for regression analysis. However, experiments run on the 1972 sample showed the correlations to be higher when the pooling of data was limited to the 15 x 15 grid area outlined in Fig. 1. Likewise results were improved when the combined spring and summer days were separated.

d. Screening Regression

The screening regression procedure (Miller, 1958) yields equations of the type

$$y = a_o + a_i x_i \quad i = 1, 2, 3, \ldots, N \qquad (1)$$

where y is the predictand, a_o is a constant, a_i denotes regression coefficients, and x_i are the predictors selected. The results discussed in this paper are only for the case of continuous predictors. The predictand is binary. Thus, Eq. (1) yields a probability estimate of a severe weather occurrence.

3. Results

Up to the present time we have derived regression equations for two times of the day. These are based on the 18 and 21 GMT surface data observations times. Each has an associated predictand projection time of 2 → 6 hrs. In the discussions to follow we examine in detail only the 21 GMT equation: this will serve the purpose of illustrating, both the make-up of each equation and how it holds up on tests with independent data. (We must point out that the present equations are preliminary, at least to the extent that we've introduced no modifications which normally can be made to improve the correlations and test results).

a. Regression Equation

The 21 GMT equation is shown in Table 2. Divergence of surface moisture flux, $\nabla . qV$, is listed as the first predictor selected, meaning that it exhibited the highest linear correlation coefficient of those screened; such has been the case in almost all the runs we've made. It is interesting to note that three of the first four predictors are quantities computed from the basic field.

The RV, i.e. the percentage of predictand variance explained by the regression equation, was 16.03% (Table 2). The sample frequency of storm events was only 5.9%.

b. Dependent Data Test

Results of an application of the 21 GMT equation to the developmental data is shown in Table 3. We find as the probability, P, increases from 0 to 50% and above, the severe weather frequency, n_s, increases monotonically from 1.6% to over 70%. Over 50% of all severe weather events are coupled with probabilities of 20% and above.

c. Independent Data Test

As expected some deterioration in the results was found when the 21 GMT equation was applied to the independent 1972 data sample. For instance, the RV for the independent data was 13.5% as compared to 16.0% for the dependent data. Note also that a greater percentage of the forecasts (F) fell into low categories while fewer forecasts reached the upper categories.

We should point out that the independent sample has some weaknesses which may have contributed to the relatively low variance reduction. For one thing, it's too small--only 16 days worth. This could have had some impact particularly since far from all severe weather occurrences are reported. Another problem is that the times involved in the independent sample were one hour earlier than 21 GMT.

d. Comparison with Operational Forecasting Systems

Currently, in the National Weather Service, there are no automated forecasting systems for severe thunderstorms for projection times less than 12 hrs in advance. There are, however, such systems making forecasts of 12 → 24 hrs (David, 1973) and 24 hrs only (Reap, 1974). These schemes are similar; they are both based on the screening regression approach and both use numerical forecasts from NMC's numerical prediction models as input. David's equation also uses 6-hour old surface observations.

Although the projection times of David's and Reap's equations are twice that of the equations discussed here, thus rendering invalid strict comparisons, it is interesting to touch on relative differences. In general, we find that our equation, valid at 21 GMT, explained somewhat more variance (25 to 50% more) and that it fared better in the respective independent tests (See David, 1973 and Mogil, 1974). These findings indicate that our 21-GMT equation, based almost entirely on surface data 2 hrs old, gives 2 → 6 hr forecasts at least as accurate as, say, David's 12 → 24 hr forecasts which are based on a combination of surface data (but 4 hrs older), and numerical model forecasts.

4. Future Plans

Work is now in progress to improve the forecasting skill of the equations discussed here. The relationships between the predictand and predictors are being linearized where necessary and some predictors are being transformed to binary form as discussed by Alaka, et al. (1973). We also intend to derive equations for all of the eastern half of the U.S. as outlined in Fig. 1. Stratification of the data into two or more regions within the general area will probably be required.

Following the 1974 storm season we will develop new equations based on additional types of data which are now being collected. To augment the surface observations we will incorporate forecast fields from NMC's numerical models along the lines of David (1973) and Reap (1974). Manually-coded radar data (Moore and Smith, 1972) will also be introduced as predictor information and, perhaps, also as a predictand.

