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SATELLITE & MESOMETEOROLOGY RESEARCH PROJECT

Department of the Geophysical Sciences
The University of Chicago

PRELIMINARY RESULTS OF TORNADO WATCH EXPERIMENT 1971

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and

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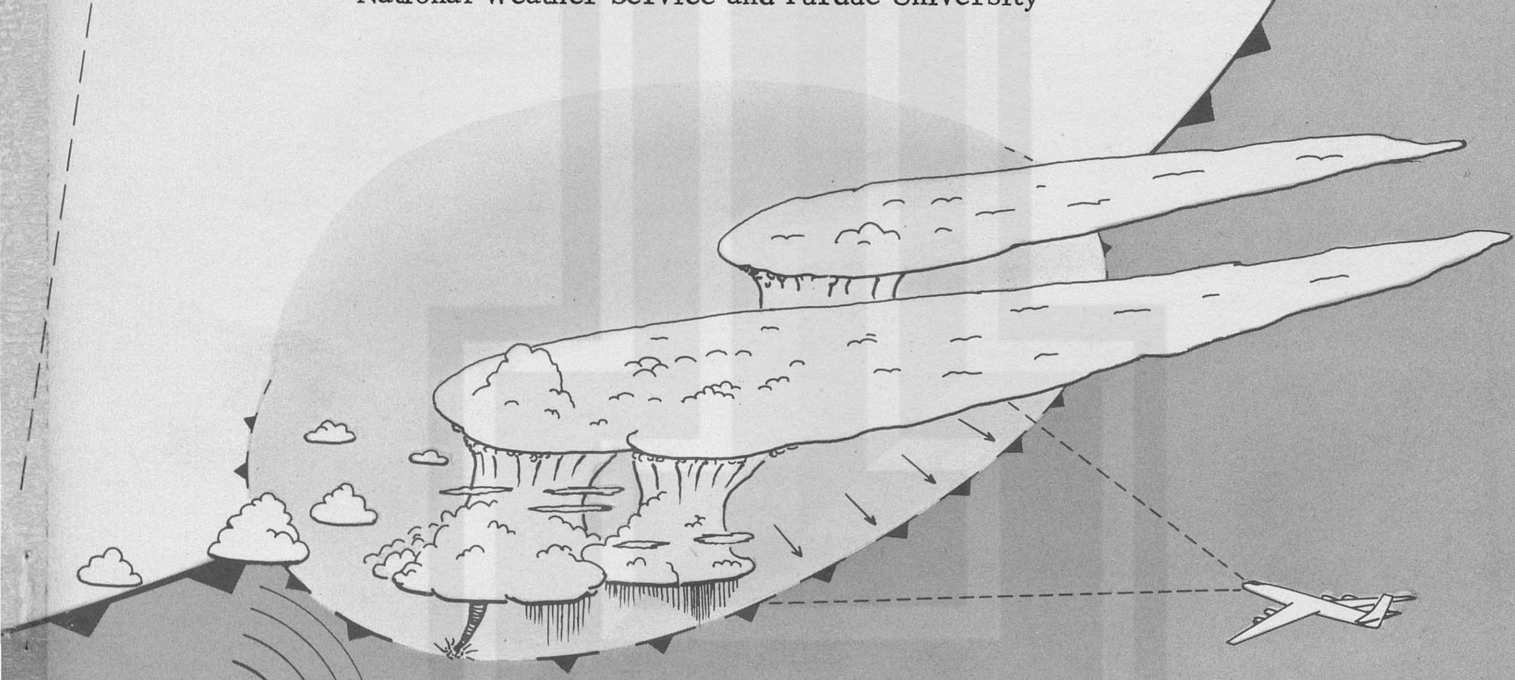

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1. INTRODUCTION

The yearly occurrence of severe local storms, prominent among which are tornadoes, hailstorms, and thunderstorms, and their consequent toll in life and damage to property is always a dreadful event for people in most of the areas in the United States, that, unfortunately, they have to live with. With tornadoes especially, considering their wicked nature and violent characteristics, any indication of their potential development is treated with utmost respect and seriousness and any threatened area in danger of possible touchdown is alerted. The need to learn more about tornadoes and related tornadic storms, like any other physical phenomena which is not, as yet, ideally duplicated under controlled laboratory conditions, demands that a closer observation and a more thorough documentation be made of the behavior and history of these severe storms as they occur.

The Tornado Watch Experiment 1971 is being carried out jointly by SMRP, The University of Chicago; the Applications Group, NESS; NASA; and NSSFC. The three major functions of this experiment are 1) to take frequent (11-12 min) ATS III pictures for enlargement of specific U.S. areas, 2) to obtain from the NOAA climatologist for each state both intensity and area categories of tornadoes appearing in Storm Data, and 3) to make aerial and ground surveys of specific tornadoes.

The research reported in this paper has been sponsored by the National Oceanic and Atmospheric Administration under grants E-22-93-71 (G) and E-198-68 (G) Mod. #2.

So far we have obtained 4X enlargements for the following 9 tornado days in 1971: February 21; April 16, 17, 23, 27, 28; and May 5, 9, 18. These pictures are now being enhanced to obtain detailed views of tornado producing clouds in the satellite pictures. To date we have received from the NOAA climatologists complete reports of tornado classification for the months January through April. A detailed analysis of the tornadoes based on these reports is presented in Section 3. Under the sponsorship of NSSL the three major tornado outbreaks of February 21, April 27, and May 5 were surveyed both from the air and on the ground. A preliminary report of the April 27 tornadoes in Kentucky is presented in Section 2.

