WINTER WIND STUDIES IN ROCKY MOUNTAIN NATIONAL PARK

D. E. GLIDDEN

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ABSTRACT

Field studies of alpine and subalpine winds in Rocky Mountain National Park (RMNP), Colorado were made during the winters of 1973-74 and 1980-81.

Detailed windspeed regimes were established for several sites, and compared to other locations in Colorado and around the world. Frequency graphs of various windspeed factors were constructed for easy use by the researcher, hiker, or visitor.

Research indicates that alpine and subalpine winds are severe and exceptionally turbulent, with maximum recorded gusts (201 mph; 89.8 m/s) among the highest which have been published for known weather stations, including Mount Washington, New Hampshire and the Antarctic continent. Maximum hourly, daily, and monthly windspeeds, on the other hand, were found to be lower than those which occur at several other stations, although the Longs Peak data base is limited and the anemometer exposure only 3.6 meters above ground.

The characteristics of severe windstorms at Hidden Valley and Longs Peak are discussed, with the suggestion for further research directed at developing an on-site capacity for anticipating these events.

Topography has a pronounced influence on windspeeds in RMNP. Unless the site differences are first defined and tested, it is not always reliable to extrapolate windspeeds from one point or region to another along the Continental Divide.

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Introduction

The overall importance of increasing our understanding of the nature and variability of winds in Rocky Mountain National Park (RMNP), Colorado, and a summary of related studies, have been previously described in earlier research (Glidden, 1981).

Wind is perhaps one of the most significant environmental factors at high altitudes which directly influence visitors, timberline flora and fauna, fire spread, or air quality in RMNP. Although some of the ecological effects of alpine winds are recognized, they are often generalized with the true scope of this interaction masked by a lack of detailed data on the variability of winds with changing topography and exposure.

It is important to understand how winds influence the many levels of activities in RMNP, and several of the more obvious examples are as follows:

- they may directly influence the safety or relative comfort levels of visitors;
- they may present both physiological and physical barriers to climbers, seriously hindering or even preventing otherwise successful climbs;
- they may quickly reduce visibility to zero in blowing snow or orographic fog, influencing not only mountaineers or skiers, but also driving conditions along Trail Ridge Road;
- they may hinder or prevent helicopter air rescue or servicing operations in the Park;
- they may have serious consequences with respect to fire ignition and suppression.

The value of continuing wind research in RMNP was also viewed in the context of improving our ability to anticipate severe windstorms. There have been two outstanding events in recent history which caused extensive damage to large areas of Hidden Valley and its facilities, posing a potential hazard to skiers or visitors and suggesting that such occurrences may reflect the peculiar dynamics of local topography and airflow.

The May 1973 storm at Hidden Valley crushed thousands of trees, laying many across the ski chairlift and tow lines. Some trees, fractured at 3 meters or more above ground level, were over 50 centimeters in diameter. Since other areas of "blowdown" attested to storms of a similar magnitude in the past, information on wind severity became particularly important.

A pilot study of the climatological characteristics of extreme winds along Trail Ridge and Upper Hidden Valley began during the Fall of 1973. (Fig. 1) Additional wind research sites were established by the end of January 1974, and extended the studies

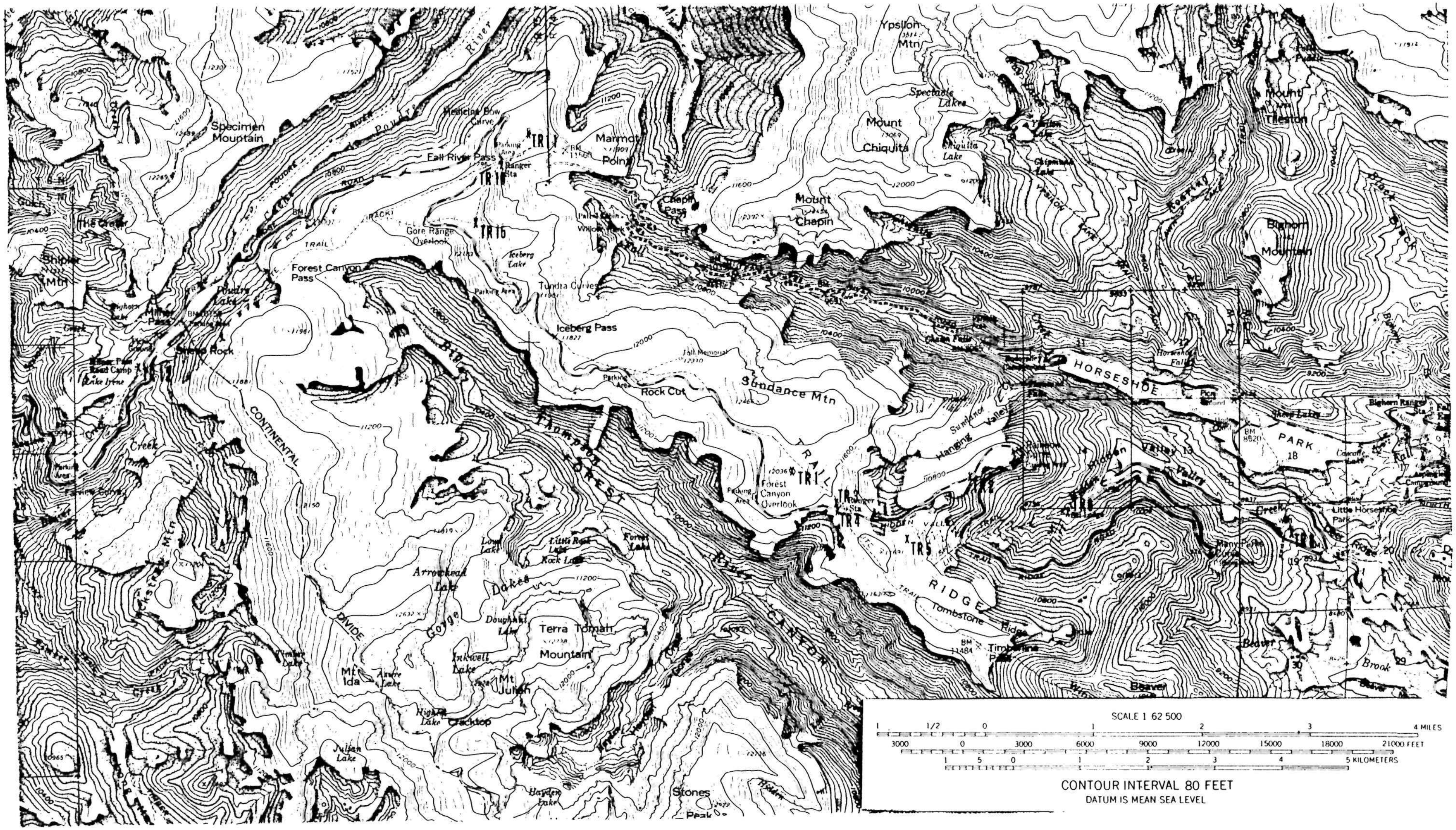


FIG. 1

Wind research sites in Rocky Mountain National Park, 1973-74, 1980. TR 7 (Park Headquarters) and Longs Peak are outside the map boundary.

on a transect from Lower Hidden Valley east to Rocky Mountain National Park Headquarters (TR 7).

The number of research sites and the scope of the wind project increased as the winter progressed. The regular servicing of alpine sites was difficult because of the severe environmental conditions prevailing. It was often risky or impossible to service TR 1 or TR 3, simply because one could not stand against the force of the wind. It was not unusual to become caught in a "whiteout" on the tundra, whereupon one could neither proceed nor turn back but had to wait for improving visibility.

Sustained zero and subzero Fahrenheit temperatures provided a challenge to the successful operation of all instruments. Anemometer icing was not a significant problem on Trail Ridge, except on a few occasions. This is in contrast to the rime problems encountered on Mines Peak (Judson, 1977) and the more severe icing conditions which occurred during wind studies of the coastal mountains of New England (Glidden, 1976a, 1976b).

Summer wind studies were conducted near the Alpine Visitors' Center during 1980, primarily to assess on-site wind energy potential but also to extend the overall data base. During the following winter, 1980-81, an attempt was made to acquire limited data from the summit of Longs Peak, at 14,256 ft (4,345 m). Since this was the highest point in the Park, it represented a major logistical problem. In addition, anemometer icing became much more pronounced at this higher exposure, and together with the low sensor height (3.6 m), may have accounted for the unexpectedly low average windspeeds. Nevertheless, several periods of very high winds were recorded.

This study presents a summary of the major data collected during the winter research.

PHOTO 1

View of Hidden Valley after May 1973 windstorm. Note two separate points of massive crushing. Ski chairlift passes through center of picture, from SW-NE, with Trail Ridge Road winding above.

GENERAL WIND CHARACTERISTICS

Winter research in RMNP indicates that alpine and subalpine winds are severe and exceptionally turbulent, with maximum recorded gusts ranking among the highest which have been published for known weather stations, including Antarctica.

Table 1 lists the published maximum gusts recorded at several mountain stations and elsewhere around the world.

Table 1. Maximum recorded wind gusts for RMNP and various sites around the world.

	MPH	M/S
RMNP, Colorado		
Longs Peak (4,345 m)		
1980	173	77.3
1981	201	89.8
TR 1 (3,669 m)		
1973	155	69.3
Berthoud Pass, Colorado		
Mines Peak (3,808 m)	130	58.1
White Mountains, New Hampshire		
Mount Washington (1,917 m)	231	103.3
Cannon Mountain (1,275 m)	199	89.0
Greenland		
Thule (500 m)	207	92.5
Japan		
Mount Fuji (3,776 m)[1]	162	72.4
Antarctica		
Port-Martin (20 m)[2]	109	48.7

1. Data reflect the 30-minute maximum.
2. Data reflect the 24-hour maximum.

Factors which influence the recording of extreme windspeeds, discussed in the summer study (Glidden, 1981, p. 36), should be considered when the values in Table 1 are compared. Correction factors for sensor height above ground are not recommended for irregular terrain. Also, the study of mountain climatology has made it evident that other factors, such as the frequency of fog, blowing snow, and low temperatures contribute to the overall severity of mountain weather.

