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SATELLITE & MESOMETEOROLOGY RESEARCH PROJECT

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ESTIMATE OF MAXIMUM WINDSPEEDS OF TORNADOES IN SOUTHERNMOST ROCKIES

by

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ESTIMATE OF MAXIMUM WINDSPEEDS OF TORNADOES IN SOUTHERNMOST ROCKIES

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Basic research on World-wide and U.S. tornadoes reported in this paper has been sponsored by the National Science Foundation under grant GI 30772. Research on New Mexico and southern Colorado tornadoes leading to the establishment of the design tornado at Los Alamos was supported by the University of California, Los Alamos Scientific Laboratory which is under contract with the U.S. Atomic Energy Commission.

SUMMARY AND CONCLUSIONS

Recent studies of tornadoes revealed that their maximum windspeeds in various parts of the world vary significantly. The latest statistics available to the author indicate that the United States is No. 1 in both tornado frequency and intensity followed by India, Canada, Europe, Australia, Japan, New Zealand, etc. An attempt was made to draw contour lines of the maximum tornado intensity on a World map (Page 4).

U.S. tornadoes show a very significant cut-off or reduction in their frequency and intensity from the Midwest to the Rockies, suggesting that a large gradient of the maximum tornado windspeed exists just to the west of the Midwestern Plains (Pages 7 and 8).

In order to determine the historical distribution of tornado frequency and intensity, all tornadoes occurring in a 22-year period, 1950-71 were plotted with F-scale intensity. As expected, both frequency and intensity diminish toward the mountains (Page 11).

New parameters called the "Mean Height" and the "Height Variation" were defined and computed for each of 15' squares of longitudes and latitudes. It was found that both tornado intensity and frequency decrease with the mean height as well as the height variation. This evidence permits us to establish a threshold for tornado intensity based on these two height parameters (Pages 28 and 29).

Further investigation of the longitudinal variation of tornado intensity was completed, together with mean height and height variation (Pages 30 and 31).

Meanwhile, meteorological characteristics of tornadoes were studied based on their annual and diurnal variations. Both variations suggest strongly that tornadoes in the mountains develop under typical meteorological conditions which give rise to the spawning of small, weak tornadoes (Pages 32 and 33).

Based on these evidences, tornado-hazard and safe areas within New Mexico and southern Colorado were established (Page 37).

Finally, the design tornado for Los Alamos was obtained and recommended to be

Maximum windspeed	200 mph
Rotational speed	170 mph
Translational speed	30 mph
Diameter of maximum rotational wind	100 ft
Maximum pressure drop at the center	0.75 psi
Maximum rate of pressure change	0.33 psi/sec.

In obtaining 200 mph, the maximum windspeed of the design tornado, a 50 mph wind was added to 150 mph, the uppermost windspeed of F 2 tornadoes which are very unlikely to occur at Los Alamos. A 200 mph windspeed including translation corresponds to F 3.9 (Pages 40 and 41).

1. INTRODUCTION

Tornadoes are accompanied by the most intense wind created by Mother Nature. It is true, however, that their intensities vary significantly from storm to storm, some of which may wipe out an entire community in open country while others may simply damage chimneys and TV antennae when a funnel cloud travels across a city. Each of these storms are to be listed as a tornado as long as the surface disturbances are confirmed beneath the path of a funnel cloud. These disturbances may be characterized by structural or tree damage or flying dust or debris in open country.

Despite the fact that most people do not realize that there are reports of tornadoes in New Zealand, Seelye (1945) attempted a pioneering work in classifying the intensities of New Zealand tornadoes using his arbitrary scale ranging from 0 to 5 units which indicates the intensities of tornadoes. They are

0 Funnel cloud and no surface phenomenon or very slight disturbance.

3 Outbuildings, verandas, and roofs carried away.

5 Well-constructed buildings demolished.

Based on these units Seelye computed the average intensity of 162 tornadoes during a 26-year period, 1919-44, obtaining the results in Table 1. It is evident that their

Table 1. Annual variation of New Zealand tornadoes in percent and their average intensity on the Seelye scale. Since the % frequencies tabulated hereunder indicate the nearest % values, their total for the year may not be 100.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% Frequency	7	10	10	9	10	10	4	10	8	9	4	7
Average Scale	1.8	1.4	1.3	1.8	2.4	1.9	2.2	2.5	1.9	1.9	1.5	1.8

frequency does not show a significant maximum; instead a flat maximum extends, more or less, from February to August which corresponds to late summer to mid-winter in the Southern Hemisphere. The average intensity exceeds 2.0 during May (November in Northern Hemisphere equivalent), July, and August, showing clearly that intense tornadoes in New Zealand are likely to occur in winter.

In Australia, however, the annual frequency of tornadoes shows a distinct maximum in early summer. According to Clarke (1962), the tornado frequency increases very

Table 2. Annual variation of Australian tornadoes in comparison with U.S. tornadoes. Frequencies in %, the total of which for the year may not be 100.

Months for U.S.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Whole U.S.	2	3	10	17	21	19	10	6	4	3	4	2
Whole Australia	5	3	5	8	17	17	16	8	5	5	5	6
Northern Aust.	8	5	6	8	12	11	13	8	6	7	7	10
Southern Aust.	1	1	4	8	23	25	21	9	4	3	1	0
Months for Aust.	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun

rapidly in November and decreases in January (see Table 2). This tendency of tornado frequency is very similar to that of the northern plains in the United States. Although Clarke does not use a tornado intensity scale to characterize Australian tornadoes, he made a frequency analysis of tornadoes based on 62 storms with published windspeeds (see Table 3). There was one report of 200 mph winds caused by the Brighton tornado of February 2, 1918 which severely damaged a bayside suburb of Melbourne.

Table 3. Frequency distribution of published windspeed in 62 Australian tornadoes. Windspeeds are in mph.

Speed Range	51-60	61-70	71-80	81-90	91-100	101-110	111-120	200
Frequency	13	18	13	2	12	0	3	1
in %	21	29	21	3	19	0	5	2

In order to cover the entire range of the speed of tornado wind, Fujita (1971) devised the Fujita scale (F scale) which connects the Beaufort Force 12 with the Mach Number 1.0 in 12 steps. As shown in Table 4, the upper limit of F5 scale is 318 mph which appears

Table 4. Fujita Scale windspeeds applicable to most tornadoes. F1.0 or 73 mph corresponds to the beginning of hurricane speed, F12.0 or 738 mph, the speed of sound at -3°C.

F scale	F 0	F 1	F 2	F 3	F 4	F 5
Speed range	40-72	73-112	113-157	158-206	207-260	261-318
Seelye scale	S 0	S 1 & 2	S 3 & 4	S 5		

to be fast enough to characterize most U.S. tornadoes. An attempt was also made to correspond the Seelye scale with the Fujita scale. When the F scale is applied to Australian tornadoes in Table 3 about 55% are likely to be F0, 38% F1, 5% F2 and 2% F3, suggesting that most tornadoes in Australia can be characterized by F0 through F3 scales.

World-wide distribution of tornadoes and their possible intensity have not been known very well due mainly to the fact that the tornado reporting system in each country varies significantly from practically non-existent to very systematic. Despite the difficulties in establishing geographic distribution of tornado intensities, the author attempted to construct a world map of tornadoes expressed in F-scale intensities. Figure 1 reveals that U.S. tornadoes rank at the top in both frequency and intensity. Western Canada shares in a small number of weak tornadoes, F3 or weaker in intensity.

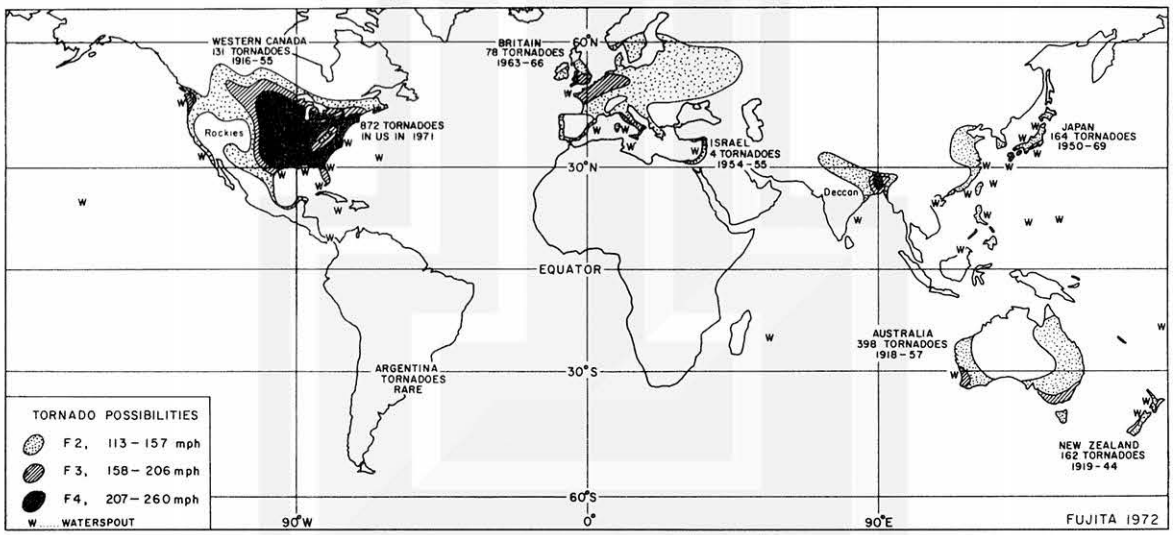

Fig. 1. World-wide distribution of tornadoes expressed in F-scale intensity. It is expected that the locations of waterspouts increase significantly. Map was produced by Fujita in January, 1972.

Unpublicized reports of tornadoes in India, such as that by Saha (1971) and others, imply that up to F 4 tornadoes are expected to occur in northern Bangladesh and western Assam where the jet of low-level moist air from the Bay of Bengal intersects westerly jet. Observed often in tornado situation is the dry westerlies crossing over the Deccan Plateau acting as the counterpart Rocky Mountains. The Indian tornado belt extends west-northeast over the Indo-Gangetic Valley to Punjab. One of the worst tornadoes of April 19, 1963 in northwest Assam killed 139 people and rendered 3760 families homeless, destroying 33 villages along a 23-mile path while traveling at the rate of 53 mph. These evidences suggest that Bangladesh to western Assam rank next to the United States in the possibility of intense tornadoes, being characterized by similar but weaker meteorological conditions often experienced in the United States.

A large area in Europe extending from the Atlantic Coast to European Russia often experiences tornadoes. Reports of tornadoes in Germany, France, Belgium, Netherlands, Britain, Russia, Austraia, Czechoslovakia, Hungary, Poland, Yugoslavia, Sweden, Switzerland, Italy, and Malta reveal that none of the European tornadoes are as intense as the strongest U. S. ones. The uppermost F 3 scale, or up to 206 mph maximum wind, would be sufficient to explain most tornado damage in Europe. It should be noted that F 3 tornadoes along the west coast of Italy are waterspouts which moved inland. Southern England experiences similar tornadoes originating from waterspouts.

In the Far East, Japanese records show a number of F 3 tornadoes along the coastal plains facing the Pacific Ocean. Japan is densely populated and has excellent historical records of natural disaster but there has been no evidence of F 4 or stronger tornadoes there.

The Southern Hemisphere counterpart of Japan would be New Zealand where the maximum intensity is likely to be F 3. A similar intensity can also be applied to most Australian tornadoes.

In the Near East, Israel experiences tornadoes along the narrow coastal region early in winter at the beginning of the rainy season. Some storms are regarded as waterspouts which moved inland.

The world-wide distribution of tornado characteristics introduced herein implies that the maximum tornado intensity is the function of the locations in various parts of the world. Not all tornadoes are produced under the unique meteorological conditions, but their causes differ rather widely. An attempt was made to list various causes of tornadoes, under the presumption that further investigation of world-wide tornadoes may improve the concept of these causes.

(Cause I) F 4 or stronger tornadoes are likely to be associated with tornado cyclones often observed as hook echoes or rotating thunderstorms. This type of thunderstorms develops where a jet of low-level moist air is topped by dry air which inhibits the growth of small clouds, thus encouraging the development of a few giant clouds. East of the U. S. Rockies and Deccan Plateau, India appear to be spawning areas of such storms.

(Cause II) Intense thunderstorms associated with active squall lines often produce funnel clouds at their low cloud base. F 3 or weaker tornadoes in U. S., Europe, Australia and other parts of the world spawn from these clouds which are often accompanied by hail.

(Cause III) Hurricanes and typhoons spawn F 3 or weaker tornadoes. They are usually limited to coastal regions such as the Gulf States and the Pacific coast of Japan.

(Cause IV) Cumulonimbus-induced waterspouts often become F 3 or weaker tornadoes upon landing. This type of waterspout occurs any time of the day. When the landing takes place at night or early in the morning, the storm's circulation often intensifies upon landing. Coastal tornadoes in Italy, Japan, Israel, New Zealand as well as the Pacific and the Gulf Coast of U. S. belong to this category.

(Cause V) Air-mass thunderstorms developing within an unstable moist air mass during the hours of effective surface heating produce funnel clouds and tornadoes with F 1 or weaker intensity. Air-mass thunderstorms develop in practically any part of the world, suggesting that F 1 or weaker tornadoes are likely to be observed anywhere if the tornado-reporting system such as that in U. S. were available all over the world.

(Cause VI) Cumulus-induced waterspouts spawn over warm tropical waters and also within cold air masses as it moves over relatively warm water surface. These waterspouts change into tornadoes upon their landing, but their intensity is usually F 1 or weaker.

The foregoing six causes of tornadoes are by no means the clear-cut causes responsible for producing tornadoes all over the world. They are subject to revision in the near or distant future when more accurate world-wide reports of tornadoes become available. Of extreme importance, nonetheless, is that the maximum intensities of tornadoes at various geographic locations are very closely related to local meteorological conditions giving rise to tornado development under various causes such as those described above.

2. INTENSITY OF U. S. TORNADOES

In early days tornado statistics were mostly based on the frequency obtained by counting each storm as a "one unit tornado" regardless of its path length, path width, intensity, etc. A major breakthrough beyond such a counting system was demonstrated by Thom (1963) who determined the frequency distributions of both path length and width of the Iowa and Kansas tornadoes. Thom's work, thus, suggested that the variation of tornado path area is so large that it would be necessary to assess tornado probability based on the average storm size which varies from state to state or even from location to location.

In an attempt to classify tornadoes based on their maximum windspeed, including both translational and rotational speeds, Fujita (1971) proposed the F-scale windspeed. After the scale had been worked out it was applied to tornadoes in three northwestern states -- Washington, Oregon, and Idaho -- during a 20-year period, 1950-69. Based on the estimated intensities of 63 tornadoes along with the associated hailswath, three areas of probable 175 mph (F3.3) and maximum 225 mph (F4.3) were established. They are the Pacific Coast Alley, Portland-Eugene Alley west of Cascades, and Caldwell Alley. For further details, refer to Fujita (1970).

During the entire year of 1971, F-scale assessments of tornado intensity were made by NOAA climatologists for the 48 states excluding Hawaii and Alaska. Fujita (1972) made an initial attempt to produce a map of 1971 tornadoes characterized by F-scale intensities. Presented in Fig. 2 is the distribution of 872 tornadoes in 1971. There are three distinct parallel belts of tornado occurrences oriented in SSW-NNE direction. The western-most belt extends from the New Mexico-Texas border to eastern North Dakota, the second belt from central Texas to northwestern Wisconsin, and the third belt from Louisiana to Lake Erie. There has been no evidence of large scale belts of tornado occurrences in past years, resulting in a suspicion that these belts as seen in only a one-year frequency might not be representative of tornado distribution. It is true, however, that these belts are not related closely to population density because 5 major midwestern cities are located outside the belts. These cities are: Chicago, St. Louis, Omaha, Kansas City and Oklahoma City.

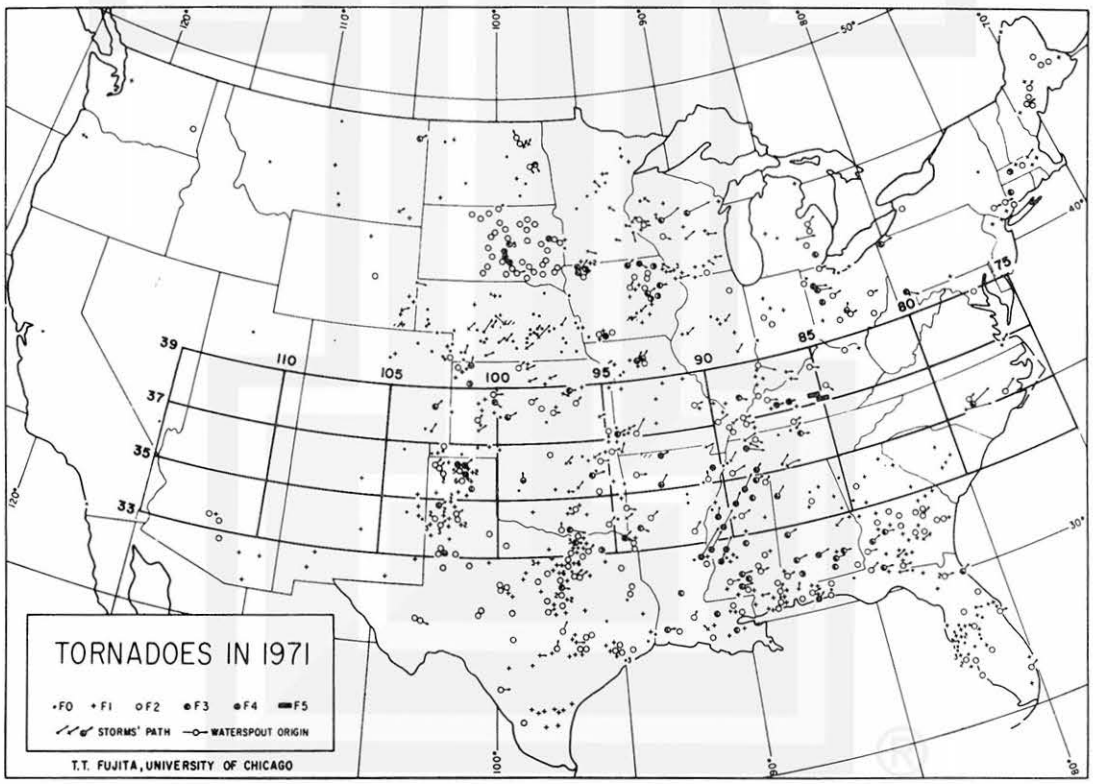

Fig. 2. Distribution of 1971 tornadoes expressed by F-scale intensities. Note that there are three belts of tornado frequency. By Fujita (1972).

