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REVIEW OF SEVERE WEATHER METEOROLOGY

at

BATTELLE MEMORIAL INSTITUTE
COLUMBUS, OHIO

by

T. Theodore Fujita
Professor of Meteorology
The University of Chicago

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1. INTRODUCTION

The Battelle Memorial Institute, Columbus, Ohio is located just to the west of the Big Darby Creek at 83°15'W and 39°58'N. The elevation of the site, estimated from the West Jefferson Quadrangle 7.5 minute topographic map, is 910 ft MSL.

As shown in Figure 1, the overall topography within the 10-mile range is flat, sloping up slightly toward the west. There are no mountains or hills of significant height which might induce orographic upslope or downslope currents. For most design purposes, the environment of this site may be regarded as being flat.

According to Pautz (1969),(1) the SELS Log reported 18 occurrences of 50 kt and greater windstorms and 20 tornadoes within the one-degree box of latitudes and longitudes which includes the Battelle site. It is the purpose of this review to determine the intensity of severe weather events which could affect this location, with return periods ranging between one and ten million years.

Both straight-line winds and tornadoes are regarded as prime phenomena, because no hurricane with significant winds has ever been reported in this area.

This site is located in Region II of WASH-1300.(2) The calculated tornado windspeed by five-degree squares for 10^{-7} per year probability is 340 mph.

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(1) Pautz, Maurice E. (1969): Severe Local Storm Occurrences, 1955-1967. ESSA Tech. Memo WBTM FCST 12.

(2) WASH-1300 by Markee, E. H., Jr., J. G. Beckerley, and K. E. Sanders (1974): Technical Basis for Interim Regional Tornado Criteria. U.S. Atomic Energy Commission, Office of Regulation.

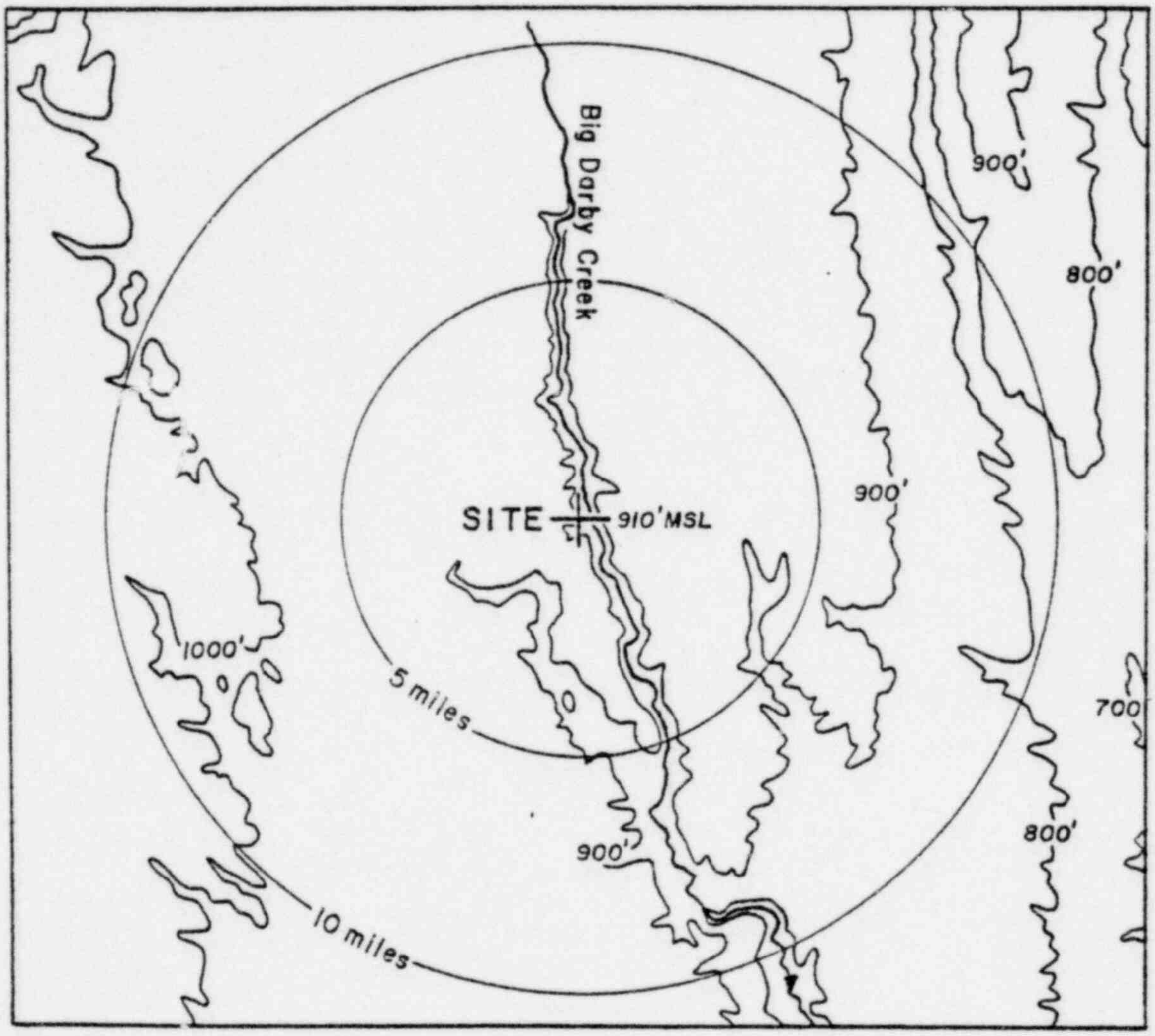

Figure 1. Battelle Memorial Institute and vicinity. The Institute is located just to the west of the Big Darby Creek. The elevation of the site is 910 ft MSL. Height contours in this map were drawn at 100-ft intervals.

2. STRAIGHT-LINE WINDS

Straight-line winds occur more frequently than tornadoes, but their interpretation and evaluation are difficult. "Climatological Data"(1) includes Columbus and Dayton, Ohio from which the fastest-mile windspeeds of the year (and month) are available.

Presented in Table 1 are the maximum fastest-mile windspeeds of each year between 1950 - 76 at both Columbus and Dayton, Ohio. It should be noted that windspeeds are highly dependent upon the anemometer environment and exposure (including the height) of the instrument.

The mean speed at Columbus is 48.4 mph which is 4.1 mph lower than the 52.5 mph mean speed at Dayton, Ohio. The two stations are 71 miles apart and their elevations are 1115 ft (Columbus) and 1274 ft (Dayton).

Table 1. Maximum fastest-mile windspeeds in mph by year at Columbus and Dayton, Ohio during the 27-year period, 1950-76. From Climatological Data for these years.

Years	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
Columbus	57	44	61	43	49	63	57	48	42	56
Dayton	78	56	62	51	56	61	56	49	56	63

Years	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Columbus	42	40	45	44	54	56	47	54	42	36
Dayton	56	59	39	53	43	41	45	60	43	40

Years	1970	1971	1972	1973	1974	1975	1976	Mean speeds
Columbus	56	47	41	42	52	37	51 mph	48.4 mph
Dayton	61	56	52	47	47	42	45 mph	52.5 mph

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(1) Climatological Data. Publication of NOAA, published monthly with an Annual Summary. May be obtained from Environmental Data Service, National Climatic Center, Federal Building, Asheville, North Carolina 28801.

In order to combine the fastest-mile speeds from these two stations and obtain windspeed probabilities, speeds were normalized by multiplying the following ratios,

$$\frac{\text{Mean of Columbus and Dayton}}{\text{Mean at Columbus}} = \frac{50.45}{48.4} = 1.04 \quad \text{(for Columbus)}$$

and

$$\frac{\text{Mean of Columbus and Dayton}}{\text{Mean at Dayton}} = \frac{50.45}{52.5} = 0.96 \quad \text{(for Dayton)}$$

Windspeeds computed by multiplying each of these ratios by the fastest-mile speeds from each station are called the "normalized fastest-mile windspeeds". They are then used in obtaining the statistical results presented in this review.

In central Ohio, the fastest-mile winds of the year in the cold seasons (late autumn, winter and early spring) are the result of well-developed continental cyclones. The fastest-mile winds in the warm seasons (late spring, summer, and early autumn) are often caused by so-called "straight-line winds" induced by severe thunderstorms.

Table 2 was prepared to show the seasonal variation of the fastest-mile winds of the year by month. April through September are regarded as warm seasons and October through March, as cold seasons.

Table 2. Normalized fastest-mile windspeeds of the year obtained by making the mean-speed correction. Speeds are tabulated by month. 27-year period at Columbus and Dayton, Ohio.

Months	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
	58	58	74	53	43		53	63	48	58	59	65 mph
	54	56	50	51	43			59	45	53	59	60
	53	50	48	49				58	43	46	57	58
	53	39	43	44				47		43	56	53
	45		38	42				37			56	49
	41			38							53	45
	41										43	45
	40										37	41
Maximum	58	58	74	53	43		53	63	48	58	59	65 mph

Table 3. Probabilities of normalized fastest-mile speeds of the year during warm seasons (April-September), cold seasons (October-March), and all year. Frequencies (Freq.), cumulative frequencies (Cum.), and probabilities per year (Prob.) are tabulated. 27-year period, 1950-76, at Columbus and Dayton, Ohio.