In addition to maximum gusts, other wind criteria are used when comparing sites. Maximum hourly and daily windspeeds recorded in RMNP were substantially lower than those for Mount Washington, which is the site of the highest average annual windspeed in the United States and the highest official surface wind gust in the world. Maximum 24-hour speeds of 129 mph (57.6 m/s) and 109 mph (48.7 m/s) have been recorded at Mount Washington (Pagliuca, 1934) and Port-Martin, Antarctica (Loewe, 1972), respectively. Averages recorded for most Antarctic stations are much lower, however.

Maximum hourly values of 173 mph (77.3 m/s) and 149 mph (66.6 m/s) were monitored on Mount Washington and Cannon Mountain, New Hampshire, respectively (Glidden, 1974). This compares to a maximum hourly speed of 101 mph (45 m/s) recorded on Longs Peak.

Table 2 compares the average monthly windspeeds, and the number of daily peak gusts ≥74 mph (33 m/s) at TR 3 with those recorded at two other Colorado sites, Berthoud Pass and Mines Peak, for January-May 1974. Figures for the 30-year averages on Mount Washington are included.

Table 2. The average monthly windspeeds, and the number of daily peak gusts ≥74 mph (33 m/s) for TR 3, RMNP, and other mountain stations, January-May.

	J	F	M	A	M	PERIOD
TR 3, RMNP, Colorado (3,536 m)						
1974						
Average (mph)	36	31	34	23	26	30
No. Days With Maximum ≥74 mph	15	11	17	5	9	57
% Days With Maximum ≥74 mph	62	39	61	20	32	43
Berthoud Pass, Colorado (3,621 m)						
1974						
Average (mph)	16	18	20	16	17	17
No. Days With Maximum ≥74 mph	0	1	5	0	M	6
% Days With Maximum ≥74 mph	0	4	16	0	M	5
Mines Peak, Colorado (3,808 m)						
1974						
Average (mph)	33	31	35	26	28	31
No. Days With Maximum ≥74 mph	12	5	14	4	M	35
% Days With Maximum ≥74 mph	39	18	46	13	M	29
Mount Washington, New Hampshire (1,917 m)						
1941-70						
Average (mph)	46	45	42	36	30	40
No. Days With Maximum ≥74 mph	15	15	14	10	7	61
% Days With Maximum ≥74 mph	48	54	45	33	23	40

Figures rounded to nearest mile per hour or percent.

It becomes clear that elevation is not the sole determinant of windspeeds, even for areas as close as RMNP and Berthoud Pass. TR 3 is about 85 m lower in elevation than the Berthoud Pass site, and yet it appears to have significantly higher winds. Mines Peak, on the other hand, approximately 272 m higher than TR 3, more closely resembles the average monthly speeds at TR 3, although the RMNP site still reflects a greater number of hurricane-force daily maxima.

The high average monthly windspeeds on Mount Washington clearly establish its predominance, but the frequency of hurricane-force daily maxima at TR 3 are respectably close to those on the New Hampshire peak.

Table 3 compares windspeed factors at TR 1 and TR 3 with those at Mines Peak and Berthoud Pass for three storm days.

Table 3. Comparison of windspeeds at TR 1 and TR 3, RMNP, with those at Mines Peak and Berthoud Pass for three storm days. (MPH)

Date	Peak Gust	Time	Maximum One-hour	Time	Average For Day
12/12/73					
TR 1	155	0527	62	0600	44
Mines Peak	116	0533	80	0600	47
Berthoud Pass	97	0621	50	0600	26
1/31/74					
TR 3	119	1410	90	1500	66
Mines Peak	81	1832	66	0200	50
Berthoud Pass	51	1845	32	0200	18
3/6/74					
TR 3	115	2125	80	2100	53
Mines Peak	72	0310	51	0400	43
Berthoud Pass	60	1805	38	2100	25

It is evident that both gusts and average speeds may vary from site to site and hour to hour. Note that for the March 6th storm, the TR 3 maximum hourly of 80 mph (35.8 m/s) occurred at 2100, while the Mines Peak maximum of 51 mph (22.8 m/s) occurred at 0400; that TR 3 recorded 76 peak gusts $\geq$100 mph (44.7 m/s), while Mines Peak recorded a maximum of 72 mph (32.2 m/s). However, on the December 12th storm, Mines Peak monitored a much higher average hourly than TR 3, although its peak gusts were much lower. It is worthwhile noting that the Mines Peak sensor height was about 8 m higher than the exposure at TR 1 or TR 3.

The information suggests that topographic influence on windspeeds is very pronounced in RMNP. Thus, it appears that unless the site differences are first tested and defined (including data on anemometer icing), it is not safe to extrapolate windspeeds from one region along the Continental Divide to another.

ALPINE AND SUBALPINE WINDS: WINTER 1973-74

Data Summary

Table 4 presents the wind regime summary by month for TR 3 (alpine) and TR 6 (subalpine), January-May 1974.

Table 4. The wind regime summary for TR 3 and TR 6, RMNP, January-May 1974. (MPH)

	J	F	M	A	M	PERIOD
Peak Gust						
TR 3	122	108	115	113	111	122
TR 6	64	77	81	88	65	88
Average Daily Maximum						
TR 3	80.4	67.4	76.3	57.0	63.5	68.9
TR 6	M	51.3	52.1	43.6	39.5	46.6
No. Peak Gusts ≥74 mph						
TR 3	392	68	1,014	158	367	1,999
TR 6	M	1	20	4	0	25
No. Peak Gusts ≥100 mph						
TR 3	322	35	79	67	22	525
TR 6	M	0	0	0	0	0
Maximum One-hour Average						
TR 3	90	80	80	87	72	90
TR 6	M	26	36	30	24	36
Maximum Daily Average						
TR 3	65.7	50.0	53.1	42.7	47.6	65.7
TR 6	M	M	13.6	11.1	9.8	13.6

The table represents the period with the most complete data, and facilitates the comparison of wind characteristics from one site to another, although several years of study are needed for a climatological analysis.

A further measure of the severity of alpine winds above Hidden Valley may be found in Table 5, which lists the distribution of weekly wind maxima for TR 2 (October-May) and TR 5 (January-May). These data were recorded weekly for each site at the same time.

Table 5. The distribution of weekly wind maxima by high wind speed classes for TR 2 and TR 5, RMNP, Winter 1973-74.

Site	No. Weeks	% Weeks ≥74 mph	% Weeks ≥90 mph	% Weeks ≥110 mph	Period Peak Gust
TR 2	30	80	57	17	139
TR 5	18	95	61	11	126

Table 6 summarizes the maximum recorded windspeeds (peak gusts) and the number of days with data for each site during the winter months. The number of days with data for peak gusts were usually greater than those for other data.

Table 6. The maximum recorded windspeeds (peak gusts) for all sites, RMNP, Winter 1973-74. (MPH)

	O	N	D	J	F	M	A	M	PERIOD
TR 1									
Peak Gust	105	90	155	-	-	-	-	-	155
Days With Data	16	17	2	-	-	-	-	-	35
TR 2									
.Peak Gust	88	99	114	139	105	98	104	75	139
Days With Data	11	30	31	31	28	31	30	10	202
TR 3									
Peak Gust	-	-	98	122	108	115	113	111	122
Days With Data			16	24	28	31	25	28	152
TR 5									
Peak Gust	-	-	-	126	114	108	100	75	126
Days With Data	-	-	-	14	28	31	30	3	106
TR 6									
Peak Gust	-	-	-	64	77	81	88	65	88
Days With Data	-	-	-	9	28	31	30	30	128
TR 7									
Peak Gust	-	-	85	78	74	78	61	66	85
Days With Data	-	-	7	28	28	31	30	18	142

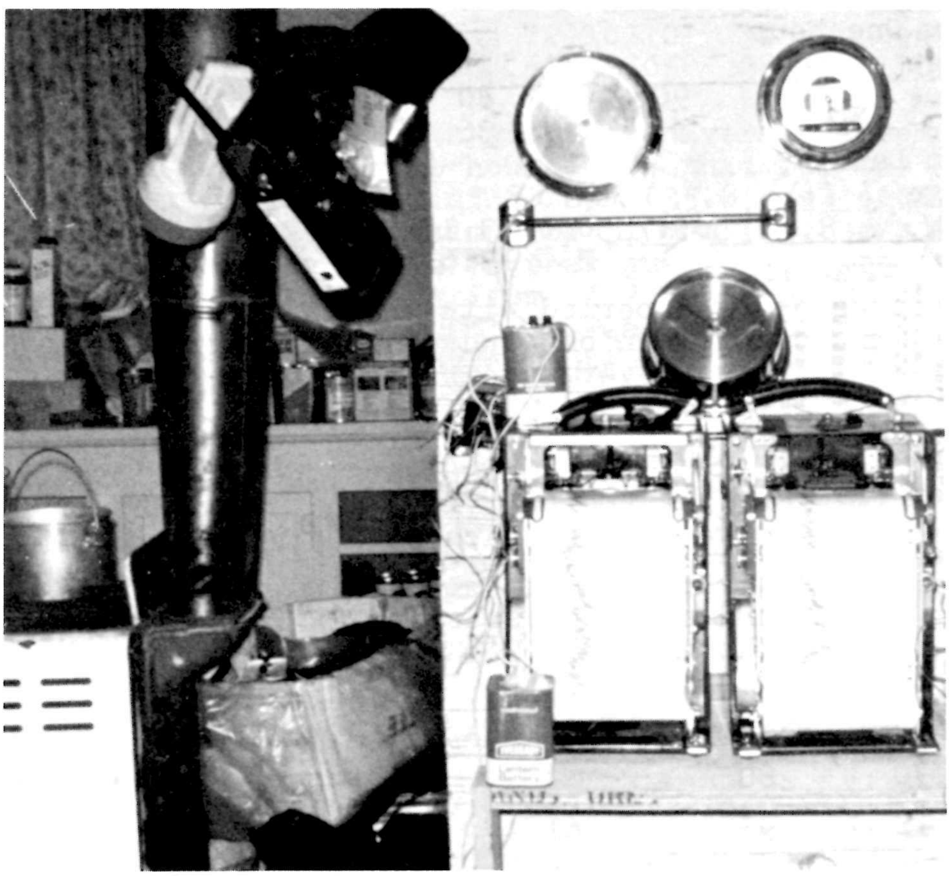


PHOTO 2

View inside Rock Cabin (since removed) on Trail Ridge Road, showing recorders and other instruments used in detailed comparison tests of wind variability between TR 3 and TR 4.

