NOAA TM NWS CR-50

NOAA Technical Memorandum NWS CR-50

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
National Weather Service

An Objective Forecast Technique For Colorado Downslope Winds

Wayne E. Sangster

CENTRAL REGION
Kansas City, Mo.

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NOAA TECHNICAL MEMORANDUM

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AN OBJECTIVE FORECAST TECHNIQUE FOR COLORADO DOWNSLOPE WINDS

Wayne E. Sangster

CENTRAL REGION

KANSAS CITY, MISSOURI
December 1972

AN OBJECTIVE FORECAST TECHNIQUE FOR COLORADO DOWNSLOPE WINDS

Wayne E. Sangster
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Kansas City, Missouri

ABSTRACT

An objective technique for forecasting the probability of strong westerly downslope winds in the Boulder, Colorado, area is presented. Wind events with thresholds of 60 mph and 80 mph in a 6-hour period were related to 2-a-day upper-air observations at upstream stations with a 6-hour lag to the beginning of the verifying period, using the screening regression technique. A test on one season of independent data was used to determine the optimum number of terms in the regression equations. Equations for a 0-hour lag between observation time and the beginning of the verifying period are also presented, even though these are of limited operational utility. Surprisingly, for the 60 mph threshold, the skill for a 0-hour lag is lower than for the 6-hour lag. Predictors picked early in the selection process were 850 mb and 700 mb height differences, but 500 mb or 300 mb (depending upon the lag time) west wind components were also found to add skill. Worksheets for operational use are provided in the Appendices.

1. INTRODUCTION

An earlier paper by the author (Sangster, 1970) dealt with the problem of forecasting the violent westerly downslope winds which occur during the colder part of the year at places such as Boulder and Ft. Collins, Colorado, which are located on the plains at the foothills of the Rocky Mountains. This paper will describe efforts to develop an improved objective forecast technique. Principal differences between this and the previous work are the following:

1. A more sophisticated statistical technique (screening regression) was used.
2. The developmental sample was larger (four cold seasons instead of one).
3. One season of independent data has been used to test equations derived.
4. More predictors have been examined.
5. A three-category rather than two-category predictand has been used.
6. The 6-hour periods beginning 6 hours after data time as well as those beginning at data time were examined.

2. DATA SOURCES

Data from four cold seasons--October 1968 through early May 1969, and September through May of 1969-70, 70-71, and 71-72--have been used in this study. Predictand data are from anemometers in Boulder, but readings from the same anemometer have not been used for the entire period.

For the first cold season, readings from the Southern Hills Junior High School, the 30th Street NOAA (then ESSA) Environmental Research Laboratories, and the National Center for Atmospheric Research Mesa Laboratory were used. For the last three cold seasons the anemometer at the National Bureau of Standards Radio Building installed by the National Weather Service in August of 1969 has been used.

Fig. 1 shows the locations of the various anemometers. It will be seen that the NBS Radio Building is located more or less between the Southern Hills Junior High and the NOAA Research Laboratories. The NCAR location is higher and closer to the foothills than the other locations, and it typically experiences appreciably higher winds than do locations farther east at lower elevations.

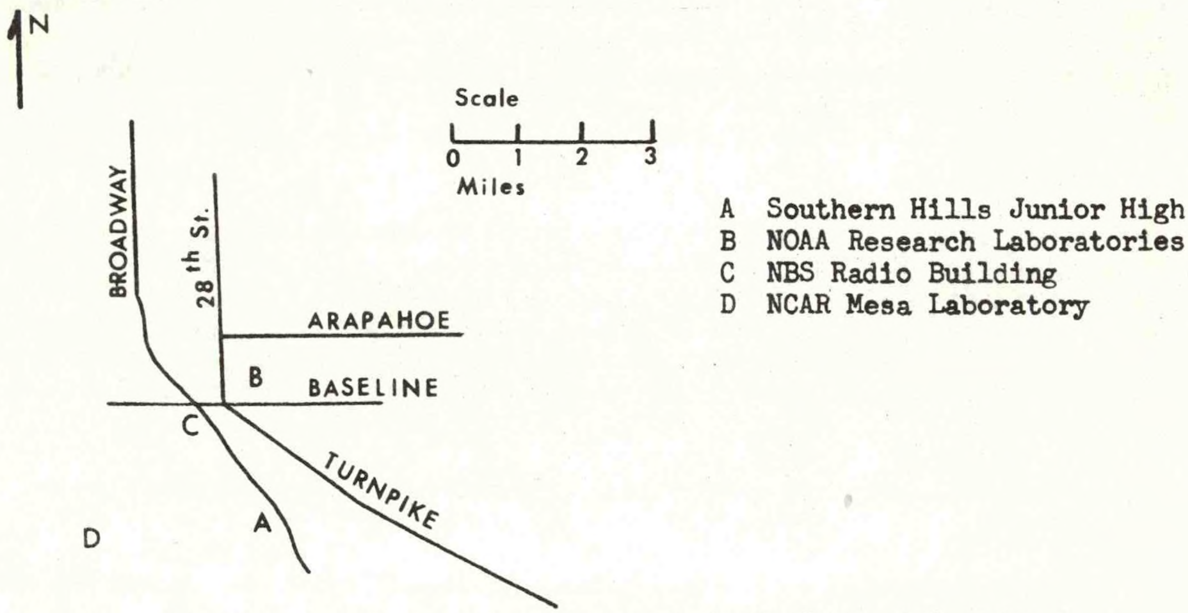

Fig. 1. Locations of anemometers in Boulder, Colorado.

A tabulation was made of the peak wind speed (usually westerly or northwesterly, at least for the stronger winds) occurring in three-hour periods (0000-0300 GMT, 0300-0600 GMT, etc.) during the day for the four cold seasons. Data for the first season were adjusted to correspond with the NBS Radio Building readings by multiplying the peak three-hour speeds by the following factors:

Average of Southern Hills Junior High and Environmental Research Laboratories	1.00
Environmental Research Laboratories alone	1.22
Southern Hills Junior High alone	.85
NCAR	.82

The last three factors were determined by comparing readings from the various anemometers when such comparisons could be made provided the Southern Hills-ERL average peak speed was 40 mph or higher. Readings from NCAR were used for most of October, November, and December, and the average of the Southern Hills and the Research Laboratories was used during most of the remaining months of the first season. On occasion, one or the other of these two anemometers had to be used alone. All subsequent references in this memorandum are to the adjusted speeds.

Data used to construct possible predictors consisted of two-a-day (at 0000 and 1200 GMT) upper-air observations at the following stations:

Denver, Colorado	DEN
Grand Junction, Colorado	GJT
Lander, Wyoming	LND
Salt Lake City, Utah	SLC

Fig. 2 shows the locations of these stations in relation to Boulder and Ft. Collins.