5. Acknowledgments

Mr. Michael Livingston deserves credit for providing much assistance in the computations and programming. I also wish to thank Mr. Harry Akens for preparing the surface data tapes and the many other TDL members who made contributions to this work. Thanks are also extended to Mr. A. D. Pearson, Director of NSSFC and to his staff for preparing at short notice the severe weather data tapes needed for this study. TDL's severe storm project leader, Dr. M. A. Alaka, provided overall guidance. The screening regression program was developed by Dr. H. R. Glahn and Mr. G. W. Hollenbaugh; Jocelyn Boss typed the manuscript.

6. References

Alaka, M. A., W. D. Bonner, J. P. Charba, R. L. Crisci, R. C. Elvander and R. M. Reap, 1973: "Objective Techniques for Forecasting Thunderstorms and Severe Weather". Final Rep. to FAA, Rep. No. FAA-RD-73-117, Grant No. FA 67 WAI-131, 97 pp.

Charba, J. P. and M. L. Livingston, 1973: "Preliminary Results On Short Range Forecasting of Severe Storms from Surface Predictors". Preprints of Eighth Conf. on Severe Local Storms, Am. Meteor. Soc., Boston, Mass., pp. 226-231.

David, C. L., 1973: "An Objective Method for Estimating the Probability of Severe Thunderstorms Using Predictors from the NMC (PE) Numerical Prediction Model and from Observed Surface Data". Preprints of Eighth Conf. on Severe Local Storms. Am. Meteor. Soc., Boston, Mass., pp. 223-225.

Endlich, H. R. and R. L. Mancuso, 1968: "Objective Analysis of Environmental Conditions Associated with Severe Thunderstorms and Tornadoes". Mon. Wea. Rev., 96, 342-350.

Foster, D. S., 1964: "Relationship Among Tornadoes, Vorticity Acceleration, and Air Mass Stability". Mon. Wea. Rev., 92, 339-343.

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.

Klein, W. H., 1970: "The Forecast Research Program of the Techniques Development Laboratory". Bull. Am. Meteor. Soc., 51, 133-142.

Miller, R. G., 1958: The Screening Procedure. Studies in Statistical Weather Prediction. Final Rep., Contract AF19(604)-1590 (B. Shorr, Ed.) The Travelers Research Center, Inc., Hartford, Conn., pp. 86-95.

Miller, R.C., 1967: Notes on Analysis and Severe Storm Forecasting Procedures of the Military Weather Warning Center. AWS Tech. Rep. 200.

Mogil, H. M., 1974: "Evaluation of Severe Weather and Thunderstorm Forecasts Using Manually-Digitized Radar Data and SELS Severe Weather Log". Preprints of Fifth Conf. on Wea. Forecasting and Analysis. Am. Meteor. Soc., Boston, Mass.

Moore, P. L. and D. L. Smith, 1972: Updating of Numerical Precipitation Guidance. NOAA Tech. Memo. NWS SR-64, 16 pp.

Newman, W. R., 1971: "The Relationship Between Horizontal Moisture Convergence and Severe Storm Occurrences". M.S. Thesis, Univ. of Okla., Dept. of Meteor., 51 pp.

Reap, R. M., 1974: "Thunderstorm and Severe Weather Probabilities Based on Model Output Statistics". Preprints of Fifth Conf. on Wea. Forecasting and Analysis. Am. Meteor. Soc., Boston, Mass.

Sasaki, Y. S. and S. A. Tegtmeier, 1974: "Synoptic and Dynamic Basis of Tornadic Storm Forecasting". Preprints of Fifth Conf. on Wea. Forecasting and Analysis. Am. Meteor. Soc., Boston, Mass.