Frequency of Winter Winds

Figures 2-10 represent the windspeed frequency graphs for TR 3 and TR 6. They include monthly data on the maximum, maximum one-hour average, and average daily windspeeds.

1. Extreme Windspeeds

Figure 2 indicates the frequency of occurrence of daily maximum windspeeds at TR 3 for January 1974. For example, hurricane-force or greater (≥74 mph; 33 m/s) winds occurred on 15 days or 68% of the days with data. (In the case of Fig. 2, 22 days were used for consistency with hourly and daily data.)

Table 7 shows a more complete picture of the frequency of extreme winter windspeeds. For the October 1973-May 1974 period, 46% of the days with data experienced hurricane-force or higher maximum windspeeds.

Table 7. The frequency of occurrence of daily wind maxima ≥74 mph (33 m/s) and ≥100 mph (45 m/s) at TR 3, October 1973-May 1974.

	O-N[1]	J[2]	F	M	A	M	PERIOD
No. Days ≥74 mph	18	15	11	17	5	9	75
% Days ≥74 mph	60	62	39	61	20	32	46
No. Days ≥100 mph	3	4	4	4	1	3	19
% Days ≥100 mph	10	17	14	14	4	11	12
Days With Data	24	24	28	28	25	28	157

1. Data from TR 1
2. January daily peak gust data for 24 days

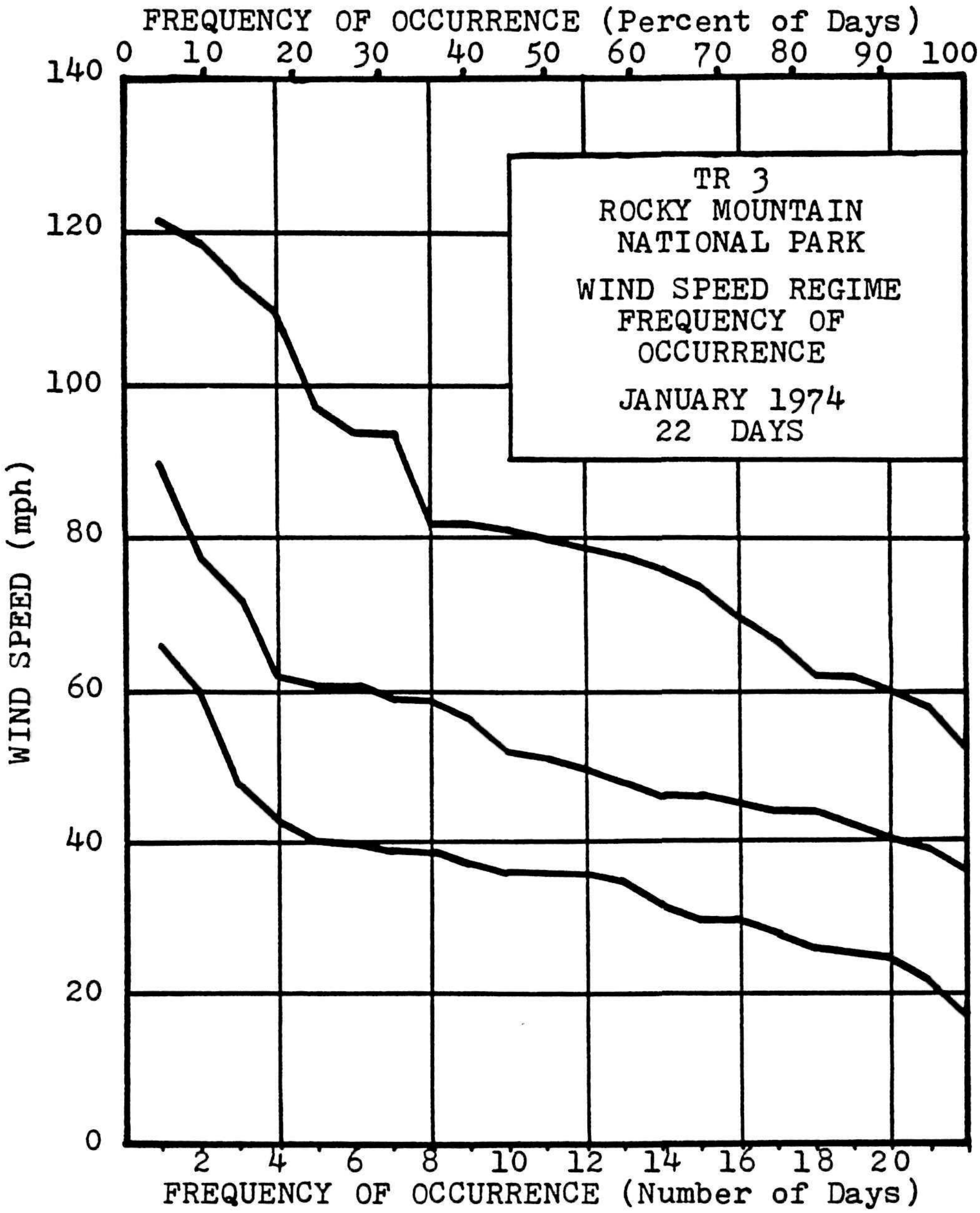
The number of days with maxima ≥100 mph (45 m/s) is included in Table 7. These severe winds ranged from 17% of the days in January to 4% in April, occurring on 19 days (or 12% of the days) of the winter period.

Frequency data on daily maxima at TR 6 (2,913 m) and TR 7 (2,377 m) are listed in Table 8.

Table 8. The frequency of occurrence of daily wind maxima ≥64 mph (29 m/s) at TR 6 and TR 7, February-May 1974.

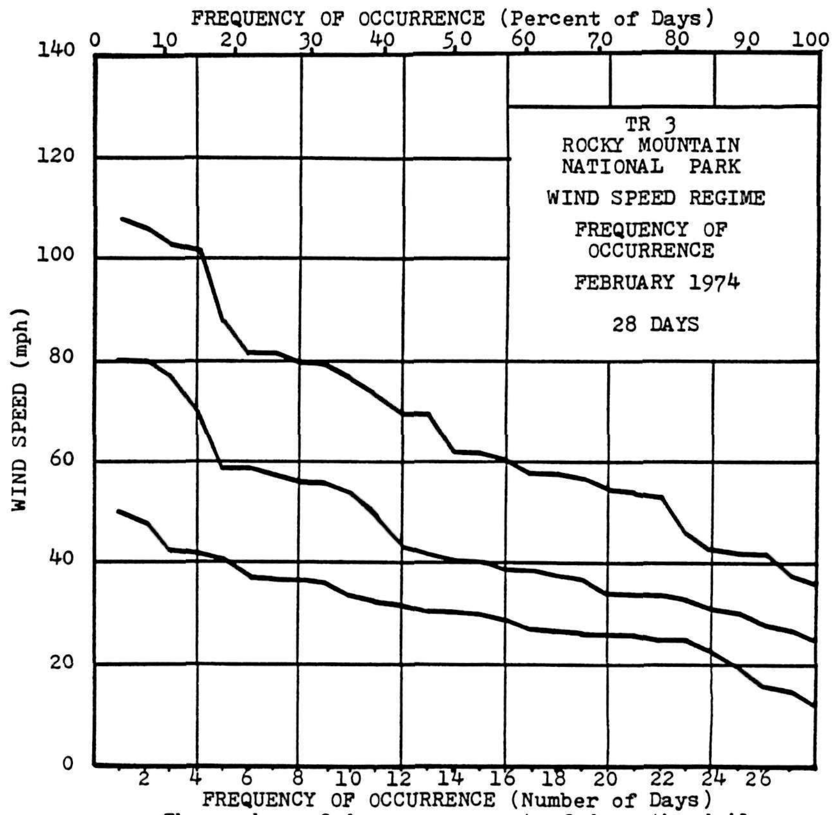
	F	M	A	M	PERIOD
TR 6					
No. Days ≥64 mph	4	3	3	1	11
% Days ≥64 mph	14	10	10	3	9
Days With Data	28	31	30	30	119
TR 7					
No. Days ≥64 mph	6	3	0	1	10
% Days ≥64 mph	21	10	0	6	9
Days With Data	28	31	30	18	107

Storm-force maxima (≥64 mph; 29 m/s), for example, occurred on 3 days in March, necessitating the closing of the former ski chairlift at Hidden Valley. It is interesting to note the varia-