For the purpose of obtaining the longitudinal variation of tornado frequency, three zonal areas between latitudes 33°, 35°, 37° and 39°, each with 2-deg. width, were established in Fig. 2. The northern zone includes 38° N ± 1° parallel; the central zone, 36°N ± 1°; and the southern zone, 34°N ± 1°. Then the counts of tornado frequencies within each parallel zone were completed as a function of longitude at one-degree intervals. The result presented in Fig. 3 reveals, as expected, three distinct peaks within each parallel zone. Note that the frequencies of F0, 1, and 2 tornadoes are stippled while those of F3, 4, and 5 are hatched.

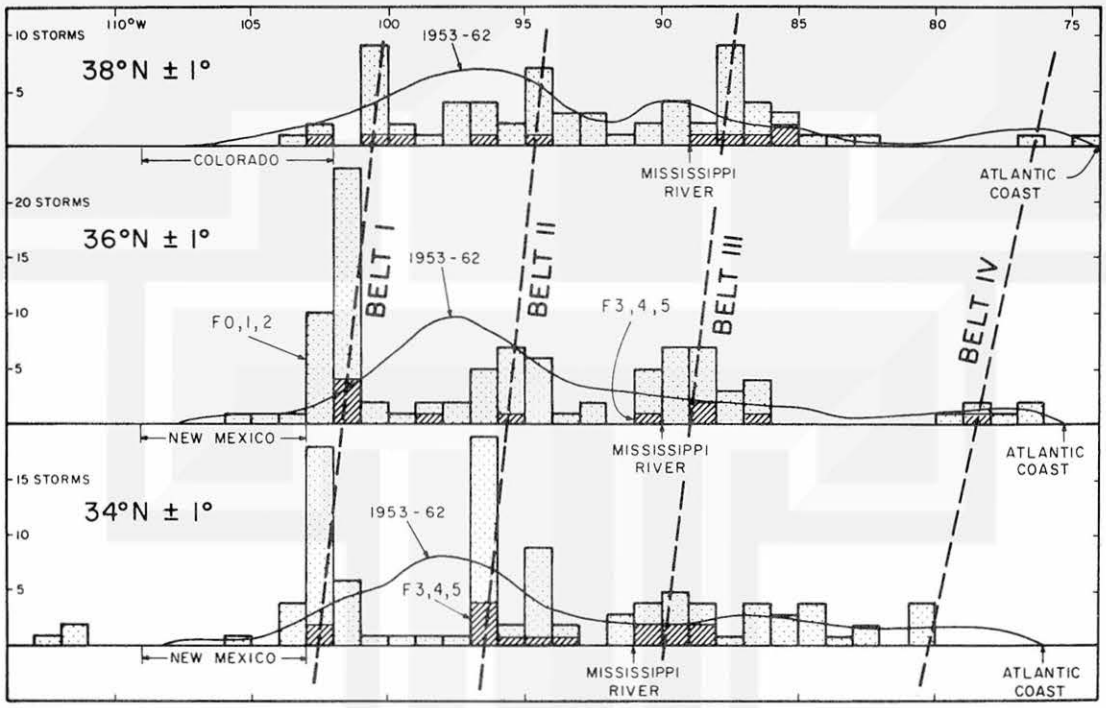

Fig. 3. Longitudinal distribution of 1971 tornadoes in three distinct belts. The fourth one along the Atlantic Coast is also identifiable.

A sharp cut-off of the tornado frequency just to the west of Belt I is very important. Within the southern zone, 34°N ± 1°, a significant drop in the frequency takes place upon entering New Mexico from Texas. There should be no suspicion of the difference in the reporting efficiency of tornadoes in New Mexico and Texas because the drop in frequency in the central zone, 36°N ± 1°, occurs within Texas, just about 1-deg. longitude east of the New Mexico border. A very similar drop is clearly seen within the northern zone, 38°N ± 1°, indicating positively that a sharp cut-off of the frequency west of Belt I is not artificial.

So far, the longitudinal variation of tornado frequencies has been discussed based on the 1971 data. The variation averaged over a much longer period fails to show the multiple tornado belts such as seen in the 1971 data. The mean annual frequency of the 1953-62 tornadoes from Thom's (1963) statistics was added to Fig. 3 for comparison purposes. Three curves in the figure do not show distinct maxima comparable to those of 1971, instead a distinct peak appears in all three zones between Belts I and II. The western cut-offs of tornado frequencies are not as sharp as in the 1971 case but they are clearly identifiable in all three parallel zones.

The need for dry air above the moist air from the south as ingredients for spawning intense tornadoes has been discussed in the previous chapter. First of all, we do not expect the unobstructed flow of moist air into high-elevation Rockies, and second, the westerly flow over the Rockies becomes drier when the air descends from the mountains as it travels eastward. Along the steep eastern slopes of the mountains, however, chinook effects practically prohibit violent convective activities. This is why a belt of maximum tornado frequencies is found 150 to 200 miles to the east of the Rockies.

The intensity distribution of 1971 tornadoes as assessed by the 48 NOAA climatologists revealed that there were only 97 tornadoes with intensities F 3 or stronger, which represent less than 12% of total frequency of 872. The breakdown of 1971 tornadoes into F scale intensity is presented in Table 5. For further information, refer to Fujita (1972). It is seen in the table that there were 152 F 0 tornadoes and that F 1 tornadoes were 42% of total frequency. This evidence leads to a conclusion that one-half of the 1971 tornadoes were accompanied by 100 mph or weaker wind. Only 2 tornadoes in 1971 were rated as F 5 tornadoes; both occurred in Kentucky on April 27.

Table 5. Frequency distribution of 872 tornadoes in 1971. The statistics are based on F-scale assessment by the 48 State Climatologists.

F Scale	F 0	F 1	F 2	F 3	F 4	F 5	Total
Frequency	152	367	256	72	23	2	872
in percent	18	42	29	8	3	0.2	

Since 1971 is the first year when the F-scale assessments of U.S. tornadoes were requested from the NOAA climatologists in the 48 states, it is not feasible to estimate the frequency of F 5 tornadoes in the United States each year. An educated guess of the frequency, based on 1971 statistics and the past years' storm data, would be only a few storms per year.

It may be concluded that the occurrences of F 5 or stronger tornadoes in the United States are rare, while both frequency and intensity of tornadoes decreases very rapidly toward the Rocky Mountains.

3. DISTRIBUTION OF TORNADOES AND POPULATION IN SOUTHERNMOST ROCKIES

It has been shown that the tornado frequency decreases sharply toward the Rocky Mountains, becoming extremely small to the west of the 105° W longitude. One might suspect that this is due mainly to the distribution of tornado-observing population decreasing westward.

Population distribution over New Mexico and southern Colorado is presented in Fig. 4. Cities and villages are plotted with three symbols designating the population of 500 or less, over 500, and over 10,000. This population map reveals, against expectation, that the density of communities in mountain areas is higher than that over the plains east of the Rockies. This does not mean that the tornado-observing efficiency is higher in mountain areas than over the plains. It is because rolling hills and forests are likely to obstruct distant views of tornadoes.

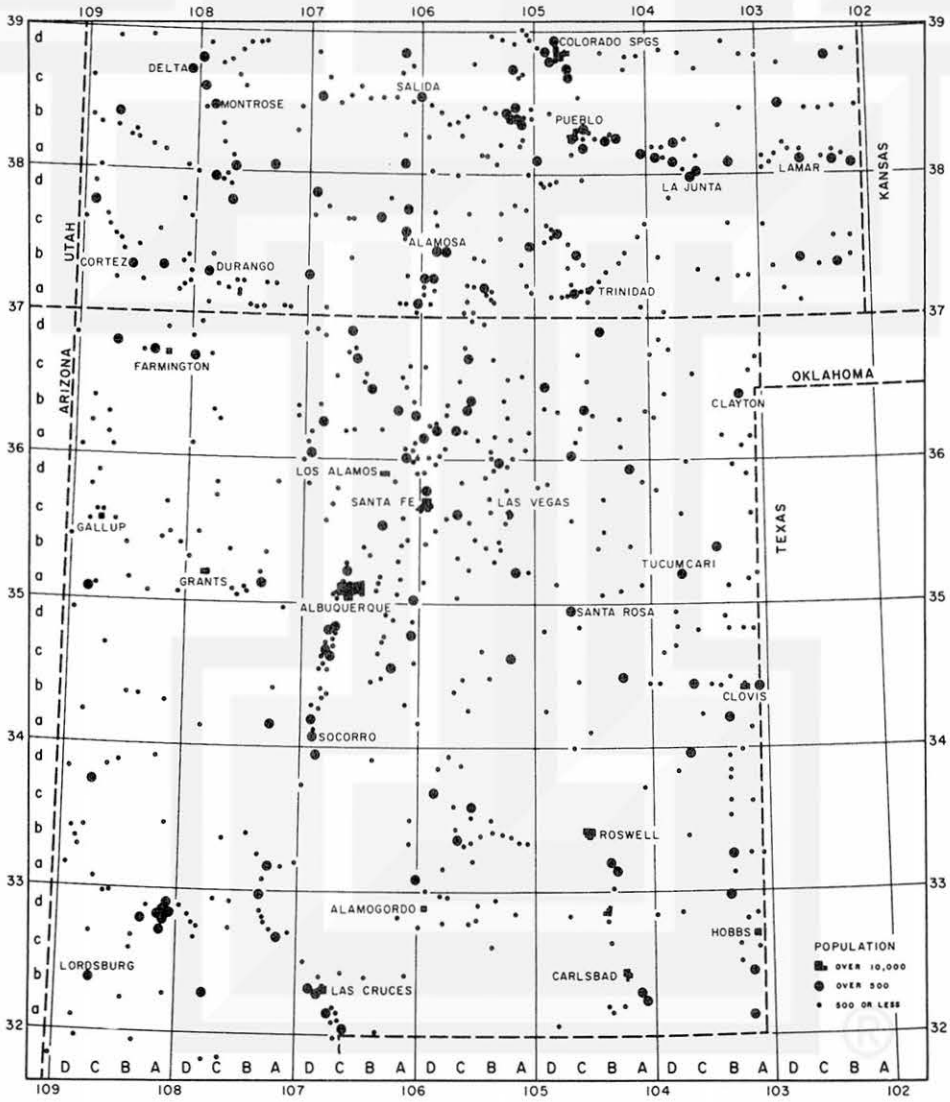

Fig. 4. Distribution of tornado-observing population in New Mexico and Southern Colorado. Based on 1970-71 highway maps.

Tornado distribution in the southernmost Rockies is plotted in Fig. 5. The map includes a total of 235 tornadoes reported during a 22-year period, 1950-71. The sources of tornado data are

1950-1958	Climatological Data, National Summary
1959-1971	Storm Data
1971	Reports from Colorado and New Mexico Climatologists.

Used in addition to the above is Herceg's (1971) work on "Intensity of Tornadoes in New Mexico, 1916-1970" which includes his F-scale assessments of all tornadoes during the 55-year statistical period.

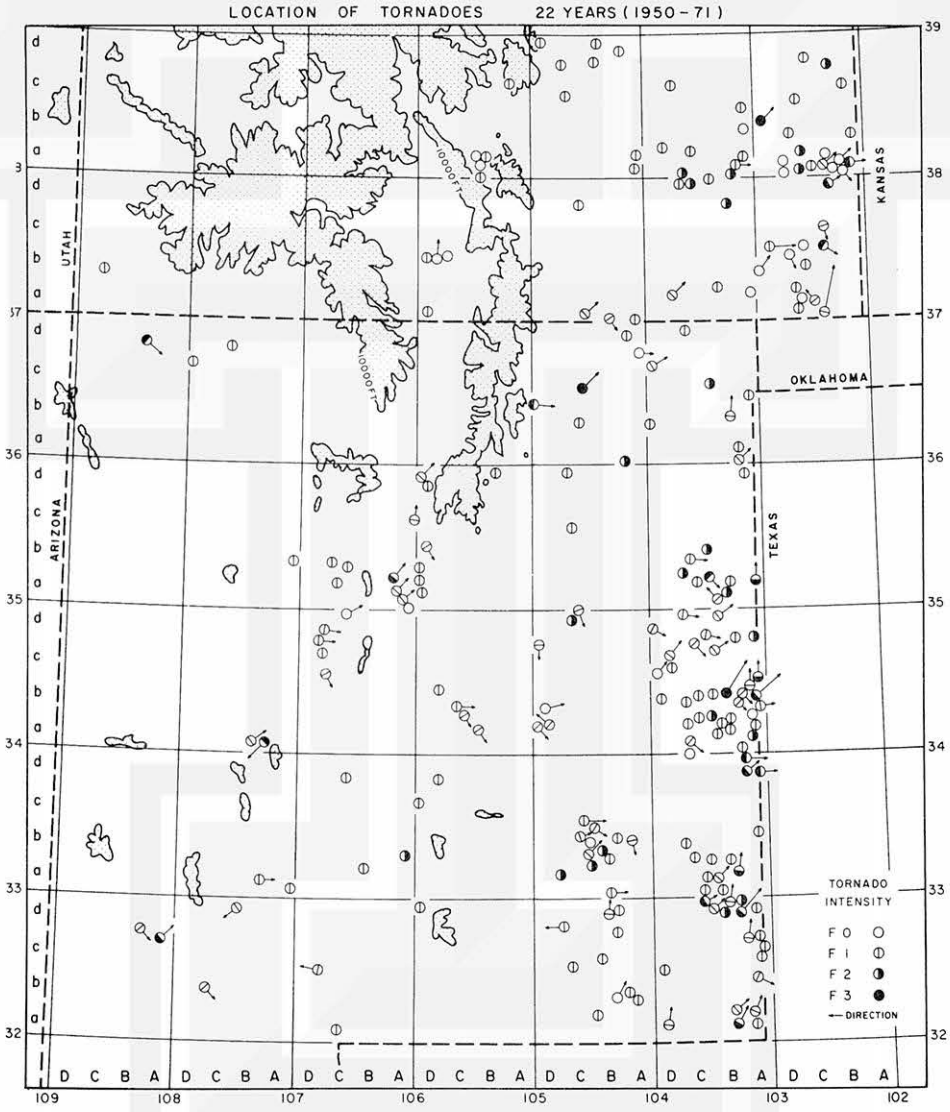

Fig. 5. Distribution of tornadoes in a 22-year period, 1950-71. A total of 235 tornadoes are included.

As shown in Fig. 5, there were 3 F 3 tornadoes to the east of 105° W longitude, while the maximum intensity of storms to the west of 105° W longitude was F 2. The breakdown of 235 tornadoes into F-scale intensities is presented in Table 6.

Table 6. F-scale distribution of 1950-71 tornadoes over southernmost Rockies including New Mexico and Colorado south of 39° N parallel.

F scale	F 0	F 1	F 2	F 3	Total
East of 105° W	19	123	36	3	181
West of 105° W	6	43	5	0	54
Entire area	25	166	41	3	235

This table reveals that the tornadoes to the east and to the west of 105° W are different both in frequency and in intensity. Namely, the former is characterized by the frequency distribution of midwestern tornadoes, while the latter by that of weak ones. The author examined all 54 tornadoes in Table 6 occurring to the west of 105° W longitude to learn that most storms are considerably weaker and smaller than those commonly observed in the midwestern plains. Listed hereunder are the digested descriptions of these tornadoes. The storm numbers are identical to those used in Tables 7 through 14 summarizing the 235 tornadoes in Table 6.

DESCRIPTION OF TORNADOES BETWEEN 108° AND 109° LONGITUDES

No. 32 F 2 tornado damage confined to 1/2 block in Farmington. Death occurred NW of city where oil rig blown over. May 10, 1957.

No. 45 F 2 tornado caused major damage at Silver City Airport. October 12, 1957.

No. 91 Small F 1 tornado (briefly on ground) damaged some outbuildings and broke down power line, June 15, 1961.

No. 182 F 1 tornado with fat, brown, dust and cone-shaped funnel hit house trailer, rising over Silver City. Railroad ties of porch lifted and dropped on trailer roof. June 15, 1967.

No. 220 Small F 1 tornado destroyed buildings and damaged fruit trees on a farm in McElmo Canyon 12 WSW Cortez. Observers reported seeing funnel cloud touched down. September 5, 1970.

DESCRIPTION OF TORNADOES BETWEEN 107° AND 108° LONGITUDES

No. 2 F 2 tornado accompanied by a plainly visible funnel unroofed several homes in Magdalena and damaged high school. Path length was 20 miles, width about 100 yards. August 2, 1950.

No. 47 F 1 tornado (5 minutes on ground) over open country 20 S Cabezon. October 20, 1957.

No. 49 F 0 tornado (remaining on ground for 10 minutes at one time) touched down 3 times over open country, SW of Truth or Consequences. May 16, 1958.

No. 75 F 1 tornado (for a short time) on ground over open country near Cutter. No damage reported. June 11, 1960.

No. 116 Small F 1 tornado snapped power line causing grass fire just N of Bloomfield. May 28, 1963.

No. 153 Small F 1 tornado pulled out a few fence posts in a pasture 11 SSW Magdalena. August 2, 1965.

No. 170 F 1 tornado moved down boat landing ramp, across Navajo Lake, and down San Juan River. Several boats capsized and damaged. Marina under construction damaged. August 30, 1966.

No. 232 F 1 tornado (touched down briefly) damaged homes and downed trees 8 S Deming. August 9, 1971.

No. 233 F 1 tornado twisted off electrical poles and lines 4 E Hillsboro. September 16, 1971.