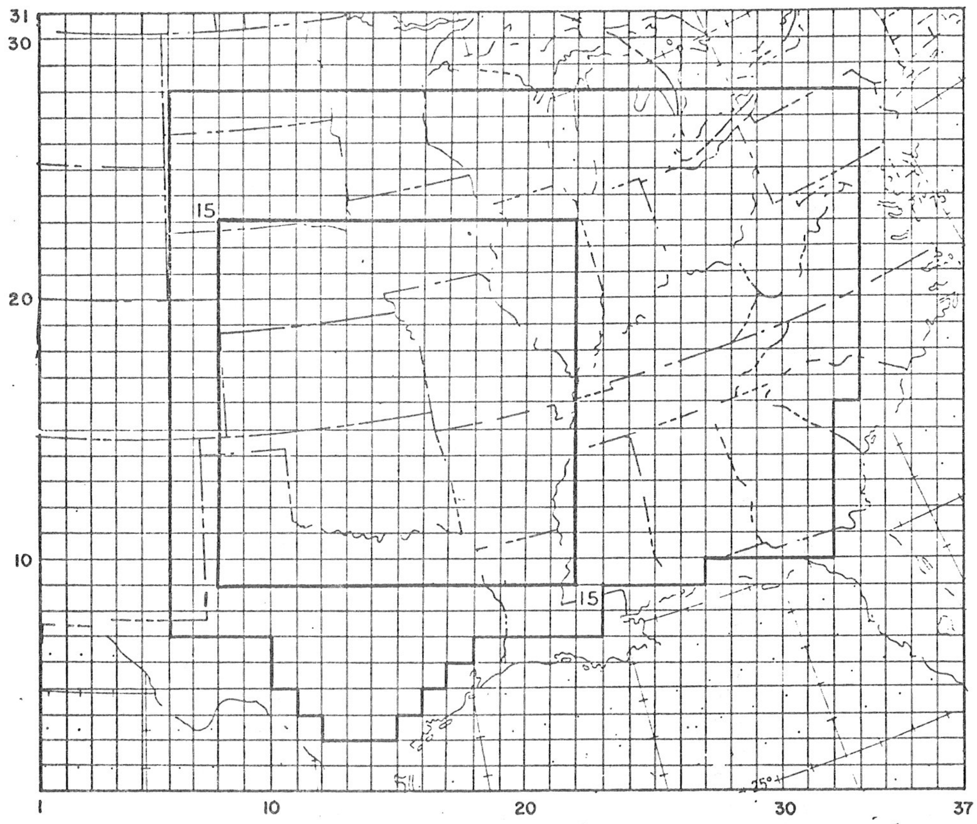

Fig. 1. Analysis grid array; grid spacing averages about 40 nm. The large area outlined by the heavy line denotes the region where predictors were archived. The inner rectangular area, i.e., 15 x 15 array of points, denotes the region where the grid-point data was pooled for the regression runs discussed in section 3.

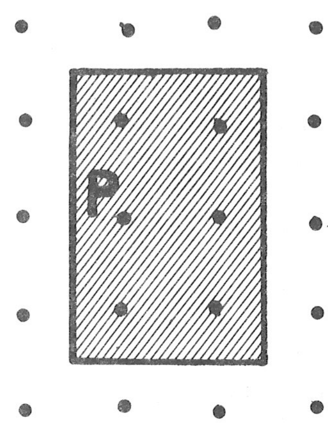

Fig. 2. Predictor-predictand configuration. The array of points represents a blown-up view of a small subset of grid points in Fig. 1. The predictors at a grid point, gridpoint P for example, are correlated with reports of severe weather occurrences in the stippled area (80 x 120 nm^2) occurring 2-to 6 hrs later than the predictor time. Predictors at each of the adjacent points are paired with a corresponding predictand "box".

Table 1. List of Predictors Subjected to Screening.

1.	T	14.	$\Theta_E\lvert\nabla\Theta_E\rvert$
2.	$\frac{\partial T}{\partial t}$	15.	$\lvert\nabla q\rvert$
3.	p	16.	$q\lvert\nabla q\rvert$
4.	$\frac{\partial p}{\partial t}$	17.	$\nabla.\vec{V}$
5.	q	18.	$\nabla x\vec{V}$
6.	$\frac{\partial q}{\partial t}$	19.	$\nabla.q\vec{V}$
7.	T_W	20.	$\frac{\partial}{\partial t}\ \nabla.q\vec{V}$
8.	$\frac{\partial T_W}{\partial t}$	21.	$\nabla.\Theta_E\vec{V}$
9.	S	22.	$\frac{\partial}{\partial t}\ \nabla.\Theta_E\vec{V}$
10.	$\frac{\partial S}{\partial t}$	23.	$\vec{V}.\nabla h$
11.	Θ_E	24.	$\Theta_E\vec{V}.\nabla h$
12.	$\frac{\partial\Theta_E}{\partial t}$	25.	$\nabla^2 p$
13.	$\lvert\nabla\Theta_E\rvert$	26.	$\frac{\partial}{\partial t}\ \nabla^2 p$