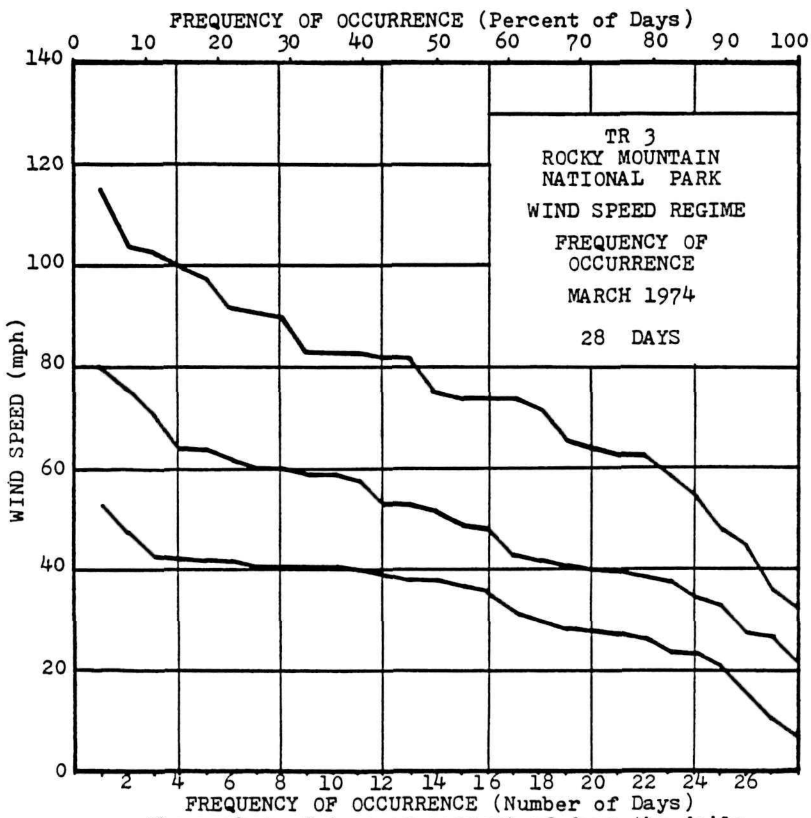
The number of days or percent of days the daily maximum, maximum one-hour average, and average daily windspeeds were equal to or greater than a particular speed.

FIG. 2



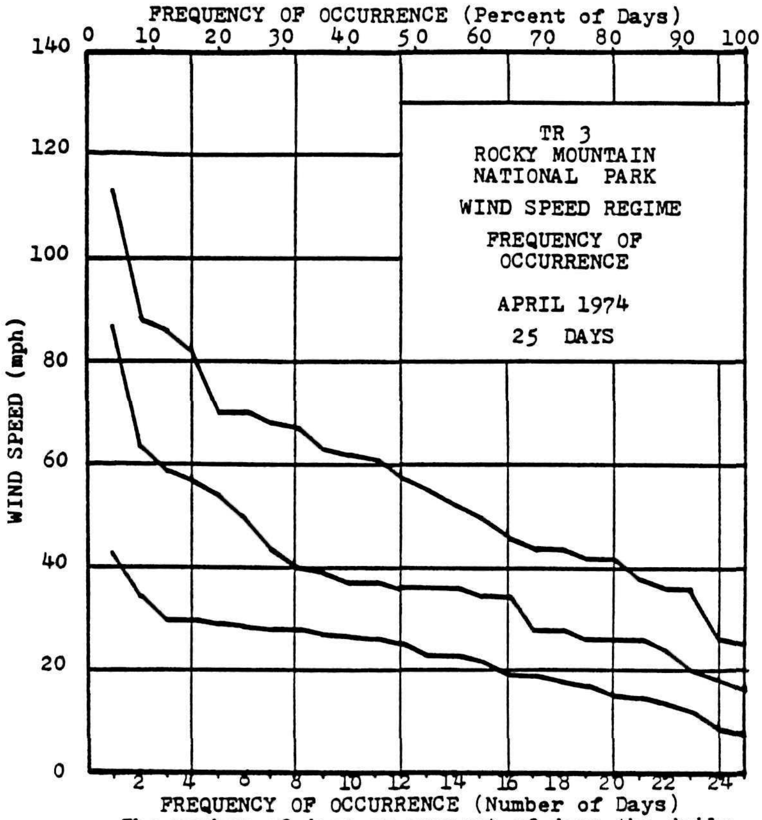
The number of days or percent of days the daily maximum, maximum one-hour average, and average daily windspeeds were equal to or greater than a particular speed.

FIG. 3



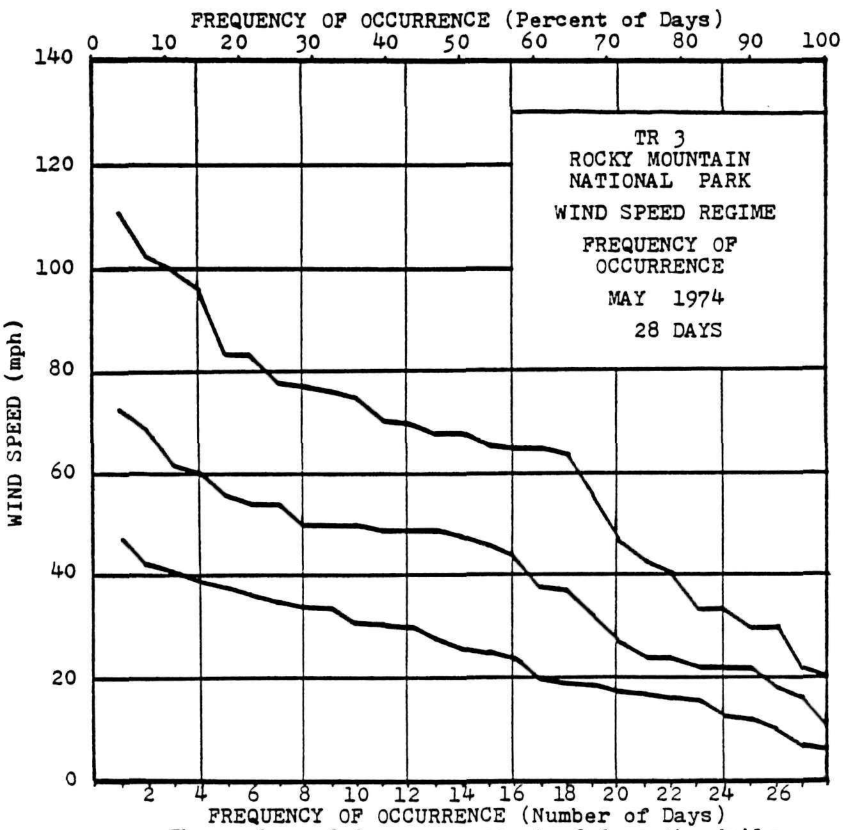
The number of days or percent of days the daily maximum, maximum one-hour average, and average daily windspeeds were equal to or greater than a particular speed.

FIG. 4



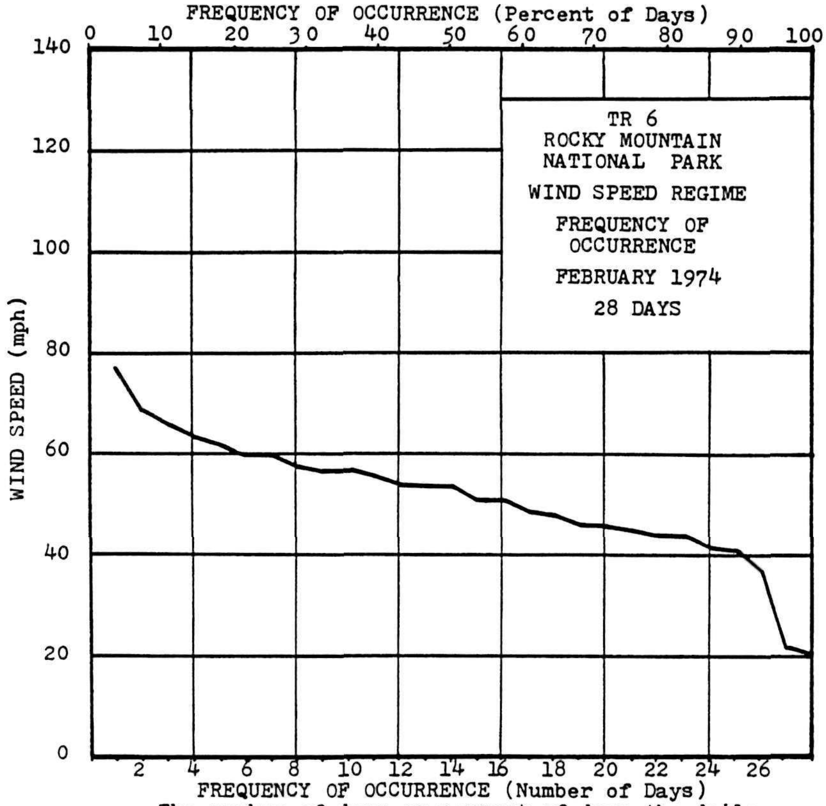
The number of days or percent of days the daily maximum, maximum one-hour average, and average daily windspeeds were equal to or greater than a particular speed.

