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NEW EVIDENCE FROM APRIL 3-4, 1974 TORNADOES

T. Theodore Fujita
The University of Chicago
Chicago, Illinois

Abstract

The 148 tornadoes spawned during the April 3-4, 1974 Superoutbreak left behind valuable information regarding their characteristics. Since so many tornadoes were simultaneously in progress, a line of tornadoes appeared ahead of the parent squall line, thus forming a "tornado line". A typical example of tornado formation inside a hook was found in the Xenia tornado. During the mature stage, the tornado moved out of the hook quickly, showing an "unhooking phenomenon".

Suction vortices were found or suspected in many tornadoes. They now appear to be the important element of tornadoes, rather than an ornament. The Xenia tornado had several suction vortices, large and small, with a few seconds of life. Without suction vortices, the Xenia tornado windspeed at ground level might have been only 150 mph. Inside strong suction vortices the windspeed probably reached 250 to 305 mph depending upon the altitude.

1. INTRODUCTION

A major effort of assessing the extent of the April 3-4, 1974 outbreak was made at the University of Chicago. First, the "Preliminary Color Map" showing the 127 tornado paths was printed and distributed to NWS, Civil Defense offices, local newspapers, and other organizations, expecting to receive more information regarding the "Superoutbreak".

During the course of data gathering and analysis, it was felt that the confirmation of all tornadoes is an impossible task no matter how hard one works. As of February 1975, just about 10 months after the tornadoes, the confirmation effort at the University of Chicago had ended.

The "Final Color Map" including 148 tornado paths was printed in April, 1975, with the hope that there would be no addition of paths to the map. 12,000 maps were printed and 80% were sent out as of June, being requested by various organizations, schools, companies, and the general public. Sent along with each map was a questionnaire form, to be filled out and returned by the map recipients. Fortunately, no debate on additional tornadoes has been received. People were simply overwhelmed by the extent of the outbreak which left behind over 300 fatalities.

Immediately after the Superoutbreak, newspapers published the count of fatalities of historical outbreaks. The outbreak involving the Tri-state tornado in 1925 has been considered to be the worst since 1916. The Palm Sunday tornadoes of April 11, 1965 were quoted as the worst in the recent decade.

Presented in Fig. 1 are the monthly counts of tornado deaths in the United States since 1916. The outbreaks, each involving in excess of 100 deaths, are entered in the figure. It is seen that most of the significant monthly deaths are attributed to one or possibly two outbreaks which occurred during the particular month.

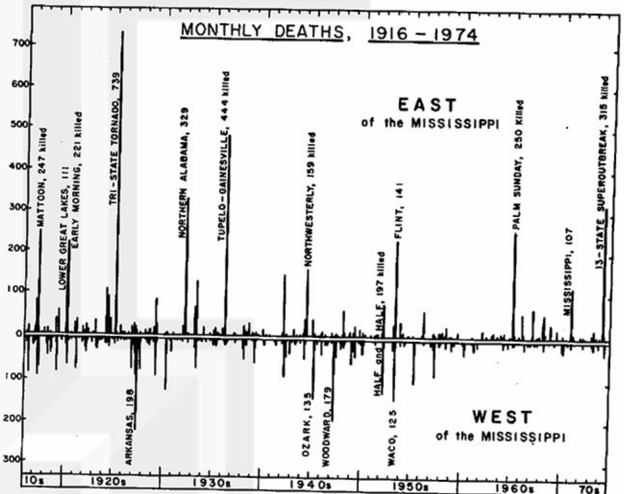

Fig. 1. The rank of the 13-state superoutbreak on April 3-4, 1974. The bar graph represents the tornado deaths by months, to the east and the west of the Mississippi.

The odd-shaped U. S. map in Fig. 2 was produced by changing the size of each state in proportion to the tornado deaths during the past 59 years. The idea of this map came from a TV show where the World map was produced by changing the size of each country in proportion to the production of oil. The paths of the 148 tornadoes on April 3 and 4 superimposed upon the map show that the outbreak affected the eastern parts of the map.

