NOAA TECHNICAL MEMORANDUM NWS CR-61

AN UPDATED OBJECTIVE FORECAST TECHNIQUE FOR COLORADO DOWNSLOPE WINDS

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UNITED STATES DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator

National Weather Service
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AN UPDATED OBJECTIVE FORECAST TECHNIQUE
FOR
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ABSTRACT

An updated 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 (97 kmph) and 80 mph (129 kmph) in a 6-hour period were related to two-a-day upper-air observations at upstream stations with a 3-hour lag to the beginning of the verifying period, using the screening regression technique. Binary predictors formed from 85- and 70-kPa height differences, an upstream 70-kPa west wind component, and from vertical temperature differences between 62 and 58 kPa, 58 and 54 kPa, and 40 and 30 kPa at the upstream sounding are used in the technique presented.

1. INTRODUCTION

More than four years have passed since the printing of an earlier Technical Memorandum by the author (Sangster, 1972) dealing 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. Four more years of data (twice as much) have been accumulated, and new predictors have been found, which is the reason for this updated Technical Memorandum which is complete, so the earlier version is obsolete.

Dickey (1955) developed a forecast scheme for wind gusts at Rocky Flats, some 8 miles south of Boulder. This scheme used, among other things, 85-kPa height differences between various stations as predictors. Williams (1958) developed an objective method for forecasting strong westerly winds at Pueblo, Colorado; the situation there is somewhat different because of different topography. Later Julian and Julian (1969) discussed the climatology and then Brinkmann (1974) discussed the conditions associated with storms. Klemp and Lilly (1975) have attacked the problem as a lee-wave phenomenon as suggested by Kuettner and Lilly (1968). Scheetz, Henz, and Maddox (1976) have presented a technique based on 14000 ft (4267 m) winds and 50-kPa vorticity tendency. These newer techniques remain untested on large samples of data.

Myers (1976) has discussed the need for a low-level stable layer (not necessarily an inversion) in producing strong downslope winds.

2. DATA SOURCES

Data from eight seasons--October 1968 through early May 1969, and September through May of 1969-70, 70-71, 71-72, 72-73, 73-74, 74-75, and 75-76--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 seven seasons the anemometer at the National Bureau of Standards Radio Building installed by the National Weather Service in August of 1969 has been used. This location should be fairly representative of the Boulder area.

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.

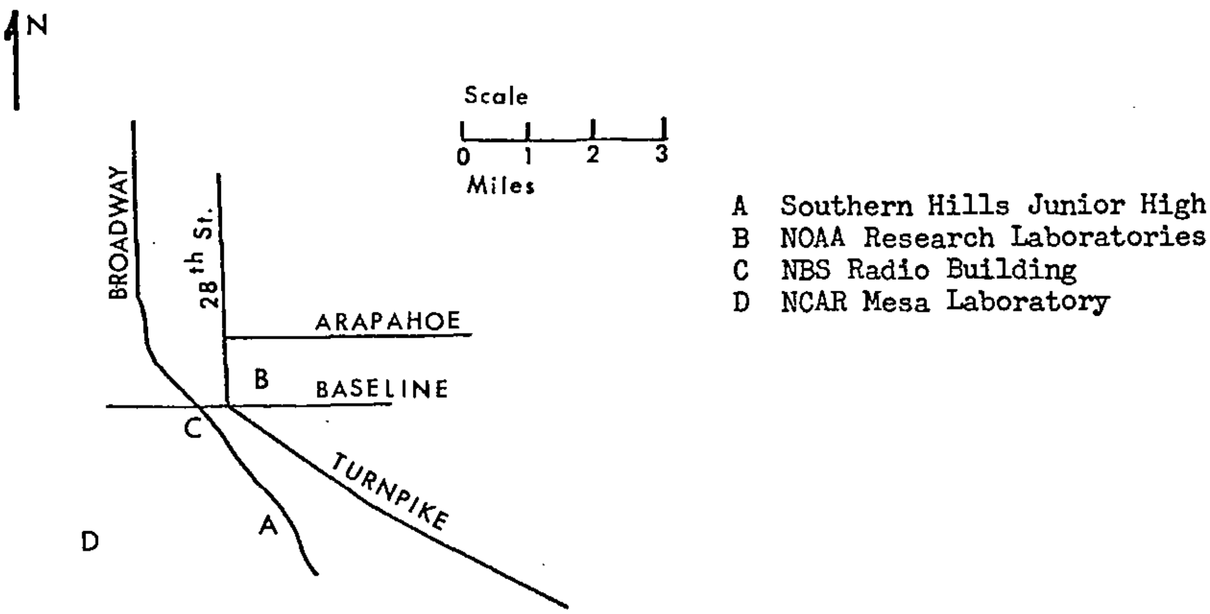

Fig. 1 Locations of anemometers used.