FIG. 5



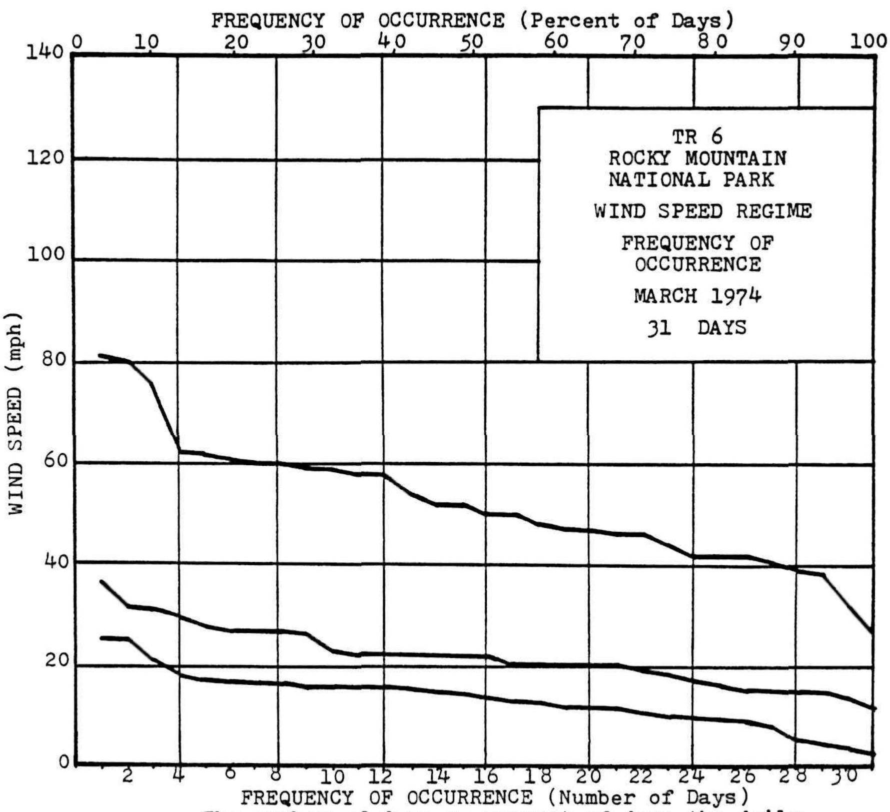
The number of days or percent of days the daily maximum, maximum one-hour average, and average daily windspeeds were equal to or greater than a particular speed.

FIG. 6



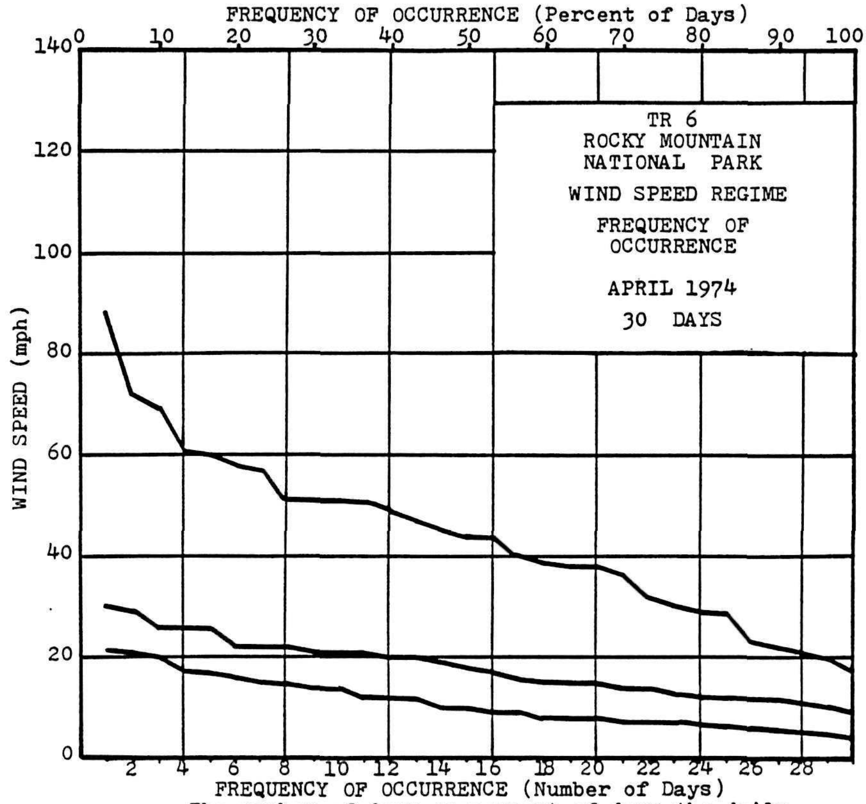
The number of days or percent of days the daily maximum windspeed was equal to or greater than a particular speed.

FIG. 7



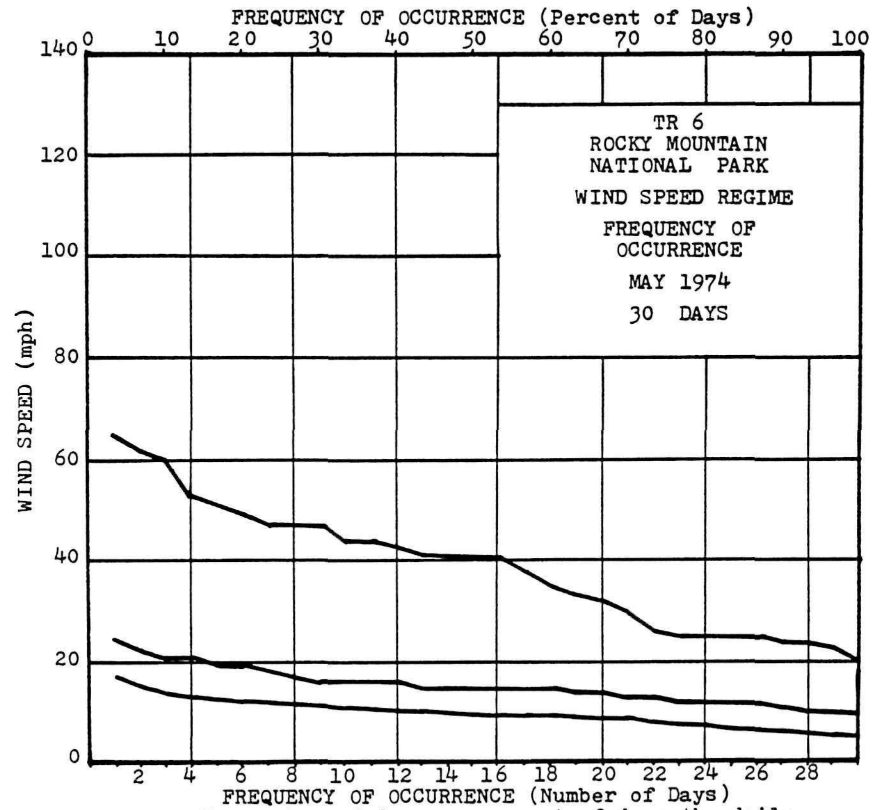
The number of days or percent of days the daily maximum, maximum one-hour average, and average daily windspeeds were equal to or greater than a particular speed.

FIG. 8



The number of days or percent of days the daily maximum, maximum one-hour average, and average daily windspeeds were equal to or greater than a particular speed.

FIG. 9



The number of days or percent of days the daily maximum, maximum one-hour average, and average daily windspeeds were equal to or greater than a particular speed.

FIG. 10

bility of storm-force maxima. In February, there were 6 occurrences at TR 7 and only 4 at TR 6. However, in April, TR 6 monitored 3 occurrences and TR 7 none. Further research into the April storm characteristics at Hidden Valley, a part of the overall problem involving topographic/wind interaction, may help us to understand why the same maxima did not show up at TR 7.

2. Maximum One-hour Average Windspeeds

At TR 1 for the October-November 1973 Fall period, hourly average windspeeds ≧64 mph (29 m/s) occurred on 2 days or 8% of the days with data (Table 9a).

Table 9a. The frequency of occurrence of daily maximum one-hour average windspeeds ≧64 mph (29 m/s) at TR 3, October 1973-May 1974.

	O-N[1]	J	F	M	A	M	PERIOD
No. Days ≧64 mph	2	3	4	5	2	2	18
% Days ≧64 mph	8	12	14	18	8	7	11
Days With Data	24	24	28	28	25	28	157

1. Data from TR 1

As more complete monthly data became available for TR 3, hourly averages ≧64 mph were detected on 4 days in February and 5 days in March. Discussed in more detail in a separate section, hourly averages ≧60 mph (27 m/s) accounted for 108 hours for all days with data.

Complete data on maximum one-hour averages at TR 6 were not available until March. High hourly averages were not common at Hidden Valley Base, with gale-force (≧32 mph; 14 m/s) hourly speeds recorded on only 4 days (Fig. 8). Hourly averages ≧20 mph (9 m/s) were registered on 19 days in March, 12 days in April, and 4 days in May.

3. Average Daily Windspeeds

Average daily windspeeds ≧32 mph (14 m/s), or gale-force, occurred on 12 days (or 50% of the days with data) at TR 1 for the October-November 1973 period (Table 9b).

Table 9b. The frequency of occurrence of daily average windspeeds ≧32 mph (14 m/s) at TR 3, October 1973-May 1974.

	O-N[1]	J	F	M	A	M	PERIOD
No. Days ≧32 mph	12	13	12	16	2	9	64
% Days ≧32 mph	50	59	43	57	8	32	41
Days With Data	24	22	28	28	25	28	155

1. Data from TR 1

On winter average, a gale-force or higher average daily windspeed occurred approximately every 2.5 days.

At TR 6, average daily windspeeds ≧20 mph (9 m/s) occurred on 3 days in both March and April. None was recorded in May.

Distribution of Average Hourly Windspeeds

A detailed analysis of average hourly windspeeds at TR 1 and TR 3 (alpine) was performed for the winter period, and is presented in Table 10.

Table 10. The frequency distribution of average hourly windspeeds at TR 1 and TR 3, RMNP, Winter 1973-74.