Normalized	Warm Seasons			Cold Seasons			All Seasons		
Windspeeds	Freq.	Cum.	Prob.	Freq.	Cum.	Prob.	Freq.	Cum.	Prob.
37 mph	0	25	0.46 yr^{-1}	2	29	0.54 yr^{-1}	2	54	1.00 yr^{-1}
38	2	25	0.46	0	27	0.50	2	52	0.96
39	1	23	0.41	0	27	0.50	1	50	0.93
40	1	22	0.41	0	27	0.50	1	49	0.91
41	2	21	0.39	1	27	0.50	3	48	0.89
42	1	19	0.35	0	26	0.48	1	45	0.83
43	3	18	0.33	3	26	0.48	6	44	0.81
44	1	15	0.28	0	23	0.43	1	38	0.70
45	1	14	0.26	3	23	0.43	4	37	0.69
46	0	13	0.24	1	20	0.37	1	33	0.61
47	0	13	0.24	1	19	0.35	1	32	0.59
48	1	13	0.24	1	18	0.33	2	31	0.57
49	1	12	0.22	1	17	0.31	2	29	0.54
50	2	11	0.20	0	16	0.30	2	27	0.50
51	1	9	0.17	0	16	0.30	1	25	0.46
52	0	8	0.15	0	16	0.30	0	24	0.44
53	3	8	0.15	4	16	0.30	7	24	0.44
54	1	5	0.093	0	12	0.22	1	17	0.31
55	0	4	0.074	0	12	0.22	0	16	0.30
56	1	4	0.074	2	12	0.22	3	16	0.30
57	0	3	0.056	1	10	0.19	1	13	0.24
58	2	3	0.056	3	9	0.17	5	12	0.22
59	0	1	0.019	3	6	0.11	3	7	0.13
60	0	1	0.019	1	3	0.056	1	4	0.074
63	0	1	0.019	1	2	0.037	1	3	0.056
65	0	1	0.019	1	1	0.019	1	2	0.037
74	1	1	0.019	0	0	0.000	1	1	0.019

From a meteorological point of view, one may assume the maximum windspeeds of a continental cyclone to be 70 to 80 mph, which correspond to the low F 1 scale or low hurricane winds. The maximum possible windspeeds of straight-line winds have not been known very well, but they could reach the 90 to 100 mph range or even higher. The Northern Wisconsin downbursts of the 4th of July, 1977 were estimated to be up to low F 2 or 110 to 120 mph fastest-1/4 mile speed.

Due to anticipated differences in the nature of winds in warm and cold seasons, their probabilities were first computed separately. They were then combined into all-season probabilities (see Table 3).

Figure 2 reveals the trend of probabilities given in Table 3. Apparently, the windspeeds in cold seasons tend to saturate at or with 10^{-3} to 10^{-4} $year^{-1}$ probabilities, while those in warm seasons keep increasing with decreasing probability. These results indicate that 1.0 to 0.1 per year probability is dominated by the winds in cold seasons (continental cyclone origin). A 0.01 per year probability or lower is, however, dominated by the winds in warm seasons, which are induced by severe convective storms.

Table 4. Frequencies of fastest-mile wind directions by seasons. During warm seasons west-northwesterly winds of connective origin dominate frequencies; while in cold seasons west-southwesterly winds of continental cyclone origin dominate frequencies.

Wind directions	E	SE	S	SW	W	NW	N	NE	Unknown	Total
Warm seasons	0	1	1	5	7	9	1	0	1	25
Cold seasons	0	0	2	12	11	3	1	0	0	29
All seasons	0	1	3	17	18	12	2	0	1	54

Directions of the fastest-mile winds in Table 4 also reveal a major difference between warm- and cold-season winds. During the cold seasons, directions are predominatnly from southwest to west, while those in warm seasons are from west to northwest (see Figure 3).

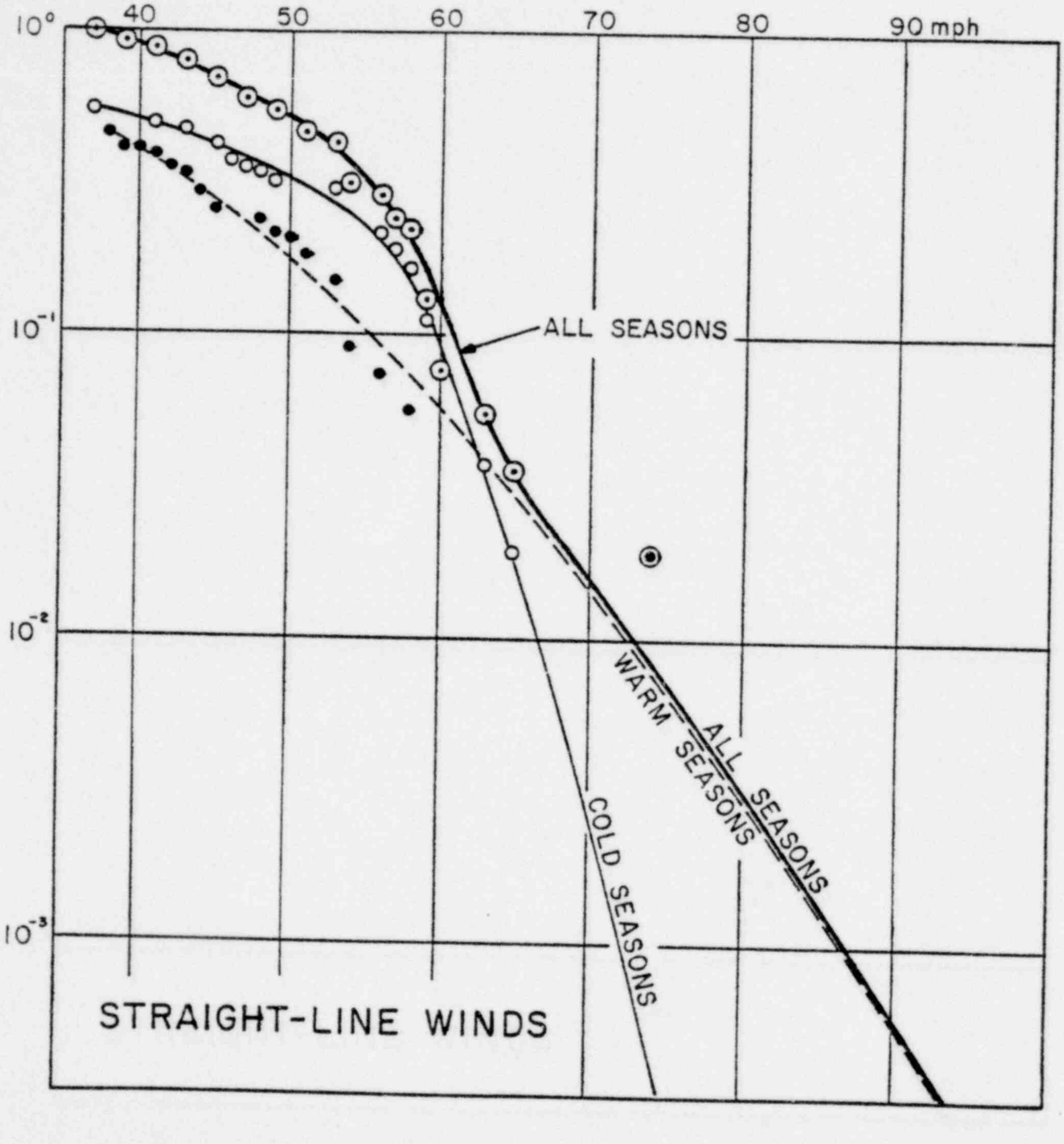

Figure 2. Probabilities of the speeds of the fastest-mile winds of the year at Columbus and Dayton, Ohio. Based on a 27-year record, 1950-76. Probabilities were estimated by separating the speeds in warm and cold seasons, because the nature of winds is apparently different in these seasons. From Table 3.

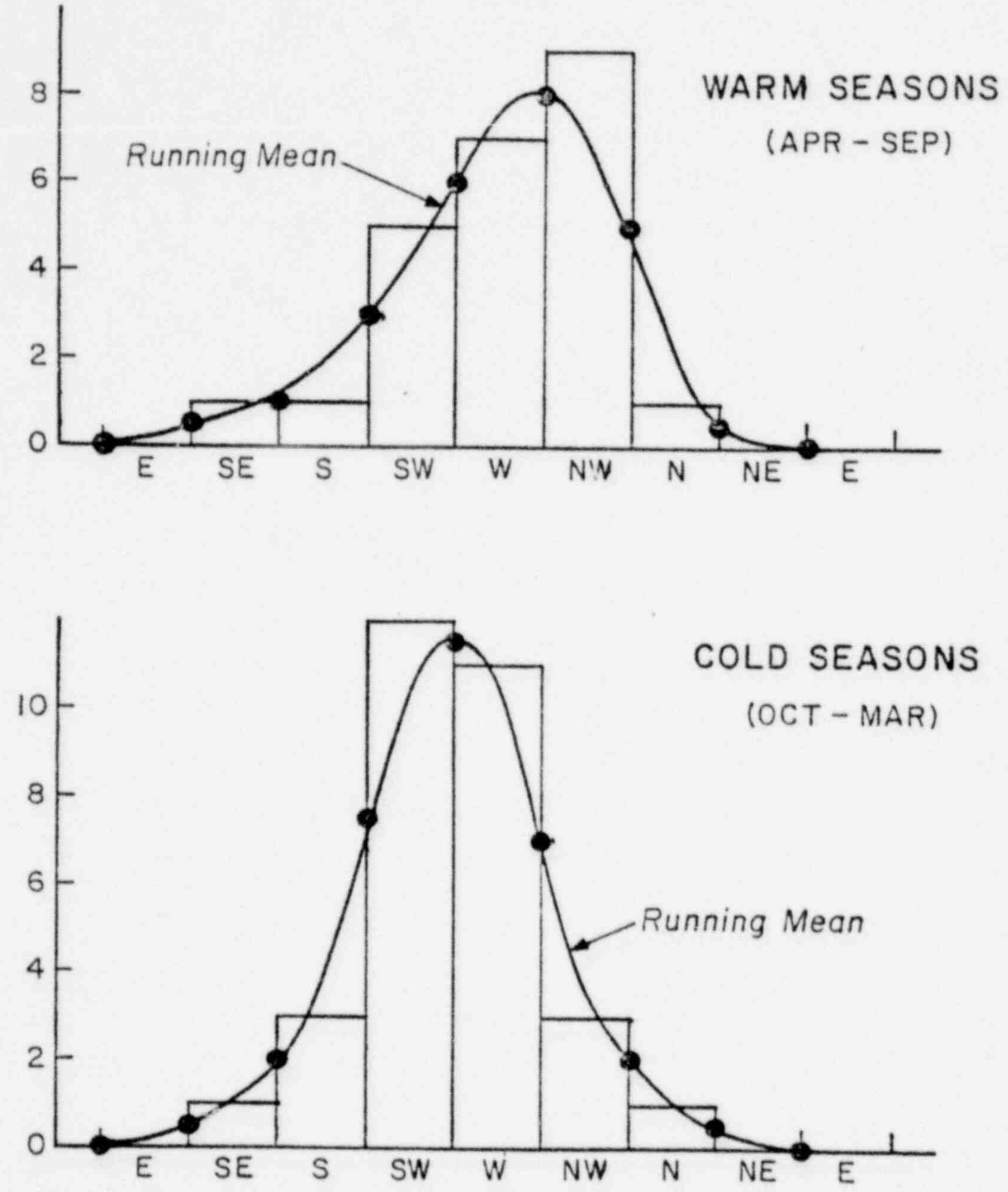

Figure 3. Directions of fastest-mile winds of the year at Columbus and Dayton, Ohio during warm and cold seasons. It should be noted that the fastest-mile winds in warm seasons are predominantly from west to northwest while those in cold seasons, from southwest to west. From Table 4.