Although the tornado frequency in summer and autumn is less than during the spring months we will be continuing our experiment throughout the year 1971. At the conclusion of the experiment a final report will be issued.

2. CHARACTERISTICS OF THE SOUTH HILL, KENTUCKY TORNADO OF APRIL 27, 1971

After receiving information from NSSFC, Kansas City on the tornadoes that occurred during the evening of April 27 in southern Illinois and north central Kentucky, plans were made to make an aerial survey over the area. A Cessna 172 aircraft piloted by L. A. Schaal, NOAA Climatologist for Indiana, was used for the survey. The plane departed from Chicago Midway Airport on the afternoon of April 28, stopping first at Thompsonville, Illinois to make a survey of the damage in this area. The survey of the Kentucky area was started early on the morning of the 29th and was completed around noon on the 30th.

Five storms which occurred in Kentucky on April 27 that were classified as tornadoes were surveyed from the air. Below are listed these storms which occurred from the early to late evening hours.

Tornado or Storm	$\ell \times \overline{w}$ (mi.)	Area (sq.mi.)	I	Time (CST)
Madisonville	2 x 0.2	0.4 (Meso)	F2	1845
Central City	0.2 x 0.1	0.02 (Micro)	F0	1915
South Hill	29 x 0.3	9 (Macro)	F3	2020
Columbia	22 x 0.6	13 (Giant)	F4	2050
Russell Springs	21 x 0.5	11 (Giant)	F5	2300

ℓ = length, $\overline{w}$ = mean width, and I = intensity on Fujita-scale

The most important damage characteristics photographed in Kentucky were those patterns of fallen trees in relation to local topography, including 300-ft gorges east of Russell Springs. A large number of color pictures taken in the gorge areas showed evidences that the tornado vortex extended all the way to the valley floor, destroying trees and farm structures in its path. Plans are being made to analyze tree-fall patterns in detail, taking into consideration the estimated intensities and chronological sequence of damage occurrences. Since the result of such an extensive analysis will not be available before submission deadline, only a portion of the research on the South Hill tornado is presented in this paper.

This tornado crossed a 150-ft. deep valley 12 miles north-northwest of Bowling Green, Kentucky. The initial aerial inspection showed extensive damage on houses and trees in the valley while the plateau region appeared to have light damage. In order to learn more about these peculiar damage patterns, the area was visited by car. The ground survey clearly revealed the fact that the tornado not only reached the valley floor, it intensified as it descended into the valley. As shown in Fig. 1, there were several swaths

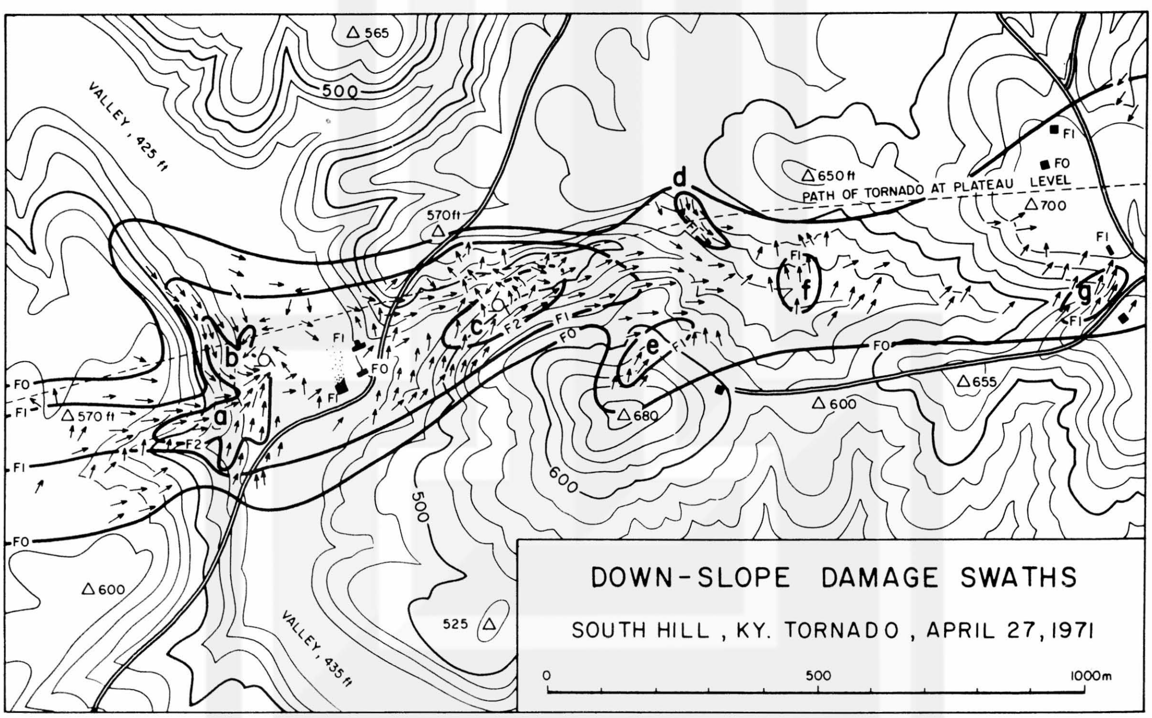

Fig. 1. Topographic chart of area over which South Hill, Ky. tornado passed. Contours in 20 ft. intervals. Heavy lines enclose areas with F 0, F 1, and F 2 damage and arrows show direction of tree fall. Suction vortices ( ) at swaths b and c.

of tree damage, mostly to the south of the path of the tornado center, which was determined from the direction of tree damage on the relatively flat plateau. The path of the center, identified as the "path of tornado at plateau level," appears in the figure. Two distinct circulation patterns of tree damage are seen near the valley floor just to the south of the tornado path.