One-hour Average Windspeed	Total Hours of Occurrence	Total Hours of Occurrence	Frequency Distribution	
MPH	Number	%	MPH	%
0-9	355	8.74	≥0	100.00
10-19	753	18.53	≥10	91.26
20-29	1,027	25.28	≥20	72.73
30-39	914	22.50	≥30	47.45
40-49	620	15.26	≥40	24.96
50-59	252	6.20	≥50	9.70
60-69	108	2.66	≥60	3.49
70-79	23	0.566	≥70	0.837
80-89	10	0.246	≥80	0.271
90-99	1	0.025	≥90	0.025

Total Hours = 4,063
Total Possible Hours = 5,832
Percent of Hours With Data = 69.7%

The data cover the period from October 1973-May 1974, and combine both sites. As discovered in the summer study, a great deal of information is available from this type of analysis. For example, average hourly windspeeds of 80-90 mph (36-40 m/s) occurred on 10 hours (or 0.246% of the hours); average hourly speeds ≥10 mph (4.5 m/s) occurred on 91% of the hours; hourly values ≥90 mph (40.2 m/s) represented only 0.025% of the total hours with data.

Storm Characteristics At Hidden Valley:
Superhurricane Winds Of March 1-7, 1974

The first week in March 1974 provided a prolonged period of high average hourly windspeeds and gusts at both TR 3 and TR 6. The 500-millibar charts reflected a week of vigorous westerlies over the state of Colorado, and a detailed hourly record was made of surface wind, pressure, temperature, and relative humidity (Fig. 11).

The solid lines in Fig. 11 represent the average hourly windspeed (bottom solid) and the hourly gust maximum (top solid) at TR 3, while the dashed lines reflect the average hourly (bottom dashed) and the hourly maximum (top dashed) at TR 6. Hourly traces of relative humidity, temperature, and pressure recorded at TR 6 appear across the top of the graph. (Absolute values on pressure should not be used for comparison elsewhere.)

Average hourly windspeed trends between the two sites may follow similar patterns, although not in all cases or with the same magnitude of change. (See, for example, the period from 1600 on March 6-0300 on March 7.) Hourly trends in gust maxima may be dissimilar in both time and magnitude. (See 0700-1000 on March 5.)

At TR 3, gusts over 100 mph (45 m/s) were associated with a rapid fall in pressure at TR 6 (see 1900 on March 2), but even the most extreme values at TR 3 may occur under a relatively steady pressure regime at TR 6 (2100 on March 6).

On March 4th, frequent gusts over hurricane-force (a potential hazard to chairlift operations at Hidden Valley) occurred during the day. An examination of surface observations during these winds is worthwhile.

At 2100 on March 3, a singular occurrence of near-calm prevailed at TR 6, with pressure rising slowly. Shortly after midnight, surface pressure began to fall under a rapidly increasing west-southwest flow of superhurricane-force gusts and moderate snow. During the early morning and day of the 4th, gusts at TR 6 were of the same order of magnitude as those which were occurring on the alpine above (at TR 3). Near sunrise, heavy blowing and drifting snow obscured the alpine, and it was virtually imposible to negotiate Upper Hidden Valley on foot. Hurricane gusts continued all day at TR 6.

On April 10th, a second storm of similar magnitude began at 2100, with hurricane gusts during the following day also exceeding those on the alpine. This suggests that perhaps one potential route to follow in determining the initiation of a severe windstorm at Lower Hidden Valley involves the simultaneous monitoring of windspeeds at TR 3 and TR 6. It appears that when gusts at Lower Hidden Valley, under at least a moderately increasing hourly flow, begin to equal or exceed those occurring on the alpine above, then the potential exists for a major windstorm at Lower Hidden Valley. Other criteria would need to be developed and considered, of course, as well as the current limited data base for the two sites, before any on-site data may be used as a viable prediction aid.

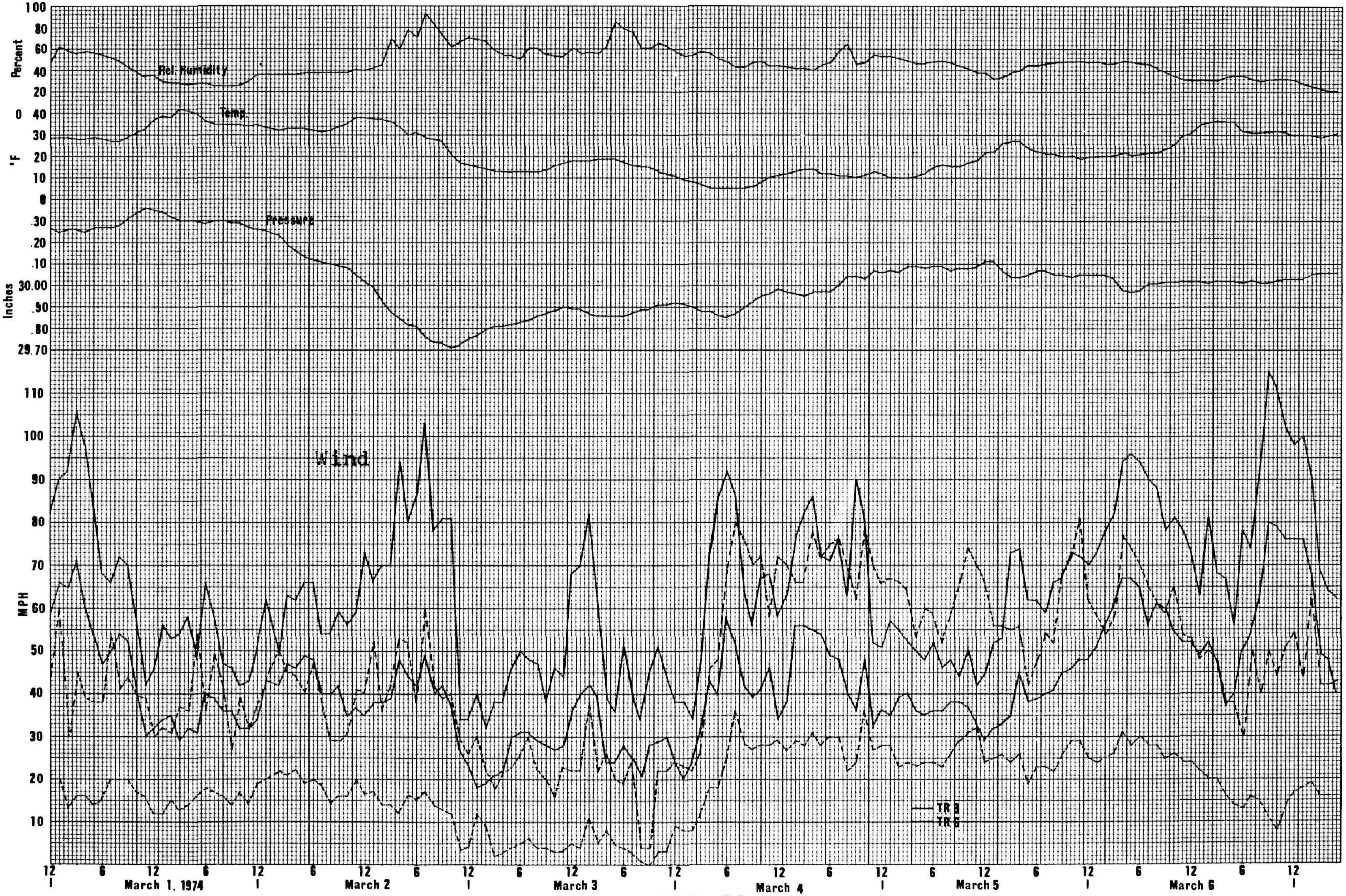


FIG. 11
Hourly wind, pressure, temperature, and relative humidity for Hidden Valley during the first week in March 1974. For wind, the solid lines represent data at TR 3; dashed lines at TR 6. See text.

PHOTO 3

The TR 3 wind sensor exposure during Winter 1973-74. At 11,600 ft (3, 536 m), the site overlooks Forest Canyon and the Continental Divide.

PHOTO 4

The TR 6 (Lower Hidden Valley) wind sensor exposure, at 9,557 ft (2,913 m). The wind sensor is mounted 42 ft (12.8 m) atop chairlift tower.

LONGS PEAK: WINTER 1980-81

Special Environmental Problems

The summit of Longs Peak, at 14,256 ft (4,345 m), presents a formidable challenge, particularly to human researchers, but also to the operation, regular servicing, and durability of even specially-designed wind instruments. Research during the winter of 1980-81 clearly demonstrated the level of human energy and logistical support which are required to secure even 74 days of data.

A specially-constructed, low profile shelter was transported to the summit in September of 1980, and afforded protection for instruments and Park Rangers while servicing the station. Since it was known that winds may induce a severe vibration on the summit, producing both an audible roar and a "noise" which has been detected through sensitive acoustic instruments as far away as Boulder, it was necessary to surround the shelter with large blocks of rock.

Hard rime ice was cleared from the 3.6 m instrument tower on some winter visits. Sensor height and location, now believed to represent a "wind shadow" on the western summit expanse, may have minimized some windspeeds under certain wind direction regimes, although this is not clear. On the other hand, the effects of rime on unheated wind sensors are quite well known. Data on rime frequency on Longs Peak are not available; however, since the summit is often in a cap cloud when Trail Ridge is clear, it is thought to be high.

Information for even 74 days offers a glimpse of what must be considered an extraordinary environment: frequent wind gusts approaching twice hurricane-force, several over 170 mph (76 m/s), and at least one registering 201 mph (89.8 m/s)!