A tabulation was made of the peak gust (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 eight 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
Ely, Nevada	ELY
Boise, Idaho	BOI
Great Falls, Montana	GTF
Winslow, Arizona	INW
Albuquerque, New Mexico	ABQ

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

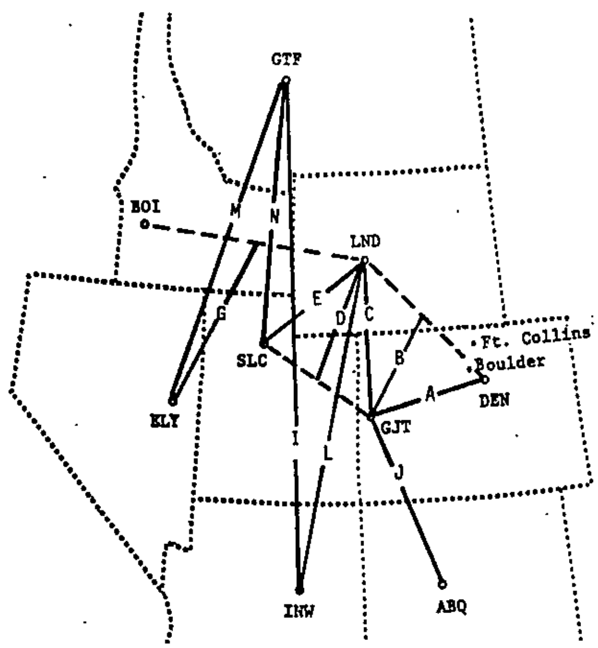

Fig. 2. Locations of upper-air stations and foothill cities. Letters refer to height differences described in section 5.

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 eight seasons of predictand data. September and May data are for seven years and the remaining months of the season are for eight 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. As a point of reference, the 6.2% frequency for ≥ 60 mph in 24-hour periods yields about two events per month through the season.

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

	Threshold				
Length of time period	≥ 40 (≥ 64	≥ 50 ≥ 80	≥ 60 ≥ 97	≥ 70 ≥ 113	≥ 80 mph ≥ 129 kmph)
3 hours	7.2	3.2	1.5	0.5	0.2
6 hours	10.4	4.9	2.2	0.8	0.3
12 hours	15.3	7.6	3.5	1.5	0.5
24 hours	23.5	12.4	6.2	2.6	1.0

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 month of the year and threshold. Six-hour periods.

Month	Threshold				
	≥ 40 (≥ 64	≥ 50 ≥ 80	≥ 60 ≥ 97	≥ 70 ≥ 113	≥ 80 mph ≥ 129 kmph)
September	3.9	1.1	0.6	0.0	0.0
October	5.8	2.4	1.1	0.4	0.0
November	9.5	5.3	1.9	0.7	0.1
December	16.2	7.8	3.9	1.4	0.4
January	18.7	11.5	6.1	3.6	1.5
February	14.1	5.6	2.5	0.2	0.1
March	11.2	4.8	1.5	0.4	0.3
April	7.3	2.9	1.7	0.4	0.0
May	5.7	1.5	0.1	0.0	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 a 16 percent frequency for winds of 60 mph (97 kmph) or more in a 24-hour period during this month, which is equivalent to more than one event a week, on the average. For the 80 mph (129 kmph) and higher events in a 24-hour period the frequency is 5 percent (1.5/month), not a small figure for such a significant event.

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

Length of time period	Threshold ≥ 40 (≥ 64	≥ 50 ≥ 80	≥ 60 ≥ 97	≥ 70 ≥ 113	≥ 80 mph ≥ 129 kmph)
3 hours	13.6	8.3	4.1	2.1	0.9
6 hours	18.7	11.5	6.1	3.6	1.5
12 hours	26.5	17.1	9.4	5.9	2.7
24 hours	38.7	25.9	16.0	9.9	5.3

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

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

Time	Threshold ≥ 40 (≥ 64	≥ 50 ≥ 80	≥ 60 ≥ 97	≥ 70 ≥ 113	≥ 80 mph ≥ 129 kmph)
0000-0600 GMT	10.3	4.7	1.7	0.6	0.2
0300-0900 GMT	9.6	4.8	2.0	1.0	0.2
0600-1200 GMT	9.1	4.8	2.2	0.8	0.2
0900-1500 GMT	9.2	4.7	2.2	1.0	0.3
1200-1800 GMT	9.3	4.5	1.9	1.0	0.4
1500-2100 GMT	11.4	5.4	2.7	1.1	0.3
1800-2400 GMT	13.0	5.4	3.0	1.0	0.3
2100-0300 GMT	11.6	4.7	2.4	0.7	0.3

For the lowest threshold of 40 mph (64 kmph) a maximum frequency is evident during the afternoon--1800-2400 GMT (1100-1700 MST). The nighttime hours of 0600-1200 GMT (2300-0500 MST) have the minimum frequency. For the threshold of 50 mph (80 mph) the frequencies are relatively uniform throughout the day, indicating that diurnal variations are pronounced in the 40-49 mph (64-79 kmph) range. From Table 4 one can deduce that for this range of speeds the relative frequency for the 1800-2400 GMT period is nearly double that for the 0600-1200 GMT period--7.6 percent vs. 4.3 percent.

The number of events for the 80 mph (129 kmph) threshold varied from 4 to 9, with the 1200-1800 GMT (0500-1100 MST) period having the most. Julian and Julian found the 0700-1300 GMT period to have the highest frequency of severe windstorms. The eight seasons treated here are probably not sufficient to detect real diurnal variations in the 80+ mph group.