The probabilities of the occurrence of maximum windspeeds should be defined differently from those of tornadoes, because windspeeds at each station are measured in time domain at a fixed point. Their spatial variations around the anemometer are usually unknown.

For tornadoes, the National Weather Service lists all storms based on the best possible information. Tornadoes are listed separately, even if they occur on the same day or even a few minutes later.

The maximum fastest-mile speeds are listed in "Climatological Data" by month and by year. There is no mention as to how often the maximum speed occurred within one month or one year. The periods of straight-line winds, especially the ones caused by continental cyclones, are long, lasting hours or even days. There will be numerous maxima during such a long period. We should, therefore, define the following terms:

Fastest-mile day -- the day on which the speed occurred
Fastest-mile month -- the month in which the speed occurred
Fastest-mile year -- the year in which the speed occurred

These are similar to the term

Tornado day -- the day in which one or more tornadoes occurred.

In these cases, the number of occurrences within the stated period is not important. Probability of the fastest-mile year can be computed by

$$P_{*} = \frac{\text{Number of years in which specific speed or larger speed occurred}}{\text{Total number of years used in statistics}}$$

where P_{*} denotes the occurrence probability per year.

The probabilities in Table 3 were computed by combining the observation years at Columbus (27 years) and Dayton (27 years), thus resulting in statistics of 54 observation years.

Windspeeds of peak gusts are higher than those of fastest mile winds, because the duration of a peak gust is considerably shorter than the period of the fastest-mile wind. In this review, the former is regarded as being 25% longer than the latter. Namely,

Peak Gust = 1.25 Fastest-mile Speed.

3. TORNADO FREQUENCIES FROM NSSFC TAPE

The NSSFC Tornado Tape lists 567 tornadoes within 144 miles from Battelle Memorial Institute during the 26-year period, 1950-75.

The cumulative frequencies were computed to determine the trend of their increase as a function of the range from the site. As shown in Figure 4, the best-fit parabolic curve is

$$N = 0.0295 R^2$$

where N is the number of tornadoes within range, R, in miles. A gradual decrease in the number of tornadoes at ranges in excess of 100 miles is in part an effect of Lake Erie. Another reason being a decrease in tornado frequencies in the southeastern sector.

A breakdown of tornado frequencies by year in Table 5 shows relatively low frequencies in the early 1950s when the tornado reporting system by the U.S. Weather Bureau was in the process of being improved. The maximum frequencies of 74 occurred in 1973 followed by 59 in 1974, which was the year of the April 3-4 super-outbreak.

Table 5. Frequencies of tornadoes within 144 miles from Battelle Memorial Institute by year. Based on the NSSFC tape, 1950-75.

Years	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
Frequencies	6	5	2	12	17	12	20	14	19	11

Years	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Frequencies	11	33	5	28	17	59	4	17	33	27

Years	1970	1971	1972	1973	1974	1975	Mean
Frequencies	31	21	14	74	59	16	21.8

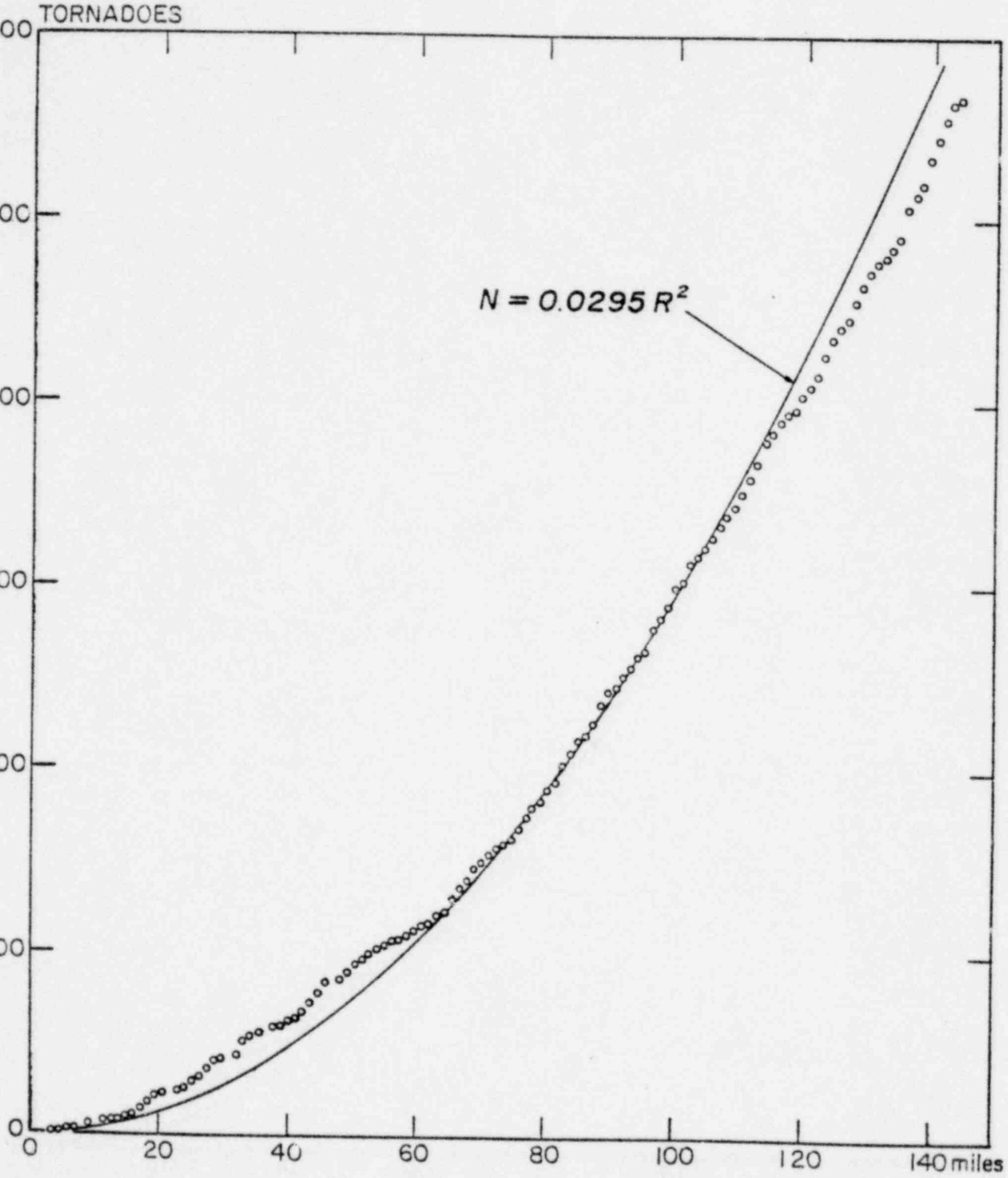

Figure 4. Cumulative number of tornadoes as a function of the distance from Battelle Memorial Institute. Based on 567 tornadoes in NSSFC tape, 1950-75.

Tornado frequencies by month reveal that April with 163 tornadoes is the month of the highest frequency. The lowest frequency month is January, with only 2 tornadoes out of 567 or 0.35% (see Table 6).

Table 6. Frequencies of tornadoes within 144 miles from Battelle Memorial Institute by month. Based on the NSSFC tape, 1950-75.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Frequencies	2	16	31	163	97	95	64	43	23	6	19	8	567

4. STATISTICS FROM DAPPLE TAPE

The DAPPLE Tornado Tape introduced by Fujita (1977)(1) can be used in computing the path lengths of F-category tornadoes within 15 x 15 min sub-boxes of longitudes and latitudes anywhere inside the contiguous United States. An attempt was made, in this review, to make use of the DAPPLE Tape as a new potential tool in assessing the tornado risk at the Battelle site.

U. S. Tornado Map by Fujita and Pearson (1976)(2) reveals a significant decrease of tornado frequencies toward the southeast from the Battelle site. The frequency gradient is, more or less, perpendicular to the line connecting Cincinnati, Ohio with Cleveland, Ohio.

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(1) Fujita, T. T. (1977): Tornado Structure for Engineering Applications. To be published as SMRP Research Paper No. 153.

(2) Fujita, T. T. and A. D. Pearson (1970): U.S. Tornadoes, 1930-74. The University of Chicago.

A realistic assessment of tornado frequencies can, therefore, be achieved by generating a coordinate system with their axes parallel and perpendicular to the maximum gradient of the frequencies.

The X-Y coordinates in Figure 5 were constructed based on the above considerations. Then, the banded areas, A through L, were drawn. Each area is 200 miles long and 20 miles wide, distributed equally on both sides of X axis.