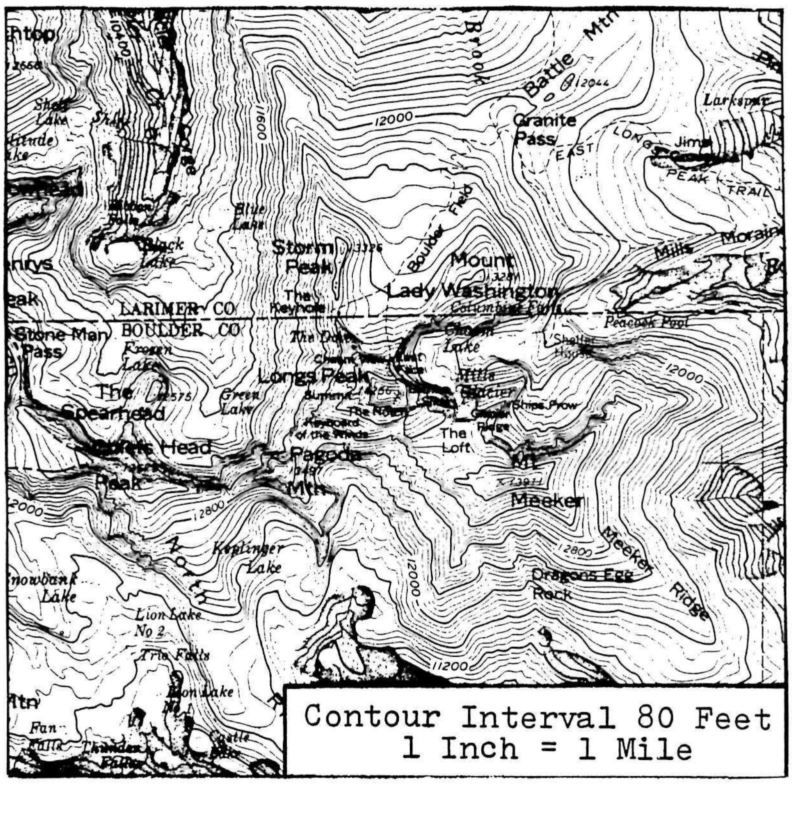


FIG. 12

Longs Peak and vicinity, Rocky Mountain National Park.

Data Summary

Table 11 lists the 74-day wind regime summary for Longs Peak during Winter 1980-81. Summer data for the Alpine Visitors' Center are included for comparison.

	WINTER[1]		SUMMER[2]	
	LONGS PEAK		AVC	
	mph	m/s	mph	m/s
Peak Gust[3]	201	89.8	79	35
Average Daily Maximum	64.9	29.0	47.8	21.4
Maximum One-Hour Average[4]	101	45.1	49	22
Maximum Daily Average	50.2	22.4	34	15.2
Period Average[5]	16.7	7.4	20.2	9.0
No. Days Peak Gust ≥74 mph	24		4	
Maximum Hourly Gust Factor[6]	5.20		4.28	
Average Maximum Hourly GF	3.20		2.20	
Average Hourly GF	2.00		1.58	
Average Minimum Hourly GF	1.30		1.21	
Minimum Hourly GF	1.00		1.00	
Days With Data[7]	74		87	
% Days With Data	27.3		95	

1. Winter - August 30, 1980-May 31, 1981
2. Summer - June 2 - August 28, 1980
3. The maximum windspeed measured.
4. The highest average hourly windspeed.
5. The average windspeed for all days with data. Exposure and sensor icing problems may have substantially reduced the Longs Peak average.
6. Gust Factors are based on 24 hourly values for each day with data.
7. Days with data vary with particular averages.

TABLE 11

The wind regime summary for Longs Peak (Winter: 74 days) and the Alpine Visitors' Center (Summer: 87 days), RMNP.

Frequency of Winter Winds

Table 12 lists the daily frequency of occurrence for selected values of peak gusts, maximum one-hour averages, and average daily windspeeds for Longs Peak over the 74-day period.

Table 12. The number of days or percent of days the daily peak gust, maximum one-hour average, and average daily windspeeds were ≥ a particular value on Longs Peak, RMNP.

		Number of Days	Percent of Days
Daily Peak Gust (mph)	≥32	63	85
	≥74	24	32
	≥100	13	18
	≥150	3	4
Maximum One-hour Average (mph)	≥10	67	97
	≥50	4	6
	≥100	1	1
Average Daily (mph)	≥10	57	83
	≥30	3	4
	≥50	1	1
Days With Data		74	27.3

Note the relatively low frequency of high hourly and daily windspeeds, which may reflect sensor icing or exposure problems. The period average for Longs Peak is actually lower than that for summer (1980) at the Alpine Visitors' Center (Table 11), although the maximum hourly speed of 101 mph (45.1 m/s) is certainly respectable for the data base. Maximum gusts and turbulence (gust factors) are exceptionally high, and a detailed analysis of the frequency of hourly peak gusts was performed for all data (1,521 hours). Table 13 provides this information.

The frequency distribution of hourly peak gusts is another indicator of the severity of the Longs Peak environment. For example, the number of hourly peak gusts which ranged from 70-79 mph (31-35 m/s) occurred on 37 hours (or 2.43% of the hours); the number ≥120 mph (53.6 m/s) occurred on 14 hours (or 0.92% of the hours). Three hours experienced gusts ≥150 mph (67.1 m/s). However, there were 141 hours (or 9.27% of the hours) with maximum winds ranging from 0-9 mph (0-4 m/s). The latter at least accounts for those winter days with low wind and sun reported by climbers. On the other hand, it may reflect hours of severe icing, when the wind sensors were either partly or completely frozen.

Hourly Peak Gust	Total Hours of Occurrence	Total Hours of Occurrence	Frequency Distribution	
MPH	Number	%	MPH	%
0-9	141	9.27	≥0	100.00
10-19	217	14.27	≥10	90.73
20-29	376	24.72	≥20	76.46
30-39	290	19.07	≥30	51.74
40-49	195	12.82	≥40	32.67
50-59	143	9.40	≥50	19.85
60-69	61	4.01	≥60	10.45
70-79	37	2.43	≥70	6.44
80-89	21	1.38	≥80	4.01
90-99	11	0.723	≥90	2.63
100-109	12	0.789	≥100	1.91
110-119	3	0.197	≥110	1.12
120-129	5	0.329	≥120	0.920
130-139	3	0.197	≥130	0.591
140-149	3	0.197	≥140	0.394
≥150	3	0.197	≥150	0.197

Total Hours = 1,521
Total Possible Hours = 6,600 (August 30, 1980-May 31, 1981)
Percent of Hours With Data = 23%

TABLE 13

The frequency distribution of hourly peak gust windspeeds on Longs Peak, RMNP, Winter, 1980-81.

PHOTO 5
View of Longs Peak in winter.

Gust Ratios

1. Gust Factor Regimes

The relationship of gust factors (GFs) and average windspeeds were discussed with some detail in the summer study (Glidden, 1981, pp. 26-35). Gust factors are determined from the ratio of the peak gust to the average windspeed for some specified period of time. For example, the hourly GF refers to the ratio of the peak gust/average hourly windspeed; the 5-minute GF is the ratio of the peak gust/average 5-minute windspeed.

Detailed hourly GFs for Longs Peak (70 days), TR 3 (29 days), and TR 10 (87 days) are listed in Table 14.

Table 14. The hourly GF regimes for Longs Peak, TR 3, and TR 10, RMNP.

	Longs Peak (Winter)	TR 3 (3/74)	TR 10 (Summer)
Maximum	5.20	3.50	4.28
Average Maximum	3.20	2.53	2.20
Average	2.00	1.61	1.58
Average Minimum	1.30	1.27	1.21
Minimum	1.00	1.00	1.00
Days With Data	70	29	87

One outstanding feature of the Longs Peak site is the very high GFs. This is reflected in the average maximum GF of 3.20, which exceeds by far the recorded data for any other site. Sensor heights at Longs Peak and TR 3 were the same, while the exposure at TR 10 was 9 meters.

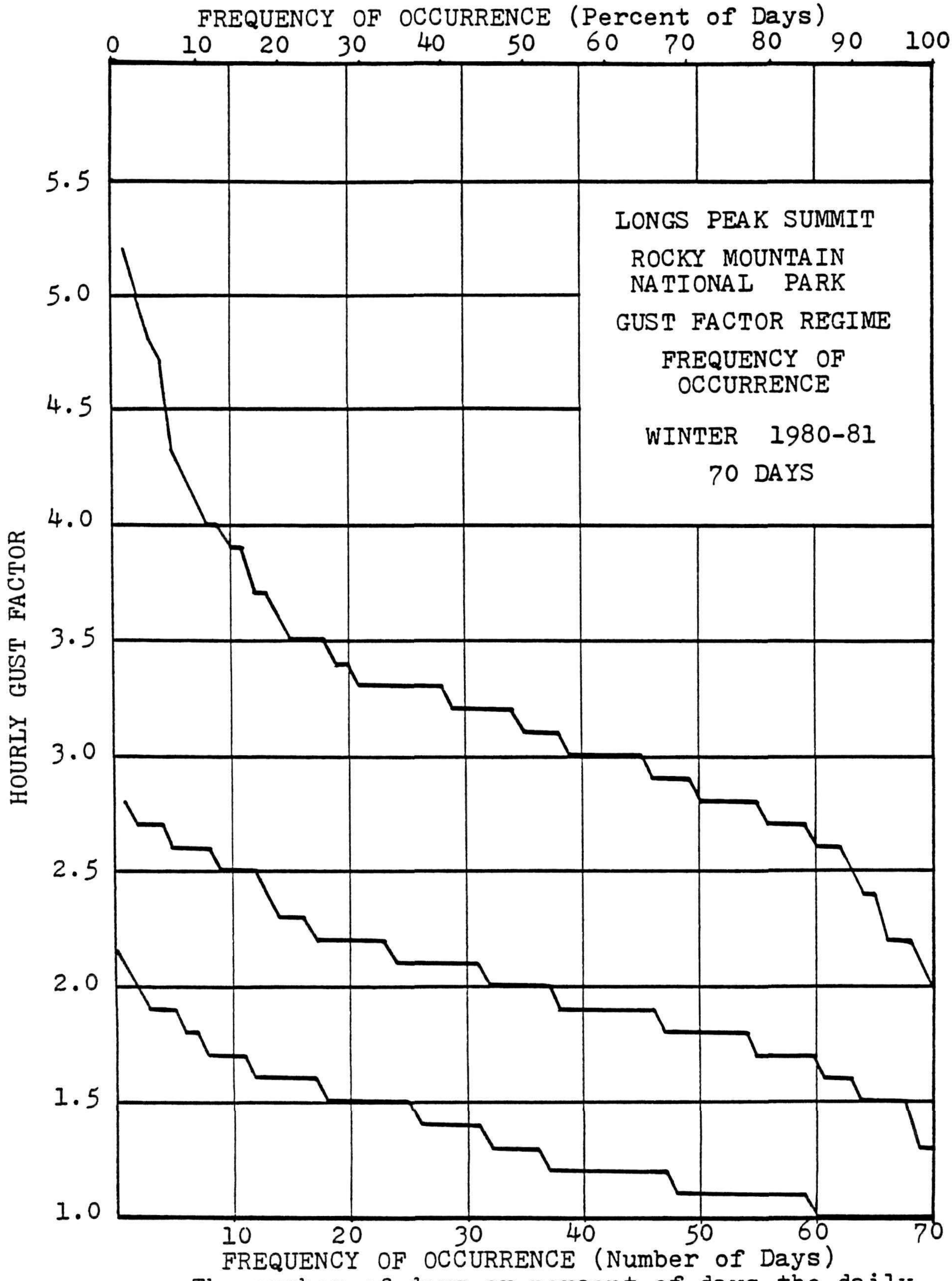
Figure 13 presents the Longs Peak GF frequency regime for a 70-day period. Mean daily GFs ≥2.0 occurred on 53% of the days; maximum daily GFs ≥4.0 were recorded on 13% of the days.