Figure 2 was prepared to show the relationship between four locations of the tornado center and the damage swaths which occurred at approximately these four different times.

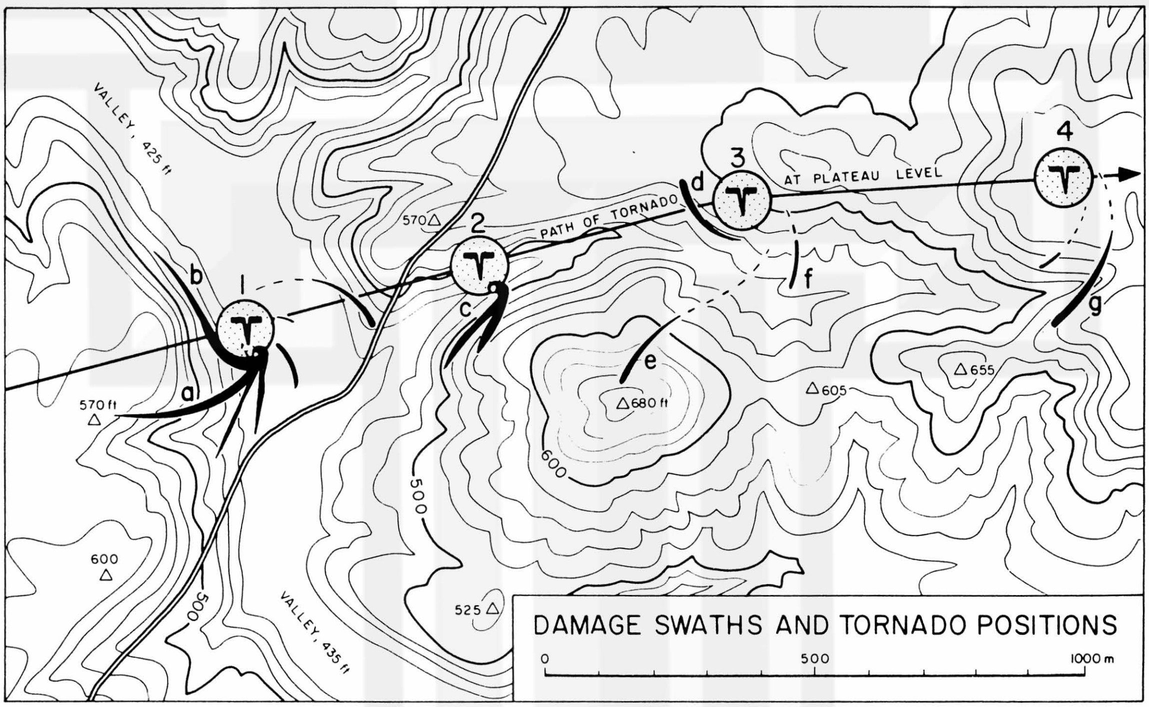

Fig. 2. Same topographic chart as Fig. 1 with 4 locations of tornado center. Heavy painted areas are the damage swaths which occurred when tornado center was at each of the 4 locations.

Very little damage to trees was found on the plateau area north of the 570-ft. hill located to the left in the figure. The tornado then moved to the west end of the valley floor at position "1". The strongest wind blowing into the tornado evidently descended from near this 570-ft. hill toward the 430-ft. valley floor, thus leaving indications that the wind speed definitely increased as the elevation decreased. Thus, swath "a" has been identified as down-slope damage swath "a". Another, swath "b", descended from about the 500-ft. contour level to the valley floor resulting in a cyclonic pattern of tree fall (see Figs. 3 and 4). Analysis indicated that the circulation center at the end of swaths "a" and "b" was located to the

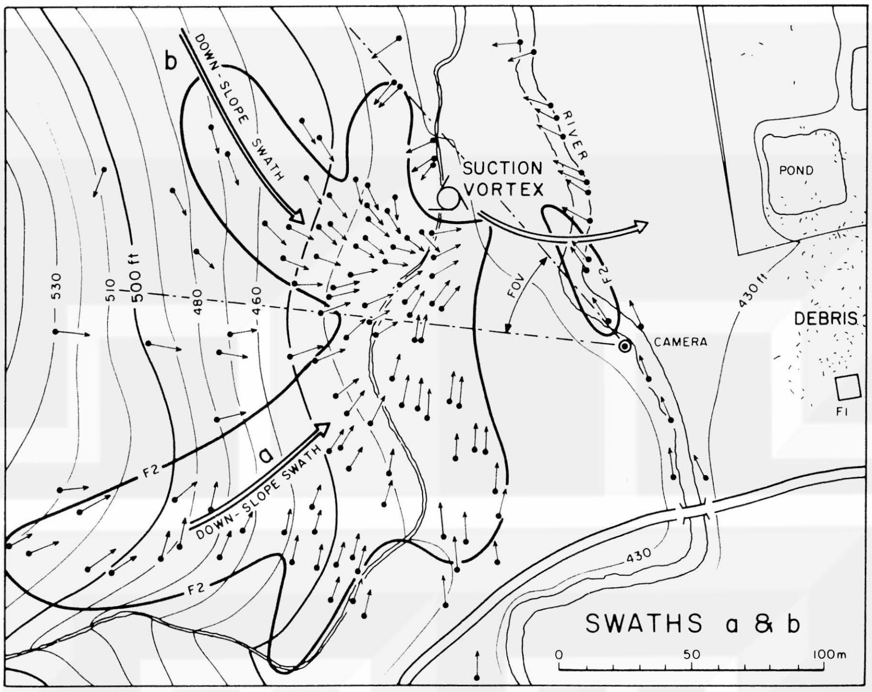

Fig. 3. Enlargement of area of swaths a and b from Fig. 1. Heavy line encloses areas with F 2 damage. Arrows indicate direction of tree fall.