The total path length within each 15 x 15 min sub-boxes of longitudes and latitudes was computed over the entire area of the bands, A through L (see Figure 6).

Path lengths in miles reveal the largest values of 50 miles (in Indiana) followed by 48 miles (in Michigan), and 44 and 43 miles (in Indiana). There are a number of sub-boxes with zero path length. As expected, we see more zero numbers to the southeast sector of the Battelle site.

In an attempt to compute the total path lengths in bands A through L, the area of each band was modified in such a manner that the band boundary becomes the composite boundaries of 15 x 15 min sub-boxes. The bands reconstructed from these sub-boxes are called the modified bands, A through L (see Figure 7).

Naturally the area of a modified band is different from that of the original band with approximately 200 x 20 = 4,000 square miles. For most bands, areas were expanded by adding a sub-box at each end of the original band.

The path length in miles per unit area or the "path-length density" in each modified band was computed from

$$\text{Path-length density} = \frac{\text{Path length within modified band}}{\text{Area of modified band}},$$

the unit of which is miles/sq. mile or mile^{-1}. The unit can be expressed also in any other units with identical dimensions, such as

$$10^{-4}\ \text{mile}^{-1} = \text{miles}/10{,}000\ \text{sq. miles etc.}$$

Path-length densities in Table 7 are given in 10^{-4} mile^{-1} unit. The last column of this table reveals that the path-length density of total tornadoes (F0 through F5) decreases from 850 to 38 between modified bands A and L.

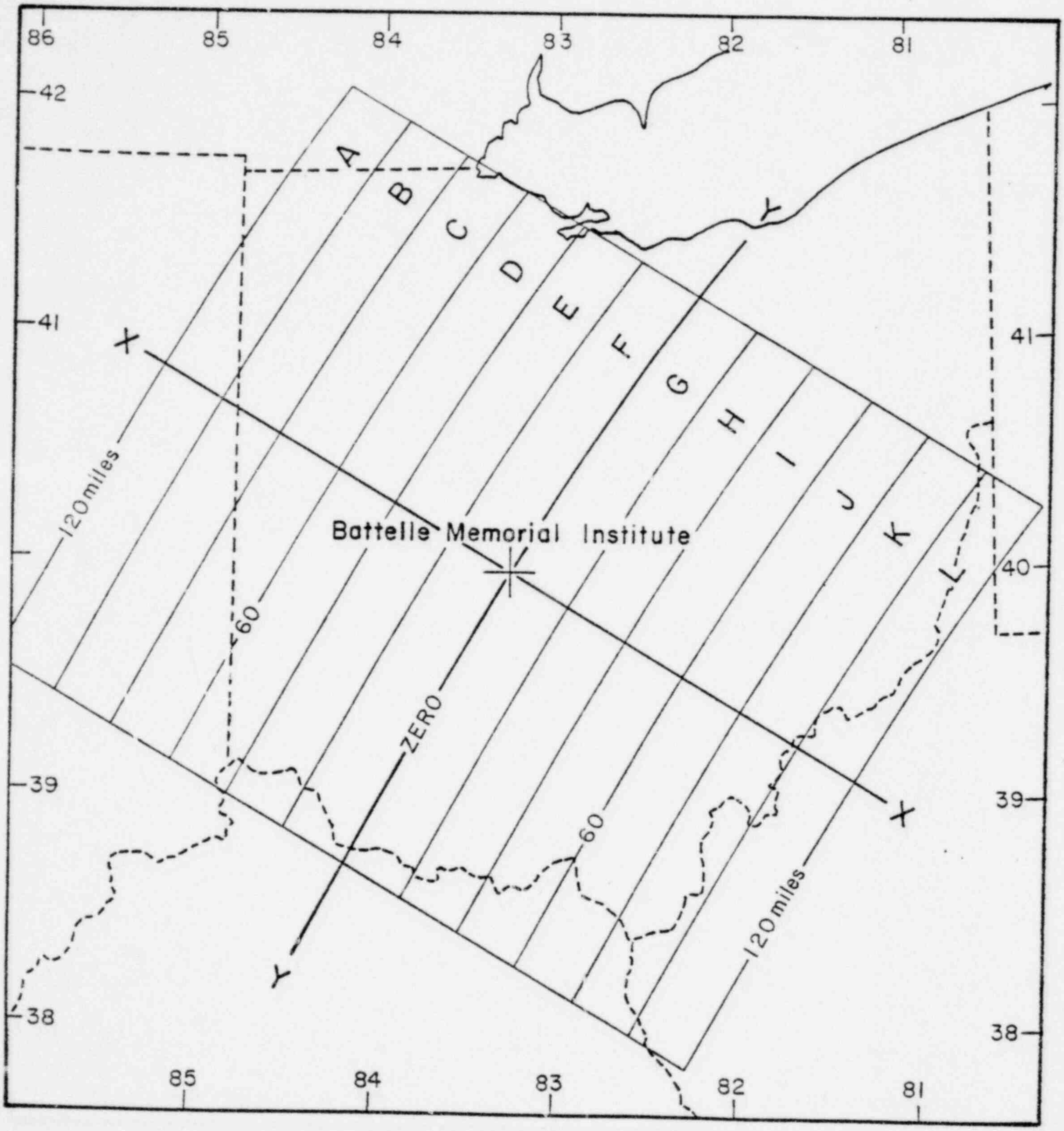

Figure 5. Bands A through L placed around the Battelle site. Each band 200-mile long and 20-mile wide, is oriented approximately in a SSW-NNE direction.

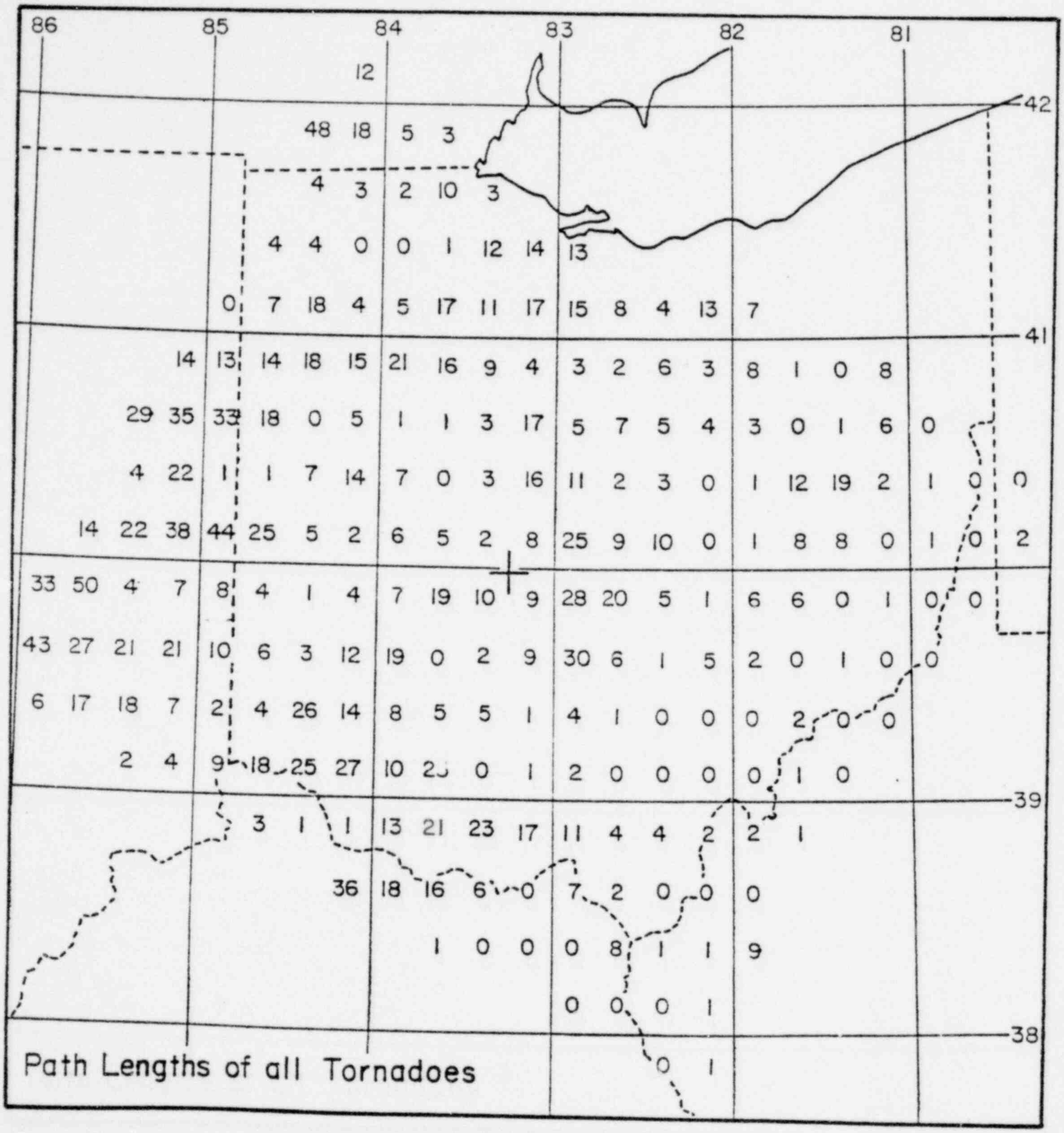

Figure 6. Total path length within each 15 x 15 min longitude-latitude sub-box. From the DAPPLE tape including 1950-75 tornadoes. For DAPPLE tape, refer to Fujita (1977): Tornado Structure for Engineering Applications.

