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STATISTICS OF U.S. TORNADOES BASED ON THE DAPPLE (Damage Area Per Path LEngth) TORNADO TAPE

Jaime J. Tecson and T. Theodore Fujita

The University of Chicago
Chicago, Illinois

and

Robert F. Abbey, Jr.

U.S. Nuclear Regulatory Commission
Washington, D.C.

1. INTRODUCTION

Under the sponsorship of the Nuclear Regulatory Commission, two independent assessments of tornado characteristics, based on published tornado reports, newspaper clippings, aerial and ground surveys, and other sources are being updated. The data on tape, called NSSFC (National Severe Storms Forecast Center) tape, is produced by NSSFC/NOAA, under the supervision of A.D. Pearson. On the other hand, the data, also stored on tape and called DAPPLE (Damage Area Per Path LEngth) tornado tape, is being kept current at the University of Chicago under the direction of T.T. Fujita.

These assessments are expected to be different as they are primarily intended. In this respect, the task of comparing the two independent sets of data is being handled by the Institute of Disaster Research, Texas Tech University.

This paper presents the results obtained from the DAPPLE tornado tape, which now contains data on 24,930 tornadoes reported in the Continental United States during the 63-year period, 1916 to 1978.

2. DATA BASE AND DAPPLE FORMAT

The DAPPLE tornado tape contains, for each tornado and in coded form, such information as the final identificaton number, year, original identification number, month, day, time of touchdown in CST (Central Standard Time), deaths, injuries, F-scale (Fujita, 1971), path length and mean width (Fujita and Pearson, 1973), path type and direction of movement. Beginning in 1975, the data include the state. The locations of tornado paths are coded for every 15' latitude and 15' longitude sub-box. Each sub-box is identified by the 1° latitude-longitude grid in which it is contained.

The data source come basically from the Report of the Chief of the Weather Bureau (until 1934), the Monthly Weather Review (until 1949), the various Climatological Data and Storm Data publications of the Department of Commerce (subsequently ESSA, NOAA). Where aerial and ground surveys were conducted, mainly by the University of Chicago group under T.T. Fujita, such information were used. Newspaper reports and personal communications were also availed of.

3. RESULTS OBTAINED FROM DAPPLE

3.1 Annual Frequencies of U.S. Tornadoes by F-scale

Since 1916, when the official collection of U.S. tornado data began, 24,930 tornadoes had been reported by the end of 1978. The average frequency during these 63 years was 396. On the average, only 98 tornadoes per year were reported during the 1910's. The annual frequencies increased gradually, and in the 1940's, the average was 165 per year. In the 1950's, a significant jump in frequency occurred; from 202 in 1950 to 605 in 1959. This increasing trend has continued since then, and in 1973, 1,110 tornadoes--the highest in U.S. history--were reported (see Fig. 1).

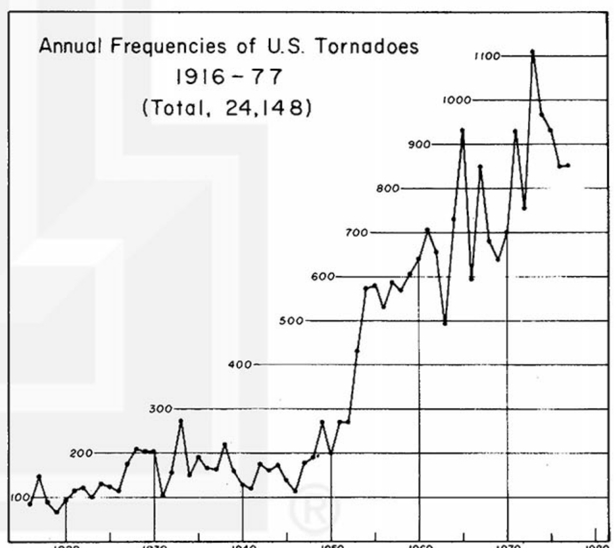

Fig. 1. Annual frequencies of U.S. tornadoes, 1916-1977. There were 782 reported in 1978, updating the total to 24,930. Note the increasing trend starting in the 1950's.

The increase in the reported frequencies is attributed to improved data reporting and collecting efficiency thru public awareness, the communications system, the increase in population density, among others.

The F-scale breakdown in tornado frequencies in Fig. 2 reveals a tremendous increase in the F0 and F1 tornadoes; while the stronger tornadoes, such as F2, F3, and F4 have increased less significantly. The F5 tornadoes, on the contrary, have decreased since 1916, suggesting that reporters over-emphasized and exaggerated the phenomena of violent tornadoes. So far, there seems no reason to believe that the 'true activities' of tornadoes have increased during the past 63 years.

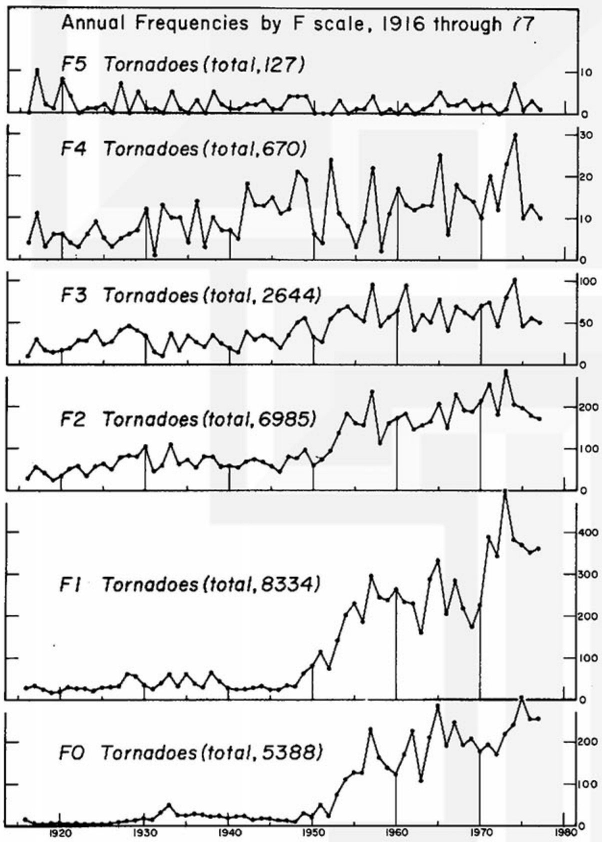

Fig. 2. Annual frequencies of U.S. tornadoes, by F-scale, 1916-1977. Data for 1978 are: F0-330, F1-311, F2-117, F3-21, F4-3, and F5-0.