Fig. 4. Aerial view of Fig. 3. Tree fall lines strongly indicate presence of suction vortex.

south of the tornado center at the plateau level. The diameter of the circulation was very small but its strong twisting action would have produced a significant suction around the circulation center. The circular symbol with 3 arms stretching in different directions represents the vertical column of the vortex which is one order of magnitude smaller than the parent tornado but probably one order of magnitude stronger both in rotational wind speed and suction effects. Since this vortex is very similar to that which will be reported by Fujita (1971) in his recent study of a giant dust devil and that responsible to Fujita's (1970) suction swaths in the Lubbock tornado, it may be called the "suction vortex". The core diameter of the suction vortex as seen in Fig. 4 is no more than the size of a farm house.

Evidence that the damage on the valley floor was more intense than that at high elevation is shown in the picture presented in Fig. 5. This picture was taken at the camera position indicated in Fig. 3 looking west-northwest toward the suction vortex position. Trees on the valley floor appear to be blown toward the picture center because those leaning toward the right were on the camera side of the suction vortex and the others leaning toward the left were located on the opposite side. It is seen that trees on high levels received practically no damage while those at lower levels were either snapped or

Fig. 5. Photograph showing close-up of tree damage at valley floor within field of view of camera set up at location indicated in Fig. 3.

blown down. At the present time it is not clear why such an intense vortex was formed on such low ground.

At position 2 (see Fig. 2) of the tornado path at plateau level, damage swath "c" developed along the northwest slope of the 680-ft. hill. Figures 6 and 7 show detailed patterns of uprooted trees caused by a small but intense suction vortex as shown in Fig. 2.

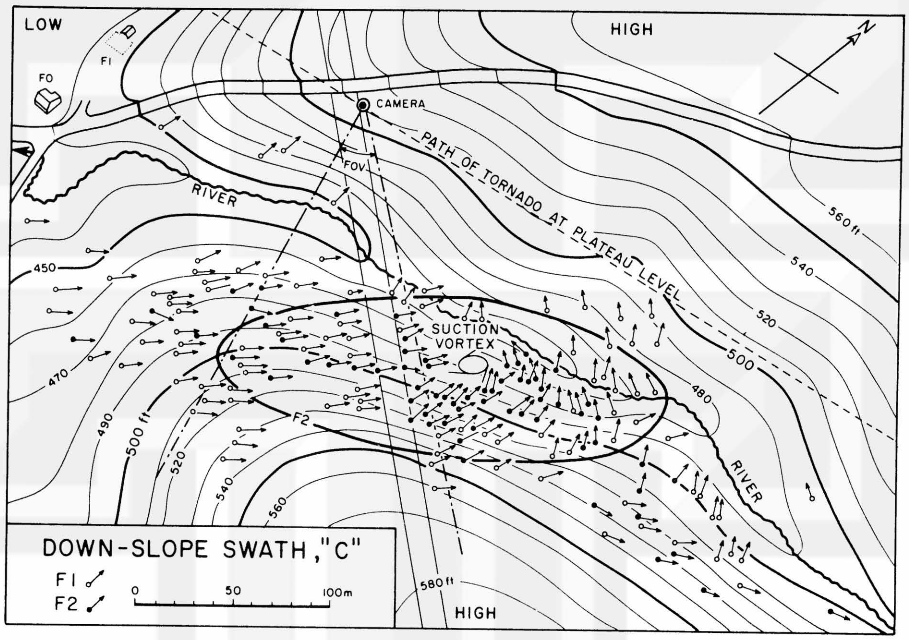

Fig. 6. Enlargement of area surrounding position 2 (Fig. 2). Heavy line encloses area with F 2 damage. Pattern of tree fall indicates location of small but intense suction vortex.

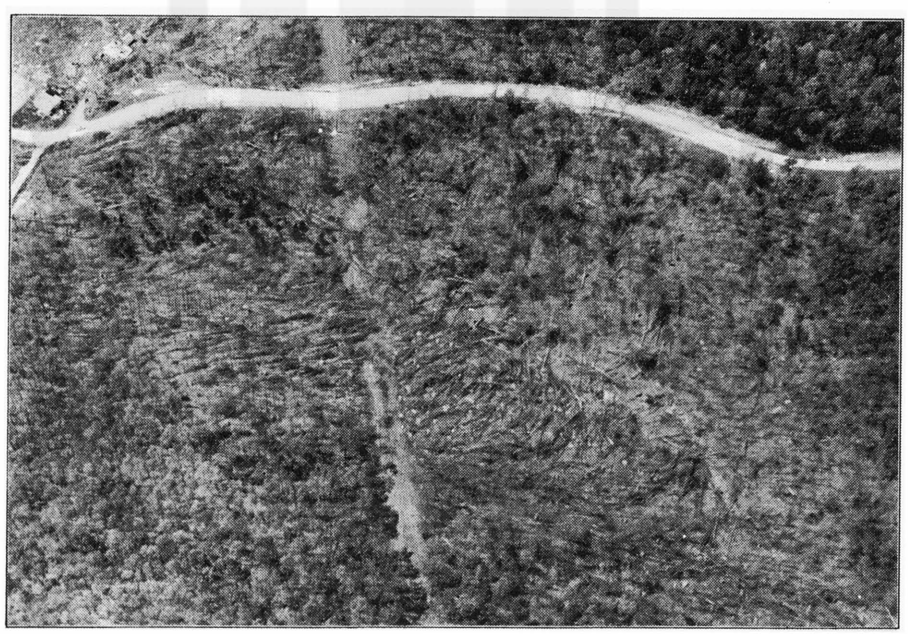

Fig. 7. Aerial photograph of Fig. 6.