DESCRIPTION OF TORNADOES BETWEEN 106° AND 107° LONGITUDE

No. 15 F 1 tornado over open range 25 SE Socorro. No damage reported. May 17, 1954.

No. 19 F 1 tornado mostly over open fields and orchards. Some damage to outbuildings 6 S Belen. July 31, 1954.

No. 25 F 1 tornado with 15 mile path moved over open country near Edgewood. May 25, 1956.

No. 30 F 2 tornado with 1/2-mile path unroofed home, damaged windmill and car at Cedar Grove. August 20, 1956.

No. 40 F 1 tornado in open country 20 SSW Albuquerque. May 31, 1957.

No. 46 F 1 tornado (only short time) over open country 8 NW Corrales. October 19, 1957.

No. 65 F1 tornado with 1 mile path over open country caused destruction of large highway sign at Bernalilllo. May 23, 1959.

No. 67 F2 tornado, 1/4-mile path wrecked farm buildings at Three Rivers. June 3, 1959.

No. 73 Small F1 tornado destroyed several sheds and two barns in a rural community near Berino. July 29, 1959.

No. 122 F1 tornado (about 2 minutes) on open range 1 S Dalies caused no damage. August 30, 1963.

No. 138 Small F0 tornado skipped around in the area followed by heavy rain. May 30, 1965.

No. 139 Small F1 tornado was spotted to the west of Alameda which destroyed a construction structure. May 31, 1965.

No. 157 F1 tornado touched down in open country 6 NW Moriarty, causing no damage. May 26, 1966.

No. 164 Brief F1 tornado, with loud roar, damaged barn, glass, trees, and electrical lines at Los Chaves. July 5, 1966.

No. 172 F1 tornado 15 N Las Cruces on Jornada range came down from cloud, producing cloud of dust on the ground. Storm split 3 16-ft. tall line poles, 6 to 8 inches in diameter, from top to bottom and damaged 3 others. Heavy rain in the area. September 26, 1966.

No. 206 F0 tornado 3 S Albuquerque sunport in uninhabited area, overturned ball washing machine at golf course. Funnel visible for few minutes. March 27, 1970.

No. 217 F1 tornado reported 38 NW Alamogordo but no damage reported. July 24, 1970.

No. 223 F1 tornado with estimated 50-75 mph wind moved into SW part of Santa Fe City. Funnel estimated 50 ft. wide, 100 ft. tall; lasting 15 min., was accompanied by roar. Damage to 12 homes mainly confined to roofs, fences, windows, carports, and outbuildings. April 15, 1971.

DESCRIPTION OF TORNADOES BETWEEN 105° AND 106° LONGITUDES

No. 7 F1 tornado with cyclonic surface wind occurred at Antonito. No funnel observed. June 17, 1953.

No. 11 F1 tornado destroyed 3 farm buildings at Westcliffe. Scattered debris over area of 1/4 square miles. February 13, 1954.

No. 23 F1 tornado damaged drive-in theater, several farm buildings, and trees in Alamosa. July 10, 1955.

No. 27 F 0 tornado broke limbs of trees and windows, damaging cars in eastern Alamosa. June 27, 1956.

No. 36 F 1 tornado in open country 20 S Santa Fe. May 30, 1957.

No. 37 F 1 tornado in open country 7 NW Corona. May 30, 1957.

No. 38 F 1 tornado in open country 8 SE Corona. May 30, 1957.

No. 50 Small F 1 tornado over open country west of Carrizozo. No damage reported. June 17, 1958.

No. 53 F 0 tornado touched ground for 7 min. 2 NW Alamosa. July 18, 1958.

No. 58 F 1 tornado moved over open country. Thought to have touched ground for few minutes. October 13, 1958.

No. 63 F 1 tornado touched ground over open country. Two small funnels were sighted. May 9, 1959.

No. 64 Small F 1 tornado on ground about 10 min. over open country and no damage reported. May 15, 1959.

No. 66 Small F 1 tornado destroyed a trailer house and damaged residence 6 N Alamogordo. June 3, 1959.

No. 70 F 1 tornado mostly over open country destroyed fences, power lines, two windmills, and many trees. July 11, 1959.

No. 77 Small F 1 tornado accompanied by a funnel for 30 min. in an area 9 S Westcliffe lifted up a power saw and dropped on a new gate demolishing it. Fences were damaged by flying lumber and a 3-ft. culvert destroyed. Part of the roof torn from the house and boards blown through the windows. July 4, 1960.

No. 80 Small F 1 tornado observed NW of Stanley was on ground only a few minutes over open country. No damage reported. September 30, 1960.

No. 94 Small F 1 tornado over open country was on ground about 2 min. No damage reported. August 16, 1961.

No. 147 F 1 tornado 2 SE Mora damaged small outbuildings and machinery. June 17, 1965.

No. 152 F 0 tornado touched down 3 to 5 S Westcliffe. No damage reported. July 24, 1965.

No. 166 F 0 tornado was observed to touch ground just west of Westcliffe. No damage reported. August 2, 1966.

No. 173 F 1 tornado unroofed a few buildings in Pojoaque. A cinder-block building exploded and a semitrailer truck tipped over by strong wind which lasted about 5 min. Blowing sand and rocks damaged car. Thunder and hail accompanied strong SW wind. December 26, 1966.

No. 191 Small F1 tornado caused minor damage to roofs and buildings in Victor. July 3, 1968.

No. 234 F1 tornado caused minor damage to 2 ranch homes near Coyote, 13 N Carrizozo. Tornado touched down twice producing estimated 80 mph wind. September 17, 1971.

The above listed tornadoes are the ones which occurred to the west of 105° W longitude. As shown in Table 6, 181 tornadoes were reported to the east of this longitude, necessitating the investigation of these tornadoes in order to clarify the nature of tornadoes in the southernmost Rockies in general.

After the examination of all tornadoes during a 22-year period, 1950-71, the characteristics of 235 tornadoes were tabulated in Tables 7 through 17. These tables include:

* Storm Number -- Identification of tornadoes chronologically numbered.
* State -- New Mexico (NM) and Colorado (CO).
* Date -- Month/Date/Year.
* Time -- Local Standard Time of tornado occurrence. AM denotes morning; PM, afternoon; DAY, daytime; EVE, evening; NITE, night; and xxxx, unknown.
* F P P -- Fujita-scale intensity, Pearson-scale path length and path width. F0 (less than 73 mph), F1 (73-112), F2 (113-157), F3 (158-206), F4 (207-260), F5 (261-318); Path length: P0 (less than 1.0 mile), P1 (1.0-3.1), P2 (3.2-9.9), P3 (10-31), P4 (32-99), P5 (100 or longer); Path width: P0 (less than 20 yd), P1 (20-50), P2 (60-170), P3 (180-550), P4 (560-1750), P5 (1.0 mi or wider).
* K/I -- Killed and injured.
* Dir -- Direction toward which the storm traveled.
* Long -- Longitude, A (00'-15'), B (15'-30'), C (30'-45'), D (45'-60').
* Lat -- Latitude, a (00'-15'), b (15'-20'), c (30'-45'), d (45'-60').
* $\bar{H}$ -- Mean height (in ft) of 15' long-lat square in which a specific tornado occurred.
* ΔH -- Height variation (in ft) of 15' long-lat square in which a specific tornado occurred.

Table 7. List of 1950-71 Tornadoes in Southernmost Rockies

No.	State	Date	Time	F P P	K/I	Dir	Long	Lat	$\bar{H}$	ΔH
1	NM	7/11/50	1600	1,3,3	0/0	NE	103B	34d	4500	800
2	NM	8/02/50	1130	2,3,2	0/0	SW	107B	34a	7500	1900
3	NM	6/05/51	1430	1,1,x	0/0	E	104B	33a	3500	400
4	CO	6/14/51	EVE	1,x,x	0/0	--	104A	38d	6200	1200
5	CO	6/18/51	1700	1,3,x	0/0	--	103C	38a	4200	300
6	NM	8/10/51	1430	1,3,1	0/0	ENE	103D	36c	6900	3500
7	CO	6/17/53	1300	1,1,4	0/0	--	105D	37a	8400	2000
8	CO	8/16/53	1700	1,x,x	0/0	--	104A	38a	4500	400
9	CO	10/20/53	1020	1,1,3	0/0	NE	103D	38a	4400	500
10	CO	10/20/53	1045	1,3,4	0/0	NE	104A	38a	4500	400
11	CO	2/13/54	0743	1,0,0	0/0	NE	105B	38a	9000	3200
12	NM	5/16/54	1400	2,0,2	0/0	ENE	103C	32d	4000	600
13	NM	5/16/54	1630	1,x,x	0/0	NNE	103A	32a	3100	400
14	CO	5/16/54	1700	1,x,x	0/0	--	104A	36d	7200	2000
15	NM	5/17/54	1500	1,x,x	0/0	--	106C	33d	5400	1200
16	NM	5/17/54	1900	2,x,x	0/0	--	103B	32d	3800	300
17	NM	5/17/54	2000	1,2,1	0/0	ENE	103B	32a	3200	700
18	NM	6/29/54	1330	1,2,3	0/0	NE	103A	36a	4600	500
19	NM	7/31/54	1730	1,2,3	0/0	SE	106D	34c	5100	600
20	NM	8/24/54	2000	0,x,x	0/0	--	103C	34a	4300	400
21	NM	5/18/55	1235	1,0,1	0/0	NE	103C	34b	4300	400
22	CO	6/19/55	1730	0,x,x	0/0	E	102C	37a	4300	500
23	CO	7/10/55	1600	1,x,x	0/0	SE	105D	37b	7800	700
24	CO	7/31/55	xxxx	1,0,2	0/0	--	103A	38a	4700	600
25	NM	5/25/56	1045	1,3,1	0/0	NE	106A	35a	7200	1900
26	NM	5/29/56	EVE	1,x,x	0/0	--	103C	33a	4200	300
27	CO	6/25/56	xxxx	0,x,0	0/0	--	105D	37b	7800	700
28	NM	7/08/56	1630	1,1,1	0/0	S	104D	34d	5200	1200
29	CO	7/19/56	1600	2,x,0	0/0	--	103A	38a	4100	400

Table 8. List of 1950-71 Tornadoes in Southernmost Rockies

No.	State	Date	Time	F P P	K/I	Dir	Long	Lat	$\bar{H}$	ΔH
30	NM	8/20/56	1230	2,0,1	0/0	NE	106A	35a	7200	1900
31	NM	4/21/57	1500	2,0,1	0/0	E	103A	33d	4100	400
32	NM	5/10/57	1820	2,x,x	1/0	SE	108B	36d	6000	2100
33	NM	5/24/57	0400	3,4,1	0/0	NE	103B	34b	4300	400
34	CO	5/24/57	PM	2,x,x	0/0	--	103C	38a	4200	300
35	NM	5/27/57	1730	1,x,x	0/0	E	103C	34d	4700	1100
36	NM	5/30/57	1220	1,x,x	0/0	SE	105D	35b	6700	1600
37	NM	5/30/57	1345	1,x,x	0/0	SE	105C	34b	6800	1400
38	NM	5/30/57	1400	1,x,x	0/0	SE	105B	34a	6200	1300
39	NM	5/30/57	1639	1,x,x	0/0	ESE	103A	32b	3400	400
40	NM	5/31/57	1415	1,x,x	0/0	E	106D	34d	5400	1000
41	CO	6/11/57	PM	1,x,x	0/0	E	103A	38a	4100	400
42	CO	6/22/57	PM	1,x,x	0/0	--	102C	37a	4300	500
43	CO	6/30/57	PM	1,x,x	0/0	--	102C	38d	4400	500
44	CO	6/30/57	PM	1,x,x	0/0	--	102A	38c	4000	300
45	NM	10/12/57	0400	2,2,1	0/0	ENE	108A	32c	5900	2300
46	NM	10/19/57	1530	1,x,x	0/0	--	106C	35b	5600	1300
47	NM	10/20/57	1330	1,x,x	0/0	--	107A	35b	6700	2600
48	NM	5/13/58	1835	1,x,x	0/0	NE	103B	34c	4400	500
49	NM	5/16/58	1400	1,0,4	0/0	E	107B	33a	5000	1400
50	NM	6/17/58	1410	1,x,x	0/0	--	105D	33c	6900	3800
51	NM	6/21/58	1733	1,x,x	0/0	--	104B	32d	3400	300
52	CO	7/08/58	1638	1,x,x	0/0	--	102C	38c	4200	600
53	CO	7/18/58	1115	0,x,x	0/0	N	105D	37b	7800	700
54	CO	7/20/58	1630	2,x,x	0/5	--	102B	38d	4300	400
55	CO	7/21/58	EVE	1,x,x	0/0	--	104C	37d	5600	1200
56	CO	7/22/58	xxxx	1,1,x	0/0	S	102B	37c	4100	500
57	NM	9/09/58	1640	1,x,x	0/0	SSE	104C	34d	4700	700
58	NM	10/13/58	1245	1,x,x	0/0	E	105C	34b	6800	1400
59	NM	4/07/59	1430	1,0,0	0/0	--	103A	32c	3600	200

Table 9. List of 1950-71 Tornadoes in Southernmost Rockies

No.	State	Date	Time	F P P	K/I	Dir	Long	Lat	$\bar{H}$	ΔH
60	NM	5/07/59	EVE	1,x,x	0/0	--	104A	32b	3200	400
61	NM	5/08/59	1100	2,x,x	0/0	--	104C	34d	4700	700
62	NM	5/08/59	1415	2,2,2	0/0	--	103A	34a	3900	300
63	NM	5/09/59	PM	1,x,x	0/0	--	105D	35a	6600	900
64	NM	5/15/59	1245	1,x,x	0/0	--	105D	35d	9100	6600
65	NM	5/23/59	1638	1,1,1	0/0	--	106C	35b	5600	1300
66	NM	6/03/59	1550	1,x,x	0/0	--	105D	32d	6900	5600
67	NM	6/03/59	1600	2,0,0	0/0	--	106A	33b	5200	2100
68	NM	6/22/59	1700	2,x,x	0/0	--	103A	34d	4300	700
69	NM	7/08/59	1700	1,x,x	0/0	--	103B	34a	4000	300
70	NM	7/11/59	1645	1,x,x	0/0	--	105D	34b	7400	2400
71	NM	7/11/59	PM	1,x,x	0/0	--	104C	32c	4000	1000
72	NM	7/14/59	PM	1,x,x	0/0	--	103C	35a	4400	1100
73	NM	7/29/59	2200	1,x,x	0/0	--	106C	32a	5300	3100
74	NM	4/26/60	1400	1,0,0	0/0	--	103A	32c	3600	200
75	NM	6/11/60	1400	1,x,x	0/0	--	107A	33a	5400	2200
76	NM	6/25/60	1800	2,1,1	0/34	E	104D	36b	7400	2900
77	CO	7/04/60	PM	1,x,x	0/0	--	105B	38a	9000	3200
78	NM	7/20/60	1120	1,x,x	0/0	--	103C	34b	4300	400
79	NM	7/24/60	1400	2,x,x	0/0	--	103B	32d	3800	300
80	NM	9/30/60	1630	1,x,x	0/0	--	105D	35a	6600	900
81	CO	5/13/61	1330	2,2,1	0/0	--	102C	38a	3800	500
82	NM	5/23/61	1830	1,0,0	0/0	NW	103C	34d	4700	1100
83	NM	5/30/61	2000	2,1,0	0/0	SW	103B	32d	3800	300
84	CO	6/02/61	1600	1,x,x	0/0	--	102B	38a	3600	300
85	NM	6/03/61	1630	2,1,1	0/1	NW	103C	35a	4400	1100
86	NM	6/05/61	1330	1,2,1	0/0	--	103C	36d	5800	1600
87	NM	6/06/61	1530	1,1,2	0/0	NW	103C	34a	4300	400
88	NM	6/07/61	1445	1,x,x	0/0	--	103D	36b	6100	1000
89	NM	6/07/61	PM	1,x,x	0/0	--	103A	32d	3700	200

Table 10. List of 1950-71 Tornadoes in Southernmost Rockies

No.	State	Date	Time	F P P	K/I	Dir	Long	Lat	$\bar{H}$	ΔH
90	NM	6/14/61	1730	2,x,x	0/2	--	104C	33b	3900	700
91	NM	6/15/61	1900	1,x,x	0/0	NNW	108D	31d	4900	1700
92	NM	7/02/61	1500	1,x,x	0/0	--	104B	32d	3400	300
93	CO	7/14/61	1615	1,2,x	0/0	NE	103C	37a	6000	1700
94	NM	8/16/61	1230	1,x,x	0/0	--	105D	35b	6700	1600
95	NM	5/16/62	1000	0,x,0	0/0	ENE	104D	34b	5200	800
96	NM	5/16/62	PM	1,x,x	0/0	--	103D	34b	4400	400
97	CO	5/17/62	1430	1,3,1	0/0	N	102B	37a	3900	500
98	NM	5/17/62	1530	2,3,x	0/0	--	103B	36c	5600	1200
99	NM	5/17/62	1730	2,2,x	0/1	--	104A	36a	5900	700
100	CO	5/28/62	PM	1,x,x	0/0	--	103C	37d	4400	700
101	CO	6/03/62	1530	1,x,x	0/0	--	104D	38d	8900	6500
102	CO	6/04/62	xxxx	2,x,x	0/0	--	103C	37d	4400	700
103	NM	6/09/62	PM	1,x,x	0/0	N	103D	32a	3200	700
104	CO	6/12/62	1328	1,x,x	0/0	SE	104B	37a	7600	3700
105	CO	6/12/62	1544	1,x,x	0/0	--	104A	37a	6900	3400
106	NM	6/12/62	PM	2,0,0	0/0	--	104B	33b	3700	400
107	CO	6/15/62	1545	0,x,x	0/0	NE	102A	38a	3500	500
108	CO	6/15/62	1545	0,x,x	0/0	SE	102A	38a	3500	500
109	CO	6/22/62	1445	1,3,x	0/0	E	102D	37c	4500	600
110	CO	6/22/62	1610	0,x,x	0/0	--	102B	38a	3600	300
111	CO	6/29/62	1530	2,x,x	0/0	--	103A	37d	4100	500
112	NM	7/11/62	PM	2,x,x	0/0	--	104D	33a	4600	1200
113	CO	7/18/62	1530	1,x,x	0/0	--	104B	38d	6300	1300
114	NM	7/27/62	1657	1,x,x	0/0	N	103A	32c	3600	200
115	NM	10/27/62	1430	1,0,0	0/0	--	104A	32b	3200	400
116	NM	5/28/63	PM	1,0,0	0/0	--	107D	36c	6300	1600
117	NM	5/30/63	PM	1,x,0	0/0	W	104D	32d	4500	1100
118	NM	6/08/63	DAY	1,0,0	0/0	--	103A	32c	3600	200
119	NM	6/19/63	1840	1,0,0	0/1	SSE	104A	33b	3700	300