3.2 Touchdown Frequencies by Day-of-Week

Touchdown frequencies or occurrences by day-of-week is presented in Table 1. To find out if frequency counts depend much on the day of the week, a statistical test of significance was made, based on the null hypothesis that the differences among the samples (the day of the week) is attributable to sampling variation alone. The F ratio test thus employed is calculated by

$$F = \frac{\hat{\sigma}^2 \text{ among groups}}{\hat{\sigma}^2 \text{ within groups}} \qquad (1)$$

where $\hat{\sigma}^2$ is the estimate of variance (Senter, 1969). In the case where all tornadoes were combined, F = 0.127, df 6/62; $p > .05$. The decision, therefore, will be to fail to reject the null ($p > .05$). Similar decisions hold for the other categories in the table.

We may conclude that touchdown frequencies of tornadoes, whether weak (F0+F1), strong (F2+F3), violent (F4+F5), or all combined, do not seem to be affected by the day of the week.

F-scale	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Total
F0 + F1	2,048	2,087	2,038	1,987	2,212	2,113	1,875	14,360
in (%)	(14)	(15)	(14)	(14)	(15)	(15)	(13)	(100)
F2 + F3	1,412	1,436	1,315	1,407	1,354	1,480	1,363	9,767
in (%)	(14)	(15)	(13)	(14)	(14)	(15)	(14)	(100)
F4 + F5	110	113	102	144	108	122	101	800
in (%)	(14)	(14)	(13)	(18)	(14)	(15)	(13)	(100)
All Tornadoes	3,570	3,636	3,455	3,538	3,674	3,715	3,339	24,927
in (%)	(14)	(15)	(14)	(14)	(15)	(15)	(13)	(100)

Table 1. Touchdown frequencies of U.S. tornadoes by day-of-week for the 63 year period, 1916-1978. Note that three tornadoes have unreported days.

3.3 Definition and Path Length of Mean U.S. Tornadoes

A mean tornado, in this report, is defined as a hypothetical tornado characterized by averaged parameters of a specified group of tornadoes. Such a group can be specified by its period and area of occurrence, as well as the F-scale intensity. Path length and path width are basic parameters that may be averaged. Specific area may be the Continental United States, any individual state or any area of specification. Since, on the average, stronger tornadoes are likely to leave behind longer paths than weaker ones, mean path lengths and/or path widths may be computed as a function of F-scale.

A mean tornado is identified, for example as:

Mean F1 U.S. tornado for 1916-1978
Mean F3 Iowa tornado for 1930-1939
Mean U.S. tornado, F0 through F5, for 1916-1978.

The path length of the third example listed above was computed as

$$\bar{L} = \frac{\Sigma L}{\Sigma N} \qquad (2)$$

where ΣL is the total path length of all U.S. tornadoes; ΣN, the total touchdown frequency; and $\bar{L}$, the path length of mean U.S. tornadoes for all F-scale categories combined.

The path length of the mean U.S. tornado, F0 through F5, during the 1916-1978 period thus computed is 4.67 miles. In other words, 24,930 tornadoes left behind a total path length of 116,435 miles. Since the path lengths of mean tornadoes are likely to vary with the F-scale, path lengths were calculated for each F-scale (see Table 2).

The results in this table reveal a significant increase in the path length of the mean tornado, from 1.41 miles (F0) to 28.55 miles (F5). The mean F5 tornado is approximately 20 times longer than the F0 type.

F-scale	Touchdown Frequencies (ΣN)	Total Path Length (mls) (ΣL)	Path Length of Mean Tornado (mls), ($\bar{L}$)	Number of Mean Tornadoes
0	5,718	8,059	1.41	5,718
1	8,645	25,426	2.94	8,645
2	7,102	39,459	5.56	7,102
3	2,665	27,306	10.25	2,665
4	673	12,559	18.66	673
5	127	3,626	28.55	127
All Tornadoes	24,930	116,435	4.67	24,930

Table 2. Touchdown frequencies, total path lengths (mls), path length of mean tornadoes (mls) and number of mean U.S. tornadoes for the 63-year period, 1916-1978. The total touchdown frequency and number of mean tornadoes are identical by definition.

The 1.41-mile length of the mean F0 tornado appears to be longer than one would expect. It is because, in the calculations, tornadoes reported as 'short' are considered as 0.5 miles long each. This decision was made by Fujita, who found out through his extensive aerial surveys that, in practically all instances, even the smallest reported tornado can be followed for a distance of a few tenths of a mile before and after the reported damage location. This decision, naturally, increased the path length of the mean F0 tornadoes to longer than 0.5 mile.

Touchdown frequencies by F-scale shown in Table 2 is presented in Fig. 3. The maximum occurrence of tornadoes belong to the F1 category.