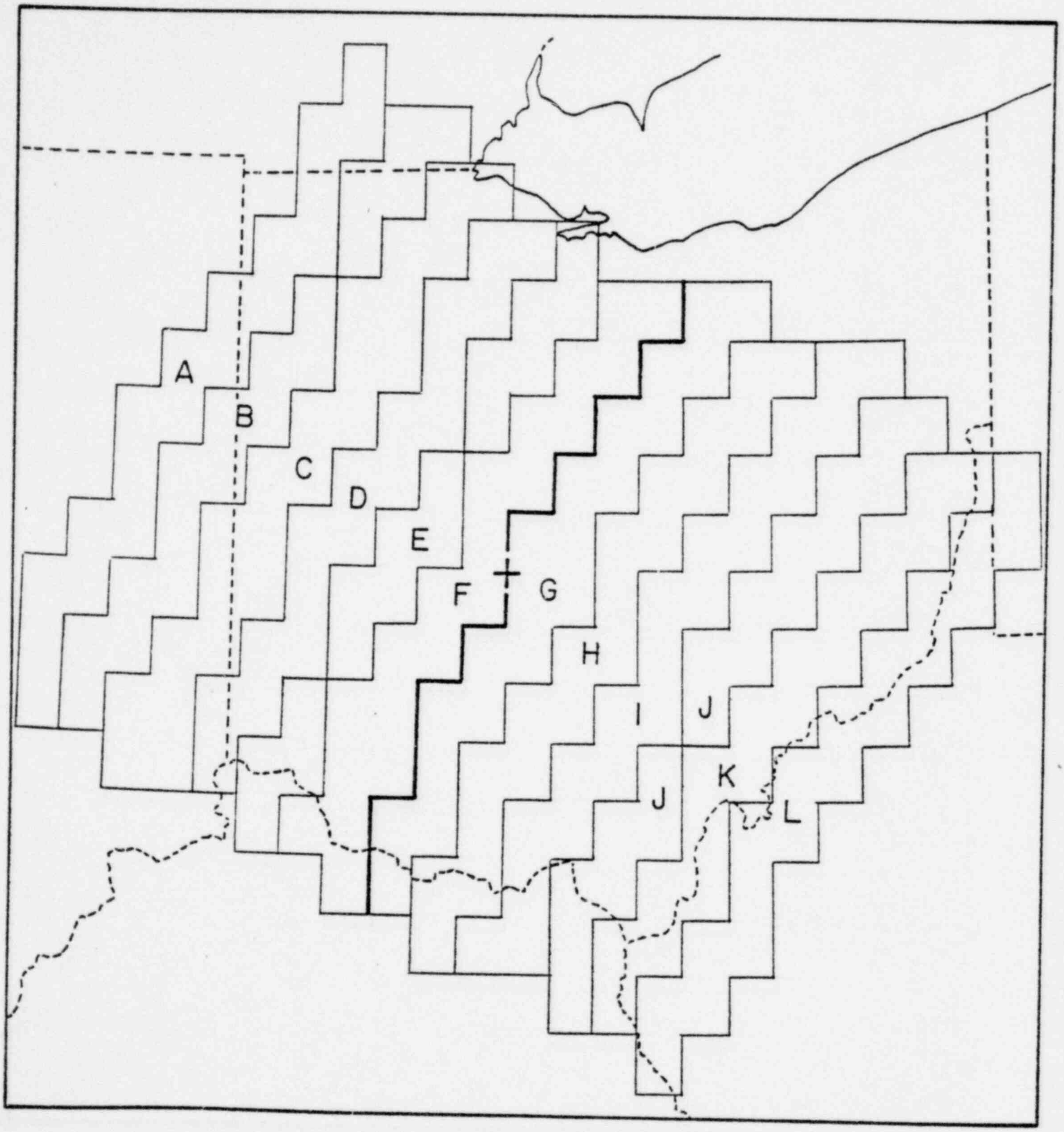

Figure 7. Modified bands A through L consisting of 15 x 15 min longitude-latitude sub-boxes.

Table 7. The path-length density is defined as the total path length divided by the area which includes the paths. The area of modified band varies from band to band. See Figure 7.

Modified band	Path-length in each band (F0+F1)	(F2+F3)	(F4+F5)	Band area (Sq. mi)	Path-length density in 10^{-4} mi^{-1} (F0+F1)	(F2+F3)	(F4+F5)	(Total)
A	100	214	58	4333	231	494	134	859
B	53	158	34	4114	129	384	83	596
C	52	119	44	5030	103	237	87	427
D	24	55	47	3904	61	141	120	322
E	26	65	82	3665	71	177	224	472
F	24	111	70	4624	52	240	151	443
G	80	112	28	4620	173	242	61	476
H	85	46	16	4406	193	104	36	333
I	12	32	17	4640	26	69	37	132
J	22	55	0	4186	53	131	0	184
K	5	11	0	4668	11	24	0	35
L	8	9	0	4440	18	20	0	38

This dramatic decrease is shown in graphical form in Figure 8. The data points given with painted circles show an appreciable scatter, probably due to the short statistical period, time variations of tornado activities, and other unknown causes. Nevertheless, a smooth line sloping down from A to L represents the general trend of the path-length density applicable to the Battelle site and vicinity.

A breakdown of the path-length density into three-category tornadoes results naturally in large scatters (see Table 7). Nonetheless, we are able to draw a smooth curve for each category tornado (see Figure 9).

Table 8 shows the path-length densities at the Battelle site obtained by this smoothing method. Results indicate that strong (F 2 + F 3) tornadoes were the largest in density, 0.02 mi^{-1} (mi/sq. mi), followed by both weak and violent category tornadoes, each with 0.01 mi^{-1} density. These path-length densities, thus obtained, can immediately be used in computing tornado probabilities using the DAPPLE Method.

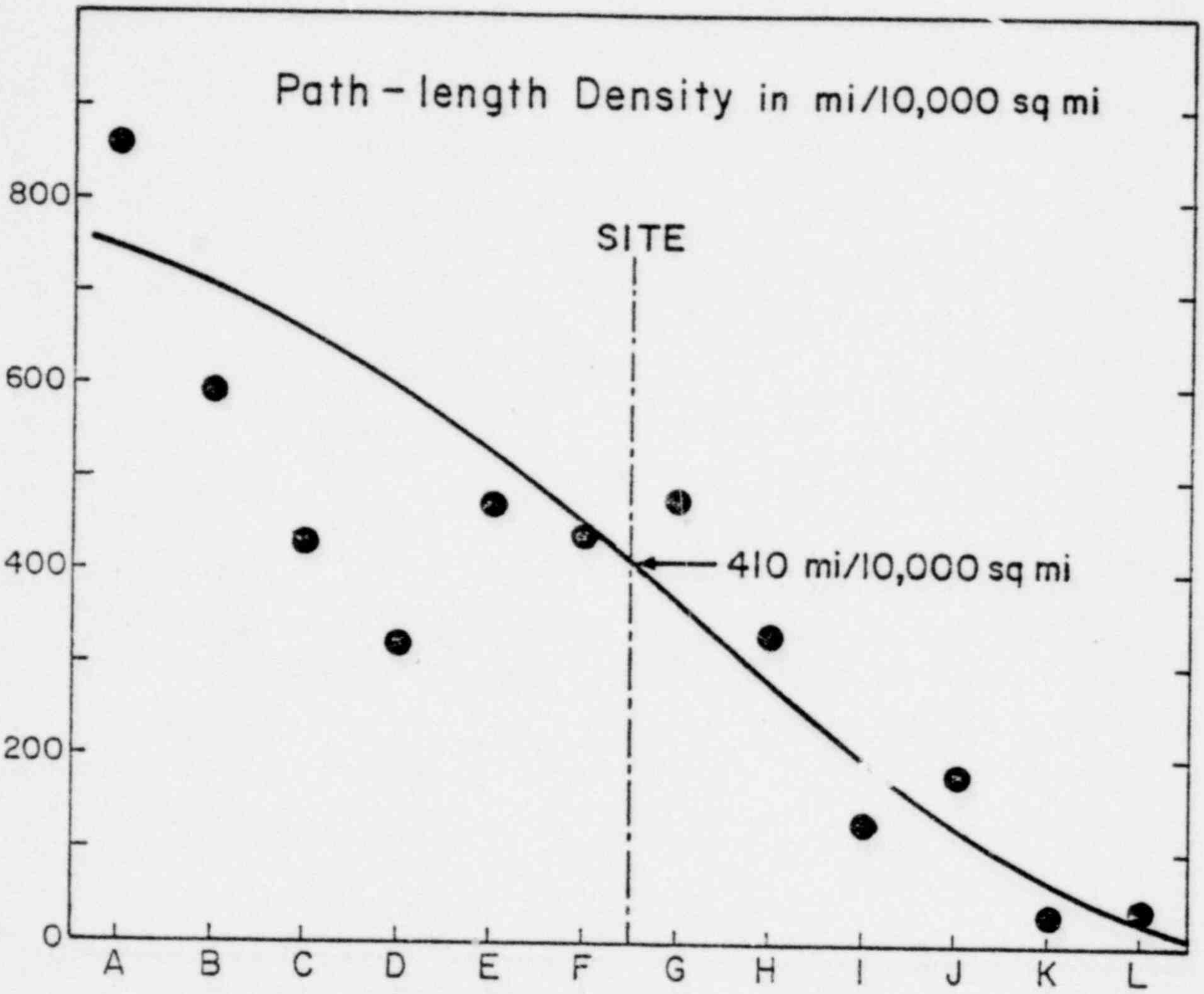

Figure 8. Path-length density (miles per 10,000 sq. mile unit) defined as the total path length within a modified band divided by the band area. Path-length density in this figure includes all tornadoes, F0 through F5. From Table 7.