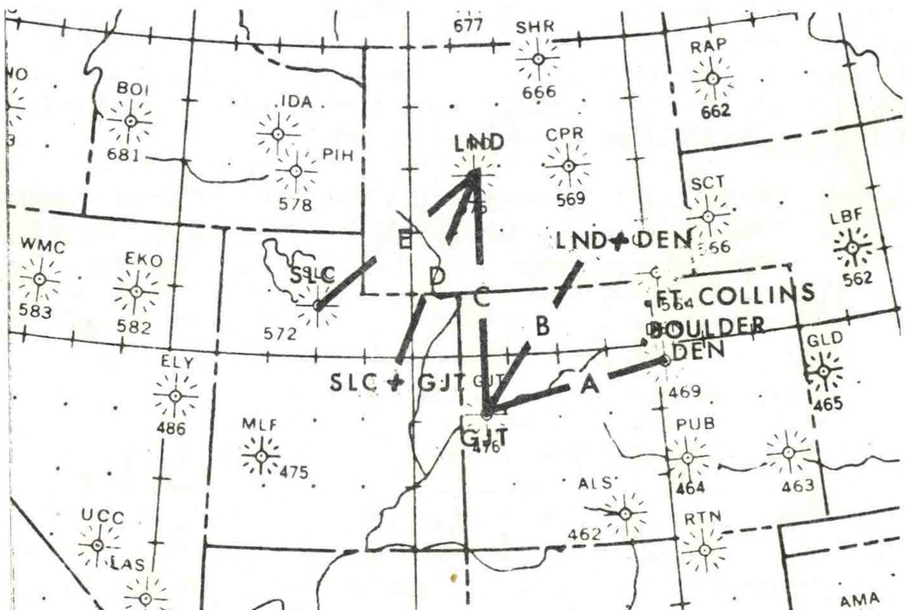

Fig. 2. Locations of upper-air stations and foothill cities. Letters A, B, C, D, and E refer to height differences described in Section 5.

3. WIND CLIMATOLOGY

Before proceeding to a discussion of the development of the forecast technique, it should be of interest to look briefly at the climatology shown by the 34-month sample of predictand data. September and May data are for three years and the remaining months for four years.

Table 1 shows the relative frequency of wind events as a function of the length of the time period and the threshold used when all the data are pooled without regard to month of the year. Note that the frequency drops off rapidly as the threshold is increased.

Table 1. Relative frequencies (in percent) of wind events as a function of threshold and length of time period. All months of the season pooled together.

	≥40	≥50	≥60	≥70	≥80 mph
3 hours	9.9	4.7	2.3	0.9	0.3
6 hours	13.9	6.9	3.4	1.4	0.5
12 hours	19.9	10.7	5.4	2.4	0.9
24 hours	30.0	17.1	9.5	4.3	1.8

The variation by month for 6-hour periods (the length to be used in the forecast technique) is shown in Table 2. January is the big month, followed by December and February in that order. The very strong winds are rare in the early fall and late spring. The annual variation shown here is similar to that given by Julian and Julian (1969).

Table 2. Relative frequencies (in percent) of wind events as a function of the threshold and the month of the year. Six-hour periods.

	≥40	≥50	≥60	≥70	≥80 mph
September	6.1	2.2	1.1	0	0
October	9.6	3.7	1.4	0.2	0
November	12.6	7.2	3.0	1.1	0.2
December	20.1	11.2	5.5	2.2	0.6
January	28.3	17.8	10.3	6.5	2.6
February	16.4	7.1	3.8	0.4	0.2
March	12.5	4.8	1.8	0.6	0.6
April	10.5	4.4	2.3	0.6	0
May	4.9	1.0	0.3	0	0

Since January stands out as a month of very high activity, another table similar to Table 1, except that only January data are included, is shown as Table 3. This shows the astounding value of nearly 51 percent frequency for winds of 40 mph or more in a 24-hour period during this month. For 80 mph and higher events in a 24-hour period the frequency is 9 percent, not a small figure for such a significant event.

Table 3. Relative frequencies (in percent) of wind events as a function of threshold and length of time period for January only.

	≥40	≥50	≥60	≥70	≥80 mph
3 hours	20.9	13.4	7.0	3.8	1.6
6 hours	28.3	17.8	10.3	6.5	2.6
12 hours	38.6	25.6	15.4	10.6	4.5
24 hours	50.8	36.1	26.2	18.0	9.0

From the forecasters' viewpoint a diurnal variation in the wind climatology, if one exists, is of considerable interest. The diurnal frequencies for overlapping six-hour periods for various thresholds and for all months pooled are shown in Table 4.

Table 4. Relative frequencies (in percent) of wind events as a function of threshold and time of day for all months of the season pooled together. Six-hour periods.

	≥40	≥50	≥60	≥70	≥80 mph
0000-0600 GMT	14.0	6.6	2.7	1.2	0.4
0300-0900 GMT	12.4	6.8	3.2	1.7	0.5
0600-1200 GMT	11.7	7.2	3.7	1.4	0.5
0900-1500 GMT	11.5	7.0	3.5	1.6	0.5
1200-1800 GMT	11.9	6.1	3.0	1.4	0.7
1500-2100 GMT	15.6	7.5	4.1	1.7	0.5
1800-2400 GMT	18.0	7.7	4.3	1.7	0.5
2100-0300 GMT	15.8	6.6	3.7	1.3	0.6

For the lowest threshold of 40 mph a maximum frequency is evident during the afternoon--1800-2400 GMT (1100-1700 MST). The nighttime hours of 0900-1500 GMT (0200-0800 MST) have the minimum frequency. For thresholds of 50 mph and higher little systematic diurnal variation can be detected, indicating that most of the diurnal variations are concentrated in the 40-49 mph range. From Table 4 one can deduce that the relative frequency for this range of speeds for the 1800-2400 GMT period is more than double that for the 0900-1500 GMT period--11.3 percent vs. 4.5 percent.

Julian and Julian showed the 0700-1300 GMT period to have the highest frequency of severe windstorms, followed by the 0100-0700 GMT period. Their data show the 1300-1900 GMT period to have a frequency less than half that of the 0700-1300 GMT period. This finding is not confirmed by the evidence presented here, but neither can it be strongly disputed, since only 4 to 7 wind events of 80 mph or more in each 6-hour period were recorded in the 4 years.

4. THE SCREENING REGRESSION PROCEDURE

A statistical technique known as screening regression was used to evaluate possible predictors. Multiple linear regression relates one variable Y (the predictand) to k other variables X_i (the predictors). The result is an equation which can be used for estimating the predictand as a linear combination of the predictors:

$$\hat{Y} = a_0 + a_1X_1 + a_2X_2 + \dots + a_kX_k$$

The carat indicates an estimate, and the a_i's are the regression constant and coefficients.