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:

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

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 (97 kmph), 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 (97 to 128 kmph), the <u>second</u> predictand was assigned the value of one and the other two set to zero. For peak winds of 80 mph (129 kmph) 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. CONSTRUCTION OF PREDICTORS

Predictors used for most of this effort consisted of height differences at various constant pressure levels between upper-air stations shown in Fig. 2 (DZ's) and west wind components at some of these stations (U's). The height differences were defined as follows:

DZppA = ZppGJT - ZppDEN

DZppB = 2 · ZppGJT - ZppLND - ZppDEN

DZppC = ZppGJT - ZppLND

DZppD = ZppSLC + ZppGJT - 2 · ZppLND

DZppE = ZppSLC - ZppLND

DZppG = 2 · ZppELY - ZppBOI - ZppLND

DZppI = ZppINW - ZppGTF

DZppJ = ZppABQ - ZppGJT

DZppL = ZppINW - ZppLND

DZppM = ZppELY - ZppGTF

DZppN = ZppSLC - ZppGTF

Here pp refers to the 85-, 70-, or 50-kPa surface and the stations are identified by call letters.

The U component of the wind was computed at various levels at Grand Junction if the 50-kPa wind direction at Grand Junction was 290 degrees or less or at Lander if the direction was 295 degrees or more. Also treated in a similar manner were Ely and Boise, using Ely if the Ely 50-kPa wind direction was 280 degrees or less or Boise if the direction was 285 degrees or more. Salt Lake City U components were also computed. In the following sections GL refers to Grand Junction or Lander, and EB refers to Ely or Boise.

Vertical temperature differences (DT's) at Grand Junction or Lander (using the above rule) were obtained between mandatory levels from 85 to 20 kPa and between levels at 4 kPa intervals from 78 to 20 kPa interpolated from the complete temperature sounding using all reported significant levels.

Binary predictors (GJTOLND and ELYOBOI) were formed by setting GJTOLND to zero if Grand Junction was the upwind station and one if Lander was the upwind station. Likewise ELYOBOI was formed by setting it to zero if Ely was the upwind station and one if Boise was the upwind station.

6. DEVELOPMENT OF TECHNIQUE FOR PERIOD 3 TO 9 HOURS AFTER DATA TIME.

Most of the author's recent effort has been devoted to developing a technique for the period 3 to 9 hours after upper-air observation time, i.e., 0300-0900 GMT and 1500-2100 GMT. No distinction was made between these two time periods, since Table 4 shows that the frequency of the event is not too much different and as large a data sample as possible was desirable, due to the rarity of the event--especially the very strong wind cases. This choice of 3 to 9 hours after data time usually allows the data to be gathered and processed by the time the forecast period starts, but is not so far away in time as to make the correlations lower. A 12-hour period was not used since this would make a period extending to 15 hours after data time--judged excessive. The poor results discussed in the next section justify not using a 12-hour period.

a. Continuous Predictors--All Cases

A blanket screening run using 33 DZ's (eleven each at 85, 70, and 50 kPa), 6 U's (GL, SLC, and EB at 70 and 50 kPa), GJTOLND, and ELYOBOI was made with the 3-category predictand (< 60, 60-79, 80+ mph). Results for two categories are shown as reductions of variance (R.V.) in Table 5. In this and following results the < 60 mph category was transformed to a 60+ mph category by subtracting the < 60 mph regression equation probability from one and changing the sign of the correlation. All correlations were positive. The top predictor for both categories was DZ70D, and the second predictor selected in the regression analysis was DZ85G, with an additional R.V. of 0.77 percent for 60+ and 0.06 percent for 80+ mph. Noteworthy is the fact that DZ70D (even DZ70C) came in ahead of any U wind component. Thus a geostrophic wind is a better predictor than the wind itself. Perhaps this is because the 70-kPa winds are unrepresentative in high mountainous regions. Note in Table 5 that by and large 70-kPa predictors are the best, followed by those at 85 kPa. 50 kPa height differences are definitely inferior to those at 70 and 85 kPa. The predictors which came in second and third for 60+ mph in the rankings in R.V.'s among the 70-kPa differences, DZ70B and DZ70E, each use two of the three stations used in constructing DZ70D (see Fig. 2). It isn't surprising that they were not selected in the regression analysis, since they can be expected to have a fairly high correlation with DZ70D. Note that DZ85G is the best among the 85-kPa differences for both 60+ and 80+ mph events.

Table 5. Reductions of variance (percent) given by continuous constant-pressure height differences (DZ), west wind components (U), and binary predictors indicating the upwind station (GJTOLND, ELYOBOI) on the binary wind predictands.

	60+ mph			80+ mph		
Pressure (kPa)	85	70	50	85	70	50
DZppA	4.08	4.91	0.49	0.87	1.25	0.27
DZppB	5.22	7.03	2.20	1.24	2.01	1.08
DZppC	5.11	6.05	2.41	1.32	1.85	1.13
DZppD	6.03	7.34	2.87	1.63	2.46	1.39
DZppE	5.23	6.50	1.93	1.50	2.38	0.99
DZppG	6.67	6.23	3.71	1.74	1.71	1.01
DZppI	4.60	5.71	4.11	1.05	1.42	1.24
DZppJ	0.20	0.72	1.06	0.02	0.24	0.55
DZppL	6.27	6.26	3.23	1.52	1.87	1.39
DZppM	4.52	5.72	3.99	1.16	1.50	1.15
DZppN	3.33	5.14	3.47	0.85	1.37	0.90
GJTOLND			0.14			0.05
UppGL		4.69	3.26		1.73	1.07
UppSLC		3.69	3.62		0.50	0.68
ELYOBOI			0.34			0.23
UppEB		3.68	3.46		0.69	0.67
		F_W =	2.67%		F_W =	0.34%
		N_W =	79		N_W =	10
			N_C = 2964			

F_W is the relative frequency of wind events, N_W is the number of wind events, and N_C is the total number of cases.