Table 11. List of 1950-71 Tornadoes in Southernmost Rockies

No.	State	Date	Time	F P P	K/I	Dir	Long	Lat	$\bar{H}$	ΔH
120	NM	7/11/63	PM	1,x,x	0/0	--	103A	34a	3900	300
121	NM	7/12/63	1500	2,0,0	0/0	--	103C	35a	4400	1100
122	NM	8/30/63	1114	1,0,0	0/0	E	106D	34d	5400	1000
123	NM	8/31/63	1815	1,0,0	0/0	N	103B	32d	3800	300
124	NM	5/18/64	1515	1,0,0	0/0	SE	104D	34a	4900	600
125	NM	5/29/64	1203	3,2,0	1/8	NE	104C	36c	6800	1800
126	NM	6/10/64	1630	1,0,0	0/1	SE	103A	34b	4200	400
127	NM	6/10/64	1800	1,0,0	0/0	NW	104D	34a	4900	600
128	NM	6/10/64	NITE	2,x,x	0/0	--	103B	35a	4200	900
129	NM	6/11/64	1630	2,3,1	0/0	NE	103A	34b	4200	400
130	NM	6/11/64	1720	2,x,x	0/0	N	103A	35a	4100	800
131	NM	6/12/64	PM	2,3,1	0/0	N	103A	34c	4300	400
132	NM	6/13/64	PM	1,x,x	0/0	--	103B	34a	4000	300
133	NM	9/21/64	1745	1,0,0	0/0	ENE	104C	33b	3900	700
134	CO	3/16/65	1304	0,x,x	0/0	--	102C	38a	3800	500
135	NM	4/04/65	1145	1,0,0	0/0	N	104B	32d	3400	300
136	CO	5/23/65	PM	1,2,x	0/0	--	103C	38c	4900	800
137	CO	5/23/65	NITE	1,x,x	0/0	--	103B	37a	5600	1900
138	NM	5/30/65	1000	0,x,x	0/0	--	106A	35a	7200	1900
139	NM	5/31/65	1845	1,0,0	0/0	--	106C	35a	6200	1500
140	NM	6/03/65	1605	1,0,0	0/0	--	103A	36a	4600	500
141	NM	6/10/65	1715	1,0,0	0/3	NE	104C	33b	3900	700
142	NM	6/10/65	EVE	0,0,0	0/0	--	104C	33b	3900	700
143	CO	6/14/65	1924	1,x,x	0/1	--	104C	38d	6600	1800
144	NM	6/15/65	PM	1,1,1	0/0	--	103C	34d	4700	1100
145	NM	6/15/65	NITE	2,0,0	0/0	NE	103A	33d	4100	400
146	CO	6/16/65	1800	1,x,x	0/0	NE	104C	37a	6800	1600
147	NM	6/17/65	1630	1,0,2	0/0	--	105B	35d	9400	4800
148	CO	6/17/65	PM	1,x,x	0/0	--	104C	38c	5400	700
149	NM	6/25/65	1240	1,0,0	0/0	E	104C	33b	3900	700

Table 12. List of 1950-71 Tornadoes in Southernmost Rockies

No.	State	Date	Time	F P P	K/I	Dir	Long	Lat	$\bar{H}$	ΔH
150	NM	6/25/65	PM	1,x,x	0/0	E	103C	35b	4300	1100
151	MN	6/25/65	1710	2,3,0	0/0	E	103A	33d	4100	400
152	CO	7/24/65	1350	0,x,x	0/0	--	105B	38a	9000	3200
153	NM	8/02/65	1300	1,0,0	0/0	NE	107B	34a	7500	1900
154	CO	9/08/65	1351	0,x,x	0/0	--	103A	38b	4400	400
155	NM	9/18/65	1800	1,2,2	0/0	N	103B	36b	5200	700
156	NM	5/10/66	1530	1,1,0	0/0	--	103A	32a	3100	400
157	NM	5/26/66	1418	1,0,0	0/0	NE	106A	35a	7200	1900
158	NM	5/26/66	1755	1,0,0	0/0	--	103C	34a	4300	400
159	NM	5/26/66	1900	1,0,0	0/0	--	103B	33b	4000	300
160	NM	5/26/66	2000	1,0,0	0/0	--	103C	33b	4300	200
161	NM	6/18/66	1430	1,0,0	0/0	--	104C	35c	5900	1200
162	NM	6/18/66	1700	1,0,0	0/0	SE	103D	34d	4700	1100
163	NM	6/18/66	NITE	2,0,0	0/0	--	103B	34b	4300	400
164	NM	7/05/66	1830	1,0,0	0/0	--	106D	34c	5100	600
165	CO	7/18/66	1800	1,x,x	0/0	--	103B	37d	4300	400
166	CO	8/02/66	1515	0,x,x	0/0	--	105B	38a	9000	3200
167	NM	8/07/66	1800	1,0,0	0/0		103C	33b	4300	200
168	CO	8/09/66	1700	1,x,x	0/0	--	102C	37a	4300	500
169	NM	8/22/66	1615	0,0,0	0/0	NE	104B	32b	3700	1000
170	NM	8/30/66	PM	1,1,0	0/0	--	107C	36d	6400	1500
171	NM	8/31/66	1500	1,0,0	0/0	--	104B	33b	3700	400
172	NM	9/07/66	1410	1,0,0	0/0	WNW	106D	32c	4800	1700
173	NM	12/26/66	1740	1,0,0	0/0	NE	105D	35d	9100	6600
174	NM	3/23/67	1600	1,0,0	0/0	N	103A	34b	4200	400
175	CO	5/28/67	1620	1,x,x	0/0	--	104B	38d	6300	1300
176	CO	5/29/67	1730	1,x,x	0/0	--	102A	38b	3900	300
177	CO	5/30/67	1740	0,x,x	0/0	--	102C	38a	3800	500
178	NM	6/04/67	1600	1,1,0	0/0	SE	104C	33b	3900	700
179	CO	6/10/67	1615	2,3,3	0/4	SE	102B	37c	4100	400

Table 13. List of 1950-71 Tornadoes in Southernmost Rockies

No.	State	Date	Time	F P P	K/I	Dir	Long	Lat	$\bar{H}$	ΔH
180	CO	6/11/67	1330	1,x,x	0/0	--	102A	37d	3600	400
181	NM	6/14/67	1840	1,0,0	0/0	--	103A	34a	3900	300
182	NM	6/15/67	1320	1,0,0	0/0	SE	108B	32d	7200	2800
183	NM	6/28/67	PM	1,0,0	0/0	--	103B	34a	4000	300
184	NM	7/03/67	1430	1,0,0	0/0	--	103A	36b	4900	600
185	CO	7/04/67	1538	1,x,x	0/0	--	102D	38b	4100	500
186	CO	7/04/67	1645	0,x,x	0/0	--	102B	38a	3600	300
187	NM	5/10/68	PM	1,x,x	0/0	--	103B	33a	4000	200
188	NM	6/18/68	1945	2,0,1	0/3	--	103B	35b	4000	600
189	CO	6/24/68	1800	2,1,2	0/0	NE	102B	37d	3900	600
190	CO	6/24/68	1815	2,x,x	0/0	NE	102A	38a	3500	500
191	CO	7/03/68	1345	1,x,0	0/0	--	105A	38c	8400	5800
192	CO	7/11/68	1500	1,x,x	0/0	NW	102C	37a	4300	500
193	NM	4/10/69	1935	2,x,x	0/2	NE	103B	32a	3200	700
194	NM	4/16/69	1215	1,0,1	0/0	SE	103A	34b	4200	400
195	NM	5/04/69	0000	1,0,0	0/0	--	103D	34c	4600	600
196	NM	5/05/69	1800	1,2,4	0/0	--	103B	34a	4000	300
197	NM	5/05/69	1900	1,0,0	0/0	--	103B	34b	4300	400
198	NM	5/06/69	1315	1,0,0	0/0	--	103C	34b	4300	400
199	NM	5/16/69	1100	1,0,0	0/0	--	104C	36b	6300	1000
200	CO	5/31/69	1615	1,0,0	0/0	--	102C	37b	4400	400
201	NM	6/03/69	NITE	1,0,0	0/0	--	103A	35d	4500	600
202	NM	6/08/69	1330	1,x,x	0/0	--	104C	35d	6200	1900
203	NM	6/13/69	PM	1,x,x	0/1	--	104B	32c	3600	800
204	CO	7/14/69	1440	1,x,x	0/0	NE	102B	38a	3600	300
205	CO	7/15/69	1730	2,0,0	0/0	--	102C	38a	3800	500
206	NM	3/27/70	1036	0,0,0	0/0	NE	106C	34d	5200	700
207	NM	3/30/70	1650	1,0,0	0/0	--	103B	35a	4200	900
208	NM	4/17/70	1730	1,2,0	0/0	NE	103B	33a	4000	200
209	NM	4/17/70	1900	2,x,x	0/0	N	103B	33a	4000	200

Table 14. List of 1950-71 Tornadoes in Southernmost Rockies

No.	State	Date	Time	F P P	K/I	Dir	Long	Lat	$\bar{H}$	ΔH
210	NM	4/17/70	EVE	1,4,1	0/0	NE	103D	34c	4600	600
211	NM	4/18/70	1500	1,0,0	0/0	--	103A	33b	3900	200
212	NM	5/25/70	0945	1,0,0	0/0	--	103C	33b	4300	200
213	NM	5/25/70	1040	1,0,0	0/0	--	104B	33b	3700	400
214	NM	5/27/70	1230	1,0,0	0/0	--	103C	33a	4200	300
215	NM	5/27/70	PM	1,0,0	0/0	NE	103D	32b	3300	600
216	CO	6/19/70	0020	1,x,x	0/0	--	102C	38b	3900	500
217	NM	7/24/70	2100	1,x,x	0/0	--	106B	33a	4000	300
218	CO	7/31/70	1407	0,x,x	0/0	--	102C	37c	4400	400
219	CO	8/12/70	1944	0,x,x	0/0	SE	102C	37b	4400	400
220	CO	9/05/70	1730	1,1,2	0/0	--	108D	37b	7400	5000
221	CO	2/18/71	1232	0,x,x	0/0	--	103A	37a	4800	1600
222	NM	3/05/71	0900	0,0,0	0/0	NE	103D	34c	4600	600
223	NM	4/15/71	1400	1,1,0	0/0	N	106A	35c	6400	2000
224	NM	4/15/71	1445	1,0,0	0/0	--	104B	32a	3900	1500
225	NM	4/15/71	1730	1,1,0	0/0	E	103A	34b	4200	400
226	NM	4/18/71	2030	1,0,0	0/0	NW	103B	35a	4200	900
227	CO	4/18/71	NITE	0,3,0	0/0	N	102D	37b	4800	600
228	NM	6/11/71	1600	1,0,0	0/0	--	103B	34d	4500	800
229	NM	6/11/71	PM	0,0,0	0/0	--	103A	34b	4200	400
230	NM	6/14/71	PM	1,0,0	0/0	NE	103B	32d	3800	300
231	NM	7/27/71	1215	0,0,0	0/0	E	104A	36d	7200	2000
232	NM	8/09/71	1756	1,0,0	0/0	SE	107D	32b	5500	2200
233	NM	9/16/71	1900	1,0,0	0/0	SW	107B	32d	4800	1300
234	NM	9/17/71	1500	1,0,0	0/0	--	105D	33d	6700	2700
235	CO	10/17/71	1730	3,2,3	0/0	NE	102D	38b	4100	500

4. MEAN HEIGHT AND HEIGHT VARIATION

It is a well known fact that the frequency of tornadoes at higher elevation is less than that over lower plains. Wolford's (1960), Thom's (1963), and Pautz's (1969) statistics equally reveal the significant decrease in tornado frequency with elevation in the southernmost Rockies.

To determine the detailed relationship between tornado intensity and the environmental topography, an analysis of the topography was undertaken by dividing the entire region into 15' squares of longitudes and latitudes. The analysis area over the southernmost Rockies including the 44 squares of one-degree longitudes and latitudes were, thus, divided into 16 X 44 = 704 small squares. Each of these 15' squares is called a "geographic spot" or simply a "spot".

16 geographic spots within one-degree squares are identified by a combination of 15' sections of longitude, A (00'-15'), B (15'-30'), C (30'-45'), D (45'-60') and of latitude a (00'-15'), b (15'-30'), c (30'-45'), d (45'-60'). The geographic spots can, thus, be identified simply as 103 A 38 a, 103 B 34 d, etc. The list of tornadoes in Tables 7 through 14 includes this identification system of the geographic spots in which tornadoes originated.

By drawing 15' lines of longitudes and latitudes on 1:250,000 USGS maps covering the entire area, the elevations of the highest and the lowest points in each spot were read off to the nearest 100 ft. Computed from these values are

$$\bar{H} = \frac{1}{2}(H_{max} + H_{min}) \quad \ldots . \text{ Mean Height}$$

and

$$\Delta H = H_{max} - H_{min} \quad \ldots . \text{ Height Variation}$$

where H_{max} and H_{min} are the elevation of the highest and the lowest points within each geographic spot. The mean height will, thus, give the approximate elevation of the mean topography over which a specific tornado originated. Height variation, on the other hand, is the simple difference between the highest and the lowest elevations. Nevertheless, this value can be used as an approximate measure of the mesoscale surface roughness. Four values, H_{max}, H_{min}, $\bar{H}$, and ΔH, in 100-ft unit for each spot are presented in the Appendix, Tables 1 through 4.

Shown in Fig. 6 are the mean heights in 100 ft of these geographic spots over the southernmost Rockies. The highest mean height is 115 or 11,500 ft at 106 B 38 d and 106 D 38 a while the lowest, 31 or 3,100 ft at 103 A 32 a and 104 A 32 a. The mean height, thus, varies tremendously within the area of discussion.

MEAN HEIGHT IN 100 FT

	D	C	B	A	D	C	B	A	D	C	B	A	D	C	B	A	D	C	B	A	D	C	B	A	D	C	B	A
38 d	75	70	63	77	75	82	94	99	107	108	115	109	98	98	93	109	89	66	63	62	56	52	49	47	45	44	43	40
38 c	68	83	70	61	67	78	96	102	91	105	114	107	90	96	85	84	85	54	56	56	50	49	46	45	43	42	41	40
38 b	66	76	76	77	73	90	89	89	98	97	104	108	96	94	74	72	55	52	49	49	47	45	44	44	41	39	39	39
38 a	61	67	70	80	105	102	113	102	115	100	96	92	105	107	90	86	63	51	49	45	44	42	41	41	40	38	36	35
37 d	69	71	100	107	107	111	114	111	113	107	96	83	75	108	102	95	85	56	55	49	45	44	43	41	41	40	39	36
37 c	66	76	85	99	103	113	112	109	108	101	104	81	75	108	108	89	66	61	57	53	51	48	46	46	45	44	41	37
37 b	74	70	76	102	90	95	98	98	97	107	112	90	78	80	93	102	101	67	58	54	51	50	52	51	48	44	41	37
37 a	68	65	67	68	70	74	74	74	89	102	102	87	84	79	100	107	78	68	76	69	60	60	56	48	45	43	39	37
36 d	54	58	60	61	64	64	68	72	79	87	96	94	85	98	105	100	80	72	74	72	69	58	52	48	41	41	39	38
36 c	69	56	56	58	63	63	69	70	75	74	91	90	79	92	106	95	72	68	69	76	69	60	56	53	46	42	39	37
36 b	73	59	60	61	68	68	69	71	78	76	80	77	70	93	102	92	74	63	62	67	61	58	52	49	44	41	39	37
36 a	74	64	60	62	65	70	69	72	86	81	87	70	72	99	97	86	70	62	55	59	53	51	49	46	43	40	39	37
35 d	76	68	61	63	67	69	70	69	78	86	79	61	91	104	94	70	73	62	56	53	49	48	49	45	41	39	37	36
35 c	69	70	72	76	73	69	73	66	72	73	71	64	85	84	82	66	62	59	51	50	46	44	44	42	38	36	35	34
35 b	67	74	77	76	73	87	76	67	60	56	73	68	67	68	67	60	59	56	47	46	44	43	40	38	37	36	36	35
35 a	67	70	80	79	74	86	70	60	56	62	82	72	66	70	62	55	52	49	49	48	46	44	42	41	40	41	39	38
34 d	67	72	80	77	75	69	63	59	54	52	76	66	65	69	61	56	52	47	48	50	47	47	45	43	42	40	39	37
34 c	67	68	76	73	79	73	68	65	51	54	79	63	63	63	62	58	51	47	45	46	46	46	44	43	41	40	39	37
34 b	69	70	74	80	81	73	69	71	51	60	65	67	74	68	64	55	52	47	42	42	44	43	43	42	39	38	38	36
34 a	79	81	85	86	81	76	75	77	58	61	59	64	72	71	62	54	49	44	41	41	44	43	40	39	39	38	36	35
33 d	76	74	80	81	81	81	77	77	54	54	65	62	67	71	59	52	47	42	39	39	44	44	42	41	39	36	35	34
33 c	71	86	83	80	78	71	77	50	50	47	67	55	69	79	79	69	45	40	38	40	41	44	41	40	38	36	35	33
33 b	70	91	75	76	77	67	65	56	59	68	56	52	85	78	63	54	45	39	37	37	41	43	40	39	38	36	34	33
33 a	67	68	68	67	84	68	50	54	58	56	40	46	66	79	68	55	46	38	35	36	41	42	40	38	37	35	33	32
32 d	61	55	72	75	77	66	48	58	47	60	41	42	69	82	65	55	45	39	34	35	40	40	38	37	35	34	32	31
32 c	46	56	67	59	61	59	48	51	48	62	55	42	66	73	62	57	49	40	36	34	35	37	37	36	34	33	31	30
32 b	44	56	55	49	55	56	47	54	48	64	55	51	47	53	52	52	52	46	37	32	33	36	35	34	33	32	31	29
32 a	49	50	47	47	47	54	43	49	40	53	45	50	51	58	45	44	55	53	39	31	32	34	32	31	31	32	30	28
	109				108				107				106				105				104				103			102

UTAH — ARIZONA — KANSAS — OKLA — TEXAS

Fig. 6. Distribution of the mean height within each geographic spot, covering a 15' longitude-latitude square.