The forward stepwise screening regression procedure was used in this study. In this procedure the first step is to select the predictor which correlates most highly (in either a positive or negative sense) with the predictand. Then, the predictor which together with the first gives the largest multiple correlation coefficient (largest reduction of variance) is chosen second. This process is repeated until some specified cutoff criterion is reached. This is usually some function of the additional reduction of variance afforded by the next best predictor. A discussion of the screening regression technique is given by Glahn and Lowry (1969).

Either or both the predictand(s) and the predictors can be continuous or binary variables. In this study the continuous predictand was divided into three binary predictands. If the peak wind speed observed was less than 60 mph the <u>first</u> predictand was assigned the value of one and the other two the value of zero. If the peak wind was 60 to 79 mph the <u>second</u> predictand was assigned the value of one and the other two set to zero. For peak winds of 80 mph and up the <u>third</u> predictand was assigned the value of one and the other two set to zero. This means that the values given by the three regression equations can be interpreted as the probabilities of each of the three possible states occurring. This is commonly known as REEP (regression estimation of event probabilities) (Miller, 1964). Lund (1955) was an early user of this technique (for a two-state situation).

Both binary and continuous predictors were used. The binary predictors were formed by giving them a value of one if the original (continuous) predictor was less than or equal to a specified limit and zero otherwise. One might expect that binary predictors would perform the best for a binary predictand and this seems to be borne out by experience. However, each continuous variable usually is converted into several binary predictors (with different limits) and it may be necessary to first use continuous variables if a large number of parameters is to be examined. The screening regression program used in this study, as adapted to the CDC-3100 computer, will handle a maximum of 50 predictors.

5. DEVELOPMENT OF TECHNIQUE FOR 0600-1200 and 1800-2400 GMT PERIODS

Most of the effort has been expended on the 6-hour periods beginning 6 hours after data time, which makes the technique completely objective for short-range forecasts twice a day. Some work (described later) has been done on the 6-hour periods beginning at data time.

a. Continuous Predictors (First Three Seasons)

A blanket screening run for the period 6 to 12 hours after data time (no distinction was made between 0000 GMT and 1200 GMT data) was made with simple parameters thought possibly to be related to the strong downslope winds. This run used various differences of constant-pressure heights (Z) from 850 mb to 300 mb plus wind components and sums of wind components from 700 mb to 300 mb. The simple correlation coefficients from this run are shown in Table 5. Two sets of correlation coefficients are given--the ones for "60 mph or higher" are simply the negative of the correlation coefficients for the first binary predictand, which took on a value of 1 if the wind was less than 60 mph and a 0 otherwise. The legend at the bottom of the table defines how the differences and sums were taken (also, see Fig. 2). The predictor which had the highest correlation coefficient was the combination "D" height difference [Z(SLC) + Z(GJT) - 2 · Z(LND)] at 850 mb--which we will label DZ85D--for the 60 mph or higher events. The same combination at 700 mb (DZ70D) was close behind.

A screening run using DZ85D with a series of limits converting it to binary predictors revealed that there were no 60 mph or above events when DZ85D was less than or equal to 45 gpm. Another run was then made with the same predictors as shown in Table 5, but including only those cases where DZ85D was greater than 45 gpm, thus eliminating almost half of the cases. (It should be mentioned here that DZ70D was found to be slightly inferior to DZ85D for the purpose of this exclusion process.) In addition to this run, another run was made using the same parameters and exclusion criterion for data from 250 mb to 100 mb. The correlation coefficients for these two runs are shown in Table 6. It will be seen that DZ85D has a wider margin over DZ70D than in Table 5 for 60 mph and up events. DZ70D and U70SM2 are tied for the highest correlation for 80 mph and up events. It is evident that the correlations at 500 mb and higher levels are appreciably lower than at 850 mb and 700 mb, though one can't conclude that these levels are not important. But Table 6 does suggest that the levels to concentrate on are 850 mb and 700 mb and possibly 500 mb or even 400 mb. This is not surprising

Table 5. Correlation coefficients between continuous constant-pressure height differences and continuous wind components and the binary wind predictands. There is a six-hour lag from the observation time to the beginning of the six-hour forecast period. Definitions of symbols are below the table. 0600-1200 and 1800-2400 GMT periods. First three seasons of data.

		Pressure (mb)	Height Differences (DZ) A	B	C	D	E	Wind Components U (west) SLC	GJT	LND	SM2	SM3	V (south) SM3
60 mph or higher		300	.01	.09	.12	.12	.08	.15	.14	.15	.16	.16	-.05
	F_w = 3.8%	400	.04	.12	.14	.14	.09	.21	.15	.17	.18	.20	-.05
	N_w = 41	500	.08	.17	.18	.18	.14	.23	.17	.18	.20	.22	-.05
	N_c = 1068	700	.21	.27	.27	.295	.28	.20	.20	.27	.29	.28	-.00
		850	.25	.28	.28	.300	.27						
80 mph or higher		300	-.01	.04	.06	.05	.02	.10	.07	.06	.07	.08	-.00
	F_w = 0.5%	400	.03	.06	.06	.05	.02	.11	.07	.06	.07	.09	-.02
	N_w = 5	500	.08	.10	.08	.08	.05	.09	.07	.06	.07	.08	-.02
	N_c = 1068	700	.10	.12	.12	.133	.130	.05	.12	.12	.15	.12	-.01
		850	.07	.09	.10	.12	.11						

DEFINITIONS

A = Z(GJT) - Z(DEN)

B = 2 · Z(GJT) - Z(LND) - Z(DEN)

C = Z(GJT) - Z(LND)

D = Z(SLC) + Z(GJT) - 2 · Z(LND)

E = Z(SLC) - Z(LND)

SM2 = U(GJT) + U(LND)

SM3 = U(SLC) + U(GJT) + U(LND)

F_w = relative frequency of wind events

N_w = number of wind events

N_c = total number of cases

Table 6. Correlation coefficients as in Table 5, except that only those cases where DZ85D was greater than 45 gpm were included in the computations. No wind cases were lost by this exclusion process.