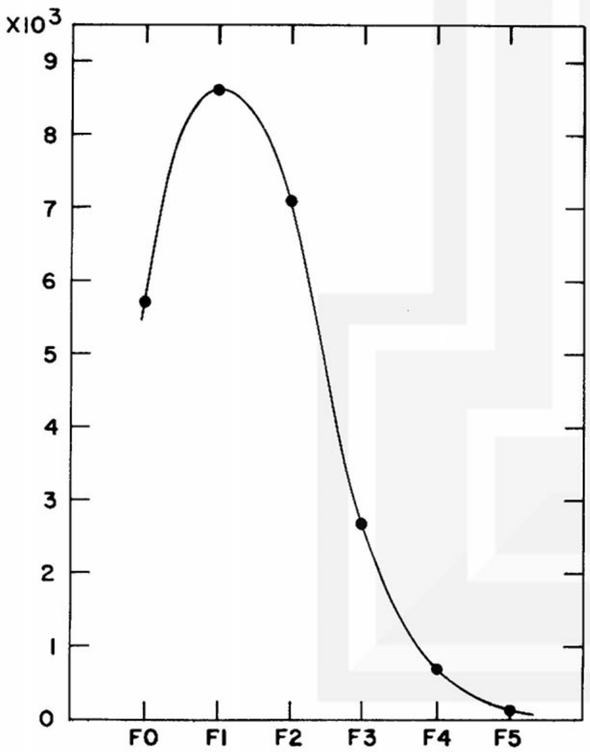

Fig.3 Total touchdown frequency of U.S. tornadoes, by F-scale, for the 63-year period, 1916-1978. Maximum occurrence is caused by F1 tornadoes.

The path length of the mean U.S. tornado, by F-scale, appears in Fig. 4. It is evident that the path length of mean U.S. tornadoes increases almost exponentially as the F-scale also increases.

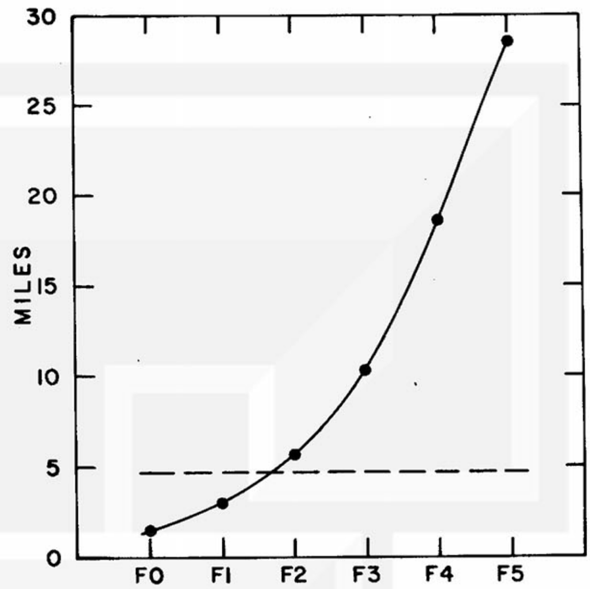

Fig. 4. Path lengths (mls) of mean U.S. tornadoes, by F-scale, for the 63-year period, 1916-1978. The path length of the mean U.S. tornado, F0 through F5, is 4.67 miles.

3.4 Distribution of Touchdown Frequencies and Number of Mean U.S. Tornadoes

The touchdown frequency, N, and the path length, P, within a Marsden square of given latitude increment ($\Delta\phi$) and longitude increment ($\Delta\theta$) can be computed using the DAPPLE tornado tape, which include this information within each of the approximately 12,734 squares of land area, 15' x 15'. Both $\Delta\phi$ and $\Delta\theta$ in the following equation, therefore, should be equal to or larger than 15'.

$$N = \sum_{\phi}^{\phi+\Delta\phi} \sum_{\theta}^{\theta+\Delta\theta} n \quad (3)$$

and

$$P = \sum_{\phi}^{\phi+\Delta\phi} \sum_{\theta}^{\theta+\Delta\theta} p \quad (4)$$

where n is the number or count of tornadoes and p is the path length of each tornado within the said $\Delta\phi \times \Delta\theta$ sub-box. In this manner, it is possible to compute N and P for every degree square of latitude and/or longitude in the United States.

Since computer printouts are most efficiently formatted to present data in rectangular coordinate fashion, it becomes most convenient, therefore, to present and analyze U.S. tornado data if the U.S. map was distorted to best fit the computer-printout coordinate (CPC) layout. (Refer to Fujita, 1978a).

As a particular case, a running 4-point (15') total within a 1° latitude overlapping Marsden square, can be computed and printed out using

$$P_{\phi,\theta} = \sum_{\phi-.5°}^{\phi+.5°} \sum_{\theta}^{\theta+1°} P \qquad (5)$$

by changing ϕ = 25°00', 25°15',..... 49°00' N and

θ = 68°, 69°,.........124°, 125° W.

The same technique applies for calculating N.

The values of $P_{\phi,\theta}$ were normalized to the area of one-degree square at latitude 37° N, with its unique area of 3814 sq. miles, by

$$\overline{P}_{\phi,\theta} = P_{\phi,\theta} \frac{\cos 37°}{\cos \phi} \qquad (6)$$

where $\overline{P}_{\phi,\theta}$ is the latitude-corrected path length.

Presented in Fig. 5 are direct printouts of 4-point (or 15') running totals computed for every degree square of latitude from 25° to 49° N and 68° to 125° W. The upper chart shows the touchdown frequencies, while the lower shows the number of mean F0+F1 tornadoes covering the 63-year period, 1916-1978. The CPC map coordinates are superimposed.