Grand Junction was the upwind station 67.6 percent of the time and Lander was the upwind station the remaining 32.4 percent of the time.

Ely was the upwind station 60.4 percent of the time and Boise was the upwind station the remaining 39.6 percent of the time.

b. Continuous Predictors--Partial Sample

Since the total sample available is likely to contain many cases which are uninteresting with respect to the strong wind events, especially in view of their rarity, it was decided to use a predictor to exclude the unimportant part of the sample from consideration. This has the practical side benefit that less computer time is needed for subsequent regression runs.

The predictor selected was DZ70D at a limit of 60 gpm. Only three 60-79 mph events and no 80+ mph events were lost by this exclusion. The relative frequency of 60+ mph events was only 0.17 percent in this part of the total sample (DZ70D less than or equal to 60 gpm). DZ85G and DZ85D were also examined as candidates for this exclusion procedure. DZ85G was found to be inferior and DZ85D only slightly better. DZ85D was not used because it did not fare as well as DZ70D in later use as a predictor. To use a predictor as a delimiter and then not use it later is slightly undesirable for a technique to be done manually.

Another screening run using exactly the same predictors as in Table 5 gave R.V.'s shown in Table 6. All correlations were again positive. DZ70D again came out on top for both the 60+ and 80+ mph events, and its R.V.'s have increased to 12.05 and 6.20 percent. The second predictor selected was DZ85G, with an additional R.V. of 1.19 percent for 60+ mph and 0.02 percent for 80+ mph. The R.V.'s for GJTOLND and ELYOBOI are quite low, indicating that it matters little which are the upwind stations. Particularly noticeable is the drop off in R.V. from 12.05 percent for DZ70D to 1.95 percent for DZ50D for 60+ mph.

Table 6. Same as Table 5, except for only those cases in which DZ70D exceeded 60 gpm.

	60+ mph			80+ mph		
Pressure (kPa)	85	70	50	85	70	50
DZppA	3.93	5.25	0.11	1.09	1.90	0.26
DZppB	5.97	11.42	1.21	1.90	4.88	1.55
DZppC	6.09	9.14	1.56	2.17	4.34	1.64
DZppD	8.28	12.05	1.95	3.10	6.20	2.09
DZppE	6.18	8.42	1.18	2.45	4.69	1.28
DZppG	8.91	8.56	3.67	2.70	3.14	1.44
DZppI	4.71	7.19	4.17	1.35	2.42	2.01
DZppJ	0.18	0.83	1.62	0.03	0.36	1.02
DZppL	8.17	8.63	3.20	2.77	3.81	2.34
DZppM	5.05	7.25	3.57	1.49	2.48	1.60
DZppN	3.35	6.21	2.64	1.04	2.23	1.10
GJTOLND			0.02			0.03
UppGL		4.93	2.94		2.69	1.54
UppSLC		3.18	3.54		0.39	0.74
ELYOBOI			0.27			0.30
UppEB		2.94	3.10		0.64	0.69

F_w = 5.04% F_w = 0.66%

N_w = 76 N_w = 10

N_c = 1507

Grand Junction was the upwind station 59.8 percent of the time and Lander was the upwind station the remaining 40.2 percent of the time.

Ely was the upwind station 53.3 percent of the time and Boise was the upwind station the remaining 46.7 percent of the time.

DZ70D has a clear lead over U70GL at both 60+ mph and 80+ mph, again indicating the superiority of geostrophic winds.

c. DZ70D as Binary Predictors

DZ70D was used to construct binary predictors in the manner described in Section 4. Limits set at 50 gpm intervals from 10 to 210 gpm gave the regression results shown by Table 7. Note that the R.V. of the first predictor selected (binary limit 210 gpm) was higher for the 80+ mph events than it was for the 60+ mph events, a rather unusual occurrence. The event probabilities as a function of the interval in which DZ70D lies is given in Table 8. Note the probability of 80+ mph events drops to zero if DZ70D is less than 110 gpm, but rises to 24 percent if DZ70D is greater than 210 gpm.

Since 70-kPa height forecasts are now available out to 48 hours, this simple parameter embodied in Table 8 gives a forecast tool for 2 days in advance. Of course, it must be remembered that the probabilities are based on the assumption of a perfect forecast and must be edged toward climatology in order to allow for 70-kPa height forecast errors.

Table 7. Regression results using DZ70D converted to binary predictors. Cum. R.V. is cumulative reduction of variance (%).