The center of U. S. population has been computed

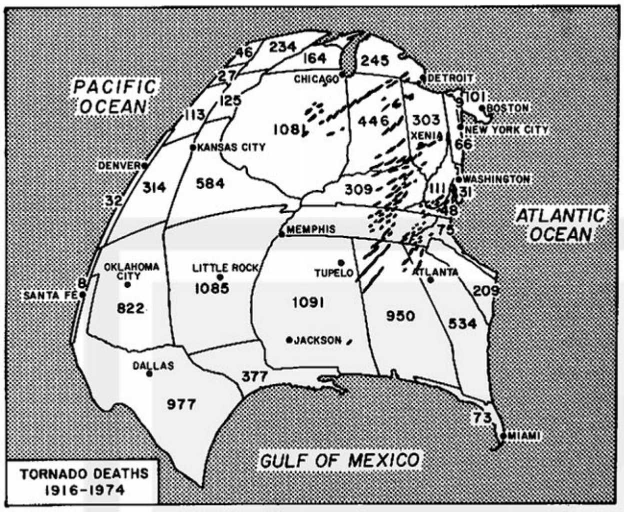

Fig. 2. An odd-shaped U. S. map including the paths of the 148 tornadoes on April 3-4, 1974. Denver and Santa Fe are seen on the west coast.

by the Bureau of Census at 10 year intervals. The center in 1970 was located in a farmland, 5 miles east southeast of Mascoutak, Illinois. Nobody lives at the U. S. population center which has been moving steadily westward.

Linehan (1957) applied the concept of the population center to tornado deaths and calculated the monthly position of "center of death". He found that the center located in Mississippi during the winter months migrates more or less northward, ending up in Iowa during the summer (Refer to U. S. W. B. Tech. Paper No. 30).

Since the 1974 Superoutbreak was a significant killer outbreak during the past two decades (Fig. 1), it was the author's personal interest to calculate its effect upon the "fatality centroid". This term will be used in lieu of the "center of death" to avoid misinterpretation of the center which is equivalent to the center of gravity where no mass may exist.

As shown in Fig. 3, the Superoutbreak affected somewhat the trend of the 10-year running means of fatality centroid. For Fourier analysis of the centroid refer to the paper "Long Term Fluctuation of Tornado Activities" in this volume by Fujita, Pearson, and Ludlum.

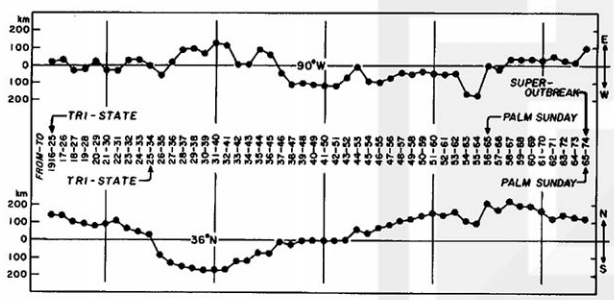

Fig. 3. Fluctuation of the center of gravity of tornado deaths, as determined by the 10-year running average.

One of the most important reasons for a better understanding of tornadoes and their causes is to minimize human casualties; i.e. deaths and injuries. The 148 tornadoes, after causing violence in 13 states and Canada, provided us with a gold mine of data for learning about the nature of tornadoes and their parent thunderstorms.

Presented in this paper is a brief outline of the research being performed by the author and his colleagues at the University of Chicago.

2. SQUALL LINE AND TORNADO LINE

It has been known for sometime that intense tornadoes often form out of thunderstorms moving ahead of a typical squall line. A similar but dramatic line of tornado-producing thunderstorms was seen during the height of activities on April 3, 1974 (Fig. 4).

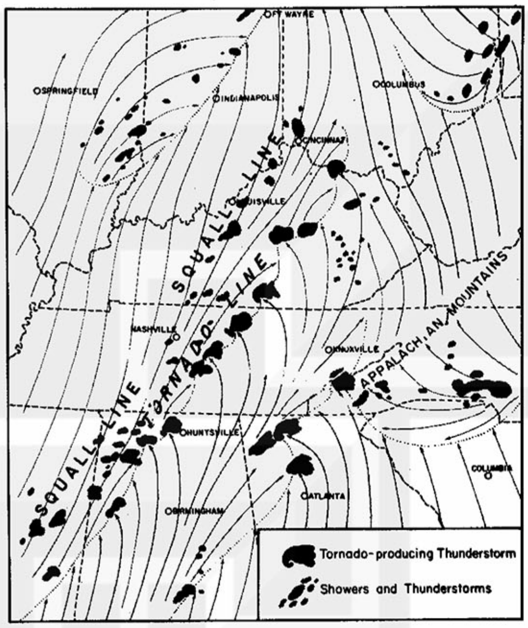

Fig. 4. A tornado line at 0000 Z, April 4, 1974.