Figure 6 shows the isolines of touchdown frequencies and number of mean tornadoes obtained by analyzing F0 through F5 tornadoes. The locations of the largest touchdown frequencies are related to the sites of large cities with tornado-conscious population (see upper chart). Hereunder is the list of touchdown frequency/identified city relationship:

Touchdown Frequency	City and State	Touchdown Frequency	City and State
200	Oklahoma City, OK	116	Indianapolis, IA
175	Tampa, FL	116	Des Moines, IA
161	Dallas-Ft. Worth	112	Miami, FL
147	Kansas City, MO	111	Little Rock, AR
137	Houston, TX	103	Birmingham, AL
128	Lubbock, TX	103	Austin, TX

In the lower chart in Fig. 6, the distribution of the peak number of mean tornadoes are slightly less affected by the existence of cities because the number of mean tornadoes is less sensitive than the simple, numerical counts of touchdown frequencies. Unfortunately, however, even the mean tornado is affected by the cities and population because the denser the population, the longer the confirmed tornado path length. The relationship between the peak number of mean tornadoes and the identified cities are:

No. of Mean Tornadoes	City and State	No. of Mean Tornadoes	City and State
195	Wichita, KS	156	Kansas City, MO
193	Jackson, MS	153	Huntsville, AL
181	Little Rock, AR	122	Chicago, IL
178	Des Moines, IA	114	Nashville, TN
164	Lubbock, TX	112	Tampa, FL
158	Oklahoma City,	105	Dallas-Ft. Worth

Figures 7 and 8 are CPC map printouts of touchdown frequencies and number of mean tornadoes for strong (F2+F3) and violent (F4+F5) tornadoes, respectively, covering the same 63-year period.

Lack of space prevents inclusion of analyses of running totals, latitude-wise and for every degree, of touchdown frequencies and path lengths of tornadoes produced in the CPC map format. They are the bi-monthly and 3-hourly (LST) distributions for the period 1916-1977 (Fujita, 1978a).

4. CONCLUSIONS

Two major products of tornado maps from DAPPLE tape data are distributions of (1) touchdown frequencies and (2) number of mean tornadoes. It was found that the center of touchdown frequency is located at central Oklahoma, while the maximum number of mean tornadoes is situated, instead, in Kansas.

Since the 63-year period of tornado data is still affected by the population distribution, there is a need to relate the isolines in Fig. 6 to the population distribution. The population correction factor, experimented by Fujita (1978b) requires the estimates of population in each 15' x 15' sub-box. It may soon become necessary to expand and generalize the contents of the DAPPLE tornado tape to eventually include population, topography, and other parameters.

Despite the need for additional parameters, the DAPPLE tape can readily be used in assessing the tornado risk by NRC ad engineering communities by means of the DAPPLE method. This is the subject of a paper by Abbey and Fujita (1979) in this preprint volume.

Acknowledgement

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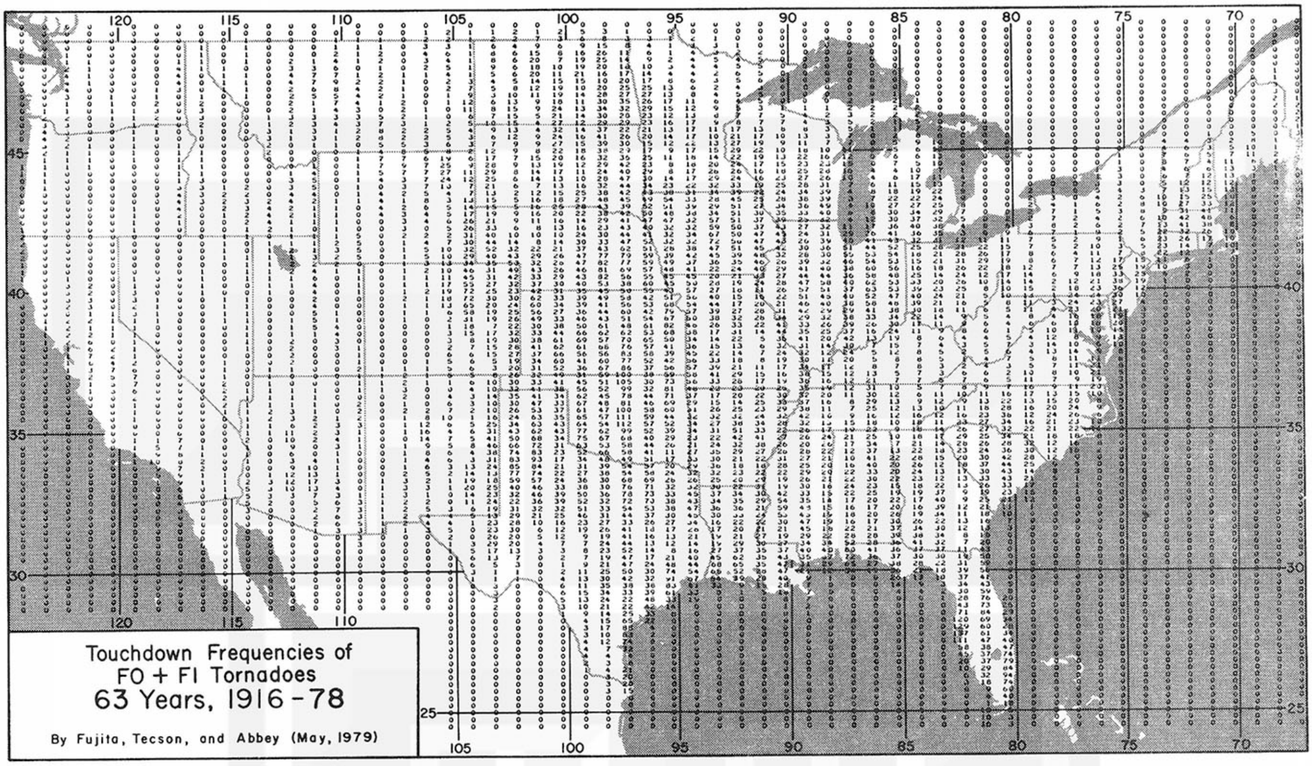