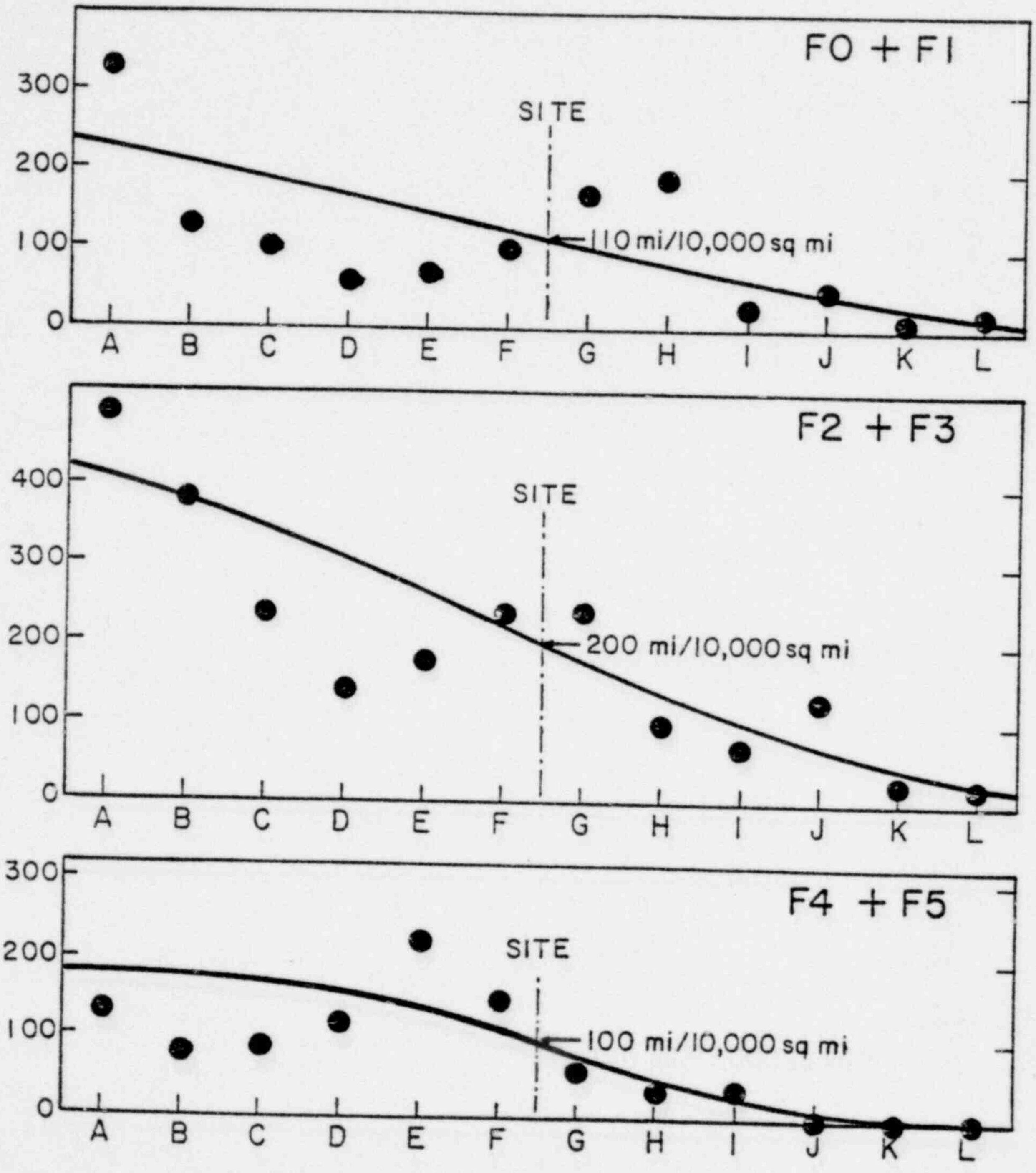

Figure 9. Path-length densities (miles per 10,000 sq. mile unit) of three-category tornadoes averaged over the area of each band, A through L. From Table 7.

Table 8. Path-length density (mi/10,000 sq mi or 10^{-4} mile^{-1}) of three-category tornadoes, Weak (F0+F1), Strong (F2+F3), and Violent (F4+F5) applicable to the Battelle Site.

Weak	Strong	Violent	All tornadoes
110	200	100	410

5. WINDSPEED PROBABILITIES OF TORNADOES

The DAPPLE (Damage Area Per Path LEngth) METHOD developed by Abbey and Fujita (1975)(1) is capable of computing tornado probabilities as a function of the F-scale damage categories, which can be converted into windspeeds (see Table 9).

Using the DAPPLE METHOD, the area of specific windspeed can be computed by the product,

$$\text{Windspeed Area} = \text{Path Length} \times \text{DAPPLE},$$

where path length denotes that of specific F-scale tornadoes and the DAPPLE values vary with F scale.

Table 9. Ranges of F-scale windspeeds and their weighted mean values. (Refer to Abbey, Robert (1977): Risk probabilities associated with tornado windspeeds. Proc. of Symp. on Tornadoes, Assessment of knowledge and implications for man.)

F Scale	F 0	F 1	F 2	F 3	F 4	F 5
Range of Windspeed	40-72	73-112	113-157	158-206	207-260	261-318 mph
Weighted mean speed	59	92	131	177	227	276

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(1) Abbey, R. F. and T. T. Fujita (1975): Use of tornado path lengths and gradation of damage to assess tornado intensity probabilities. Preprint of 9th Conf. on Severe Local Storms, 286-293.

Since F-scale assessments assume an accuracy of one scale, tornadoes are classified into three categories: WEAK (F 0 + F 1), STRONG (F 2 + F 3), and VIOLENT (F 4 + F 5). DAPPLE values were then obtained based on the 147 tornadoes of April 3-4, 1974 Super-outbreak tornadoes (see Table 10).

At the present time, DAPPLE values are being updated by adding new survey data. Since we do not expect to survey a large number of F 5 tornadoes in the near future, we will have to use these DAPPLE values for our immediate solutions.

Table 10. DAPPLE, in miles, as a function of tornado windspeed. Unit in sq. mile per path mile. DAPPLE values are given for 3 categories of tornadoes. From Abbey, R. F. and T. T. Fujita (1975): Use of tornado path lengths and gradations of damage to assess tornado intensity probabilities. Preprint of 9th Conf. on Severe Local Storms. 286-293.

Windspeeds	Violent (F4&5)	Strong (F2&3)	Weak (F0&1)
50 mph	0.51 mile	0.43 mile	0.074 mile
100	0.14	0.062	0.0028
150	0.036	0.0098	0.000052
200	0.0081	0.0012	0.000000
250	0.0016	0.000087	0.000000
300	0.00023	0.000000	0.000000
350	0.000016	0.000000	0.000000

Now the path-length density in Table 8 and the DAPPLE values in Table 10 can be combined into a product which may be called the "area density",

$$\text{area density} = \frac{a(v)}{A}, \quad \left(\text{unit} = \frac{\text{sq. miles}}{\text{sq. miles}}\right)$$

where A denotes the area in which the area of a specific windspeed is located. For example, a 0.03 square-mile area located inside a 10 square-mile area results in 0.003 area density. Naturally, the area density decreases with windspeed.

The areas of three-category tornadoes in Table 11 are given as square miles of windspeed area per 10,000 square miles or 10^{-4}. Values were computed from Tables 8 and 10.

Table 11. Areas of three-category tornadoes during a 26-year period, 1950-75 applicable to the Battelle Site. Values are in sq mi/10,000 sq mi or 10^{-4}.

Windspeeds	Violent	Strong	Weak	All tornadoes
50 mph	51	86	8.14	145.1
100	14	12.4	0.308	26.7
150	3.6	1.96	0.0057	5.6
200	0.81	0.24	0.0000	1.05
250	0.16	0.0174	0.0000	0.18
300	0.023	0.0000	0.0000	0.023
350	0.0016	0.0000	0.0000	0.0016

The windspeed probabilities are now computed from

$$\text{Probability} = \frac{\text{Area Density}}{\text{Years of Statistics}} \quad \left(\text{unit } \frac{1}{\text{Year}}\right)$$

The total number of years used in these statistics is 26 years, 1950-75. The probability of any windspeed can be obtained by simply dividing the area density of specific windspeed by 26 years.

Shown in Table 12 are probabilities per year of various windspeeds at 50 mph intervals. Values indicate that 10^{-7} year^{-1} probability occurs when windspeeds are between 250 and 300 mph.

Table 12. Probabilities (year^{-1}) of various windspeeds by all tornadoes at the Battelle Site.

Windspeeds	Probabilities (yr^{-1})
50 mph	5.58×10^{-4}
100	1.03×10^{-4}
150	2.15×10^{-5}
200	4.04×10^{-6}
250	6.92×10^{-7}
300	8.85×10^{-8}
350	6.15×10^{-9}

6. SUMMARY AND CONCLUSIONS

Results of the foregoing computations of windspeed probabilities are summarized in Figure 10 which includes three curves applicable to the Battelle site. The fourth curve represents the peak-gust probabilities from the SELS Log. The three curves are

(A) Probability of fastest-mile year
(B) Probability of fastest-mile year
(C) Tornado probability

These curves reveal that the speeds of straight-line winds are higher than tornado winds when the probability is greater than about 10^{-4} per year.

Table 13 gives the maximum windspeeds corresponding to curves (A), (B), and (C). Values for the return periods of one to 10-million years are tabulated. It is seen that tornadoes dominate the windspeeds when the probability decreases below one in 100,000 years.

Three-category probabilities are used in this site analysis:

High probability -- 10^{-3} per year
Low probability -- 10^{-6} per year
Remote probability -- 10^{-7} per year

It should be noted that 10^{-7} per year is used in determining the design-basis tornadoes for nuclear power plants in WASH-1300.

Table 13. Maximum windspeeds expected at the Battelle Memorial Institute Site as a function of the probability per year. (A)……fastest-mile speeds of straight-line winds. (B)……gust speeds computed as 125% of A. (C)……tornado windspeeds based on 1950-75 data.