A similar chart for height variation, Fig. 7, reveals that there is a spot near Alamosa, Colo., where ΔH is 0 or less than 100 ft. The height variation in the western Texas Panhandle is generally very small, increasing toward the west. Within New Mexico and Colorado, height variation increases gradually westward, showing a significant increase just east of the easternmost ridges. The maximum value of 72 or 7,200 ft is seen at 107D 38a in Colorado.

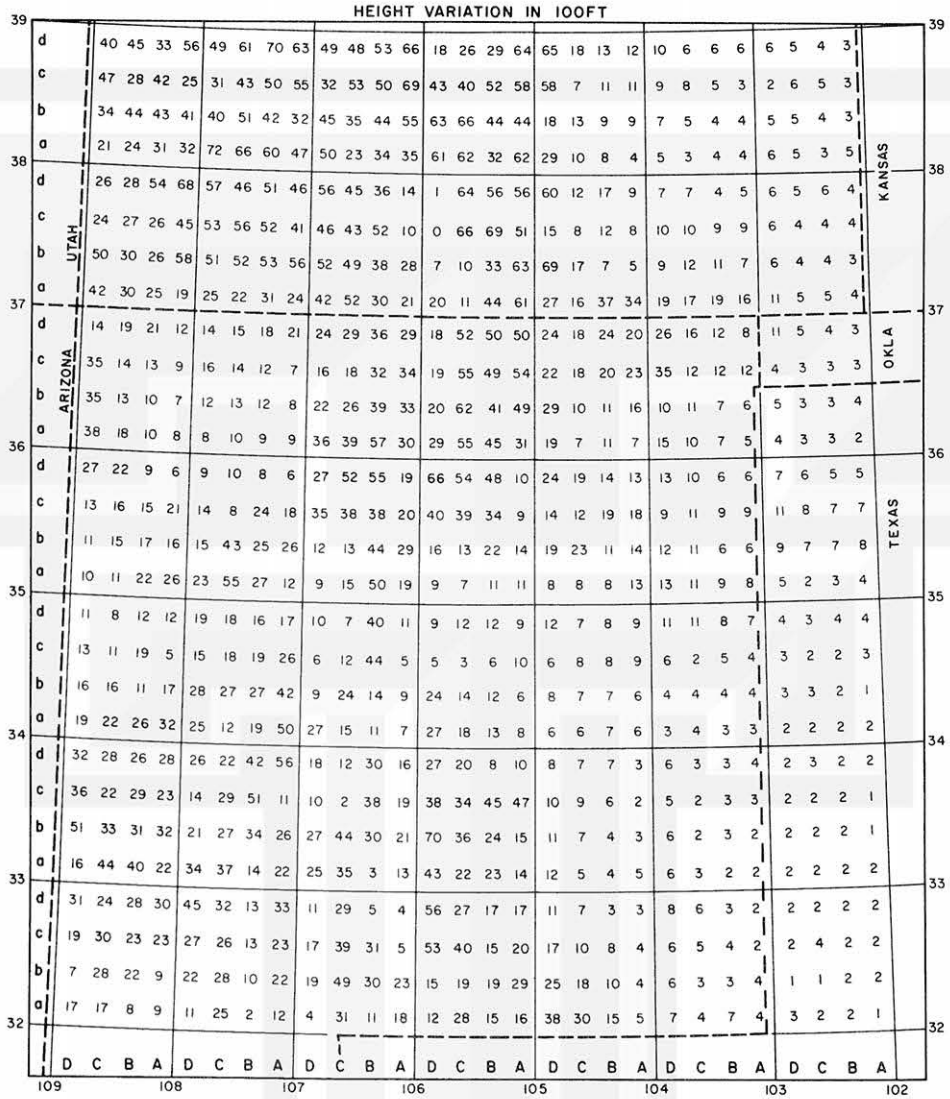

Fig. 7. Distribution of the height variation defined as the difference of the maximum and the minimum height within each spot.

In an attempt to determine the probability of tornado frequency and intensity as a function of the mean height, the two diagrams in Fig. 8 were constructed. The left diagram shows the frequency distribution of geographic spots within each 1000 ft interval. The diagram reveals that the maximum spot frequency occurs between 4000 and 5000 ft mean height. Above these heights the spot frequency decreases gradually reaching zero above 12,000 ft.

Presented in the right diagram of Fig. 8 is the tornado probability expressed in occurrence per spot in 22 statistical years. The contributions by F0 and F1 tornadoes are shown in stippled area, those of F2 and F3 in hatched and painted areas, respectively. Of interest is the occurrence of an F3 tornado between 6 and 7000 ft. Probabilities of F0 and F2 tornadoes, however, decrease faster than exponential reduction as the mean height increases from 3000 ft to 12,000 ft. We may, thus, conclude that the probability of experiencing an F2 or stronger tornado is very small above the 8,000 ft mean height. Above the 9,000 ft mean height, the chance of an F2 tornado may be regarded as zero for most practical purposes.

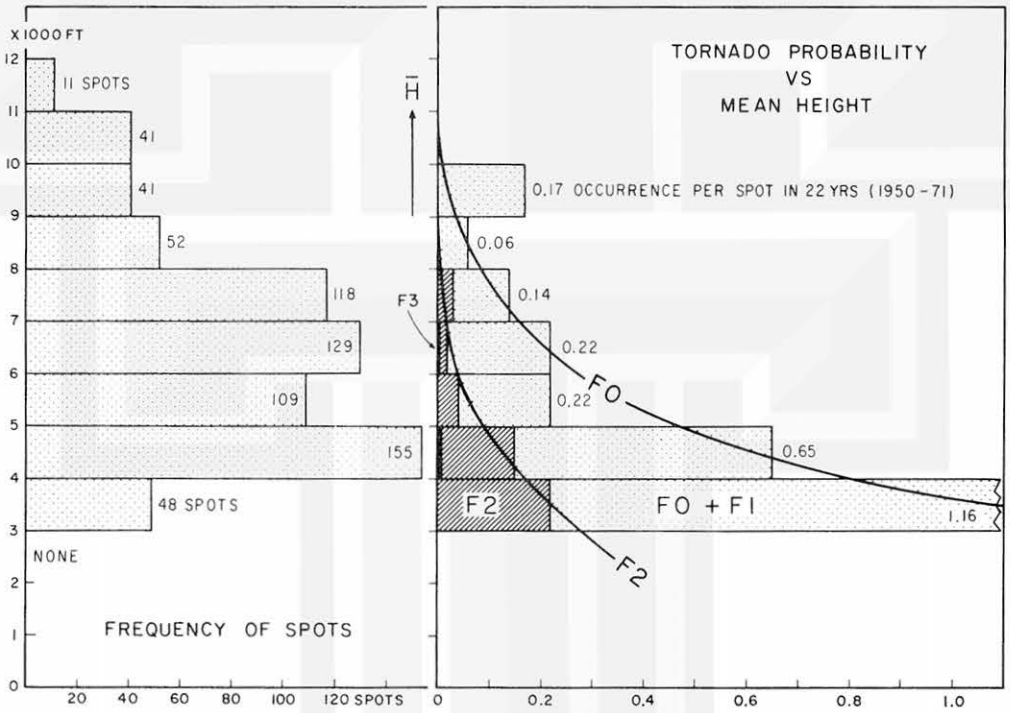

Fig. 8. Left: Frequency of geographic spots as a function of the mean height. Right: Tornado probability.

Similar diagrams for height variation and tornado intensity are presented in Fig. 9. The frequency of geographic spots in this case is the largest between 0 and 1000 ft, revealing the existence of a large number of relatively flat spots. As the height variation increases, the frequency of spots decreases almost exponentially to zero at 8,000 ft. The tornado probability in relation to the height variation is of particular importance. As shown in the figure on the right, F0 tornado probability decreases to zero at 7,000 ft height variation. F2 and F3 tornado probabilities terminate at 3,000 and 2,000 ft, respectively. These evidences would mean that the upper limit of the tornado intensity is extremely sensitive to the roughness of the surface as expressed by the height variation.

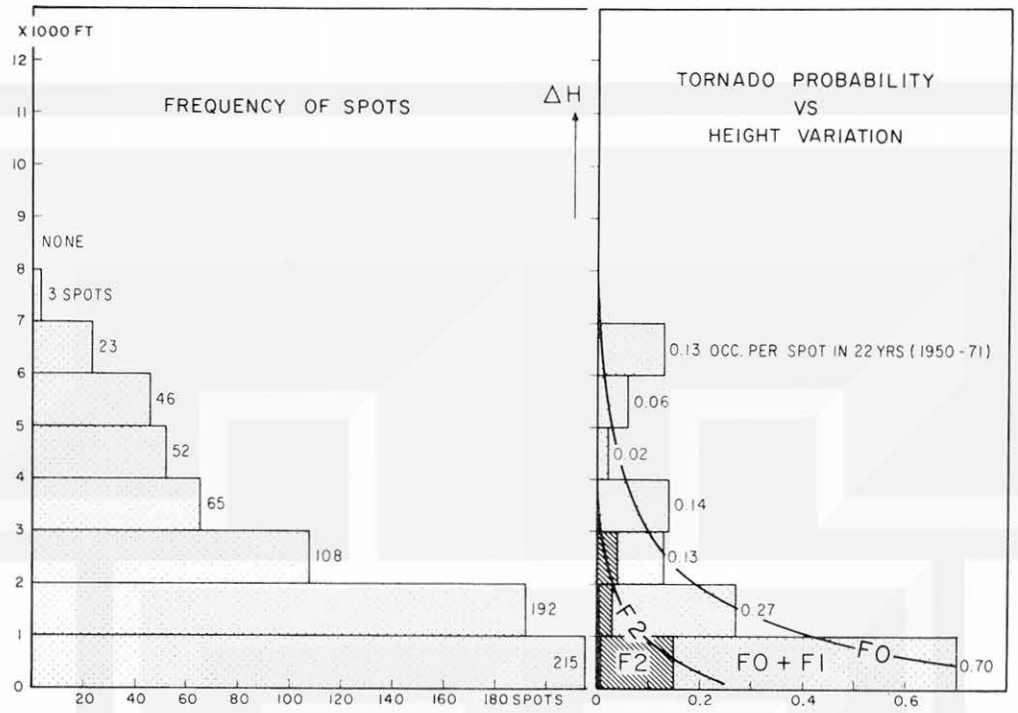

Fig. 9. Left: Frequency of geographic spots as a function of the height variation. Right: Tornado Frequency.

It may be concluded, therefore, that the probability of experiencing an F 2 or stronger tornado within a spot of 4000-ft height variation is extremely small. Above 5000-ft height variation the chance of an F 2 tornado will be practically zero.

The above statistical analysis involving both mean height and height variation of geographical spots in the southernmost Rockies reveals that the roughness of the tornado environment is acting as an effective agent for suppressing the formation of intense tornadoes. Mean height of the environment is also playing an important role, but its contribution is not as effective as that of environmental roughness.

5. LONGITUDINAL AND OROGRAPHIC VARIATION OF TORNADO INTENSITY

Further investigation of the probability of tornado intensity as functions of the mean height and the height variation was performed together with longitudinal cross sections of both mean height and height variation. Three cross sections were constructed for each of the latitudinal zones, 2-degree wide. These zones, 38° N ± 1°, 36° N ± 1°, and 34° N ± 1° correspond to those in Figs. 2 and 3 used for national statistics.

Results of these cross-sectional analyses are presented in Figs. 10-12. The tornado frequencies shown in the middle diagram are those in 1/4-deg. sections of longitude. Tornado intensities F0, F1, F2, and F3 are distinguished by different shadings.

The top diagram includes the distribution of the mean height at 1/4-deg. intervals. If there were no tornado at a spot a short line appears at the longitude and the mean height of the spot. When a spot includes one or more tornadoes reported during the 1950-71 period, a circle identified with the largest F scale within the spot is added on the line designating the specific spot. Thus the cross-sectional diagram clearly shows the distribution of tornadoes within the three zonal profiles of the southernmost Rockies.

The bottom diagram gives the height variation profile corresponding to the top diagram. It should be noted that F2 or stronger tornadoes are found only where the height variation is relatively low. Dashed lines at 4,000 and 5,000 ft height variation were drawn to indicate that the chance of experiencing F2 or stronger tornado above 4,000 ft is rare and above 5,000 ft, practically none. It should be noted that dashed lines equivalent to these are at 8,000 and 9,000 ft in the mean height profile because the elevation of the tornado environment does not appear to be effective for tornado suppression as does the height variation, the mesoscale surface roughness.

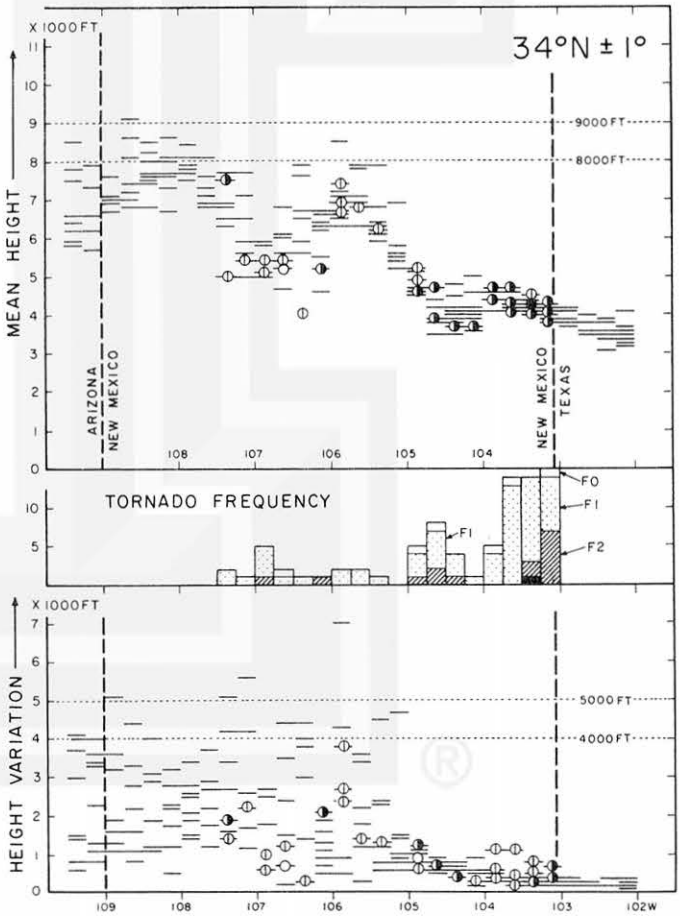

Fig. 10. Top: Distribution of the mean height within latitude 34°N ± 1°. Bottom: Distribution of the height variation. Based on 22-year (1950-71) tornadoes.

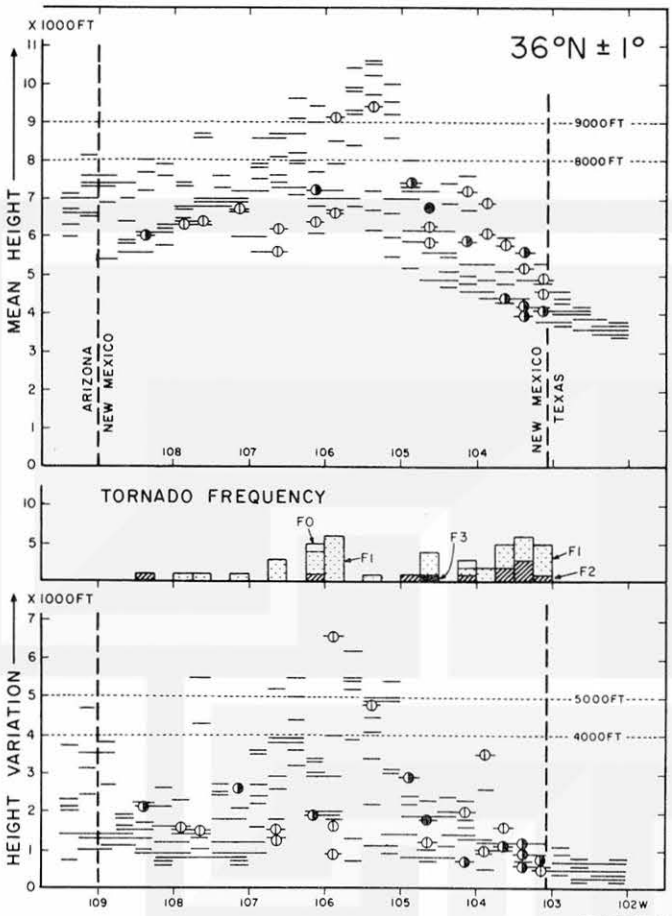

Fig. 11. Top: Distribution of the mean height within latitude 36° N ± 1°. Bottom: Distribution of the height variation. Based on 22-year (1950-71) tornadoes.