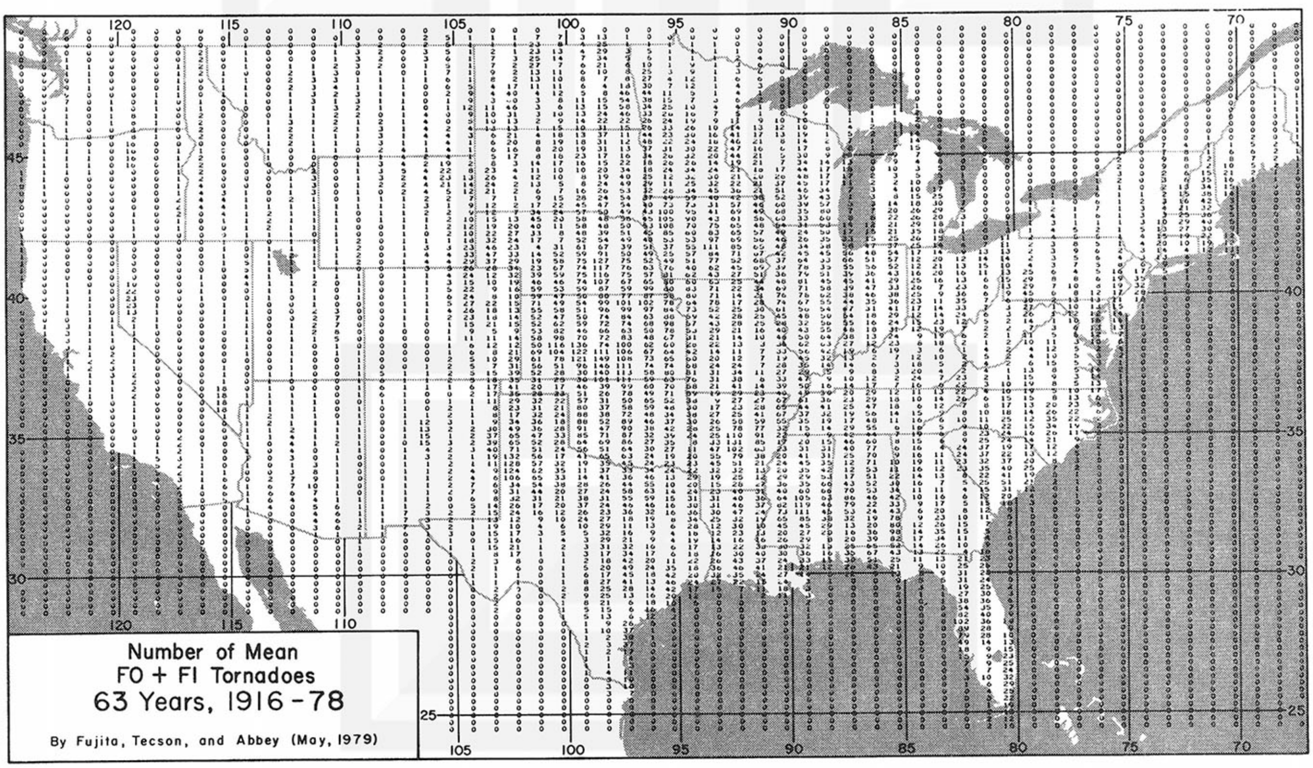
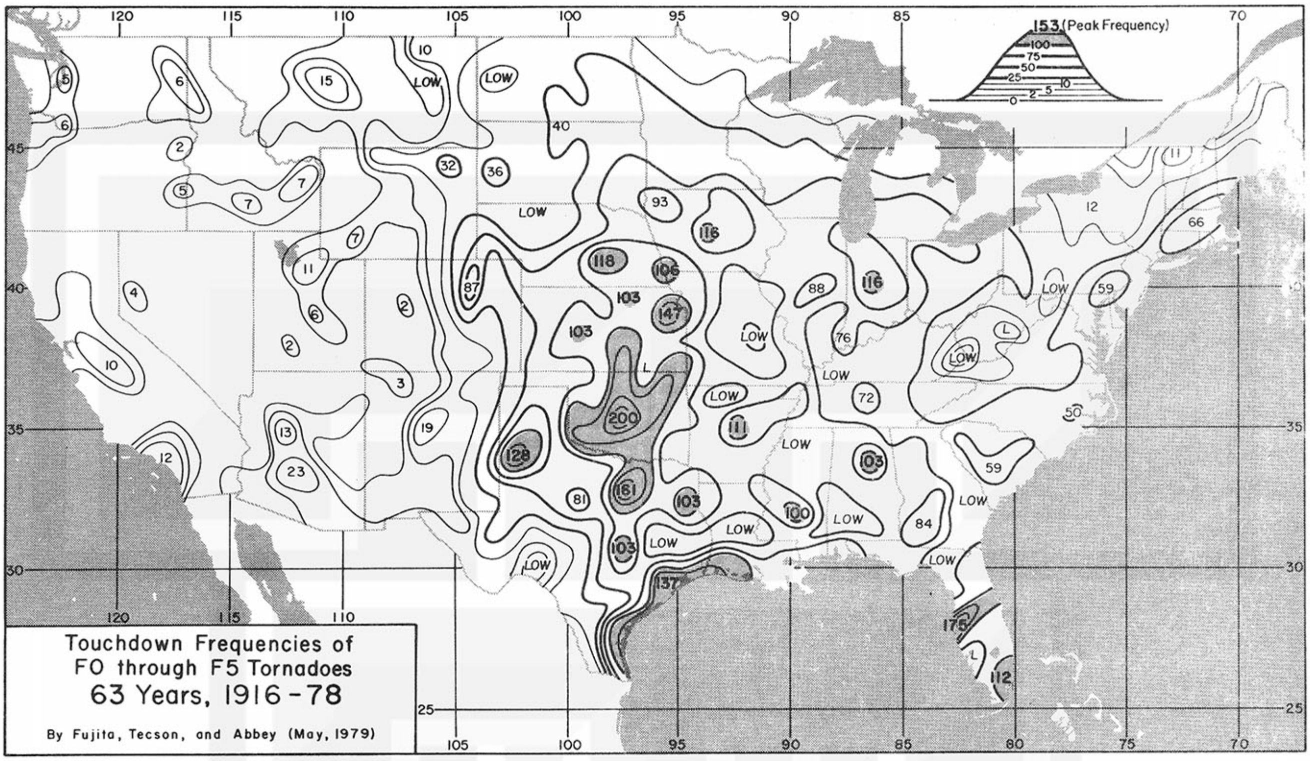


Fig. 5. Touchdown frequencies (top) and number of mean F0+F1 U.S. tornadoes (bottom) covering the 63-year period, 1916-1978. The CPC (computer-printout coordinate) map shown. Each value, printed for every 15-min. latitude and every degree longitude, is the total for one degree, which is centered at that particular subbox. The number of mean tornadoes for combined F-scale categories is the sum of the individual mean tornado value of each category specified.