	60+ mph		80+ mph	
	Contribution to Probability (%)	Cum. R.V.	Contribution to Probability (%)	Cum. R.V.
Constant	57.14		23.81	
1) DZ70D ≤ 210 gpm	-34.37	6.64	-20.84	9.73
2) DZ70D ≤ 110 gpm	-7.11	12.13	-0.83	10.33
3) DZ70D ≤ 160 gpm	-14.23	13.92	-2.14	10.64
4) DZ70D ≤ 60 gpm	-1.17	14.05	0.00	10.64
5) DZ70D ≤ 10 gpm	-0.26	14.05	0.00	10.64
	F_w = 2.68%		F_w = 0.33%	
	N_w = 97		N_w = 12	

N_c = 3622

Table 8. Probability of 60+ mph and 80+ mph events as a function of DZ70D obtained from regression analysis shown in Table 6.

DZ70D (gpm)	Probabilities (%) 60+	80+	Percent of Total Sample
≤ 10	0	0	16.4
11-60	0.3	0	32.2
61-110	1.4	0	34.8
111-160	9	0.8	13.2
161-210	23	3	2.8
≥ 211	57	24	0.6

d. The Scheme for DZ70D 61 to 160 gpm.

In the 3-to 9-hour scheme, different equations were used depending upon the range of DZ70D, using limits at 60, 160, and 210 gpm. The 61 to 160 gpm range will be discussed first. No temperature differences were used in this range, it having been found that little was to be gained by their inclusion. Only DZ70D, DZ85G, U70GL, and GJTOLND were used as binary predictors in the final scheme, the regression results of which are shown in Table 9. Note that a 2-category predictand was used. This is because efforts to obtain fairly high probabilities for the 80+ mph category were unsuccessful. There were four 80+ mph events in this range of DZ70D, the lowest DZ70D being 125 gpm for such an event.

Appendix A shows the regression equation of Table 9 converted to a worksheet. Rounding and a division of the constant has been accomplished in order to arrive at this worksheet. Note that this worksheet gives instructions to stop (the probabilities are near zero) if DZ70D is 60 gpm or less, and to proceed to a supplemental worksheet if DZ70D is 161 gpm or more.

Table 9. Regression results using DZ70D, DZ85G, U70GL, and GJTOLND as binary predictors. DZ70D 61-160 gpm.

	60+ mph	
	Contribution to Probability (%)	Cum. R.V.
Constant	38.35	
1) DZ85G ≤110 gpm	-2.14	4.01
2) U70GL ≤ 36 kt	-17.79	5.59
3) DZ85G ≤138 gpm	-9.11	6.57
4) DZ85G ≤ 82 gpm	-2.79	7.33
5) U70GL ≤ 18 kt	-2.50	7.87
6) DZ70D ≤110 gpm	-2.47	8.22
7) GJTOLND	-1.93	8.44
8) DZ85G ≤ 54 gpm	-1.70	8.58

F_W = 3.41%

N_W = 56

N_C = 1643

e. The Scheme for DZ70D 162 to 210 gpm.

The vertical temperature difference (DT4030), 40-kPa temperature minus the 30-kPa temperature at Grand Junction or Lander was found to add appreciable R.V. to this range and so was used as a binary predictor, along with DZ85G and U70GL. The regression results are shown in Table 10.

Table 10. Regression results using DT4030, DZ85G, and U70GL as binary predictors. DZ70D 161-210 gpm.

	60+ mph		80+ mph	
	Contribution to Probability (%)	Cum. R.V.	Contribution to Probability (%)	Cum. R.V.
Constant	39.29		5.17	
1) DT4030 ≤ 14.7 °C	1.02	2.04	7.15	6.29
2) U70GL ≤ 34 kt	-21.05	5.69	-5.09	7.60
3) DT4030 ≤ 7.2 °C	28.80	7.92	5.22	7.91
4) DZ85G ≤ 116 gpm	-18.66	10.89	-5.55	9.37
	F_W = 23.08%		F_W = 3.30%	
	N_W = 21		N_W = 3	
		N_C = 91		

This regression analysis is converted to a worksheet as shown in Appendix B.

f. The Scheme for DZ70D 211 gpm or Greater.

Vertical temperature differences for the sample in which DZ70D was greater than 211 gpm were looked at by examining all the vertical temperature differences mentioned at the close of Section 5 at Grand Junction or Lander, whichever was the upwind sounding. The predictand in this case, since only a small number of cases was available, was continuous. It was formed by setting it to zero if the peak wind speed was less than 60 mph, one if the peak wind speed was 60 to 79 mph, and two if the peak wind speed was 80 mph or more. The regression analysis gave the results shown in Table 11.

Table 11. Regression results using vertical temperature differences (DT's) as continuous predictors. The predictand is also continuous (see text). DZ70D is 211 gpm or higher.

	Coefficient	Cum. R.V.
Constant	2.38	
1) DT5854 (58 kPa minus 54 kPa)	-0.31	48.56
2) DT6258 (62 kPa minus 58 kPa)	-0.18	54.43

Mean of predictand = .80

N_c = 20

Because of the very small sample size, the regression equation was held to 2 terms, even though appreciable additional R.V. was given by more terms. The R.V. given by two terms is gratifyingly large, indicating that a stable lapse rate in the region from 62 kPa to 54 kPa is highly favorable for wind events.