		Pressure (mb)	Height Differences (DZ) A	B	C	D	E	Wind Components U (west) SLC	GJT	LND	SM2	SM3	V (south) SM3
60 mph or higher	F_w= 6.3%	100	-.03	.03	.08	.07	.03	.07	.04	-.06	-.01	.02	.05
	N_w= 26	150	-.11	.01	.12	.12	.09	.13	.12	.14	.14	.14	.02
	N_c= 411	200	-.09	.02	.13	.13	.09	.12	.15	.12	.15	.14	.01
		250	-.07	.03	.12	.11	.07	.12	.15	.12	.15	.15	-.02
		300	-.04	.06	.12	.11	.06	.13	.15	.13	.15	.15	-.04
	F_w= 7.4%	400	-.01	.09	.13	.13	.08	.21	.16	.17	.19	.20	-.04
	N_w= 41	500	.05	.16	.18	.17	.12	.24	.17	.17	.19	.22	-.04
	N_c= 554	700	.20	.29	.28	.33	.30	.22	.21	.26	.29	.30	-.02
		850	.24	.30	.30	.38	.29						
80 mph or higher	F_w= 0.5%	100	-.06	.04	.12	.10	.05	.03	-.04	.02	-.01	.00	.09
	N_w= 2	150	-.07	.03	.11	.07	.01	.07	.02	.05	.04	.05	.05
	N_c= 411	200	-.10	.01	.11	.08	.02	.08	.03	.11	.07	.08	.04
		250	-.11	-.03	.07	.05	.00	.10	.07	.08	.08	.09	.02
		300	-.03	.03	.06	.04	.01	.11	.08	.06	.08	.09	.00
	F_w= 0.9%	400	.02	.06	.07	.05	.01	.14	.08	.05	.08	.10	-.01
	N_w= 5	500	.09	.12	.10	.08	.04	.11	.08	.06	.08	.09	-.02
	N_c= 554	700	.11	.15	.15	.174	.16	.04	.16	.13	.174	.14	-.02
		850	.06	.09	.11	.16	.14						

for a simple approach to the problem, since we are dealing with surface winds as the forecast problem. The correlations for VSM3 were poor at all levels.

Unfortunately, when dealing with even as few as three stations and several levels the probability of encountering missing or incorrect data is disturbingly high. The computer program has to have all of the information being requested in that run and will eliminate cases from the sample if data are missing. In order to increase the sample size from that shown in Table 6, only those parameters having the highest correlation coefficients were included in another run. This run included only height differences "C", "D", and "E" at 850 mb and 700 mb and wind components at 700 mb and 500 mb. Results are shown in Table 7.

Table 7. Same as Table 6, except that fewer predictors are involved, so the sample size is larger.

			Height Differences (DZ)			Wind Components					
						U (west)					V (south)
		Pressure (mb)	C	D	E	SLC	GJT	LND	SM2	SM3	SM3
60 mph or higher	F_w = 7.9%	500				.23	.18	.17	.19	.22	-.04
	N_w = 55	700	.26	.32	.29	.22	.21	.23	.27	.28	-.04
	N_c = 697	850	.28	.36	.28						
80 mph or higher	F_w = 1.0%	500				.10	.07	.06	.08	.09	-.02
	N_w = 7	700	.13	.16	.15	.05	.13	.09	.13	.11	-.01
	N_c = 697	850	.10	.15	.13						

The main difference between Table 6 and Table 7 is that DZ70D has moved out on top as the best single predictor for the 80 mph and up events, no longer being tied with U70SM2. One can see that U50SLC and U50SM3 as continuous predictors are almost of equal skill, regardless of the category of wind event being predicted.

b. Binary Predictors and Independent Data Test

The preceding runs used continuous predictors because a larger number of different parameters could be examined this way. We now turn to binary predictors, which generally give a higher reduction of variance. After much experimentation, it was decided to use DZ85D, DZ70D, and U50SM3 with a number of limits each converting them to a number of binary predictors. As before, only those cases where DZ85D was greater than 45 gpm were used in the regression analysis. The equations resulting from this run were then tested on the sample of independent data from the season of 1971-72 using 1 through 10 predictors. If DZ85D was not greater than 45 gpm, probabilities of zero were used. The Sanders (1963) improvement over climatology skill scores using a climatology which varied by month as a comparison for each of these 10 equations are shown in Fig. 3. Three or four predictors would seem to be an optimum from this figure and it was decided to use the four-predictor equations. This choice agreed with a subjective evaluation based on additional reductions of variance provided by each additional predictor and the signs of the coefficients.

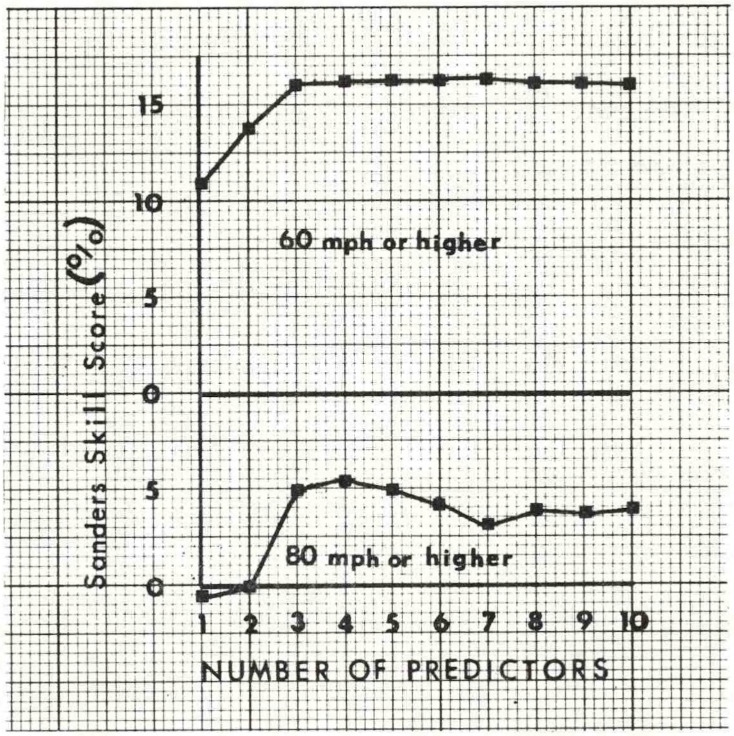

Fig. 3. Sanders skill scores on independent data as a function of the number of predictors when DZ85D, DZ70D, and U50SM3 were used with several limits each converting them to binary predictors. 0600-1200 and 1800-2400 GMT periods. Sample size was 523 cases.

The regression analysis showing coefficients and reductions of variance (R. V.) for the three seasons is shown in Table 8. A similar analysis for four seasons is shown in Table 9. Only two sets of coefficients are shown, since the third set can be deduced from these two. The "60 mph and up" set is obtained from the set for the first predictand (1 if wind is less than 60 mph, zero otherwise) by subtracting the constant from 100 and changing the signs of the remaining coefficients. Note that the order of selection for predictors 2 and 3 is reversed; otherwise, Tables 8 and 9 are essentially the same. The reductions of variance of the equations from Table 8 when applied to the one season of independent data for those cases where DZ85D was greater than 45 gpm were 18.41 and 8.33 percent for the two classes of events, which are comparable with those given in Table 8. These facts suggest that these equations are rather stable and that even with a very large sample of developmental data similar results would be obtained.