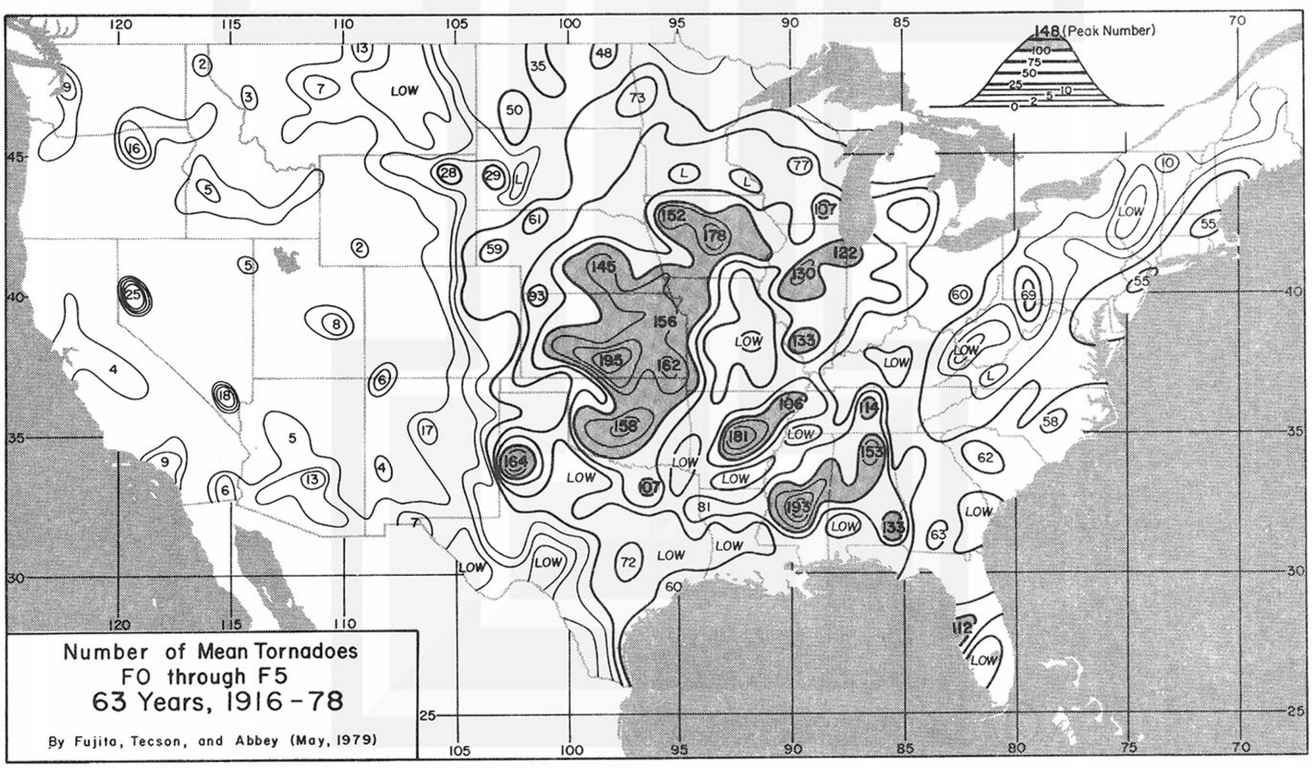
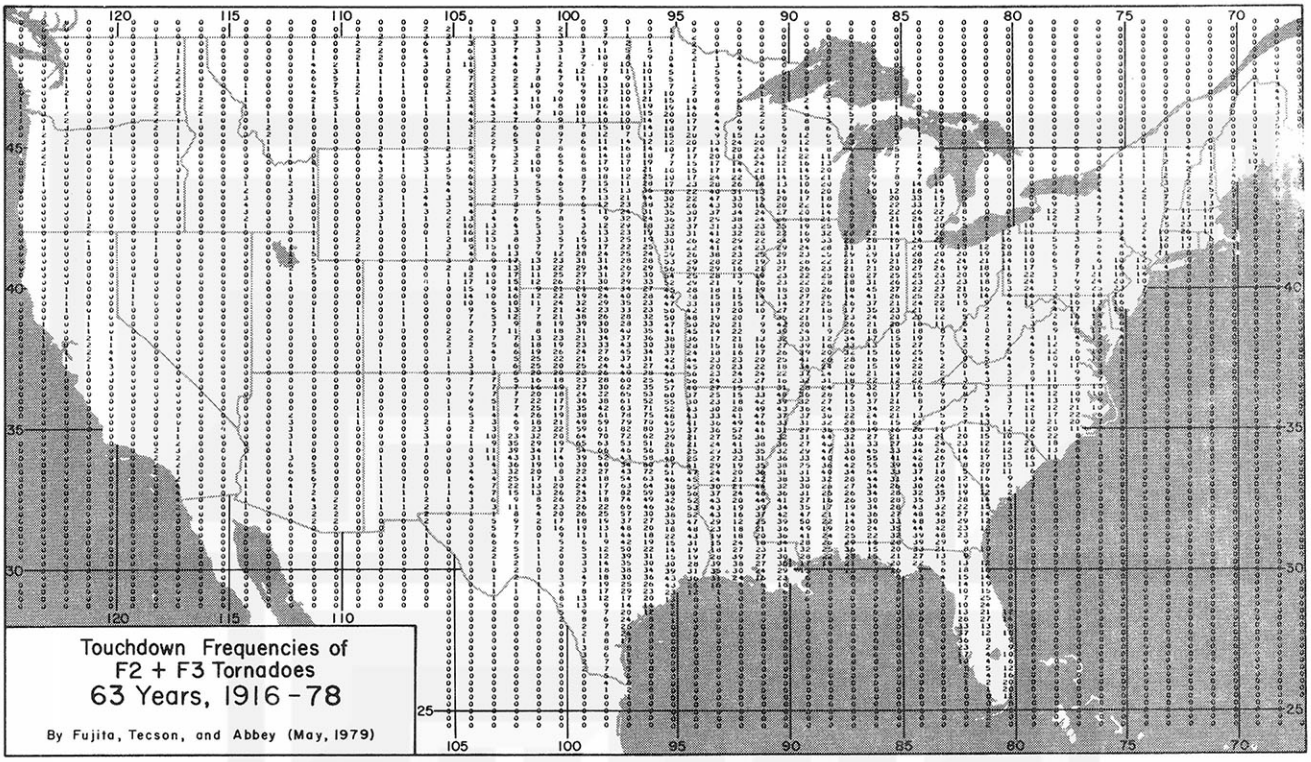