Note that a distinct pattern of tree-fall directions exists to the right of the power line clearing near the picture center. The diameter of this suction vortex was no more than 50 ft, while the core diameter of the parent tornado was estimated to be about 300 ft. The tree-fall directions prior to the formation of the suction vortex were more or less straight with definite down-slope motion. A photograph (see Fig. 8) taken from the edge of the road in the power line clearing at the camera position indicated in Fig. 6 shows that most trees were blown down by down-slope winds which were more or less straight in nature. When this picture is compared with that of Fig. 7, it is evident that an intense suction vortex formed slightly to the east of the power line clearing.

At the tornado position "3" in Fig. 2, three damage swaths, "d", "e", and "f" are apparent. Swath "d" originated at the plateau edge and descended toward the south of the parent tornado. Strangely enough, swath "e" appeared near the top of the 680-ft. hill and descended over 50 ft. into the valley, but it failed to continue all the way into the valley floor. On the contrary, swath "f" appeared near the valley floor and ascended to the north a short distance. Another swath, "g", descended into a V-shaped valley from the south of the tornado position "4", causing the most destructive tree damage at the valley floor.

Fig. 8. Photograph taken with camera set up at location indicated in Fig. 6. These trees appear to have been felled by straight downslope winds.

3. INTENSITY AND AREA OF THE 1971 TORNADOES

In an effort to learn more about the characteristics and behavior of tornadoes, it was felt that instead of merely naming such occurrences as tornadoes, per se, certain parameters as length, width, intensity, time, and location, among others, could be utilized in order to distinguish them individually. Thus, Fujita (1970a) proposed to classify tornadoes according to their damage areas and defined the "individual tornado area, a" as

$$a = \ell \times \overline{w} \tag{1}$$

where ℓ is the length and $\overline{w}$, the mean width of the tornado damage path. Earlier, an attempt to categorize tornadoes by intensity was made by Seelye (1945) in a survey of tornadoes in New Zealand wherein an arbitrary scale ranging from 0 to 5 units was adopted to indicate tornado intensity. Fujita (1970b) devised a scale (Fujita- or F-scale) of damaging wind consisting of 13 ranges, designed to connect smoothly the wind speed of Beaufort wind force 12 with the speed of sound in the atmosphere since winds in excess of the range of the Beaufort scale are increasingly being encountered. Of these ranges, only those from range F 0 to range F 5 are commonly observed in classifying tornadoes. To aid in F-scale determinations from damage descriptions or accounts, or from photographs or actual surveys, whether from the air or ground, a damage chart containing typical damage scenes for the ranges from F 1 to F 5 is used in addition to the plain-word description for each F-scale number.

Thus, it is now possible to "characterize" a tornado with two parameters, that is, according to intensity of damaging wind (F-scale) and individual tornado area "a" (log a scale). Table 1 shows the resulting tornado classification according to intensity of damaging wind and damage area of an individual tornado.

Consequently, a tornado can be characterized by a combination of intensity and area in such manner that each one can be expressed as two adjectives; the first, describing the intensity, and the second, the damage area, such as "Strong Micro Tornado", etc.

We have received from NOAA climatologists both intensity and area classifications of all confirmed tornadoes occurring during the first four months of this year. These reports consist of their own evaluation of tornado characteristics based on the Fujita-scale damage chart and damage descriptions which were distributed to them early in January. During the early stage of this characterization experiment, Mr. L. A. Joos, Regional

Table 1. Classification of Tornadoes according to Intensity and Individual Damage Areas.

TORNADO INTENSITY

(I = Estd. Damaging Wind in mph)

	Intensity Category	Range
F 0	Gale Tornado	$(40 < I \leq 72)$
F 1	Weak Tornado	$(72 < I \leq 112)$
F 2	Strong Tornado	$(112 < I \leq 157)$
F 3	Severe Tornado	$(157 < I \leq 206)$
F 4	Devastating Tornado	$(206 < I \leq 260)$
F 5	Incredible Tornado	$(260 < I \leq 318)$
F 6-F 12	Inconceivable Tornado	$(318 < I \leq 738)$

TORNADO DAMAGE AREA

(a = Individual Tornado Area in sq. mi.)

	Area Category	Range
TR	Trace Tornado	$(0.0 < a < 0.001)$
DM	Decimicro Tornado	$(0.001 \leq a < 0.01)$
MI	Micro Tornado	$(0.01 \leq a < 0.1)$
ME	Meso Tornado	$(0.1 \leq a < 1.0)$
MA	Macro Tornado	$(1.0 \leq a < 10.0)$
GI	Giant Tornado	$(10.0 \leq a < 100.0)$
DG	Decagiant Tornado	$(100.0 \leq a < 1000.0)$

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Climatologist for the Central Region, has rendered assistance in making best possible assessment of tornadoes by climatologists.

Considering that there are no absolute ways of determining tornado intensity and area, we should expect uncertainties of 1 or possibly 2 in the F-scale estimate. Nevertheless, the statistical analysis of such data will be of great value in understanding both intensity and area distributions of storms classified as tornadoes.