A new predictor, YHAT, was constructed according to the regression equation given in Table 11 as follows:

$$YHAT = 2.38 - 0.18 \cdot DT6258 - 0.31 \cdot DT\ 5854 \qquad (1)$$

This predictor was then converted to binary predictors and subjected to screening on a 3-category predictand along with GJTOLND. The results are shown in Table 12.

Table 12. Regression results using YHAT as binary predictors and GJTOLND. DZ70D is 211 or greater.

	60+ mph		80+ mph	
	Contribution to Probability (%)	Cum. R.V.	Contribution to Probability (%)	Cum. R.V.
Constant	55.26		100.00	
1) YHAT $\leq$ 1.50	-2.63	14.44	-75.00	52.94
2) YHAT $\leq$ 0.50	-55.26	38.27	-25.00	60.00
3) GJTOLND	44.74	55.34	0.00	60.00
	F_W = 55.00 %		F_W = 25.00 %	
	N_W = 11		N_W = 5	
		N_C = 20		

The results of Table 12 are given in worksheet form in Appendix C.

It can be seen that this worksheet gives an impossible situation--a probability of 55 percent for 60+ mph and a probability of 100% for 80+ mph. This could occur if YHAT is 1.51 or more and Grand Junction is the upwind station. This particular combination did not happen in the 8-season sample. All three YHAT's of 1.51 or more were with Lander as the upwind station. This is one of the nonbeautiful things that happen in the use of statistical techniques.

g. Verification of the Composite Scheme on Developmental Data

Verification of the composite scheme given in sections d, e, and f on developmental data yields the breakdown of wind events by forecast probability as shown in Table 13. 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 13. Verification statistics for the composite equations on developmental data.

60 mph and above

Prob. (%)	0	2	5	10	20	30	40	50	70	100	ALL
Rel. Freq.	0.2	0.8	3.9	13.8	18.0	20.0	40.7	42.9	100.0	100.0	2.6
Winds	5	3	16	17	25	2	11	3	2	7	91
Fcsts	2412	378	409	123	139	10	27	7	2	7	3514

R.V. = 22.05%

80 mph and above

Prob. (%)	0	2	5	10	20	30	40	50	70	100	ALL
Rel. Freq.	0.1	0.9	3.4	8.3	50.0	25.0	-	-	-	100.0	0.3
Winds	3	1	1	1	1	2	0	0	0	3	12
Fcsts	3343	117	29	12	2	8	0	0	0	3	3514

R.V. = 32.12%

One could question whether a scheme which jumps from 30 to 100 percent really means what it says. With an eighty-(instead of eight-) year sample there would more than likely be some in between (and probably no 100's).

7. ATTEMPTS TO DEVELOP A TECHNIQUE FOR THE PERIOD 9 TO 15 HOURS AFTER DATA TIME.

The techniques presented in the preceding section cover only half of the day. This is the obvious consequence of using a 6-hour forecast period with observations twelve hours apart. The happiest solution to this problem would be to have observations taken 6 hours apart in the future. This isn't likely to come about, so the period 9 to 15 hours after data time was looked at briefly. R.V.'s obtained from this investigation did not exceed 11 percent for the 60+ mph events and 4 percent for the 80+ mph events. For this reason this time period has not been pursued, it being felt that it would be best to use the 3-to 9-hour technique and "predict the predictors" by whatever means available. This is deemed reasonable since the prediction is only for six hours, and the forecast need only to indicate if the predictors will cross into another category, i.e., cross a threshold.

8. DISCUSSION

The importance of temperature differences in the vertical has been shown by the results in sections 6e and 6f, especially the latter. This latter is accord with the findings by Brinkmann of the importance of a stable layer at or slightly above mountain-top level, and with the statement by Myers that a low-level stable layer is a necessary condition for strong winds. Strong westerly geostrophic winds at 70 kPa are obviously favorable for strong downslope winds, but are not a sufficient condition.

That the stable layer of importance changes when the range of DZ70D is shifted is puzzling. Perhaps a dynamical lee-wave model such as that of Klemp and Lilly could either confirm or disprove this apparent finding. It is highly unlikely that the particular ranges of DZ70D chosen in this study are precise, even if it is physically true that a shift takes place. It will be interesting to see how this technique stands up on independent data.

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: presence of an inversion; vertical and horizontal wind component differences; wind direction and speed; geostrophic wind direction and speed; Scorer parameter; lee wavelength; tropopause pressure and temperature; vorticity, divergence, and 12-hr local changes of vorticity at 70 and 50 kPa; and dew-point temperature depressions.

Winds and height gradients at other than the customary mandatory pressure levels would seem to be a logical step further in finding better predictors. The west wind components at the usual reporting levels (every 1000 ft. up to 10,000 ft. above MSL and then at 2000 ft. intervals) were tried, but were judged to be so little better than 70-kPa winds that the additional complication of waiting for the complete sounding to arrive offset the advantages. It would seem almost certain that using height differences at, say, 5-kPa intervals from 85 to 50 kPa one would find a better single level than 70 kPa. This is left to future investigation.