Fig. 6. Isolines of touchdown frequencies (top) and number of mean U.S. tornadoes (bottom), F0 through F5, obtained by analyzing computer printout data. Note the association of maximum values with location of urban areas.



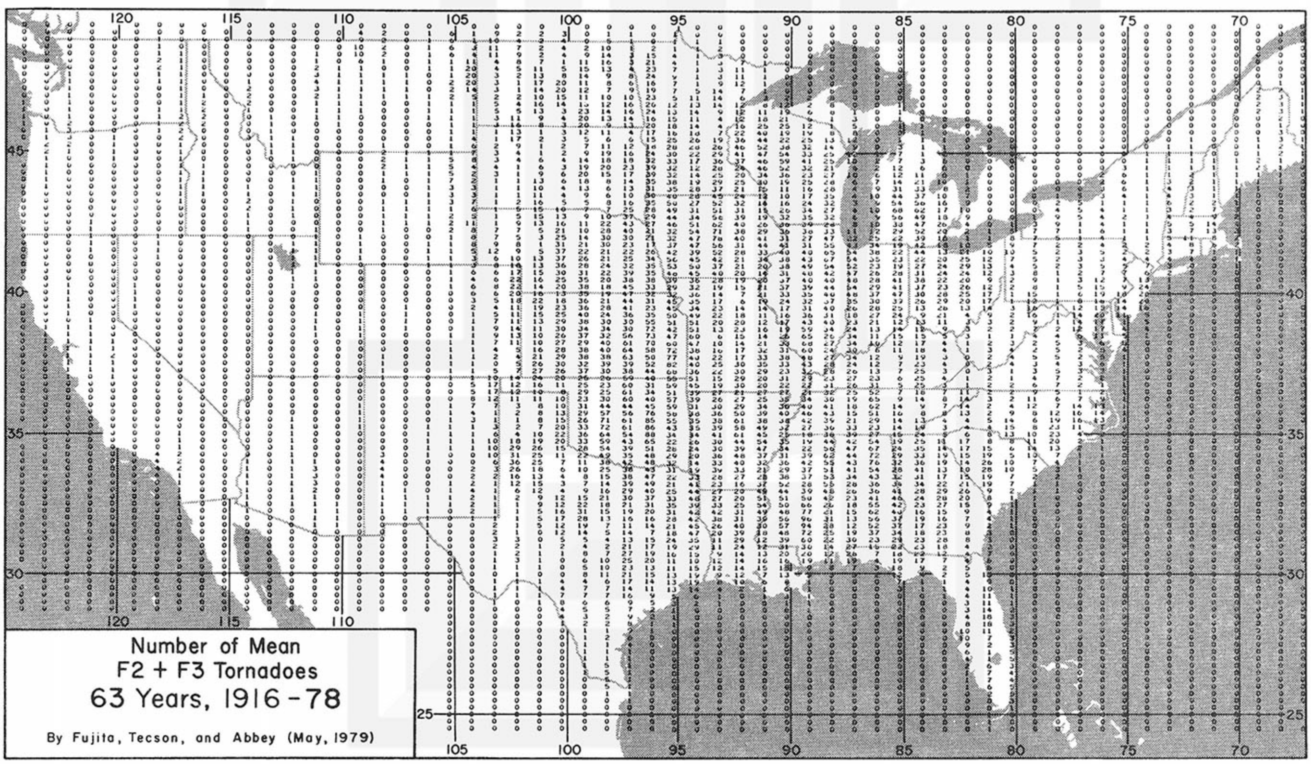
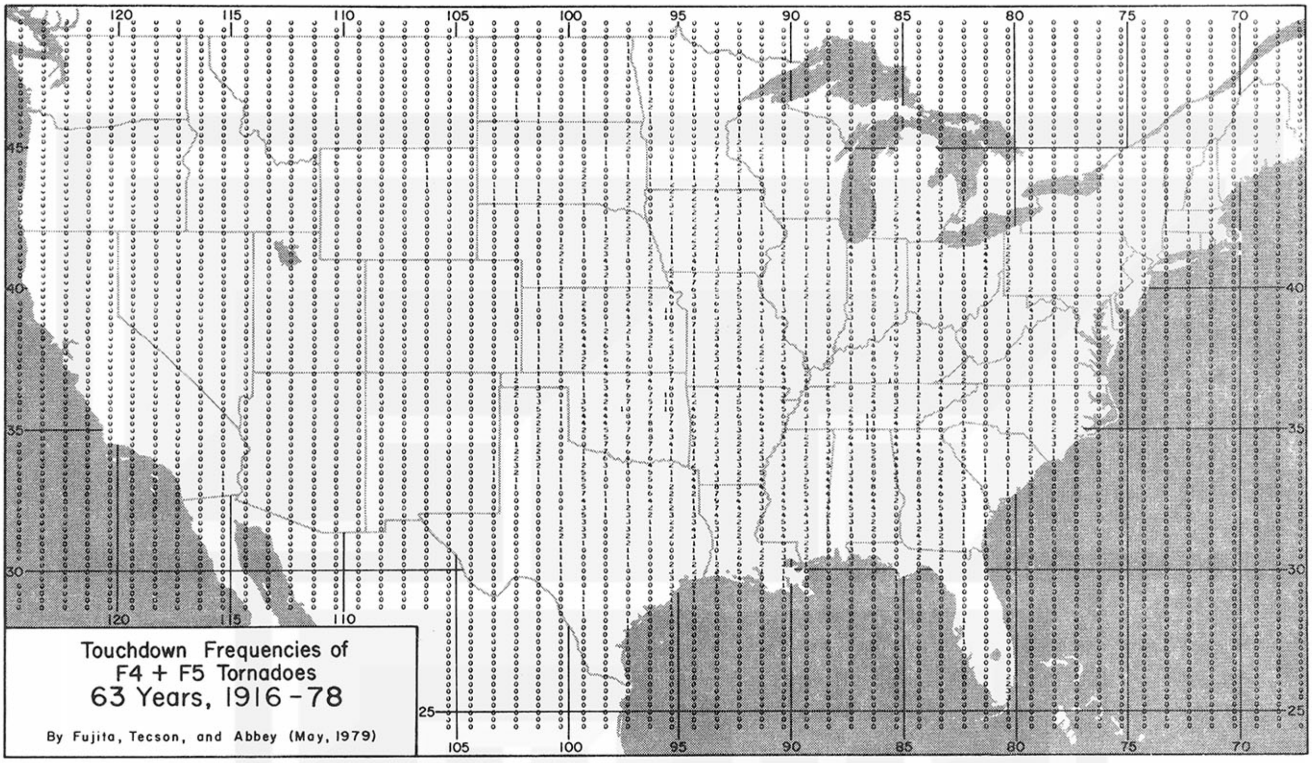