All data from NOAA Climatologists were then punched in cards and processed through the IBM System/360 Model 65 computer facility of the University of Chicago.

In analyzing the data, one restraint is imposed to minimize the possibility of inflationary effects and bias that could result in counting individually the occurrences of weak intensity and small area tornadoes that appear to be in groups or clusters. The restraint defines that if 2 or more F0 or TR or DM tornadoes occur within 1 hour and less than 10 miles of each other, then it is counted only as 1 occurrence.

Table 2 shows the breakdown of tornadoes as reported from January through April 1971, classified according to intensity and individual damage area categories for the continental United States.

Table 2. Occurrences of Tornadoes in the Continental United States from January through April 1971 Classified according to Intensity and Individual Damage Area.

INTENSITY	INDIVIDUAL AREA						TOTAL
	TR	DM	MI	ME	MA	GI	
F5	0	0	0	0	0	0	0
F4	0	0	1	1	3	5	10
F3	0	0	4	8	6	1	19
F2	3	10	15	30	3	0	61
F1	8	31	36	17	1	0	93
F0	17	7	5	0	0	0	29
TOTAL	28	48	61	56	13	6	212

Fig. 9a shows the monthly percentage frequency distribution of the occurrences of tornadoes classified according to intensity. Except for January, which incidentally had no reports on severe and more intense tornadoes, the most frequent occurrences were of the F1 category (73-112 mph winds). Fig. 9b shows the same frequency distribution classified according to individual damage area. For each area, the values appear to fluctuate during the period except in the occurrence of meso tornadoes which ranged from 24-29 percent. When frequency distributions are constructed for the 4-month period, the first for intensity (see Fig. 10a) and the second for individual damage area (see Fig. 10b), it is rather interesting to note the remarkable similarity in the shapes and maximum percentage values

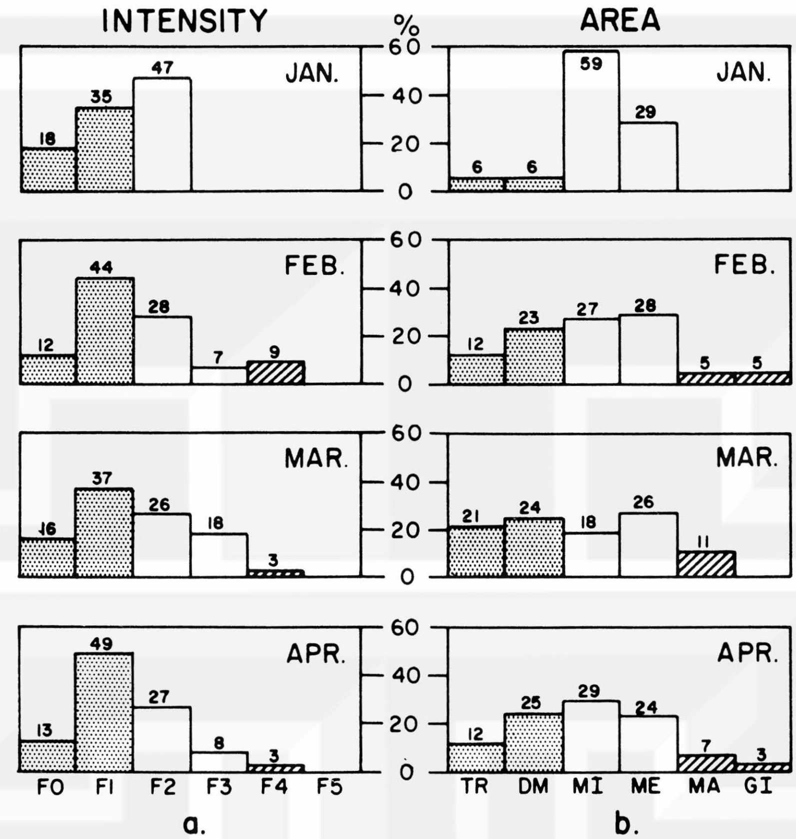

Fig. 9. Monthly percentage frequency distribution of 212 tornadoes in the U.S. for January through April 1971 according to (a) intensity and (b) individual damage area.

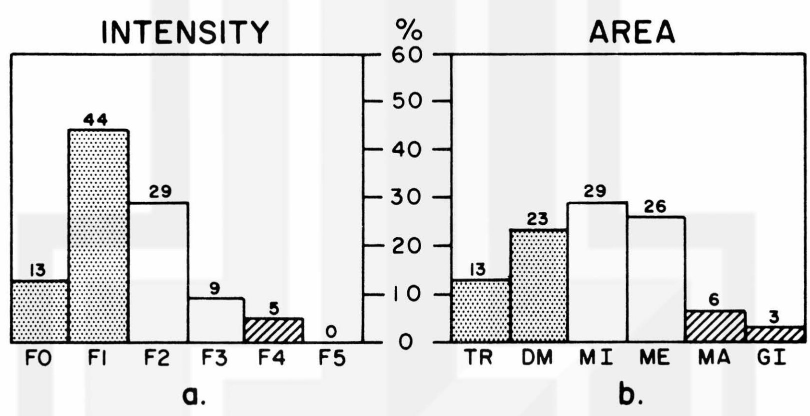

Fig. 10. Percentage frequency distribution of 212 tornadoes in the U.S. for January through April 1971 according to (a) intensity and (b) individual damage area.

with those depicted in the characterization of the 893 tornadoes reported in the United States in 1965 (Tecson 1971) and reproduced as Fig. 11a and 11b, respectively.