Probabilities implied by Table 9 are given in Appendix I in a form easily usable by the forecaster. For the 60 mph and higher events the probabilities range from 0 to 53 percent, and for the 80 mph and higher events the probabilities range from 0 to 14 percent.

Table 8. Regression results using DZ85D, DZ70D, and U50SM3 converted to binary predictors. Only those cases where DZ85D was greater than 45 gpm were used. 0600-1200 and 1800-2400 GMT periods. First three seasons of data.

	60 mph and up Contr. to Prob. (%)	60 mph and up Cum. R.V. (%)	80 mph and up Contr. to Prob. (%)	80 mph and up Cum. R.V. (%)
Constant	53.43		13.68	
1) DZ85D ≤150 gpm	-21.50	13.66	-2.19	2.22
2) U50SM3 ≤140 kt	-10.99	17.11	0.32	2.33
3) DZ70D ≤180 gpm	-13.79	17.83	-10.95	5.58
4) DZ85D ≤105 gpm	-6.18	18.76	-0.68	5.67
	F_w = 7.8%		F_w = 1.0%	
	N_w = 56		N_w = 7	

N_c = 723

Table 9. Same as Table 8, except all four seasons of data were used instead of three. One wind case in the 60-79 mph range was lost due to the exclusion process (in the fourth season).

	60 mph and up Contr. to Prob. (%)	60 mph and up Cum. R.V. (%)	80 mph and up Contr. to Prob. (%)	80 mph and up Cum. R.V. (%)
Constant	53.19		13.65	
1) DZ85D ≤150 gpm	-19.12	13.51	-1.43	2.17
2) DZ70D ≤180 gpm	-17.18	15.80	-11.16	4.09
3) U50SM3 ≤140 kt	-10.26	18.01	-0.20	6.28
4) DZ85D ≤105 gpm	-5.72	18.80	-0.78	6.38
	F_w = 7.7%		F_w = 1.0%	
	N_w = 76		N_w = 10	

N_c = 993

c. Verification

Verification of the four-season equations on <u>developmental</u> data yields the breakdown of wind events by forecast probability value as shown by Table 10. For the purpose of this table, the forecasts were assigned the nearest probability value of those given in the top line of each group.

Table 10. Verification statistics for the equations given by Table 9 on developmental data. 0600-1200 and 1800-2400 GMT periods. Four seasons of data.

<u>60 mph and above</u>

Fcst. Prob.(%)	0	2	5	10	20	30	40	50	ALL
Wind Freq.(%)	.7	-	6.5	1.9	16.7	21.1	51.4	50.0	4.0
No. Winds	11	-	12	1	9	15	19	10	77
No. Fcsts.	1510	0	184	54	54	71	37	20	1930

S = 20%

<u>80 mph and above</u>

Fcst. Prob.(%)	0	2	5	10	ALL
Wind Freq.(%)	.1	2.1	-	13.2	.5
No. Winds	2	3	-	5	10
No. Fcsts.	1748	144	0	38	1930

S = 7%

S = Sanders skill score

More than a third of the 60 mph and above events were caught with a probability of 40 or 50 percent and almost another third with a probability of 20 or 30 percent. Half of the 80 mph and above events were in the 10 percent category, but obviously the skill for these strong winds [redacted] leaves much to be desired.

6. <u>DEVELOPMENT OF EQUATIONS FOR 0000-0600 GMT AND 1200-1800 GMT PERIODS</u>

The work of the preceding section used predictand data from only two of the four six-hour periods in the day. This section deals with the other two periods. An attempt was made to use a 12-hour lag from observation time to the beginning of the forecast period, but no equations could be derived which gave any significant skill on independent data. Therefore, it was decided to try a zero-hour lag, even though this is not too useful from a practical standpoint since much of the forecast period will have elapsed by the time the observational data are received, processed, and the forecasts communicated to the user.

a. Continuous Predictors (First Three Seasons)

As described in the preceding section a blanket screening run was made for the period 0 to 6 hours after data time (again with no distinction between 0000 GMT and 1200 GMT data). The simple correlation coefficients are shown in Table 11.

Table 11. Correlation coefficients as in Table 5, except that there is <u>no</u> lag from the observation time to the beginning of the six-hour forecast period. 0000-0600 and 1200-1800 GMT periods. First three seasons of data.

			Height Differences (DZ)					Wind Components					
								U (west)					V (south)
		Pressure (mb)	A	B	C	D	E	SLC	GJT	LND	SM2	SM3	SM3
60 mph or higher		300	-.04	.07	.14	.13	.08	.17	.18	.12	.16	.17	-.01
	F_w= 3.0%	400	-.01	.09	.14	.13	.09	.18	.18	.13	.17	.18	-.03
	N_w= 32	500	.03	.12	.16	.16	.12	.19	.17	.15	.18	.19	-.04
	N_c= 1072	700	.22	.256	.24	.262	.25	.16	.21	.21	.252	.24	.00
		850	.263	.257	.23	.253	.24						
80 mph or higher		300	-.05	.00	.05	.07	.07	.04	.08	.02	.05	.05	-.03
	F_w= 0.4%	400	-.01	.03	.05	.07	.06	.05	.08	-.00	.04	.05	-.05
	N_w= 4	500	.02	.06	.06	.08	.08	.03	.08	.02	.06	.05	-.05
	N_c= 1072	700	.09	.11	.10	.13	.14	.02	.11	.10	.12	.10	-.06
		850	.09	.10	.10	.13	.14						

After some experimentation, it was decided to use DZ85A with a limit of 30 gpm to exclude uninteresting cases. Table 11 shows that this parameter has the highest simple correlation coefficient of those examined, though it has close competition from several other parameters. Note that in the preceding section DZ85<u>D</u> with a limit of 45 gpm was used for this purpose. Simple correlation coefficients after excluding cases on the basis of DZ85A are shown in Table 12. DZ70D and DZ85D are now tied for the lead with a slight margin over DZ85A. A notable feature of Table 12 is that for the 60 mph and above correlations the U component at GJT shows the highest correlation at 700 mb which drops off and then increases again as one passes to higher levels in the atmosphere. Also, the sign of the correlation coefficients of the "A" height gradients reverses between 700 and 500 mb--interesting, but so far not particularly useful, information.