Table 15 compares various GFs at Longs Peak (winter) with those at TR 10 (summer).

Table 15. The percent of days with GFs ≥ particular values, Longs Peak and TR 10, RMNP.

	Longs Peak (Winter)	TR 10 (Summer)
Mean Daily GFs		
≥1.5	97	80
≥2.0	53	1
Maximum Daily GFs		
≥3.0	64	10
≥4.0	13	1
Days With Data (Number)	70	87

For example, in winter, Longs Peak experienced maximum daily GFs ≥4.0 on 13% of the days (or 9 days), while TR 10, in summer, monitored such values on only 1% (or 1 day).



The number of days or percent of days the daily maximum, mean, and minimum gust factors were equal to or greater than a particular value.

FIG. 13

Gust factors were also resolved for the daily maximum 5-minute average windspeeds (Table 16).

Table 16. Five-minute GFs for daily maximum 5-minute average windspeeds, Longs Peak, RMNP.

Maximum	6.17
Mean	1.79
Minimum	1.10
Days With Data	61

The high value of 6.17 occurred with an average 5-minute windspeed of 12 mph (5.3 m/s) and a sudden gust to 74 mph (33 m/s). Although still impressive, the next highest GF was only 3.30.

Since GFs, as used in this study, indicate the peak gust over some average windspeed for a specified time, the true range of gustiness on Longs Peak may not always be apparent. Figure 14 reproduces an anemograph of continuous winds (calibrated in knots) for Longs Peak during a severe storm in January, and clearly shows the extreme range of gusts. At this chart speed, gusts range in minutes (or less) from 10-120 mph (5-54 m/s). Such traces represent enormous changes in the wind force at sensor height, and it becomes difficult to imagine the impact of standing on the summit of Longs Peak under a breeze one moment and a superhurricane the next.

2. Diurnal Tides

Table 17 shows the average hourly GFs at 6-hour intervals for Longs Peak and TR 3 during winter.

Table 17. Average hourly GFs at 6-hour intervals, Longs Peak (70 days) and TR 3 (29 days), RMNP.

Hour Ending	0100	0700	1300	1900
Longs Peak	2.16	2.23	2.08	1.96
TR 3	1.58	1.84	1.62	1.51

As defined by hourly GFs, data from both sites suggest that, on average, maximum turbulence occurs near sunrise and minimum turbulence after sunset. It is interesting to compare this to summer at TR 10, where the maximum and minimum turbulence were found to occur, on average, near mid-day and sunrise, respectively. Since the information is limited, however, further data collection is necessary.

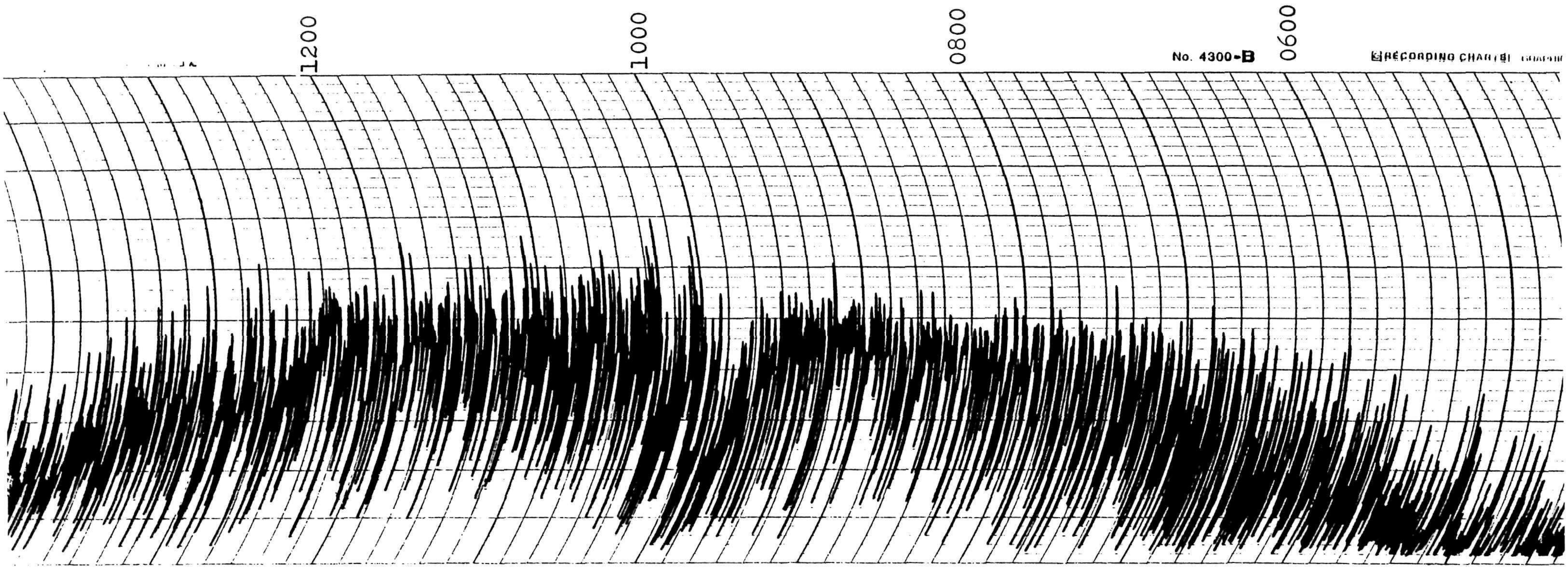


FIG. 14

Anemograph of severe winter storm on Longs Peak, January 24, 1981. Scale: 0-200 knots (uncorrected). Note the extreme range of turbulence.

APPENDIX A

WIND RESEARCH IN ROCKY MOUNTAIN NATIONAL PARK: SITE HISTORY AND INSTRUMENT EXPOSURE[1]

SITE[2]	INSTALLED	REMOVED	ELEVATION/SENSOR HEIGHT (M)	
TR 1	10/12/73	12/15/73	3,669	3.6
TR 2	10/21/73	5/10/74	3,365	4.3
TR 3	12/16/73	6/1/74	3,536	3.6
	6/6/80	9/23/80	3,536	3.6
TR 4	1/3/74	1/8/74	3,498	3.5
TR 5	1/18/74	5/4/74	3,469	4.3
TR 6	1/23/74	6/1/74	2,913	12.8
TR 7	12/25/73	6/2/74	2,377	12.2
TR 8	2/28/74	6/1/74	2,810	3.6
TR 10-01	6/2/80	8/28/80	3,602	9.0
TR 10-02	6/2/80	9/19/80	3,602	9.0
TR 11	6/6/80	9/18/80	3,658	6.0
LP 1	8/29/80	6/2/81	4,345	3.6

1. Does not include temporary field study sites, such as TR 9, 13, 14, and 15.
2. See Figure 1 for location of research sites. For information on sites for atmospheric pressure, temperature, and relative humidity, see Appendix B, Glidden, 1981.

APPENDIX B

WIND INSTRUMENTATION AND CALIBRATION

All wind sensors and meters were manufactured and calibrated by Maximum, Inc., Dover, Massachusetts.

Specifications:

Sensors:

- cup rotation versus true windspeed nearly linear; 100 mph (44.7 m/s) = 1,760 rpm.
- distance constant: 10 ft.
- error due to angle of attack above and below the plane of the cups is always positive, reaching a peak of 46° off level.
- dynamic response: acceleration from full stopped conditions to full speed rotation in steady 40 mph (18 m/s) wind is achieved in 0.45 second without overshoot.
- calibration tests: Maximum Labs, Wright Brothers wind tunnel, MIT; Air Force Cambridge Research Laboratory 200 mph (89 m/s) wind tunnel.

Meters

- meter movement: 300 microamps, full scale; meter resistance: 450 ohms.
- response rate: 180° / second; gust register response rate: 75% delta V / 5 seconds; overall system accuracy: ±3% full scale, 0-200 knots (103 m/s).

Recorders

- type: Esterline-Angus; ½ sec full scale response.

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