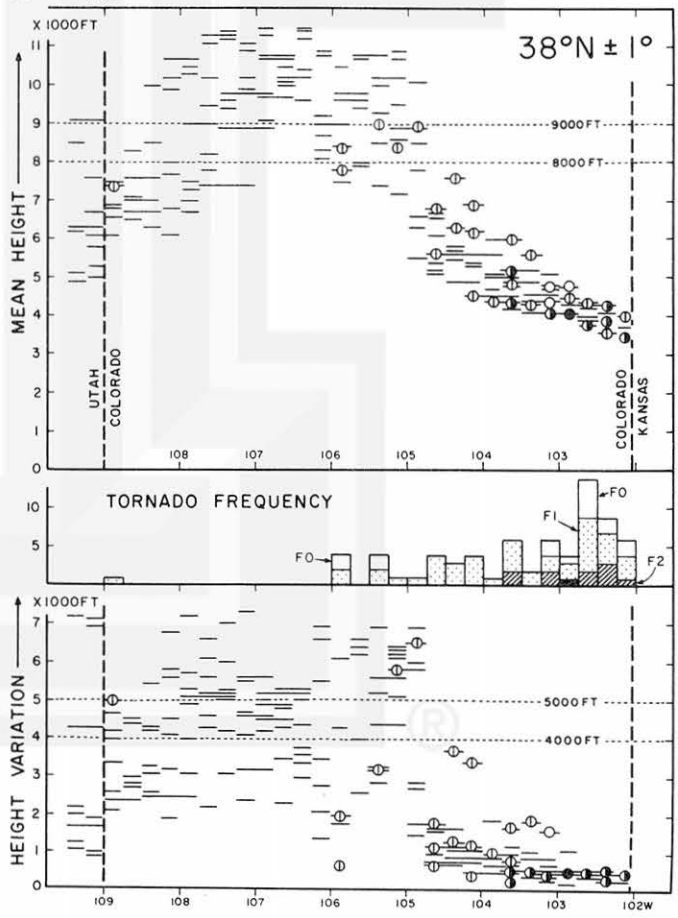

Fig. 12. Top: Distribution of the mean height within latitude 38° N ± 1°. Bottom: Distribution of the height variation. Based on 22-year (1950-71) tornadoes.

6. ANNUAL AND DIURNAL VARIATION OF TORNADOES

During the course of investigating tornadoes in the southernmost Rockies very interesting local characteristics of the storms were found. Namely, most tornadoes in this area occur during May through July, very similar to those in Australia as shown in Table 2. The time of tornado occurrences during the tornado season is considerably later than that of off-season storms.

Figure 13 was prepared in order to reveal the local characteristics of tornadoes. In constructing the diagram all tornadoes in Tables 7-14 with reported occurrence time were sorted by the month then by the hour. The tornado frequencies thus obtained were plotted as the function of the hour for each month of the year. It will be seen in the figure that the tornado frequency distributes inside a crescent area extending from the morning in February to about noon in October. In June when an annual peak frequency is reached, practically all tornadoes occur between local noon and early evening.

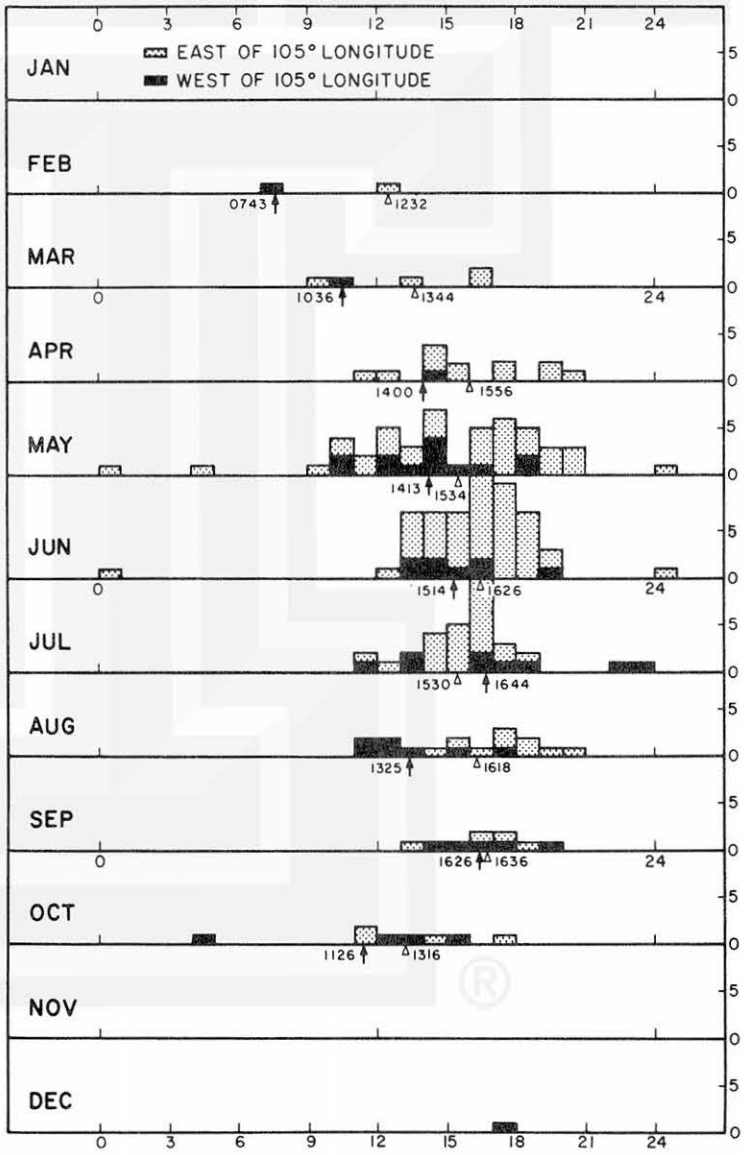

Fig. 13. Annual and diurnal distribution of tornado frequencies in New Mexico and southern Colorado.

Figure 13 also includes interesting characteristics of the tornado time. The average time of tornadoes occurring to the west of 105° longitude appears to be earlier than that occurring to the east of this longitude. To distinguish these tornadoes in the figure, the former is painted black while the latter is stippled. The arrows pointing upward indicate the mean time of western tornadoes and the triangle that of eastern tornadoes separated by 105° W longitude. Note that all arrows except the one in July are located to the left of the triangle for each month.

Fujita (1972) concluded in his 1971 tornado statistics that strong tornadoes tend to occur, on the average, much later than weaker ones. Although the real mechanism

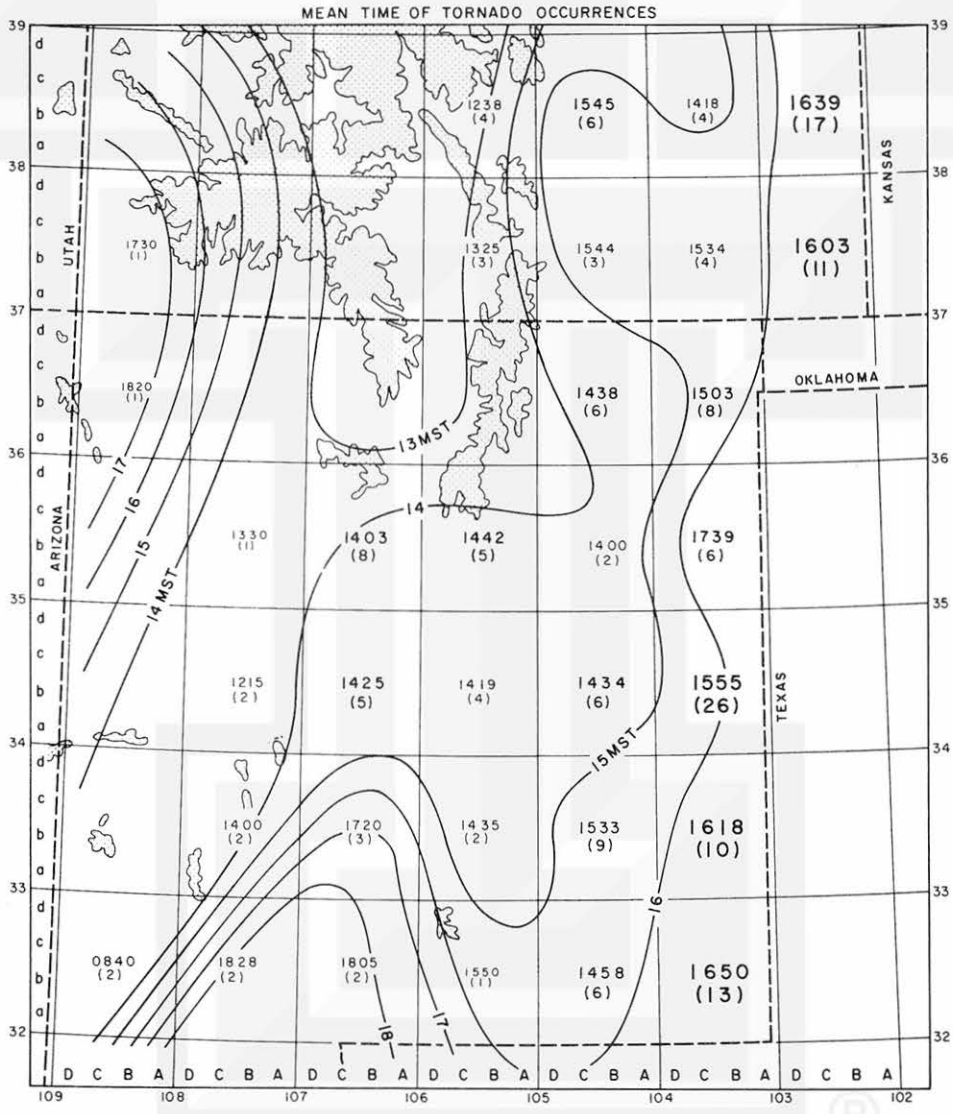

Fig. 14. The mean time of tornado occurrences within each square of longitude and latitude. Time in local standard time.

of late-occurring strong tornadoes has not been established, it is very likely that noon to early afternoon thunderstorms in the mountains are closely related to the high-level heating. This type of thunderstorm is somewhat like air-mass thunderstorm which produces weak tornadoes.

The mean times of tornado occurrences computed over the southernmost Rockies revealed an extremely interesting statistical result. As shown in Fig. 14, the mean occurrence time of all tornadoes within each one-degree square was computed and plotted. The four-digit number in each square denotes the mean occurrence time in local standard time, and the number in parenthesis, the storm frequency during 1950-71.

The isochrones drawn at one-hour intervals clearly show that the mean occurrence time of tornadoes in the mountain is much earlier than those over the plain. Note that the mean time computed from a large number of tornadoes is drawn with large and heavy letters in order to distinguish reliable ones from less reliable mean time computed from one or two tornadoes. About noon to 1 PM mean occurrence time will be found over the Colorado Rockies. Over the plain, along the Texas and Kansas borders the mean occurrence time is as late as 6 PM, showing that a 5 hour difference in the mean occurrence time of tornadoes exists within such a short longitudinal distance of about 3 degrees.

It is very likely that the tornadoes in mountain areas, which tend to occur during midday, spawn from premature thunderstorms. Intensity of these midday tornadoes is considerably weaker than midwestern storms.

7. MAXIMUM TORNADO INTENSITY IN SOUTHERNMOST ROCKIES

In order to summarize the tornado intensity in relation to the mean heights of geographic spots, the mean height values in Fig. 6 were contoured for every 1000 ft. Superimposed on this contour map are the maximum intensity of tornadoes in each geographic spot (see Fig. 15).

Examination of the figure reveals that there were no tornadoes, F 2 or stronger, above the 8000 ft contour of the mean height. As the elevation decreases, both frequency and intensity of tornadoes increases.

A very similar contour map of height variation and the maximum tornado intensity in each geographic spot are presented in Fig. 16. The maximum and the minimum spots of height variation are indicated by + and − symbols, respectively.

As stated in the previous sections, the maximum tornado intensity is very sensitive to the height variation. It will be seen in the figure that no tornado, F 2 or stronger, exists where height variation is above 4000 ft.

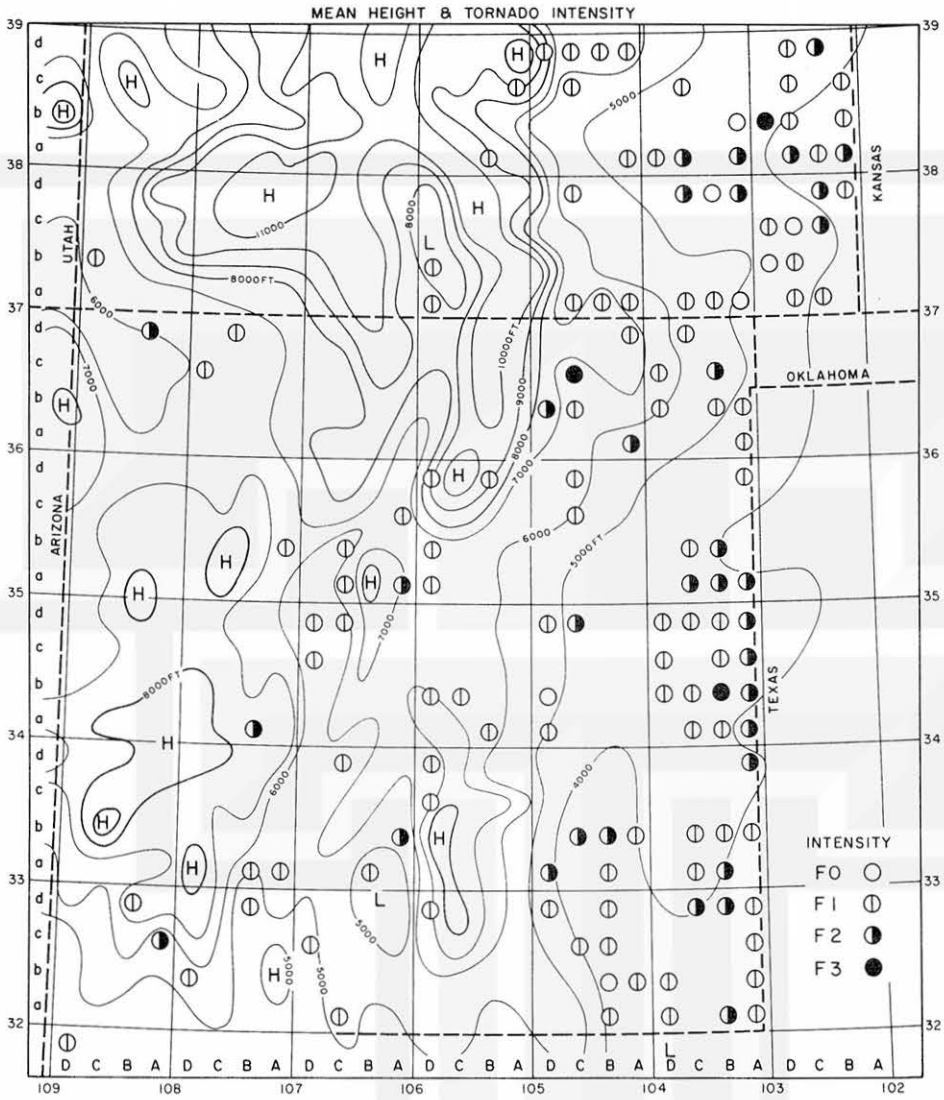

Fig. 15. Maximum tornado intensity in relation to the mean height of geographic spots in New Mexico and southern Colorado.

In order to perform the maximum intensity estimate in the southernmost Rockies, threshold values of both $\bar{H}$, the mean height, and ΔH, the height variation for F 2 and F 3 tornadoes, were established. The results thus obtained are given in Table 15.

Table 15. Threshold values of $\bar{H}$ and ΔH for F 2 and F 3 tornado probabilities

Geographic Spots	F 2 tornadoes (113-157 mph)	F 3 tornadoes (158-206 mph)
ΔH > 4000' or $\bar{H}$ > 8000'	not reported, 1950-71	very unlikely
ΔH > 5000' or $\bar{H}$ > 9000'	very unlikely	no possibility
ΔH > 6000' or $\bar{H}$ > 10000'	no possibility	no possibility

The table includes the tornado possibilities as functions of $\bar{H}$ and ΔH for both F 2 and F 3 tornadoes.

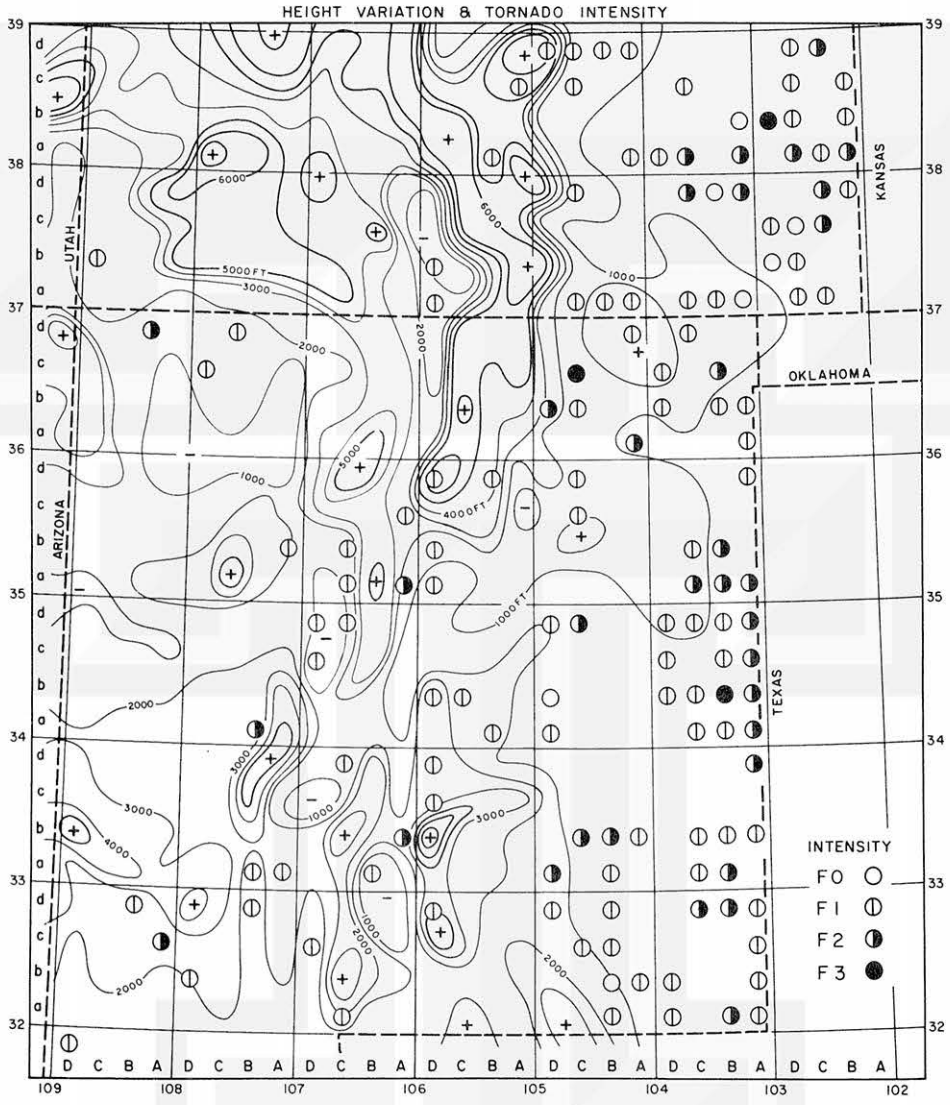

Fig. 16. Maximum tornado intensities in relation to the height variation of geographic spots.