The primary reason for the separation of the tornado line from the squall line appears to be the basic difference in the motion of rotating and non-rotating thunderstorms. The former tend to deviate to the right of the latter. As the time goes on, the difference in their positions becomes so large that two separate lines may appear in a composite radar map such as Fig. 4. It should be noted that an outflow field produced by the squall line tends to maintain a shear line beneath the line of the rotating thunderstorms.

ATS-III pictures taken at 13-min intervals during the daylight hours of the Superoutbreak showed relatively wide cloud bands. The squall-line echoes were imbedded in the western portion of the cloud band while the tornado line ran through the center of the band. The eastern part was characterized by the blow-off cirrus.

Due to the lack of space, a sequence of 14 satellite pictures with tornado locations is not reproduced in this paper. For the full sequence, refer to Fujita and Forbes (1974).

3. HOOK ECHO AND TORNADO (RECYCLING HYPOTHESIS)

Since 1953 when CPS-9 radar of Illinois State Water Survey took a picture sequence of a hook echo, the radar hooks have been used in locating tornadoes. There has been little evidence of the radar hook in cloud photographs including tornadoes and environmental clouds.

The first of the 10 pictures in a sequence taken by Mr. Thomas Benadum shows a large, immature funnel cloud. It was located just about 0.5 mile to the southwest of Xenia. The picture was taken 30 seconds before the devastation started. The neck of the cloud, somewhat like an upside down volcano, was surrounded by a necklace of cloud. The cloud which may be called the "collar cloud" was whitish gray, accompanied by streaks of rain and/or hail falling from inside the collar (see Fig. 5). The second picture taken about 20 seconds later still shows identifiable features of the collar cloud, making it possible to determine the displacement of the collar cloud.

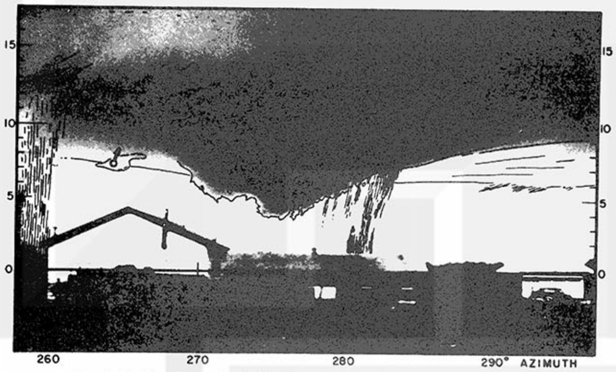

Fig. 5. The first picture taken by Mr. Thomas Benadum. Picture time, 4:40 PM EDT.

Within a few seconds of the cloud picture, at 4:40 PM EDT, a CPS-9 picture of a hook echo was obtained by the 15th Weather Squadron at Wright-Patterson AFB. As shown in Fig. 6, the hook was comma shaped with the tornado at the comma head.

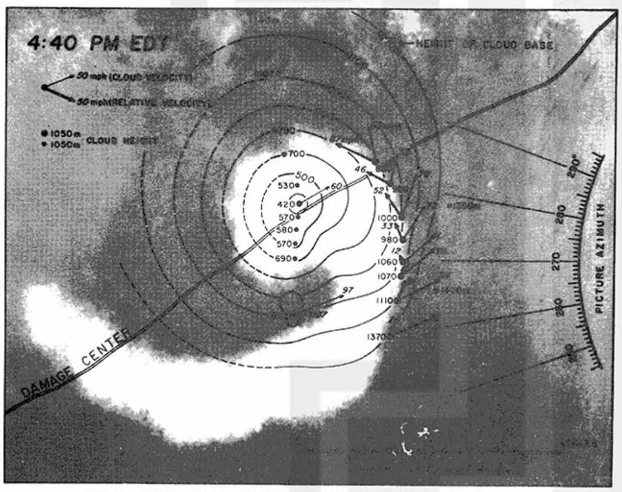

Fig. 6. A comma-shaped hook echo photographed by 15th Weather Squadron, Wright-Patterson AFB. Attenuation was -47 to -63 dBm.

The photogrammetric matching of the hock echo and the cloud picture revealed that the collar cloud was located along the outside edge of the hook echo. Heavy rain is seen to the left of the 260° azimuth, tornado on 275°, and right-side edge of rain on 284°.