Fig. 7. Touchdown frequencies (top) and number of mean U.S. tornadoes (bottom), F2+F3, covering the 63-year period, 1916-1978. Occurrence of these strong tornadoes comprise 39 % of all touchdowns. Similar to Fig. 5, this is the direct computer printout. The CPC map is superimposed.



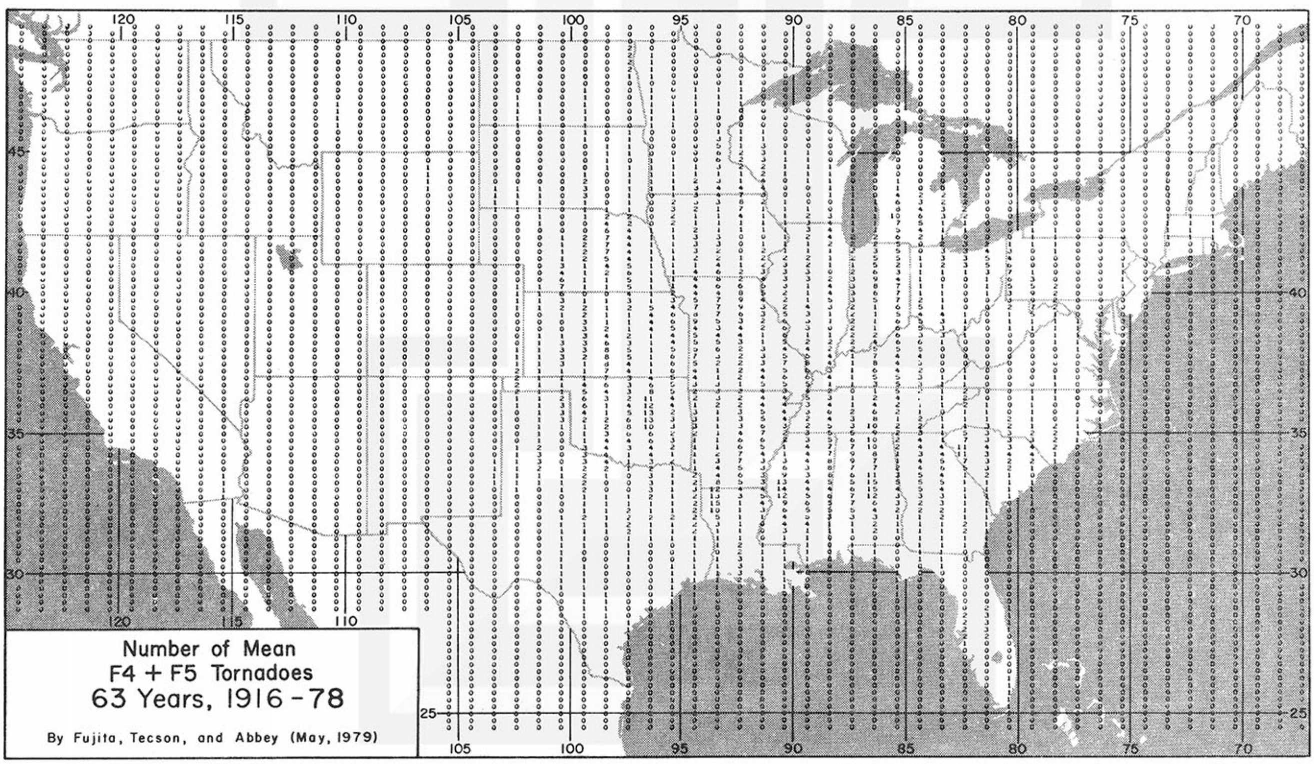


Fig. 8. Touchdown frequencies (top) and number of mean U.S. tornadoes (bottom), F4+F5, covering the 63-year period, 1916-1978. Occurrence of these violent tornadoes comprise 3 % of all touchdowns. Similar to Fig. 5, this is the direct computer printout. The CPC map is superimposed.