ACKNOWLEDGEMENTS

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NOAA-NATIONAL WEATHER SERVICE

COLORADO DOWNSLOPE WIND FORECAST WORKSHEET*
0300-0900 and 1500-2100 GMT Forecast Periods

This technique gives the point probability of surface wind gusts of 60 mph (97 kmph) or more and of 80 mph (129 kmph) or more in Boulder, Colorado (NBS Radio Building) in the 6-hour period beginning 3 hours after data time. Compute DZ70D and then proceed according to the following rules:

DZ70D	
≤60	The probabilities are near zero--stop.
61-160	Continue on this page. Probability of 80+mph is small, but nonzero.
161-210	Continue on supplemental worksheet--Side A. (Do DZ85G & U70GL first.)
≥211	Continue on supplemental worksheet--Side B.

DZ85G = 2 • Z85ELY - Z85BOI - Z85LND (gpm)
DZ70D = Z70SLC + Z70GJT - 2 • Z70LND (gpm)
U70GL = west wind component at 70 kPa at GJT if DIR50GJT is 290 degrees or less or LND if DIR50GJT is 295 degrees or more. Speed in knots.
GJTOLND = upwind station (GJT or LND) according to above rule.

Data Time__________Z____________________19__________

Do this first

Z85ELY______	Z70SLC______	DIR70GJT______	DIR50GJT______	ELY 486
	Z70GJT______	SPD70GJT______		BOI 681
Z85BOI______				LND 576
Z85LND______	Z70LND______	DIR70LND______		SLC 572
		SPD70LND______		GJT 476

DZ85G______ DZ70D______ U70GL______

		Probability Increment (60+) %	
DZ85G	≤54	0	
	55-82	2	
	83-110	4	
	111-138	7	
	≥139	16	______
DZ70D	61-110	0	
	111-160	2	______
U70GL	≤18	0	
	19-36	2	
	≥37	20	______
GJTOLND	LND	-2	
	GJT	0	______

Observed peak wind gust
______mph

Final Probability (SUM) ______

*See NOAA Technical Memorandum NWS NWS CR-61 for details.

Central Region Headquarters
Scientific Services Division
Kansas City, Missouri
December 1976 (589/613)

Maximum probability is 38%
Minimum probability is -2%

NOAA-NATIONAL WEATHER SERVICE

COLORADO DOWNSLOPE WIND FORECAST WORKSHEET*
0300-0900 and 1500-2100 GMT Forecast Periods

This technique gives the point probability of surface wind gusts of 60 mph (97 kmph) or more and of 80 mph (129 kmph) or more in Boulder, Colorado (NBS Radio Building) in the 6-hour period beginning 3 hours after data time. Compute DZ70D and then proceed according to the following rules:

DZ70D	
≤60	The probabilities are near zero--stop.
61-160	Continue on this page. Probability of 80+mph is small, but nonzero.
161-210	Continue on supplemental worksheet--Side A. (Do DZ85G & U70GL first.)
≥211	Continue on supplemental worksheet--Side B.

DZ85G = 2 • Z85ELY - Z85BOI - Z85LND (gpm)
DZ70D = Z70SLC + Z70GJT - 2 • Z70LND (gpm)
U70GL = west wind component at 70 kPa at GJT if DIR50GJT is 290 degrees or less or LND if DIR50GJT is 295 degrees or more. Speed in knots.
GJTOLND = upwind station (GJT or LND) according to above rule.

Data Time__________Z____________________19________

Do this first

Z85ELY______ Z70SLC______ DIR70GJT______ DIR50GJT______ ELY 486
Z70GJT______ SPD70GJT______ BOI 681
Z85BOI______ LND 576
Z85LND______ Z70LND______ DIR70LND______ SLC 572
SPD70LND______ GJT 476

DZ85G______ DZ70D______ U70GL______

		Probability Increment (60+) %	
DZ85G	≤54	0	
	55-82	2	
	83-110	4	
	111-138	7	
	≥139	16	______
DZ70D	61-110	0	
	111-160	2	______
U70GL	≤18	0	
	19-36	2	
	≥37	20	______
GJTOLND	LND	-2	
	GJT	0	______

Observed peak wind gust
______mph

Final Probability (SUM) ______

*See NOAA Technical Memorandum NWS NWS CR-61 for details.

Maximum probability is 38%
Minimum probability is -2%

Central Region Headquarters
Scientific Services Division
Kansas City, Missouri
December 1976 (589/613)

SUPPLEMENTAL COLORADO DOWNSLOPE WIND FORECAST WORKSHEET--SIDE A
(0300-0900 and 1500-2100 GMT Forecast Periods)

Use only if DZ70D is 161 to 210 gpm.
Record 40- and 30-kPa temperatures below at upwind station (GJT or LND) and compute difference--DT4030 = T40 - T30.

Data Time____________Z_________________19___________Upwind Station_________

T40 ________ (°C)
T30 ________

DT4030 _________

		Prob. Increment % 60+	Prob. Increment % 80+	Prob. Increment % 60+	Prob. Increment % 80+
DT4030	≤7.2	30	7		
	7.3-14.7	1	2		
	≥14.8	0	-5	______	______
DZ85G	≤116	0	0		
	≥117	19	5	______	______
U70GL	≤34	0	0		
	≥35	21	5	______	______
		Final Probabilities (Sums)		______	______

Maximum probabilities are 70 and 17%.
Minimum probabilities are 0 and -5%.