Figure 17 was constructed, based on Table 15, to designate the areas of potential tornadoes in New Mexico and southern Colorado. Single hatched areas represent $\Delta H > 4000'$ or $\bar{H} > 8000'$. No F 2 or stronger tornado was reported during 1950-71. F 3 tornadoes are very unlikely in this area. The cross-hatched areas consist of those spots with $\Delta H > 5000'$ or $\bar{H} > 9000'$. F 2 tornadoes are very unlikely. There will be no possibility of experiencing F 3 tornadoes there.

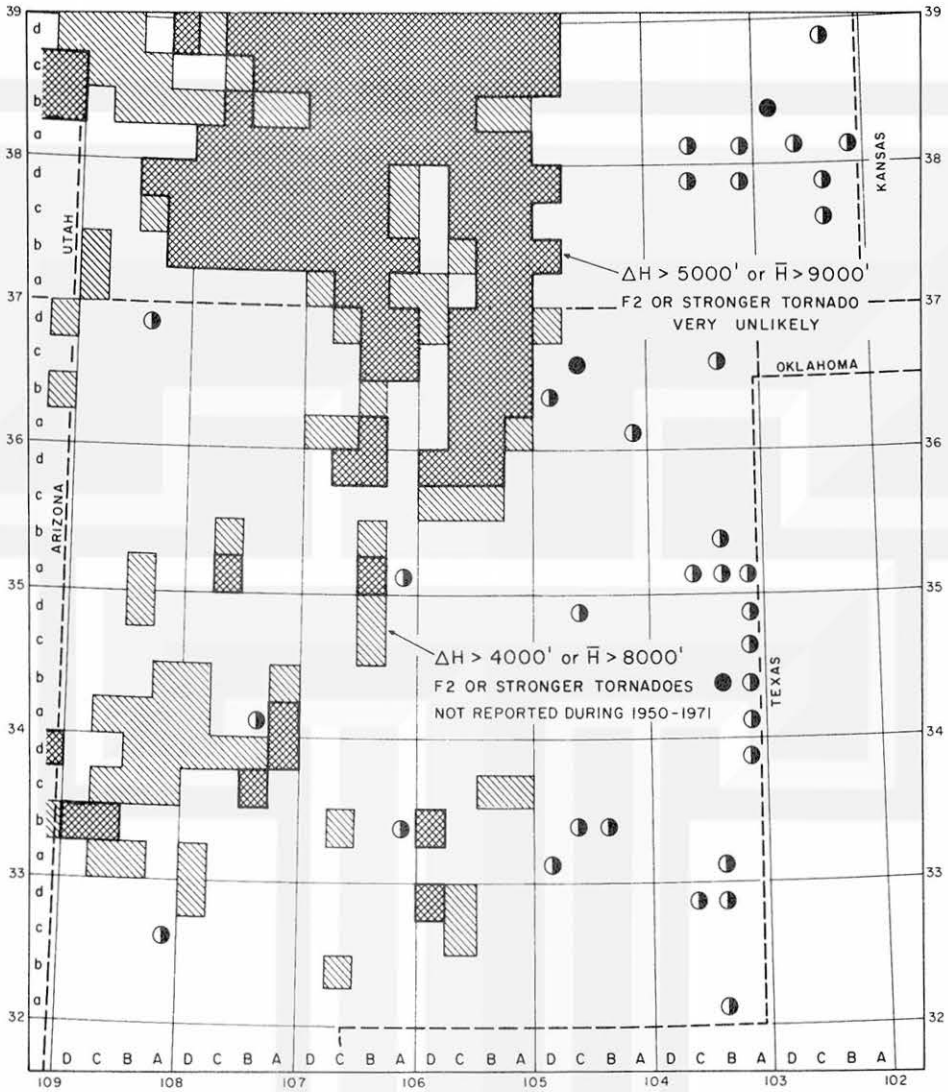

Fig. 17. Threshold of the expected occurrence of strong tornadoes in the southernmost Rockies. Cross-hatched areas indicate where F 2 or stronger tornadoes are very unlikely to occur.

Table 15 combined with Fig. 17 will now permit us to estimate the maximum windspeed of tornadoes in various geographic spots in New Mexico and southern Colorado.

If a structure is located outside the hatched areas it would be necessary to expect F 2 or stronger tornadoes no matter how small the probability might be.

Inside the cross-hatched area, however, the windspeed of the top F 2 tornado, 157 mph, may be adopted for most practical purposes. If the "no possibility" category is desired for tornado protection purposes, it would be necessary to protect against the top F 3 tornadoes with 206 mph windspeed.

8. DESIGN TORNADO AT LOS ALAMOS SITE

In view of the fact that the intensity of world-wide and U. S. tornadoes is closely related to the climatological and orographic conditions, it is feasible to establish the maximum windspeed of the design tornado applicable to given locations, provided that these conditions are known in detail. An attempt was made, based on the author's analyses of tornadoes in southernmost Rockies, to establish a design tornado for the Los Alamos spot, 106 B 35 d characterized by

Maximum height	.....	10,700 ft
Minimum height	.....	5,200 ft
Mean height	.....	7,900 ft
Height variation	.....	5,500 ft

A topographic map of the Los Alamos spot is shown in Fig. 18 in which contour lines are drawn for every 1000 ft. The spot includes the eastern rim of Jemez caldera with a remaining central cone, Redondo Peak. The rim of the caldera to the southwest through northwest of Los Alamos exceeds 9000 ft MSL. Numerous canyons, 200 to 800-ft deep, such as Canon de los Frijoles, Pajarito Canyon, Los Alamos Canyon, Agua Piedre Canyon, etc. extend radially out from the rim. The Rio Grande runs through 1000-ft deep White Rock Canyon somewhat like a miniature Grand Canyon.

An aerial photograph of the Los Alamos area taken by the author is superimposed by the longitudes and latitudes outlining the Los Alamos spot. The AEC site and the town of Los Alamos are also shown in the photograph (see Fig. 19).

In addition to the statistical threshold of intense tornadoes by mean height and height variation of geographic spots, the following meteorological evidence was used in making the final assessments of the design tornado applicable to Los Alamos spot, 106 B 35 d.

1. The moisture inflow from the Gulf of Mexico to this geographical spot of $\bar{H}$ = 7900 ft takes place along Rio Grande Valley which is likely to restrict the flow and promote the formation of thunderstorms.
2. Los Alamos spot is located near the eastern edge of the source region of dry air. Thus the stratification of dry air above the moist air is not as significant as that over the midwestern plain.
3. Nearby peaks acting as heat sources tend to produce small to medium convective clouds which may develop into big ones after drifiting into the plain.
4. The midday occurrence of tornadoes over the mountain is too early for the growth of intense tornadoes mostly spawned out of rotating thunderstorms.
5. There was no report of tornado within Los Alamos spot during the 22-year period, 1950-71.

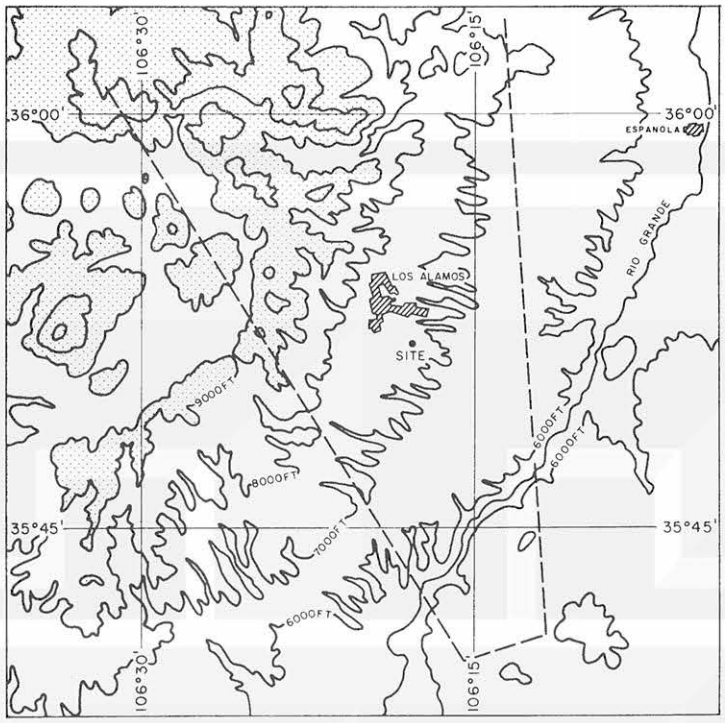

Fig. 18. Topographic map of the geographic spot including Los Alamos, NM. The boundary of the aerial photograph is shown by dashed lines.

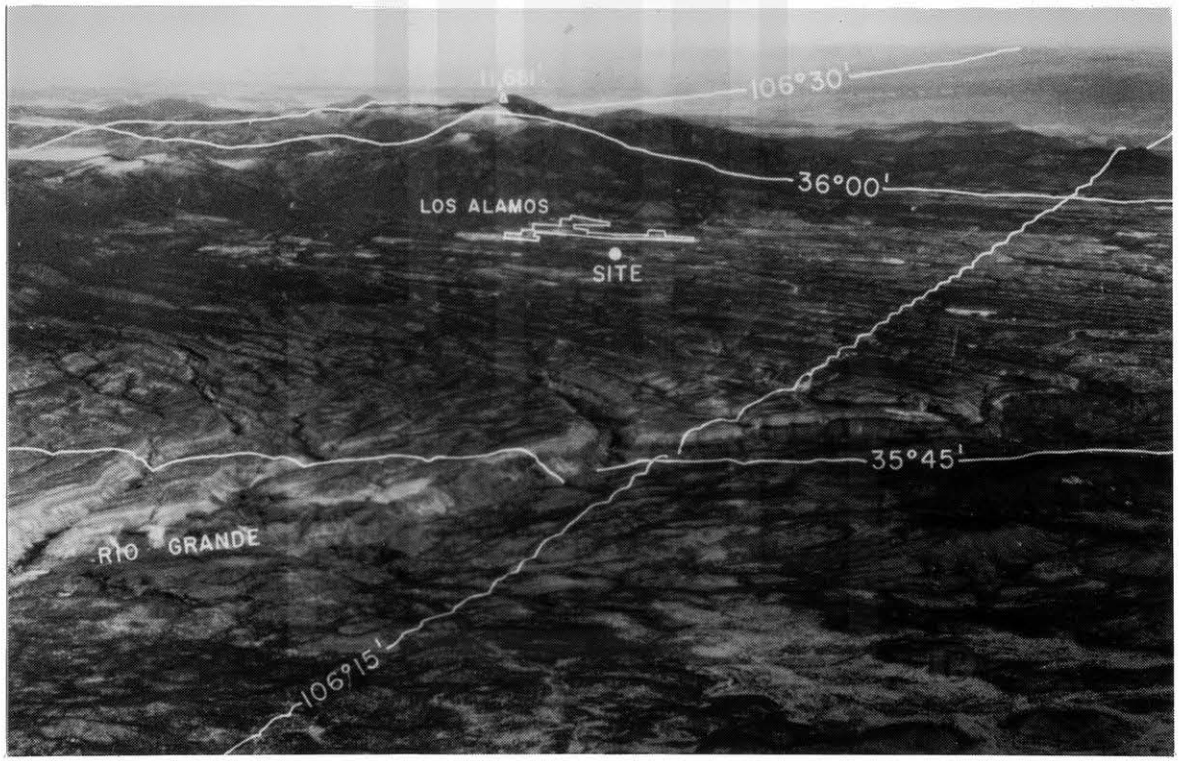

Fig. 19. Aerial photograph showing the topography of the Los Alamos area where the mean height is 7900 ft.

6. It may be assumed that "Cause V" on Page 6 is responsible for the formation of tornadoes within Los Alamos spot. As already stated, F 1 or weaker tornadoes are likely to be produced by air-mass thunderstorms (Cause V).

7. The most intense vortex-type winds to be experienced in Los Alamos spot are dustdevils which may be accompanied by uppermost F 1 wind or 112 mph.

Table 15, along with the foregoing 7 meteorological explanations, leads to the conclusion that

"F 2 tornadoes are very unlikely and no possibility of F 3 tornadoes."

In terms of F-scale windspeed defined as the fastest 1/4-mile speed, we may state

"113-157 mph tornadoes are very unlikely and no possibility of 158-206 mph tornadoes."

The author thus recommends the uppermost F 2 scale windspeed plus 50 mph as being the safety factor for the maximum windspeed of the Design Tornado in Los Alamos spot. The windspeed thus recommended is

$$150 \text{ mph} + 50 = 200 \text{ mph}$$

including the translational speed of tornado.

In view of meteorological reasons that tornado-producing thunderstorms under discussion are small ones with orographic influences, the maximum translational speed of the design tornado is recommended to be 30 mph which is only one-half of that of midwestern design tornadoes. Thus the rotational speed of the design tornado is 170 mph.

Based on his past research on various tornadoes the author recommends the diameter of the circle of the maximum wind for the design tornado be 100 ft at the structure level.

Under the assumption that the Design Tornado is expressed by a Rankine vortex, we obtain the pressure drop at the tornado center

$$P_\infty - P_o = \rho V_m^2$$

where P_∞ is the pressure far away from the tornado, P_o, the central pressure, ρ, the mean air density, and V_m, the maximum rotational windspeed. The mean density of the air at Los Alamos spot can be computed from approximate station pressure of 750 mb and temperature, 20° C early in summer to obtain

$$\rho \cong 0.9 \quad \text{kg/m}^3 .$$

Thus the pressure drop at the design-tornado center is

$$P_\infty - P_o = \rho V_m^2 \cong 52 \text{ millibar} \cong 0.75 \text{ psi.}$$

The instantaneous rate of pressure drop reaches a maximum when the circle of the maximum wind moves at a given point. The space gradient can be approximated as

$$-\frac{1}{\rho}\left(\frac{\partial P}{\partial r}\right)_{r_m} = \frac{V_m^2}{r_m}$$

Using the time space conversion,

$$dr = T\,dt$$

where T is the translational speed, dr the radius increment in the direction of tornado motion, we write

$$\frac{dP}{dt} = -\frac{T}{r_m}\rho V_m^2$$

Using the values r_m = 100 ft and T = 30 mph, we have

$$\frac{dP}{dt} = -0.44 \times 0.75 = -0.33 \text{ psi/sec.}$$

We shall now summarize the characteristics of the design tornado for Los Alamos.

Table 16. Design Tornado for Los Alamos. Density of the air assumed constant was computed for 750 mb pressure and 20 C air temperature at the mean height, 7900 ft. MSL.

Parameters	Values
Maximum windspeed	200 mph
Rotational speed	170 mph
Translational speed	30 mph
Diameter of maximum rotational wind	100 ft
Max. pressure drop at the center	0.75 psi
Maximum rate of pressure change	0.33 psi/sec

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APPENDIX - TABLES 1—4

Characteristics of geographic spots, including maximum and minimum heights, mean height, and height variation.

Example:

Maximum Height → 058 041 ← Minimum Height

Mean Height → 049 (17) ← Height Variation

All in 100 foot units.