In order to eliminate the possibility of an artificial discontinuity between 300 mb and 250 mb caused by different sample sizes and to increase the sample size, another run with selected variables from those in Table 12 was made, giving the results shown in Table 13. Again, there is a secondary maximum in correlation at 300 mb or 400 mb in the U component at GJT for the 60 mph threshold. The reversal in correlation on the "A" height gradients is still apparent, though 200, 250, and 300 mb now all have the same correlation coefficient.

Table 12. Correlation coefficients as in Table 11, except that only those cases where DZ85A was greater than 30 gpm were included in the computations. No wind cases were lost by this exclusion process.

			Height Differences (DZ)					Wind Components					
								U (west)					V (south)
		Pressure (mb)	A	B	C	D	E	SLC	GJT	LND	SM2	SM3	SM3
60 mph or higher	F_W= 6.0%	100	-.16	-.05	.06	.03	-.01	.09	.04	.02	.04	.06	.20
	N_W= 19	150	-.19	-.04	.12	.08	.02	.11	.10	.08	.10	.11	.16
	N_c= 316	200	-.21	-.03	.16	.11	.03	.16	.18	.13	.17	.17	.13
		250	-.20	-.02	.17	.12	.04	.18	.22	.11	.19	.19	.09
		300	-.12	.03	.15	.12	.05	.20	.23	.10	.18	.20	.05
	F_W= 7.2%	400	-.09	.04	.14	.11	.04	.19	.21	.12	.18	.19	.03
	N_W= 32	500	-.05	.08	.15	.14	.08	.19	.18	.14	.18	.19	.02
	N_c= 442	700	.20	.277	.25	.284	.26	.18	.25	.22	.281	.27	.05
		850	.281	.27	.22	.284	.27						
80 mph or higher	F_W= 1.3%	100	-.11	-.07	-.01	-.01	-.01	.09	.02	.04	.03	.06	.10
	N_W= 4	150	-.08	-.03	.03	.04	.04	.03	-.00	.03	.01	.02	.04
	N_c= 316	200	-.11	-.02	.07	.09	.09	.04	.06	.07	.07	.06	.01
		250	-.08	.01	.10	.11	.09	.09	.11	.06	.09	.10	-.04
		300	-.10	-.02	.06	.08	.08	.04	.11	-.00	.06	.05	-.03
	F_W= 0.9%	400	-.04	.01	.05	.07	.07	.04	.10	-.03	.03	.04	-.05
	N_W= 4	500	.00	.05	.06	.08	.08	.01	.10	-.00	.05	.04	-.05
	N_c= 442	700	.10	.13	.12	.17	.19	-.01	.15	.11	.16	.11	-.07
		850	.09	.12	.12	.19	.21						

b. Binary Predictors and Independent Data Test

After a reasonable amount of experimentation with binary predictors formed from various combinations of the continuous predictors of Table 13, a test on independent data was performed as in the previous section, using ten equations with 1 to 10 predictors. The Sanders skill scores are shown in Fig. 4.

Table 13. Same as Table 12, except that fewer predictors are involved, so the sample size is larger.

		Pressure (mb)	Height Differences (DZ) A	B	C	D	E	Wind Components U (west) GJT	SM2	SM3	V (south) SM3
60 mph or higher		200	-.12					.19			
		250	-.12					.22			
	F_W = 7.1%	300	-.12					.24			
	N_W = 33	400	-.09					.24			
	N_c = 466	500	-.04					.21			
		700	.23	.31	.28	.31	.28	.27	.31	.32	.06
		850	.33	.30	.22	.29	.27				
80 mph or higher		200	-.09					.06			
		250	-.07					.10			
	F_W = 1.1%	300	-.06					.12			
	N_W = 5	400	-.00					.15			
	N_c = 466	500	.05					.13			
		700	.14	.18	.16	.21	.22	.18	.22	.18	-.02
		850	.15	.17	.16	.22	.21				

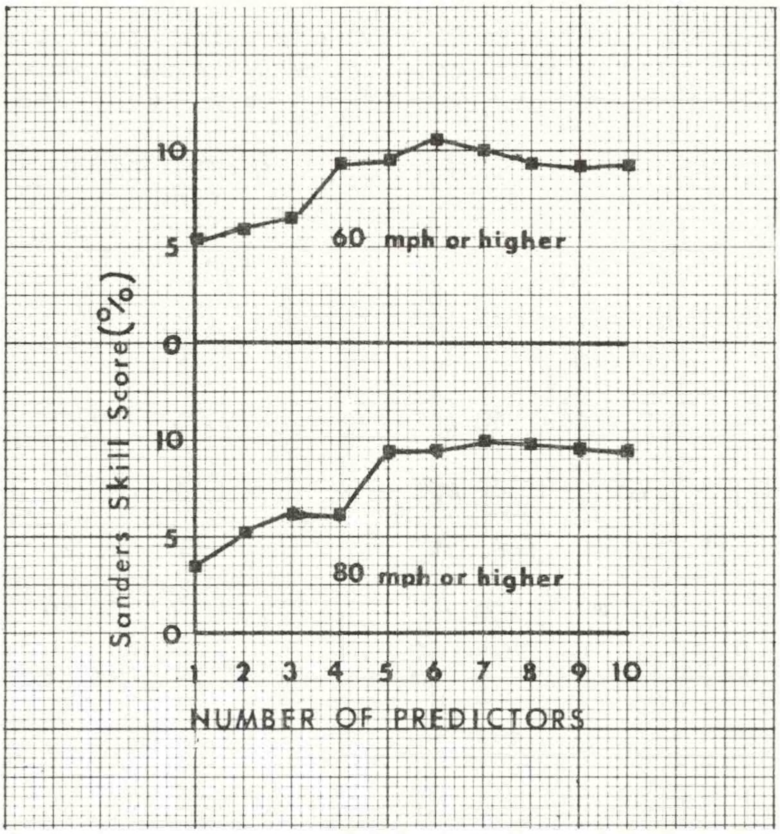

Fig. 4. Sanders skill scores on independent data as a function of the number of predictors when 850 and 700 mb height gradients and U30GJT were used with several limits each converting them to binary predictors. 0000-0600 and 1200-1800 GMT periods. Sample size was 511 cases.

It is apparent that little is to be gained by going beyond 5 predictors. Regression results for this number of predictors for both three seasons and four seasons are shown in Tables 14 and 15. Note that predictor number 3 in Table 14 is in fifth place in Table 15, but the same five predictors were selected in each case. One could question the validity of the coefficients of predictors 4 and 5 in Table 15, since the magnitudes for the 80 mph and higher events are greater than for the 60 mph and higher events. While this is not out of the realm of possibility, it seems also possible that it is a quirk of the small sample (only 10 wind cases). The reductions of variance of the equations from Table 14 when applied to the one season of independent data for those cases where DZ85A was greater than 30 gpm were 14.72 and 11.27 percent for the two classes of events (compare with Table 14), so the skill on independent data was not much different from that on the developmental sample.