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December 1976 (617)

Appendix C

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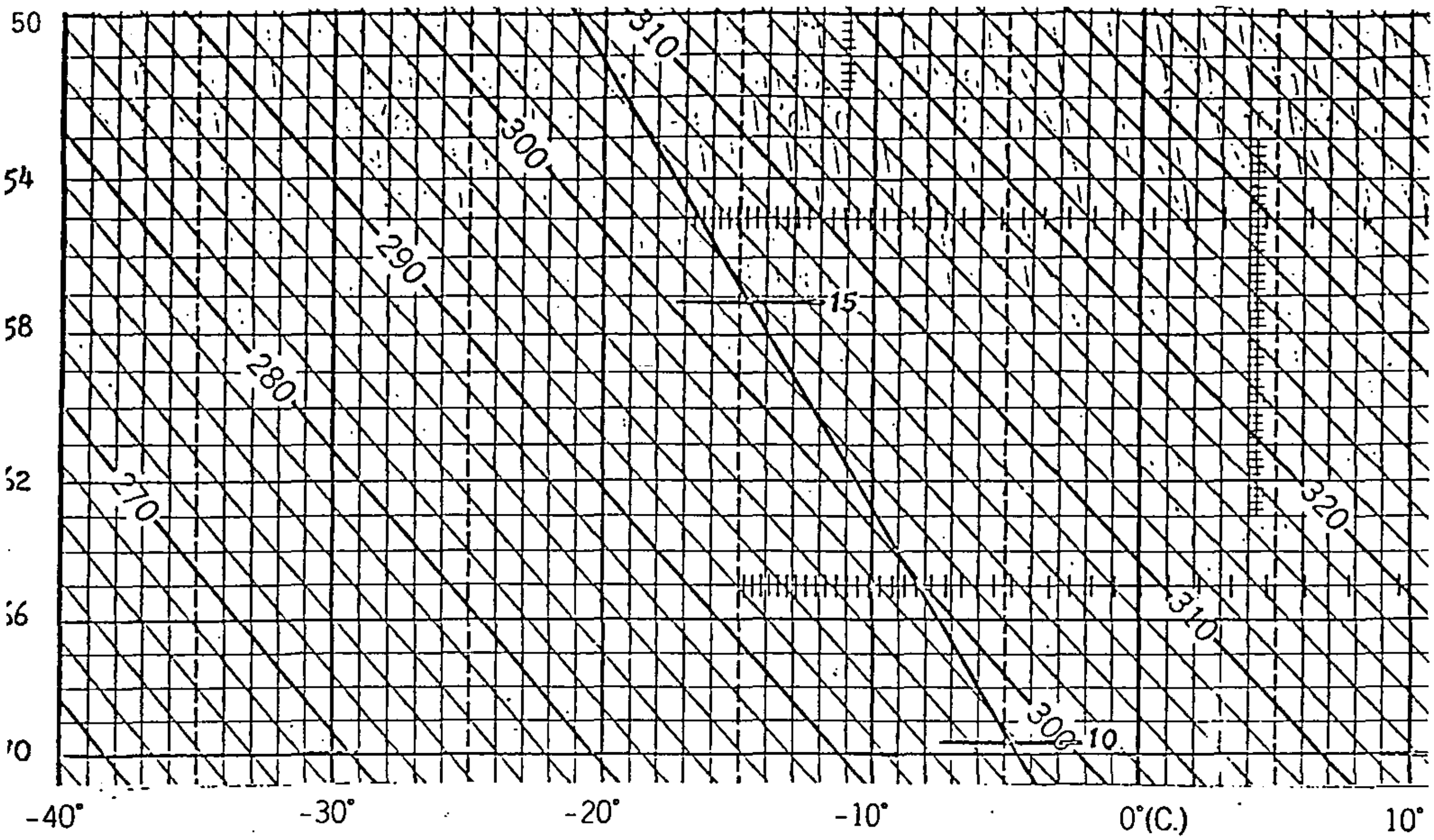
SUPPLEMENTAL COLORADO DOWNSLOPE WIND FORECAST WORKSHEET--SIDE B

Use only if DZ70D is 211 gpm or more. Plot 70- and 50-kPa temperatures and all significant level temperatures between these pressures. Read off temperatures interpolated to 62, 58, and 54 kPa and record below (to tenths of a degree). Compute DT6258 and DT5854 and then YHAT according to the equations given.



Data Time______Z________________19_____ Upwind Station_______________

YHAT= 2.38 - (.18 • DT6258) - (.31 • DT5854)
where DT6258 = T62 - T58 and DT5854 = T58 - T54 (°C)

See rule on basic worksheet.

	(-)		(-)	
T62	______	T58	______	
T58	______	T54	______	YHAT______
DT6258	______	DT5854	______	
2.38 .18 • DT6258	______	.31 • DT5854	______	

		Prob. Increment % 60+	Prob. Increment % 80+	Prob. Increment % 60+	Prob. Increment % 80+
YHAT	≤.50	-3	0		
	.51-1.50	53	25		
	≥1.51	55	100	______	______
GJTOLND	LND	45	0		
	GJT	0	0	______	

Maximum 100 and 100%
Minimum -3 and 0%

Final Probabilities (Sum) ______ ______

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Kansas City, Missouri
December 1976 (593/618)