APPENDIX - TABLE 1

	109-D	109-C	109-B	109-A	108-D	108-C	108-B	108-A
38-d			058 041	085 042	095 055	093 048	080 047	105 049
			049(17)	063(43)	075(40)	070(45)	063(33)	077(56)
38-c			111 039	111 042	092 045	097 069	091 049	074 049
			075(72)	076(69)	068(47)	083(28)	070(42)	061(25)
38-b			123 047	127 056	083 049	098 054	098 055	098 057
			085(76)	091(71)	066(34)	076(44)	076(43)	077(41)
38-a			072 052	070 053	072 051	079 055	086 055	096 064
			062(20)	061(17)	061(21)	067(24)	070(31)	080(32)
37-d			113 070	073 062	082 056	085 057	127 073	141 073
			091(43)	067(11)	069(26)	071(28)	100(54)	107(68)
37-c			074 052	068 049	078 054	090 063	098 072	122 077
			063(22)	058(19)	066(24)	076(27)	085(26)	099(45)
37-b			055 044	062 045	099 049	085 055	089 063	131 073
			049(11)	053(17)	074(50)	070(30)	076(26)	102(58)
37-a			058 045	055 045	089 047	080 050	080 055	078 059
			051(13)	050(10)	068(42)	065(30)	067(25)	068(19)
36-d			075 052	094 047	061 047	068 049	071 050	067 055
			063(23)	070(47)	054(14)	058(19)	060(21)	061(12)
36-c			090 053	088 053	087 052	063 049	063 050	063 054
			071(37)	070(35)	069(35)	056(14)	056(13)	058(09)
36-b			073 053	093 069	091 056	066 053	065 055	065 058
			063(20)	081(24)	073(35)	059(13)	060(10)	061(07)
36-a			078 057	092 061	093 055	073 055	065 055	066 058
			067(21)	076(31)	074(38)	064(18)	060(10)	062(08)
35-d			082 059	081 068	090 063	079 057	066 057	066 060
			070(23)	074(13)	076(27)	068(22)	061(09)	063(06)
35-c			077 063	080 066	076 063	078 062	080 065	087 066
			070(14)	073(14)	069(13)	070(16)	072(15)	076(21)
35-b			073 059	073 059	073 062	082 067	086 069	084 068
			066(14)	066(14)	067(11)	074(15)	077(17)	076(16)
35-a			064 057	070 060	072 062	076 065	091 069	092 066
			060(07)	065(10)	067(10)	070(11)	080(22)	079(26)
34-d			066 058	066 058	073 062	076 068	086 074	083 071
			062(08)	062(08)	067(11)	072(08)	080(12)	077(12)
34-c			061 055	068 057	074 061	074 063	086 067	076 071
			058(06)	062(11)	067(13)	068(11)	076(19)	073(05)
34-b			071 057	073 060	077 061	078 062	080 069	089 072
			064(14)	066(13)	069(16)	070(16)	074(11)	080(17)
34-a			093 063	091 068	089 070	092 070	098 072	102 070
			078(30)	079(23)	079(19)	081(22)	085(26)	086(32)
33-d			093 078	109 075	092 060	088 060	093 067	095 067
			085(15)	092(34)	076(32)	074(28)	080(26)	081(28)
33-c			094 057	085 052	089 053	097 075	098 069	092 069
			075(37)	068(33)	071(36)	086(22)	083(29)	080(23)
33-b			087 046	082 042	096 045	108 075	091 060	092 060
			066(41)	062(40)	070(51)	091(33)	075(31)	076(32)
33-a			079 039	075 039	075 059	090 046	088 048	078 056
			059(40)	057(36)	067(16)	068(44)	068(40)	067(22)
32-d			065 032	072 034	077 046	067 043	086 058	090 060
			048(33)	053(38)	061(31)	055(24)	072(28)	075(30)
32-c			057 034	059 036	056 037	071 041	079 056	071 048
			045(23)	047(23)	046(19)	056(30)	067(23)	059(23)
32-b			041 034	065 036	048 041	070 042	066 044	054 045
			037(07)	050(29)	044(07)	056(28)	055(22)	049(09)
32-a			081 036	060 036	058 041	059 042	051 043	052 043
			058(45)	048(24)	049(17)	050(17)	047(08)	047(09)

APPENDIX - TABLE 2

	107-D	107-C	107-B	107-A	106-D	106-C	106-B	106-A
38-d	100 051	113 052	129 059	131 068	132 083	132 084	142 089	142 076
	075(49)	082(61)	094(70)	099(63)	107(49)	108(48)	115(53)	109(66)
38-c	083 052	100 057	121 071	130 075	107 075	132 079	139 089	142 073
	067(31)	078(43)	096(50)	102(55)	091(32)	105(53)	114(50)	107(69)
38-b	093 053	116 065	110 068	105 073	121 076	115 080	126 082	136 081
	073(40)	090(51)	089(42)	089(32)	098(45)	097(35)	104(44)	108(55)
38-a	141 069	135 069	143 083	126 079	140 090	112 089	113 079	110 075
	105(72)	102(66)	113(60)	102(47)	115(50)	100(23)	096(34)	092(35)
37-d	136 079	134 088	140 089	134 088	141 085	130 085	114 078	090 076
	107(57)	111(46)	114(51)	111(46)	113(56)	107(45)	096(36)	083(14)
37-c	130 077	141 085	138 086	130 089	131 085	123 080	130 078	086 076
	103(53)	113(56)	112(52)	109(41)	108(46)	101(43)	104(52)	081(10)
37-b	116 065	121 069	125 072	126 070	123 071	132 083	131 093	104 076
	090(51)	095(52)	098(53)	098(56)	097(52)	107(49)	112(38)	090(28)
37-a	083 058	085 063	090 059	086 062	110 068	128 076	117 087	098 077
	070(25)	074(22)	074(31)	074(24)	089(42)	102(52)	102(30)	087(21)
36-d	071 057	072 057	077 059	083 062	091 067	102 073	114 078	109 080
	064(14)	064(15)	068(18)	072(21)	079(24)	087(29)	096(36)	094(29)
36-c	071 055	070 056	075 063	074 067	083 067	083 065	107 075	107 073
	063(16)	063(14)	069(12)	070(07)	075(16)	074(18)	091(32)	090(34)
36-b	074 062	075 062	075 063	075 067	089 067	089 063	100 061	094 061
	068(12)	068(13)	069(12)	071(08)	078(22)	076(26)	080(39)	077(33)
36-a	069 061	075 065	074 065	077 068	104 068	101 062	116 059	085 055
	065(08)	070(10)	069(09)	072(09)	086(36)	081(39)	087(57)	070(30)
35-d	072 063	074 064	074 066	072 066	092 065	112 060	107 052	071 052
	067(09)	069(10)	070(08)	069(06)	078(27)	086(52)	079(55)	061(19)
35-c	080 066	073 065	085 061	075 057	090 055	092 054	090 052	074 054
	073(14)	069(08)	073(24)	066(18)	072(35)	073(38)	071(38)	064(20)
35-b	081 066	109 066	089 064	080 054	066 054	063 050	095 051	083 054
	073(15)	087(43)	076(25)	067(26)	060(12)	056(13)	073(44)	068(29)
35-a	086 063	114 059	084 057	066 054	061 052	070 055	107 057	082 063
	074(23)	086(55)	070(27)	060(12)	056(09)	062(15)	082(50)	072(19)
34-d	085 066	078 060	071 055	068 051	059 049	056 049	096 056	072 061
	075(19)	069(18)	063(16)	059(17)	054(10)	052(07)	076(40)	066(11)
34-c	087 072	082 064	078 059	078 052	054 048	060 048	101 057	066 061
	079(15)	073(18)	068(19)	065(26)	051(06)	054(12)	079(44)	063(05)
34-b	095 067	087 060	083 056	092 050	056 047	072 048	072 058	072 063
	081(28)	073(27)	069(27)	071(42)	051(09)	060(24)	065(14)	067(09)
34-a	094 069	082 070	085 066	102 052	072 045	069 054	065 054	068 061
	081(25)	076(12)	075(19)	077(50)	058(27)	061(15)	059(11)	064(07)
33-d	094 068	092 070	098 056	105 049	063 045	060 048	080 050	070 054
	081(26)	081(22)	077(42)	077(56)	054(18)	054(12)	065(30)	062(16)
33-c	085 071	086 057	103 052	056 045	055 045	048 046	086 048	065 046
	078(14)	071(29)	077(51)	050(11)	050(10)	047(02)	067(38)	055(19)
33-b	088 067	081 054	082 048	069 043	073 046	090 046	071 041	063 042
	077(21)	067(27)	065(34)	056(26)	059(27)	068(44)	056(30)	052(21)
33-a	101 067	087 050	057 043	065 043	071 046	074 039	042 039	053 040
	084(34)	068(37)	050(14)	054(22)	058(25)	056(35)	040(03)	046(13)
32-d	100 055	082 050	055 042	075 042	053 042	075 046	044 039	044 040
	077(45)	066(32)	048(13)	058(33)	047(11)	060(29)	041(05)	042(04)
32-c	075 048	072 046	055 042	063 040	057 040	082 043	071 040	045 040
	061(27)	059(26)	048(13)	051(23)	048(17)	062(39)	055(31)	042(05)
32-b	066 044	070 042	052 042	065 043	058 039	089 040	070 040	063 040
	055(22)	056(28)	047(10)	054(22)	048(19)	064(49)	055(30)	051(23)
32-a	053 042	067 042	044 042	055 043	042 038	069 038	051 040	059 041
	047(11)	054(25)	043(02)	049(12)	040(04)	053(31)	045(11)	050(18)

APPENDIX - TABLE 3

	105-D	105-C	105-B	105-A	104-D	104-C	104-B	104-A
38-d	107 089	111 085	108 079	141 077	122 057	075 057	070 057	068 056
	098(18)	098(26)	093(29)	109(64)	089(65)	066(18)	063(13)	062(12)
38-c	112 069	116 076	111 059	113 055	114 056	058 051	062 051	062 051
	090(43)	096(40)	085(52)	084(58)	085(58)	054(07)	056(11)	056(11)
38-b	128 065	127 061	096 052	094 050	064 046	059 046	054 045	054 045
	096(63)	094(66)	074(44)	072(44)	055(18)	052(13)	049(09)	049(09)
38-a	136 075	138 076	106 074	117 055	078 049	056 046	053 045	047 043
	105(61)	107(62)	090(32)	086(62)	063(29)	051(10)	049(08)	045(04)
37-d	076 075	140 076	130 074	123 067	115 055	062 050	064 047	054 045
	075(01)	108(64)	102(56)	095(56)	085(60)	056(12)	055(17)	049(09)
37-c	075 075	141 075	143 074	115 064	074 059	065 057	063 051	057 049
	075(0)	108(66)	108(69)	089(51)	066(15)	061(08)	057(12)	053(08)
37-b	082 075	085 075	110 077	134 071	136 067	076 059	062 055	057 052
	078(07)	080(10)	093(33)	102(63)	101(69)	067(17)	058(07)	054(05)
37-a	094 074	085 074	122 078	138 077	092 065	076 060	095 058	086 052
	084(20)	079(11)	100(44)	107(61)	078(27)	068(16)	076(37)	069(34)
36-d	094 076	124 072	130 080	125 075	092 068	081 063	086 062	082 062
	085(18)	098(52)	105(50)	100(50)	080(24)	072(18)	074(24)	072(20)
36-c	089 070	120 065	131 082	122 068	083 061	077 059	079 059	088 065
	079(19)	092(55)	106(49)	095(54)	072(22)	068(18)	069(20)	076(23)
36-b	080 060	124 062	123 082	117 068	089 060	068 058	068 057	075 059
	070(20)	093(62)	102(41)	092(49)	074(29)	063(10)	062(11)	067(16)
36-a	087 058	127 072	120 075	102 071	080 061	066 059	061 050	063 056
	072(29)	099(55)	097(45)	086(31)	070(19)	062(07)	055(11)	059(07)
35-d	124 058	131 077	118 070	075 065	085 061	072 053	063 049	060 047
	091(66)	104(54)	094(48)	070(10)	073(24)	062(19)	056(14)	053(13)
35-c	105 065	104 065	099 065	071 062	069 055	065 053	061 042	059 041
	085(40)	084(39)	082(34)	066(09)	062(14)	059(12)	051(19)	050(18)
35-b	075 059	075 062	078 056	067 053	069 050	068 045	053 042	053 039
	067(16)	068(13)	067(22)	060(14)	059(19)	056(23)	047(11)	046(14)
35-a	071 062	074 067	068 057	061 050	056 048	053 045	053 045	055 042
	066(09)	070(07)	062(11)	055(11)	052(08)	049(08)	049(08)	048(13)
34-d	070 061	075 063	067 055	061 052	058 046	051 044	052 044	055 046
	065(09)	069(12)	061(12)	056(09)	052(12)	047(07)	048(08)	050(09)
34-c	066 061	065 062	065 059	063 053	054 048	051 043	049 041	051 042
	063(05)	063(03)	062(06)	058(10)	051(06)	047(08)	045(08)	046(09)
34-b	086 062	075 061	070 058	058 052	056 048	051 044	046 039	045 039
	074(24)	068(14)	064(12)	055(06)	052(08)	047(07)	042(07)	042(06)
34-a	086 059	080 062	069 056	058 050	052 046	047 041	045 038	044 038
	072(27)	071(18)	062(13)	054(08)	049(06)	044(06)	041(07)	041(06)
33-d	081 054	081 061	063 055	057 047	051 043	046 039	043 036	041 038
	067(27)	071(20)	059(08)	052(10)	047(08)	042(07)	039(07)	039(03)
33-c	088 050	096 062	102 057	093 046	050 040	045 036	041 035	041 039
	069(38)	079(34)	079(45)	069(47)	045(10)	040(09)	038(06)	040(02)
33-b	120 050	096 060	075 051	062 047	051 040	043 036	039 035	039 036
	085(70)	078(36)	063(24)	054(15)	045(11)	039(07)	037(04)	037(03)
33-a	088 045	090 068	080 057	062 048	052 040	041 036	037 033	039 034
	066(43)	079(22)	068(23)	055(14)	046(12)	038(05)	035(04)	036(05)
32-d	097 041	096 069	074 057	064 047	051 040	043 036	036 033	037 034
	069(56)	082(27)	065(17)	055(17)	045(11)	039(07)	034(03)	035(03)
32-c	093 040	093 053	070 055	067 047	058 041	045 035	040 032	036 032
	066(53)	073(40)	062(15)	057(20)	049(17)	040(10)	036(08)	034(04)
32-b	055 040	063 044	062 043	067 038	065 040	055 037	042 032	034 030
	047(15)	053(19)	052(19)	052(29)	052(25)	046(18)	037(10)	032(04)
32-a	057 045	072 044	053 038	052 036	074 036	068 038	047 032	034 029
	051(12)	058(28)	045(15)	044(16)	055(38)	053(30)	039(15)	031(05)

APPENDIX - TABLE 4

	103-D	103-C	103-B	103-A	102-D	102-C	102-B	102-A
38-d	061 051	055 049	052 046	050 044	048 042	047 042	045 041	042 039
	056(10)	052(06)	049(06)	047(06)	045(06)	044(05)	043(04)	040(03)
38-c	055 046	053 045	049 044	047 044	044 042	045 039	044 039	042 039
	050(09)	049(08)	046(05)	045(03)	043(02)	042(06)	041(05)	040(03)
38-b	051 044	048 043	046 042	046 042	044 039	042 037	041 037	041 038
	047(07)	045(05)	044(04)	044(04)	041(05)	039(05)	039(04)	039(03)
38-a	047 042	044 041	043 039	043 039	043 037	041 036	038 035	038 033
	044(05)	042(03)	041(04)	041(04)	040(06)	038(05)	036(03)	035(05)
37-d	049 042	048 041	045 041	044 039	044 038	043 038	042 036	038 034
	045(07)	044(07)	043(04)	041(05)	041(06)	040(05)	039(06)	036(04)
37-c	056 046	053 043	051 042	051 042	048 042	046 042	043 039	039 035
	051(10)	048(10)	046(09)	046(09)	045(06)	044(04)	041(04)	037(04)
37-b	056 047	056 044	058 047	055 048	051 045	046 042	043 039	039 036
	051(09)	050(12)	052(11)	051(07)	048(06)	044(04)	041(04)	037(03)
37-a	070 051	069 052	066 047	056 040	051 040	046 041	042 037	039 035
	060(19)	060(17)	056(19)	048(16)	045(11)	043(05)	039(05)	037(04)
36-d	082 056	066 050	058 046	052 044	047 036	044 039	041 037	040 037
	069(26)	058(16)	052(12)	048(08)	041(11)	041(05)	039(04)	038(03)
36-c	087 052	066 054	062 050	059 047	048 044	044 041	041 038	039 036
	069(35)	060(12)	056(12)	053(12)	046(04)	042(03)	039(03)	037(03)
36-b	066 056	064 053	056 049	052 046	047 042	043 040	041 038	039 035
	061(10)	058(11)	052(07)	049(06)	044(05)	041(03)	039(03)	037(04)
36-a	061 046	056 046	053 046	049 044	045 041	042 039	041 038	038 036
	053(15)	051(10)	049(07)	046(05)	043(04)	040(03)	039(03)	037(02)
35-d	056 043	053 043	052 046	048 042	045 038	042 036	040 035	039 034
	049(13)	048(10)	049(06)	045(06)	041(07)	039(06)	037(05)	036(05)
35-c	051 042	050 039	049 040	047 038	044 033	040 032	039 032	038 031
	046(09)	044(11)	044(09)	042(09)	038(11)	036(08)	035(07)	034(07)
35-b	050 038	049 038	043 037	041 035	042 033	040 033	040 033	039 031
	044(12)	043(11)	040(06)	038(06)	037(09)	036(07)	036(07)	035(08)
35-a	053 040	050 039	047 038	045 037	043 038	042 040	041 038	040 036
	046(13)	044(11)	042(09)	041(08)	040(05)	041(02)	039(03)	038(04)
34-d	053 042	053 042	049 041	047 040	044 040	042 039	041 037	039 035
	047(11)	047(11)	045(08)	043(07)	042(04)	040(03)	039(04)	037(04)
34-c	049 043	047 045	047 042	045 041	043 040	041 039	040 038	039 036
	046(06)	046(02)	044(05)	043(04)	041(03)	040(02)	039(02)	037(03)
34-b	046 042	045 041	045 041	044 040	041 038	040 037	039 037	037 036
	044(04)	043(04)	043(04)	042(04)	039(03)	038(03)	038(02)	036(01)
34-a	046 043	045 041	042 039	041 038	040 038	039 037	037 035	036 034
	044(03)	043(04)	040(03)	039(03)	039(02)	038(02)	036(02)	035(02)
33-d	047 041	046 043	044 041	043 039	040 038	038 035	036 034	035 033
	044(06)	044(03)	042(03)	041(04)	039(02)	036(03)	035(02)	034(02)
33-c	044 039	045 043	043 040	042 039	039 037	037 035	036 034	034 033
	041(05)	044(02)	041(03)	040(03)	038(02)	036(02)	035(02)	033(01)
33-b	044 038	044 042	042 039	040 038	039 037	037 035	035 033	034 033
	041(06)	043(02)	040(03)	039(02)	038(02)	036(02)	034(02)	033(01)
33-a	044 038	044 041	041 039	039 037	038 036	036 034	034 032	033 031
	041(06)	042(03)	040(02)	038(02)	037(02)	035(02)	033(02)	032(02)
32-d	044 036	043 037	040 037	038 036	036 034	035 033	033 031	032 030
	040(08)	040(06)	038(03)	037(02)	035(02)	034(02)	032(02)	031(02)
32-c	038 032	040 035	039 035	037 035	035 033	035 031	032 030	031 029
	035(06)	037(05)	037(04)	036(02)	034(02)	033(04)	031(02)	030(02)
32-b	036 030	038 035	037 034	036 032	034 033	033 032	032 030	030 028
	033(06)	036(03)	035(03)	034(04)	033(01)	032(01)	031(02)	029(02)
32-a	036 029	036 032	036 029	033 029	033 030	033 031	031 029	029 028
	032(07)	034(04)	032(07)	031(04)	031(03)	032(02)	030(02)	028(01)

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