Probabilities implied by Table 15 are given in Appendix II in a form easily usable by the forecaster. For the 60 mph and higher events the probabilities range from 0 to 64 percent, and for the 80 mph and higher events the probabilities range from 0 to 24 percent.

Table 14. Regression results using binary predictors. Only those cases where DZ85A was greater than 30 gpm were used. First three seasons of data.

	60 mph and up Contr. to Prob. (%)	60 mph and up Cum. R.V. (%)	80 mph and up Contr. to Prob. (%)	80 mph and up Cum. R.V. (%)
Constant	68.70		20.14	
1) DZ70B ≤150 gpm	-27.75	9.85	-7.24	5.25
2) DZ70D ≤120 gpm	-10.95	14.13	-1.24	6.16
3) U30GJT ≤ 80 kt	-2.58	15.23	-5.25	8.77
4) U30GJT ≤100 kt	-18.33	16.59	0.68	8.79
5) DZ85B ≤195 gpm	-7.71	16.88	-7.67	10.52
	F_w= 7.1%		F_w= 1.1%	
	N_w= 39		N_w= 6	

N_c= 550

Table 15. Same as Table 14, except four seasons of data were used instead of three. One wind case in the 60-79 mph range was lost due to the exclusion process (in the fourth season).

	60 mph and up Contr. to Prob. (%)	60 mph and up Cum. R.V. (%)	80 mph and up Contr. to Prob. (%)	80 mph and up Cum. R.V. (%)
Constant	64.11		23.88	
1) DZ70B ≤150 gpm	-25.54	8.72	-7.85	5.66
2) DZ70D ≤120 gpm	-9.53	12.12	-1.60	6.74
3) U30GJT ≤100 kt	-19.71	14.84	-1.13	7.52
4) DZ85B ≤195 gpm	-6.78	15.11	-9.26	9.90
5) U30GJT ≤80 kt	-0.97	15.12	-4.75	11.33
	F_w= 7.0%		F_w= 1.4%	
	N_w= 52		N_w= 10	

N_c = 740

c. Verification

Verification of the four-season equationson developmental data yields the breakdown shown by Table 16.

Table 16. Verification statistics for the equations given by Table 15 on developmental data. Four seasons of data. 0000-0600 and 1200-1800 GMT periods.

60 mph and above

Fcst. Prob.(%)	0	2	5	10	20	30	40	ALL
Wind Freq.(%)	.2	2.0	-	10.7	13.9	40.0	39.5	2.8
No. Winds	2	10	-	16	5	6	15	54
No. Fcsts.	1170	502	0	149	36	15	38	1910

S = 16%

80 mph and above

Fcst. Prob.(%)	0	2	5	10	20	ALL
Wind Freq.(%)	.1	-	3.1	4.4	26.7	.5
No. Winds	1	-	3	2	4	10
No. Fcsts.	1753	0	97	45	15	1910

S = 10%

Somewhat over one-fourth of the 60 mph and up events were on a probability of 40 percent, and over half of the 80 mph and up events were on a 10 or 20 percent probability. Even though the equation used for the 60 mph and up events has a maximum possible value of 64 percent, not once in four seasons was that value indicated by the data.

7. THE DILEMMA OF TRYING TO MAKE OBJECTIVE FORECASTS FOR FOUR 6-HOUR PERIODS A DAY FROM TWO-A-DAY OBSERVATIONS

It is somewhat disheartening to find that skill scores for a 0-hour lag as shown in Section 6 are poorer than for the 6-hour lag as given in Section 5 for the 60 mph threshold. The reasons for this are not clear, but it may be an indication that there is a diurnal or semi-diurnal influence not being handled, that the data for these times are just more "stubborn" due to sampling variations, or that the upper-air stations used are not as fortuitously located with respect to Boulder for the 0-hour lag.

Since the 0-hour lag equations would require a 12-hour forecast of the predictors in order to use them operationally with only 2 observations a day, it seems that it would be just as well to use the 6-hour lag equations with a 6-hour forecast of the predictors. This presumes that there is no diurnal factor in operation--perhaps a risky assumption, but borne out by the climatology herein. Since binary predictors are used and it is only necessary to know whether a parameter is above or below a certain limit or limits, small errors in the forecasts may not make any difference at all.

To sum it up, it is recommended that the 6-hour lag equations of Section 5 be be used for all four 6-hour periods of the day, using a short-term "prediction of the predictors" twice a day. The 0-hour lag equations are presented here mainly for whatever scientific interest they may have.

In a study such as this it is easy to develop a longing for complete radiosonde observations four times a day. This obviously fits the 6-hour forecast period better, since then all four periods could have been pooled, thereby doubling the sample size. One could ask why a 12-hour forecast period was not used. The shorter period was selected for two important reasons: (1) for a short-range forecast the greater time resolution is highly desirable; and (2) for a classical technique the longer period would extend to 18 hours after data time--a bit long (as evidenced by the failure of efforts to develop a technique with a 12-hour lag to the beginning of a 6-hour forecast period).

8. NEAR MISSES AND TIME-SPACE RELATIONSHIPS

Table 10 shows that half of the forecasts under the 50 percent heading (these were all 53 percent forecasts) had winds of 60 mph or more in the verifying period (only 2 of the 20 had winds of 80 mph or more). One could wonder what happened in the case of the 10 "no-wind" events. If the verifying period is lengthened to 12 hours by adding 3 hours on either side of the original 6-hour period, 18 of the 20 forecasts had winds of 50 mph or more, and all 20 had winds of 40 mph or more. So with this high probability (53 percent) one can be quite confident that there will be strong winds, but how strong and exactly when is more difficult to say.

In order to get an idea of whether the lag of 6 hours to the beginning of the forecast period is an optimum one, the relative frequency of wind events by overlapping 6-hour periods with varying lags for the 53 percent forecasts is shown in Table 17. For the 60 mph and up events it would appear that a lag of 3 hours might be as good as or better than the 6-hour lag. The 80 mph and up events were distributed remarkably uniformly with time--a rather disenchanting result.

Table 17. Frequency of wind events for 6-hour periods as a function of time after observation time for the 53 percent forecasts shown in Table 10.

	Hours after ob. time	0-6	3-9	6-12	9-15	12-18
Event	≥60 mph	7	11	10	8	5
	≥80 mph	2	2	2	3	2

9. DISCUSSION

The preceding results represent only the above-water portion of an iceberg of computer analyses in which numerous things were tried with no great success. Some of the parameters investigated included the following: vertical temperature differences, vertical and horizontal wind component differences, wind direction and speed, geostrophic wind direction and speed, Scorer parameter, lee wavelength, and tropopause pressure and temperature.