Following the definition of a tornado day given by Fujita (1970b) 6 a.m. to 6 a.m. local standard time, the diurnal distribution of frequencies of tornado occurrences during

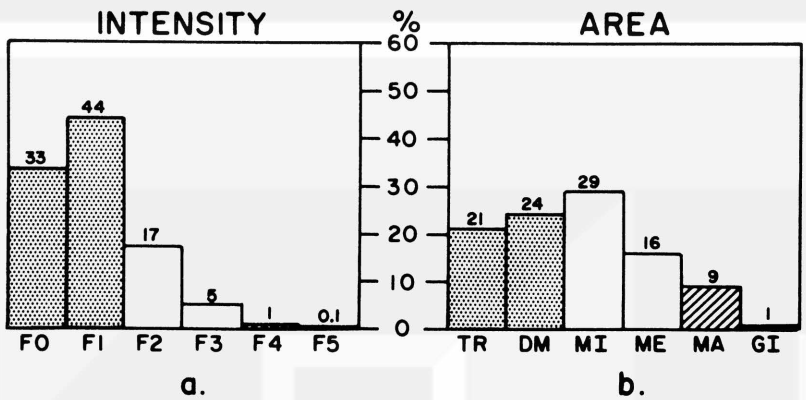

Fig. 11. Same as Fig. 10 except for 893 tornadoes in 1965.

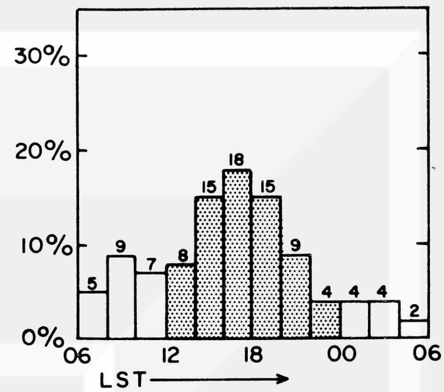

Fig. 12. Diurnal distribution in percent of tornadoes with specified time of occurrence.

2-hour periods was determined. Of the 212 tornadoes characterized 94 percent specified the beginning time of occurrence in Storm Data. Fig. 12 shows the diurnal distribution in percent of tornado occurrences. About one-half of the storms were reported between 1400 H and 2000 H, two-thirds occurred between noon and midnight (shown by stippled area). On the other hand, Figs. 13a and 13b depict the distribution for each range in the F-scale (intensity) and log a-scale (individual area) categories, respectively. For each graph, the mean time of occurrence is indicated and the position shown by the vertical broken line. While it appears that the mean time of occurrence shifts toward later hours as the individual damage area increases, the same is not conclusively revealed in the intensity graphs. However, by employing k-statistics for these sample observations which are not large (Kenney and Keeping, 1954), the skewness of each distribution is determined by

$$g_1 = k_3 / (k_2)^{3/2} \qquad (2)$$

where g_1 is an estimate of a measure of skewness, and k_2 and k_3 are the unbiased estimates of the population variance and the third moment about the mean, respectively.

Fig. 14a is a graph of skewness (g_1) as a function of the F-scale. It is noted that since the skewness value increases positively as the F-value increases, this indicates, except for F0, the tendency for more intense tornadoes to occur later in the day than the less intense ones. Fig. 14b, which is a graph of skewness (g_1) as a function of individual area, does not clearly exhibit such tendency except from meso tornadoes to the much larger ones. On the whole, these observations seem to be similar to the results of the characterization of the 1965 tornadoes.