Symbols: $\vec{V}$ - surface wind vector
T - surface temperature
p - MSL pressure
q - surface mixing ratio
T_W- wet bulb potential temperature
Θ_E- equivalent potential temperature
S - air-parcel stability: defined as the difference between the temperature of an air-parcel lifted from the surface to 500 mb and the ambient 500-mb temperature
∇ - horizontal gradient
∇^2- Laplacian in horizontal plane
t - time

Table 2. Spring season regression equation for forecasting severe weather occurrences during the period 2300 → 0300 GMT from predictors at 2100 GMT. (Local time-change predictors use data observed 3 hrs earlier). The developmental sample included 71 spring days of 1973; combining the statistics within the 15 x 15 array in Fig. 1 for the regression runs gave a total of 15975 cases. Listed below is the order of predictors selected, the coefficient of each predictor, and the reduction (or explained) variance (RV) of the predictand with each predictor added to the equation.

Predictor (Units)	Coefficient	RV (%)
	constant - 3.338	
1. $\nabla \cdot q\vec{V}$ (g/kg. sec)	$- 2.539 \times 10^{2}$	7.94
2. q (g/kg)	6.976×10^{-3}	11.36
3. $\Theta_E \lvert \nabla \Theta_E \rvert$ (C^2/km)	2.352×10^{-2}	12.48
4. $\nabla \cdot \vec{V}$ (sec^{-1})	5.038×10^{3}	13.27
5. P (mb)	$- 3.215 \times 10^{-3}$	14.25
6. T (C)	$- 6.557 \times 10^{-3}$	14.71
7. S (C)	$- 6.626 \times 10^{-3}$	15.28
8. $\frac{\partial p}{\partial t}$ (mb/hr)	$- 3.458 \times 10^{-2}$	15.69
9. $\nabla \cdot \Theta_E \vec{V}$ (C/sec)	$- 9.970 \times 10^{1}$	16.03

Table 3. Dependent data test for 21 GMT equation in Table 2. Definition of parameters: P-probability of severe weather; N_s-number of severe weather events; N-number of forecasts; n_s-frequency of severe weather events; CP_s-cumulative percentage of all severe weather events in sample; F-frequency of probability category.

P(%)	N_s	N	n_s(%)	CP_s(%)	F(%)
P > 50	13	18	72.2	1.4	0.1
40 < P ≤ 50	44	77	57.1	6.1	0.5
30 < P ≤ 40	107	258	41.5	16.4	1.6
20 < P ≤ 30	323	997	32.4	51.8	6.3
10 < P ≤ 20	319	2889	11.0	85.8	18.1
0 < P ≤ 10	118	7274	1.6	98.4	45.5
P ≤ 0	16	4462	0.4	100.0	28.0
	Total=940	Total=15975	n_s(sample)=5.9%		

Table 4. Test of 21 GMT equation on independent data. The independent data is comprised of 16 selected "storm" days of the period 20 April → 10 June 1972. The equation is applied to the same 15 x 15 array as used in its derivation. Symbols are the same as defined in Table 3.

P(%)	N_s	N	n_s(%)	CP_s(%)	F(%)
P > 50	0	0	-	-	-
40 < P ≤ 50	0	3	0.0	0.0	0.1
30 < P ≤ 40	18	33	54.5	7.4	0.9
20 < P ≤ 30	76	186	40.9	38.4	5.2
10 < P ≤ 20	97	711	13.6	78.0	19.8
0 < P ≤ 10	50	1916	2.6	98.6	53.6
P ≤ 0	4	751	0.5	100.0	20.9
	Total=245	Total=3600	n_s(sample)=6.8%		

Explained Variance = 13.5%