It would seem doubtful that any appreciable improvement by a statistically-derived objective scheme over the skill shown by the technique of this memorandum can be achieved without additional insight based on experience or physical-dynamical reasoning. What level of skill one can ever expect to achieve with the observations currently available, no matter how much insight is gained, is open to speculation. Another unknown is the current skill of the human forecaster.

The problem of distinguishing the really destructive storms from the lesser-but-more-frequent variety remains an extremely important subject for investigation. In order to be really useful one would like to be able to issue a probability forecast considerably higher than the maximum of 14 percent given here for the 80 mph and up events. Lilly and Zipser (1972) have pointed out the difficulty of recognizing the conditions for the severe wind events. It is one thing to have brief gusts to 50 or 60 mph and quite another to have the damage-causing higher winds such as those of January 7, 1969, and January 11, 1972. One would really like to know in advance which it is going to be.

A statistical approach to this problem is hampered by the fact that the severe events are (fortunately) rare. Five or six or even ten such events hardly constitute an adequate sample. But as the years go by more and more data will be collected and this situation will improve.

The use of surface data, available on a more frequent basis, and a breakdown by time of year within the cold season used here(this would require a large data sample) could perhaps yield a somewhat better technique.

ACKNOWLEDGEMENTS

The screening regression analyses used in this study were performed using a computer program which is a slightly modified version (to fit the CDC-3100) of a program generously supplied to the author by Dr. Harry R. Glahn of the Techniques Development Laboratory. The author would like to express his appreciation to Mrs. Dorothy Babich for invaluable assistance in data tabulation, card punching, and the drafting of figures. Mrs. Janice Wilson expertly typed the manuscript. Mr. Sidney Cornell and his staff of computer operators in the National Severe Storms Forecast Center gave cheerful and competent computer support. NSSFC historical data tapes were used to obtain the predictor data. Predictand data for the first season were provided by Dr. Douglas Lilly of NCAR. Mr. Robert Doeker and his staff at the Space Environment Services Group of the Environmental Research Laboratories maintained the strip chart on the NWS anemometer on the NBS Radio Building.

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APPENDIX I

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NATIONAL WEATHER SERVICE

PROBABILITY TABLE FOR COLORADO DOWNSLOPE WIND FORECASTS

0600-1200 and 1800-2400 GMT Forecast Periods

The following table gives the probabilities (in per cent) of surface wind gusts of 60 mph or more and, in parenthesis, of 80 mph or more in Boulder, Colorado (NBS Radio Building) in the 6-hour period beginning 6 hours after data time. The tables should have applicability to other parts of Northeastern Colorado subject to strong downslope winds, but some adjustment may have to be made in the probability numbers.

If DZ85D ≤ 45 gpm do not use the table--the probabilities are near zero.

		DZ85D		
DZ70D	U50SM	46-105	106-150	>150
≤180	≤140	1 (0)	7 (1)	26 (2)
	>140	11 (0)	17 (1)	36 (2)
>180	≤140	18 (11)	24 (12)	43 (13)
	>140	28 (11)	34 (12)	53 (14)

Definitions:

DZ85D = Z_{850}(SLC) + Z_{850}(GJT) - 2 • Z_{850}(LND) (gpm)

DZ70D = Z_{700}(SLC) + Z_{700}(GJT) - 2 • Z_{700}(LND) (gpm)

U50SM = U_{500}(SLC) + U_{500}(GJT) + U_{500}(LND) (knots)

A worksheet is provided to obtain the input parameters for the table.

Central Region Headquarters
Scientific Services Division
Kansas City, Missouri
September 1972

Year__________

COLORADO DOWNSLOPE WIND FORECASTS (0600-1200 and 1800-2400 GMT

WB Form 41[illegible]
2 - 63

Ob.Time	850 mb heights (Z_{850})			700 mb heights (Z_{700})			500 mb wind - use table to convert to U component						forecast periods		
Month/Day							SLC		GJT		LND		Probabilitie[illegible]		
[illegible]r(GMT)	SLC	GJT	LND	SLC	GJT	LND	Dir	Spd	Dir	Spd	Dir	Spd	U50SM	Objective 60+	80+
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				
		DZ85D=			DZ70D=		U50=		U50=		U50=				

APPENDIX II

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NATIONAL WEATHER SERVICE

PROBABILITY TABLE FOR COLORADO DOWNSLOPE WIND FORECASTS

0000-0600 and 1200-1800 GMT Forecast Periods

The following table gives probability increments (in percent) of surface winds of 60 mph or more and of 80 mph or more in Boulder, Colorado (NBS Radio Building) in the 6-hour period beginning at data time. The tables should have applicability to other parts of Northeastern Colorado subject to strong downslope winds, but some adjustment may have to be made in the probability numbers.

If DZ85A $\leq$30 gpm do not use the table--the probabilities are near zero.

		Probability Increment	
		$\geq$60 mph	$\geq$80 mph
1) DZ85B	$\leq$195 gpm	0	0
	>195 gpm	7	9
2) DZ70B	$\leq$150 gpm	1	0
	>150 gpm	26	8
3) DZ70D	$\leq$120 gpm	1	0
	>120 gpm	10	1
4) U30GJT	$\leq$80 kt	0	0
	81-100 kt	1	5
	>100 kt	21	6

Sum the increments from the four predictors to obtain the total probabilities.

Definitions:

DZ85A = Z_{850}(GJT) - Z_{850}(DEN) (gpm)

DZ85B = 2 · Z_{850}(GJT) - Z_{850}(LND) - Z_{850}(DEN) (gpm)

DZ70B = 2 · Z_{700}(GJT) - Z_{700}(LND) - Z_{700}(DEN) (gpm)

DZ70D = Z_{700}(SLC) + Z_{700}(GJT) - 2 · Z_{700}(LND) (gpm)

U30GJT = U_{300}(GJT) (knots)

A worksheet is provided to obtain the input parameters for the table.

Central Region Headquarters
Scientific Services Division
Kansas City, Missouri
November 1972

Year________________

COLORADO DOWNSLOPE WIND FORECASTS (0000-0600 and 1200-1800 GMT forecast periods)

WB Form 613-50
2 - 63

Ob. Time Month/Day Hour (GMT)	850 mb heights (Z_{850}) GJT DZ85A	LND	DEN	700 mb heights (Z_{700}) GJT	LND	DEN	DZ70D	300 mb wind GJT Dir	Spd	Prob. Increment 1	2	3	4	Probabilities Objective 60+	80+
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							
		DZ85B=			DZ70B=			U30=							

(Continued from front inside cover)

NWS CR 48 Manual of Great Lakes Ice Forecasting. C. Robert Snider - December 1971

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