In reference to the tornado movement between the first and the second pictures, the vector motion of the collar cloud was computed. The azimuth change will give the tangential motion and the elevation angle will give the radial motion, under the assumption of horizontal cloud motion. The heavy arrows, thus obtained, represent the relative velocity of the east edge of the hook. It was spiraling into the tornado while conserving, more or less, its angular momentum.

As the tornado was moving over the Arrowhead district, where devastation and death occurred, the collar cloud went around the back side of the upside down volcano and reappeared on the left side. The collar quickly wrapped around the tornado, resulting in a tight spiral, something like that of an "ammonite". A complete photogrammetric analysis of the Benadum pictures is being made.

If the angular momentum of the air spiraling into the tornado is transported toward the ground due to precipitation, it will be drawn into the tornado near the surface. A number of Benadum pictures show significant curvature and tilt of the rain streaks toward the tornado, implying a recycling of the downdraft into the bottom of the tornado. As shown in Fig. 7, the dust column above the ground is pushed toward the left, showing an apparent tilt of the tornado axis toward the right.

According to the "recycling hypothesis," the downdraft air will recirculate into the tornado. This process will result in an appreciable convergence on the back side of the tornado in the picture. The downward transport of the angular momentum by precipitation and the recycling of the air into tornado will create a tangential acceleration required for the intensification of tornado. The angular momentum of the collar cloud would be adequte to account for the development of the Xenia tornado as it approached the Arrowhead section.

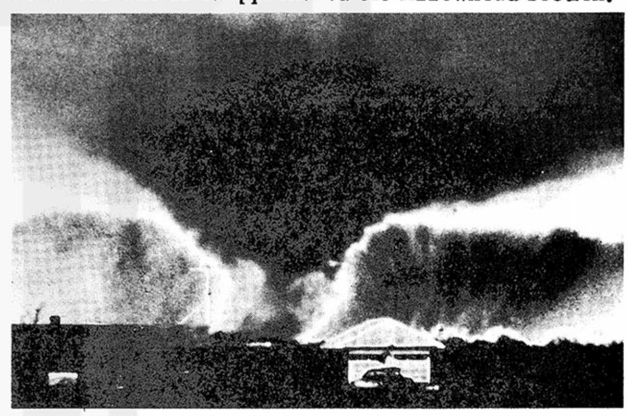

Fig. 7. Precipitation streaks from the hook-echo region. The streaks curve toward the tornado, suggesting a recycling inflow. Special enhancement was applied to bring up precipitation.

In the forested areas to the south of Guin tornado in Alabama, numerous patterns of trees blown down in radial directions were found. Figure 8 reveals the distribution of such a diffluence pattern. A localized, microscale downdraft could be a reasonable explanation for the generation of such a pattern of tree damage. These diffluence patterns of trees were found predominantly to the right of the tornado path. Found to the left of the path are predominantly the confluence patterns as shown in the figure.

The author had heard stories that persons in cars near tornadoes felt that wind forces above them were just like someone dancing on the car top. In view of the finding of the diffluence pattern in the Alabama forest, we should not disregard such stories because they are likely to be true.

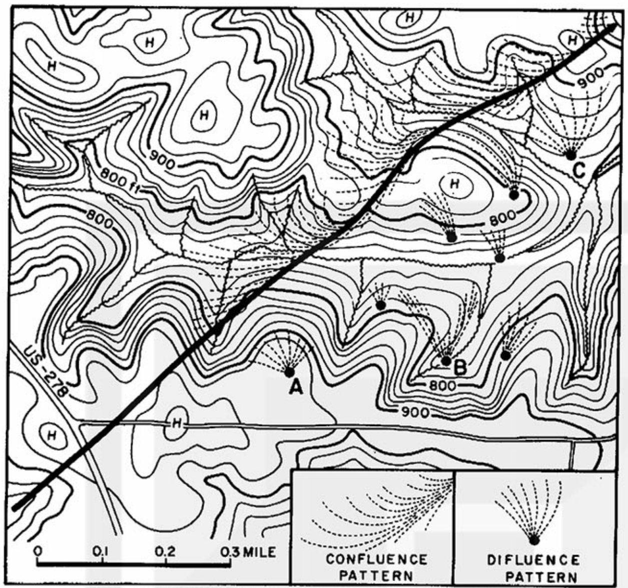

Fig. 8. Diffluence patterns of blown down trees in William B. Bankhead National Forest. These patterns are likely to be caused at the landing spots of localized downdraft beneath the hook echo.