Probabilities	Return periods	Windspeeds in miles per hour (A)	(B)	(C)
10^{0} per year	1 year	38 mph	48 mph	-
10^{-1}	10	61	76	-
10^{-2}	100	72	90	-
10^{-3}	1,000	86	108	-
10^{-4}	10,000	101	126	102 mph
10^{-5}	100,000	113	141	171
10^{-6}	1,000,000	125	156	237
10^{-7}	10,000,000	-	-	297

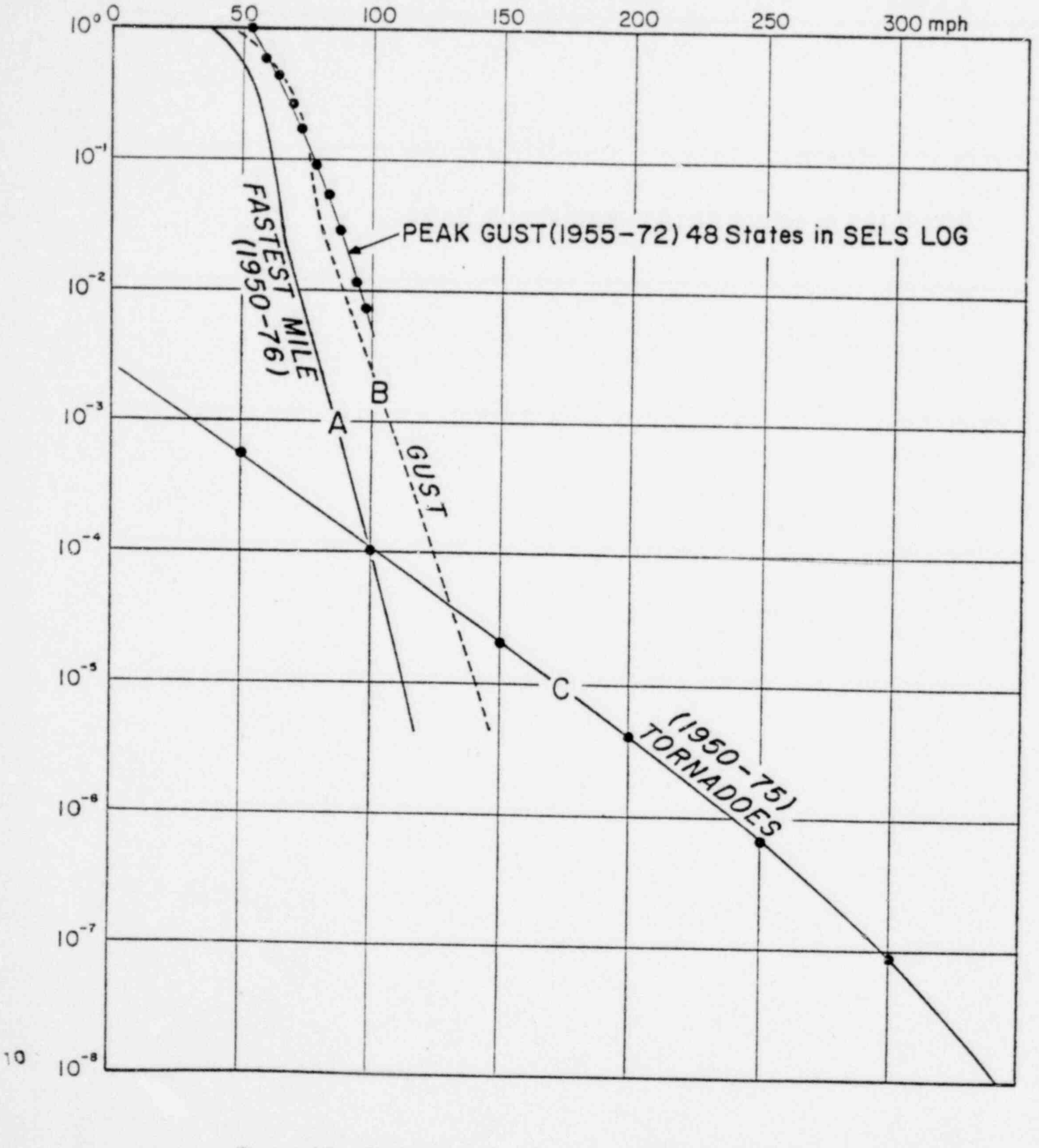

Figure 10. Probabilities of straight-line and tornado winds. The probability of straight-line winds (gust) is higher than tornado winds when windspeeds are less than 130 mph. Peak gusts from SELS LOG are also shown in this figure for comparison purposes.

For secondary or short-life structures, one may wish to use the maximum windspeeds corresponding to the low- or even high-probability category defined above.

The storm characteristics in Table 14 were computed for these three probabilities. If one wishes to protect a structure against the high-probability (10^{-3}) windspeed, a 108-mph gust of straight-line wind is to be used as design criteria. Tornadoes may be disregarded for such a high-probability case.

Table 14. Characteristics of storms corresponding to three probability categories, remote (10^{-7}), low (10^{-6}), and high (10^{-3} per year). Air density at the Institute site, 910-ft MSL, is assumed 1.2 kg/m^3 and radius of maximum wind, 150m for computational purposes.

Probabilities (per year)	Remote (10^{-7})	Low (10^{-6})	High (10^{-3})
Storm types	Tornado	Tornado	Straight wind
Maximum total speed (mph)	297	237	108
Translational speed (mph)	59	47	-
Max. tangential speed (mph)	238	190	-
Total press. drop (mb)	135.8	86.6	-
(psi)	1.97	1.26	-
Rate of pr. drop (mb/sec)	23.9	12.1	-
(psi/sec)	0.35	0.18	-

The translational speed, T, was assumed to be

$$T = 0.20\ V_{mt} \quad .$$

where V_{mt} is the maximum total speed expected to occur at the radius of maximum wind, r_m. The radius of maximum wind or that of tornado's outer core was assumed to be

$$r_m = 150\ \text{m} \ .$$

Under the assumption of the combined Rankine vortex and cyclostrophic wind equation, the total pressure drop was computed from

$$P_o = \rho V_m^2 ,$$

where ρ at the 910-ft MSL Institute site was assumed to be 1.2 kg/m^3

The rate of pressure drop was computed from

$$\frac{dP}{dr} = \frac{\rho V_m^2}{r_m} \quad \text{and } dr = Tdt$$

or

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

which is identical to Equation (3) of WASH-1300.

It is recommended that the team of structure analysts determine the proper probability category to be applied to each structure or portions of structure of the Battelle Memorial Institute. Table 14 will, then, be used to determine the characteristics of the design-basis storm.

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APPENDIX

LIST OF VIOLENT TORNADOES WITHIN 140-MILE RANGE OF BATTELLE MEMORIAL INSTITUTE

The DAPPLE Tape (1950-75) includes 16 violent (F 4 & 5) tornadoes which affected the area within a 140-mile range of the site. These tornadoes are listed in Table 15 and shown in Figure 11 in this appendix.

Table 15. Violent tornadoes (F 4 & 5) within 140-mile range of the Battelle Memorial Institute. 16 tornadoes of this category are included in DAPPLE tape. Tornado with * was surveyed by Fujita.

No.	Year	Month	Day	Name of tornadoes	F scale	Path length
1	1953	Jun	8	Cleveland Tornado, OH	4	100 miles
2	1961	Apr	25	Shelbyville Tornado, OH	4	65
3	1965	Apr	11	*Grafton Tornado, IN	4	25
4	1965	Apr	11	*Kokomo Tornado, IN	5	75
5	1968	Apr	23	Newtonsville Tornado, OH	4	25
6	1968	Apr	23	Ripley Tornado, KY-OH	4	50
7	1969	Aug	9	Cincinnati Tornado, OH	5	22
8	1972	May	14	Indianapolis Tornado, IN	4	29
9	1974	Apr	3	*Bear Branch Tornado, IN	4	28
10	1974	Apr	3	*Frankfort Tornado, KY	4	36
11	1974	Apr	3	*Hamburg Tornado, IN	4	37
12	1974	Apr	3	*Kennard Tornado, IN	4	20
13	1974	Apr	3	*Madison Tornado, IN	4	38
14	1974	Apr	3	*Parker Tornado, IN	4	22
15	1974	Apr	3	*Sayler Park T., IN-KY-OH	5	21
16	1974	Apr	3	*Xenia Tornado, OH	5	32