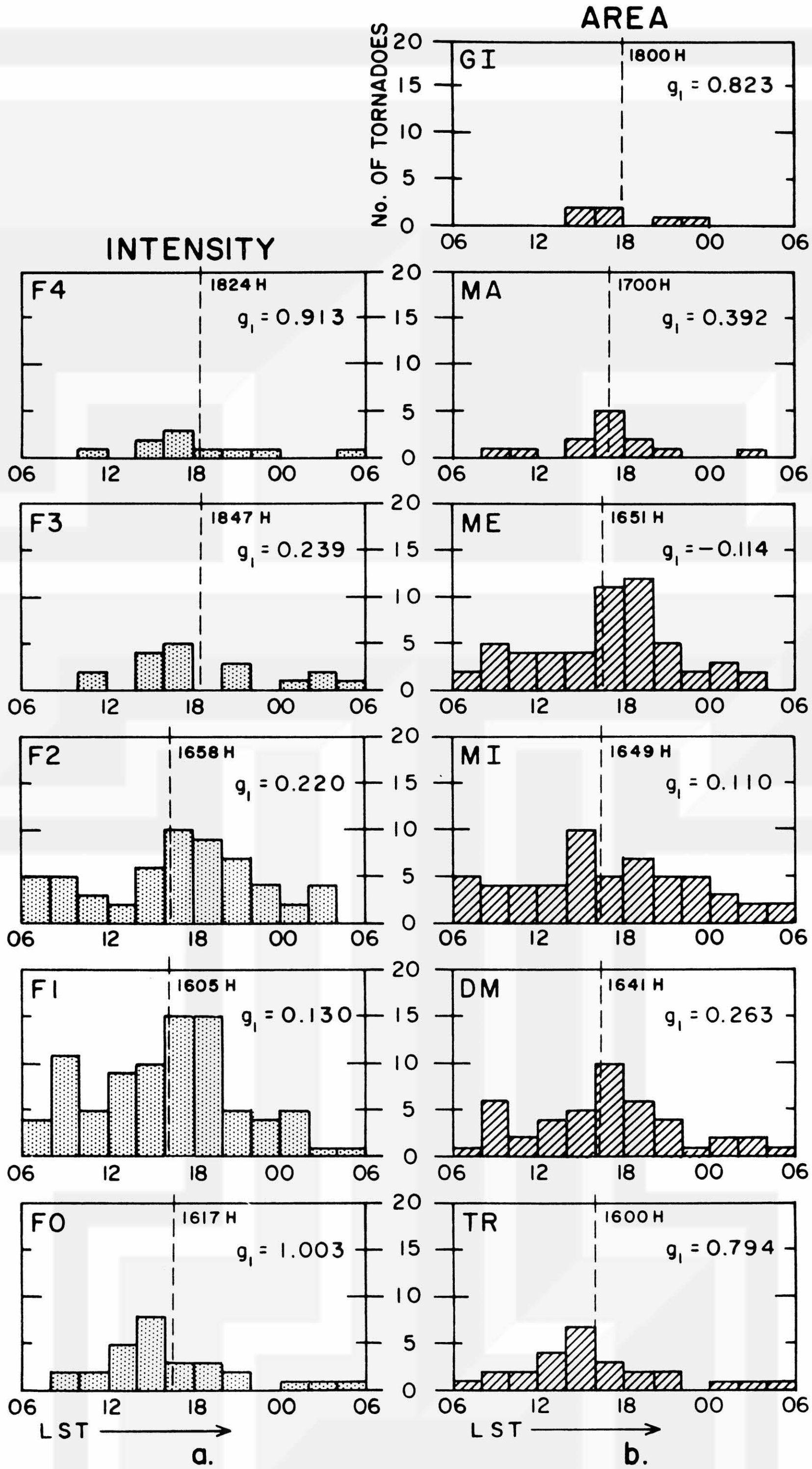

Fig. 13. (a) 2-Hourly distribution for damaging wind scales for tornadoes in U. S. for January through April 1971. (b) 2-Hourly distribution according to individual damage area.

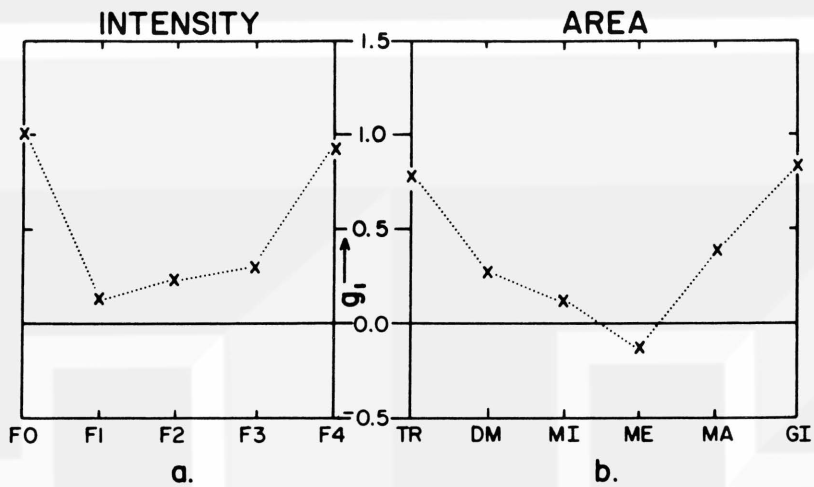

Fig. 14. Skewness value (g_1) as a function of (a) intensity and (b) individual damage area.

4. CONCLUSIONS

Prior to the damage survey of the South Hill tornado, it was assumed that high spots would receive more significant damage than low spots and valley floors. According to the tornado occurrence time of about 2000 CST received from NSSFC, we did not expect a dry-adiabatic or super-adiabatic lapse rate to prevail inside the valley atmosphere, thus expecting a skipping action of the tornado without disturbing the potentially cold valley atmosphere.

Contrary to such an expectation, we began to spot more damage at low levels. It was first assumed that an expected high moisture content in the valley soil would help weaken the tree resistance against tornado winds. This concept was corrected very quickly because trees in the valleys in this area did not appear weak at all. We often observed large trees in the valley which were snapped at about 6 to 9 ft. above the ground while leaving the root structure undisturbed. We also observed old trees and farm houses on plateaus which were untouched despite their locations very close to the storm's path.

The mystery still remains as to how the vortex of a travelling tornado tends to extend downward to the valley floor after sunset when we do not expect an unstable lapse rate below the plateau level. Besides, the overall intensity of this tornado was significantly stronger in the valleys compared with plateau areas within the comparable distance from the tornado center.

This part of the research will be continued in two ways: The first is the analysis of the Russell Springs tornado which moved over several gorges some 300-ft. deep. A large number of color photographs of excellent quality is being processed for analysis. Results of this proposed analysis will reveal important and unknown characteristics of gorge-crossing tornadoes.

This preliminary report on the characterization according to intensity and area of the 1971 tornadoes on data from January through April 1971, showed that, quite similar to the results obtained from the study of the 1965 tornadoes using the same characterization scheme, the most frequently reported tornadoes that occurred belong to the F1 scale of intensity (73-112 mph winds) and to the micro tornado category (individual damage area between 0.01 and 0.1 sq. mi.). Also noteworthy could be the fact that, again similar to those observed in the study of the 1965 tornadoes, there appears the tendency for the more intense tornadoes and also those with large damage areas to occur later in the day than the weaker and also the smaller damage-area tornadoes. However, final analyses and conclusions must eventually be based on complete data for 1971.

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