4. TORNADOES GET OUT OF HOOKS

It has been found that many tornadoes during the Superoutbreak made left turns before their dissipation. The left-turn tornadoes were stronger, on the average, than their right-turn and no-turn counterparts. The author, as well as his colleagues, assumed at first that a tornado starts turning cyclonically around the tornado-cyclone center when its fury decreases. We thought that this mechanism could explain the left-turn motion of tornadoes before their dissipation.

Detailed examination of the Brandenburg tornado proved that the tornado was outside the parent hook when it was moving over the city of Brandenburg at 4:11 PM CDT. A sequence of radar pictures in Fig. 9 revealed that the tornado had been outside the hook since 4:04 PM when the storm had reached the estimated F5 intensity.

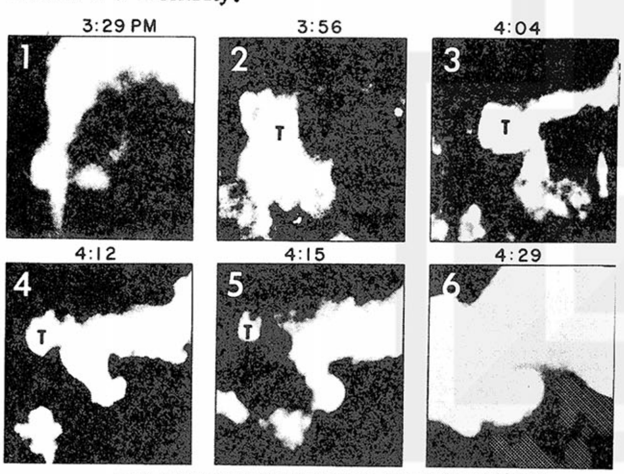

Fig. 9. The location of the Brandenburg tornado. The radio station and the town were hit with F5 tornado at 4:08 and 4:11 PM CDT.

The motion of the Brandenburg tornado relative to the parent hook is given in Fig. 10. The ground survey confirmed that the tornado started getting out of the hook upon reaching its maturity. The Louisville tornado departed the hook, heading toward the south very slowly. Its path made a slight right turn before its dissipation.

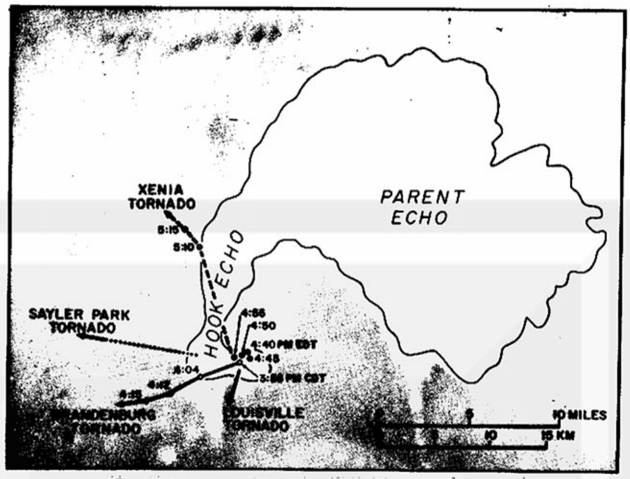

Fig. 10. Relative motion of tornadoes when they got out of the parent hook. The "unhooking" toward the west or northwest causes a left turn of tornadoes.

The Sayler Park tornado, as seen in the picture sequence by Mr. James Carter, II, was swirling practically under the blue sky far to the west of the parent cloud. When the Mack community, north of Sayler Park received an estimated F4 scale damage, the tornado was already outside the main convective area. Mr. Carter who is working with the author during this summer plans to complete this study.

The Xenia tornado also moved out of the hook during its dissipating stage. As shown in Fig. 11, the tornado at 5:10 PM was on the west edge of the hook and accompanied in part by a spiral echo.

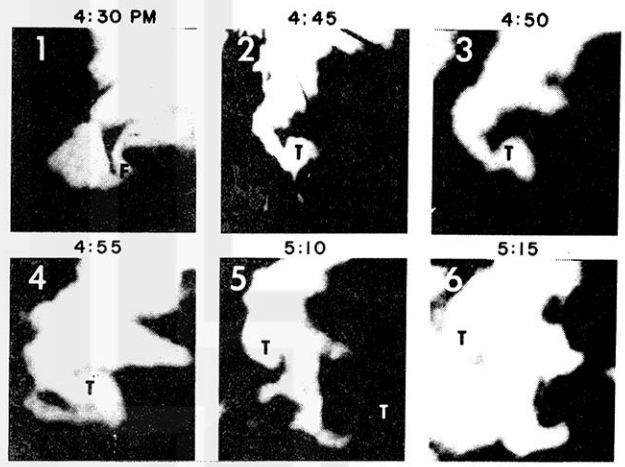

Fig. 11. The Xenia tornado also got out of the hook. There was a funnel aloft at 4:30 PM at the location of "F".