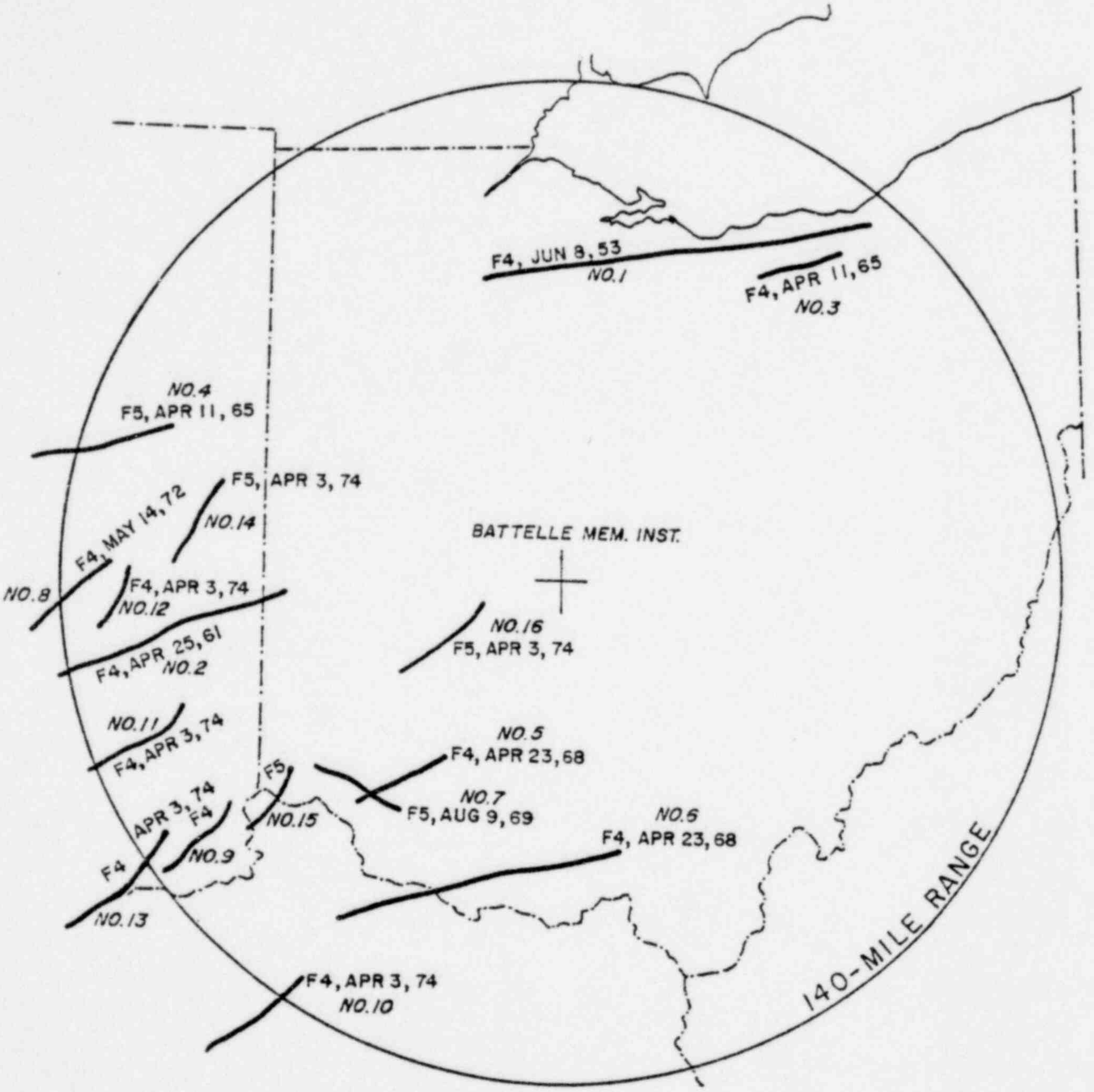

Figure 11. Paths of violent tornadoes within 140 miles of the Battelle site. The Xenia tornado (F5) of April 3, 1974 was the closest to the site.

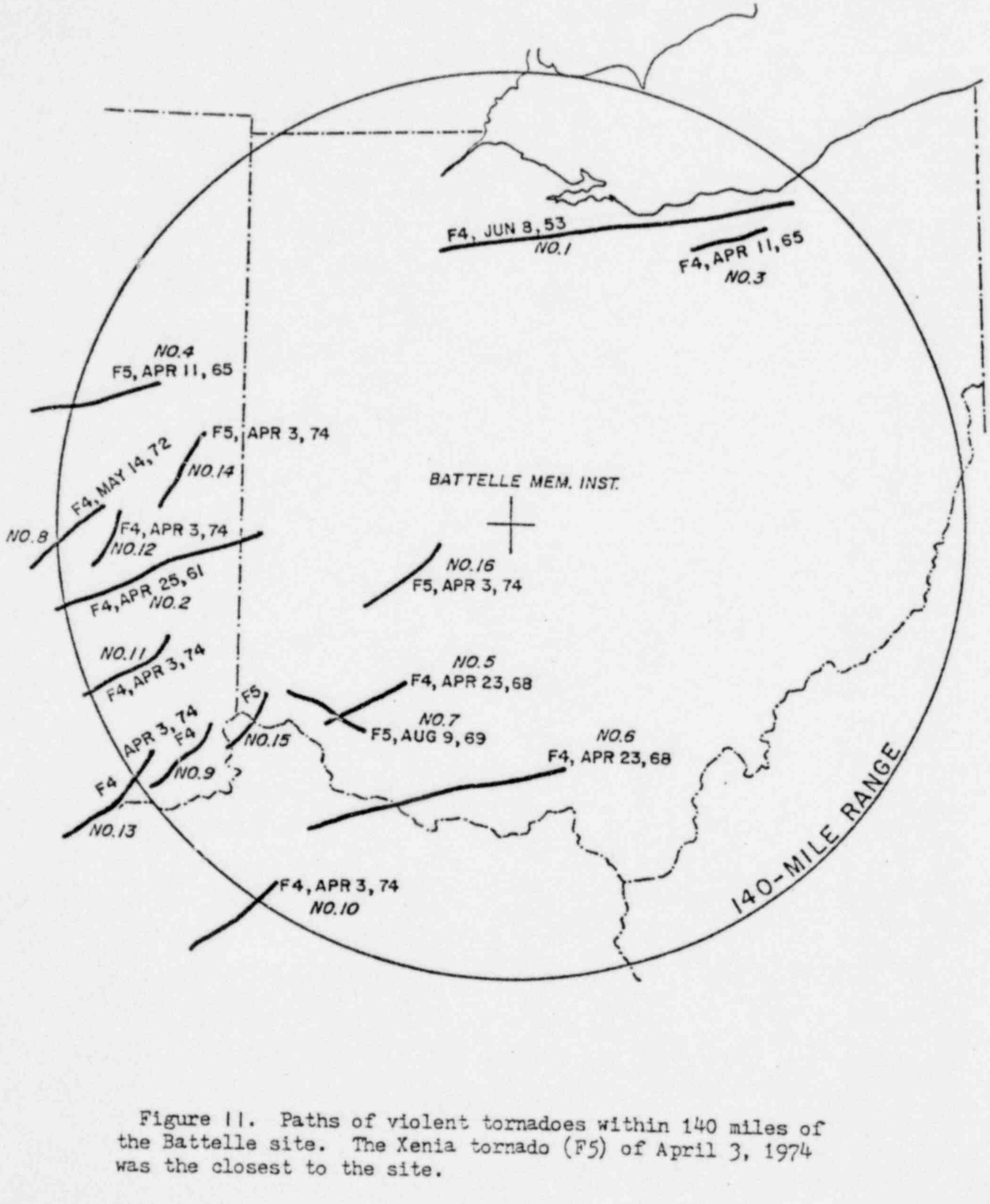

Figure 11. Paths of violent tornadoes within 140 miles of the Battelle site. The Xenia tornado (F5) of April 3, 1974 was the closest to the site.

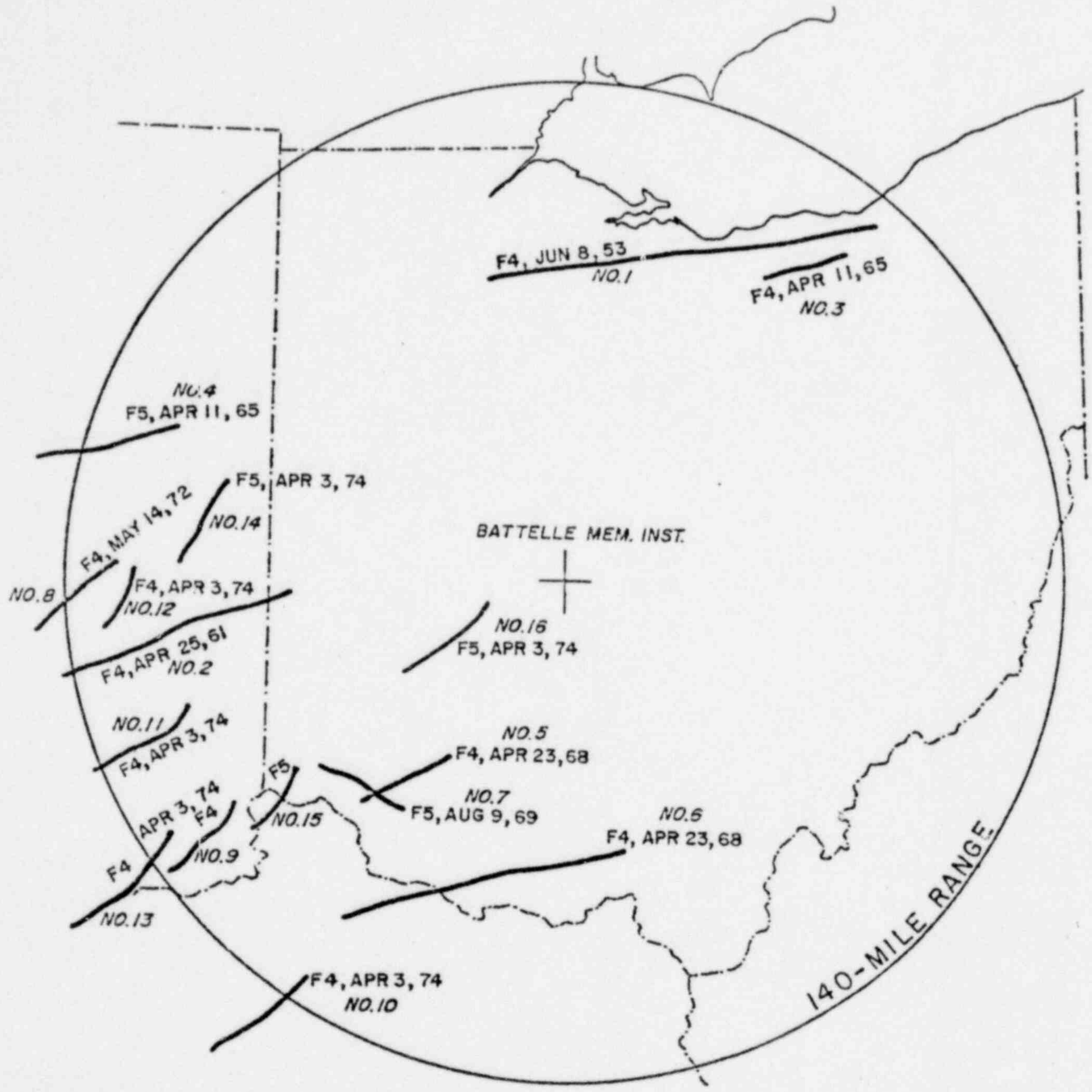

Figure 11. Paths of violent tornadoes within 140 miles of the Battelle site. The Xenia tornado (F5) of April 3, 1974 was the closest to the site.