Those who watch radarscope during tornadic activities have a tendency to consider the location of a hook as being that of a tornado. This is not entirely true, because some intense tornadoes could be far outside the parent hooks. The maximum distance could be 10 miles or even further.

5. TORNADOES DISREGARD TOPOGRAPHY

In the statistics sheet distributed along with the color map, the author commented that the

*Obey River Tornado (No. 87) descended into a 1,000-ft deep canyon with its full strength, and then climbed to the top of the cliff on the other side.

*Blue Ridge Tornado (No. 120) moved over the 3,300ft Betty Mountain, the highest of all tornado paths.

*Murphy Tornado (No. 121) left behind the largest number of debarked, shiny trees. Leaves were completely stripped off. This was a mountain-climbing tornado. Examples of damage on rough terrains are presented in Fig. 12 and 13.

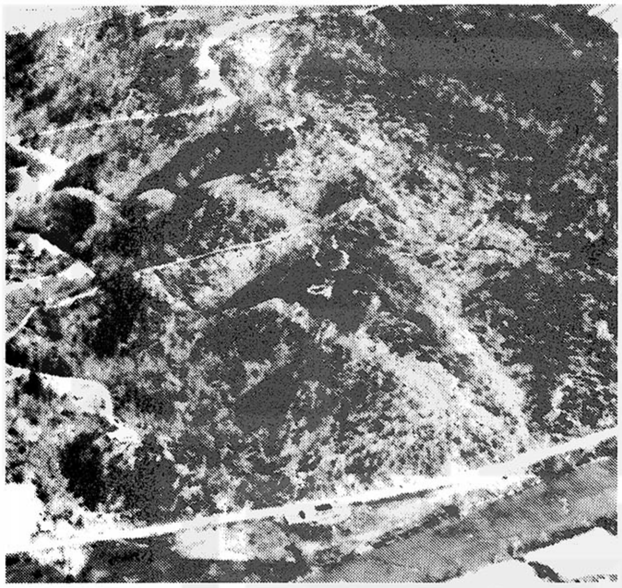

Fig. 12. The Murphy tornado (No. 121) climbed straight up a mountain. Two persons were killed at the foot of the mountain.

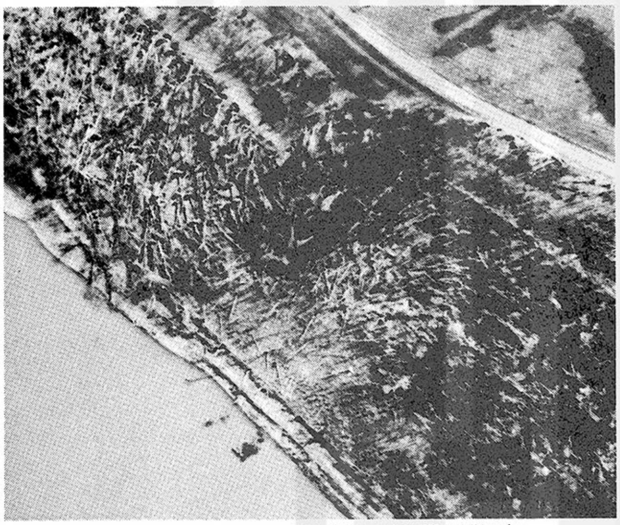

Fig. 13. The Campbellsville tornado (No. 62) descended a 200 ft cliff into the dammed-up Robinson Creek.

6. SUCTION VORTICES NOTED IN MANY TORNADOES

Since the author proposed the suction-spot concept based on the ground marks of Palm Sunday tornadoes, 1965, new characteristics of suction spots have been unveiled almost every year.

The Tokyo tornado of 1970 left a distinct circulation pattern in a sweet-potato field. Similar circulation patterns were found elsewhere; young wheat fields in southern Texas, corn fields in Iowa, and forests in Alabama, etc.

Now, the suction swaths on the ground may be classified into the following three types:

a. Single, light-colored line along the path of a single-vortex tornado (see Fig. 14).

b. Repetition of small cycloidal curves, typical of intermediate-sized tornado core (see Fig. 15).

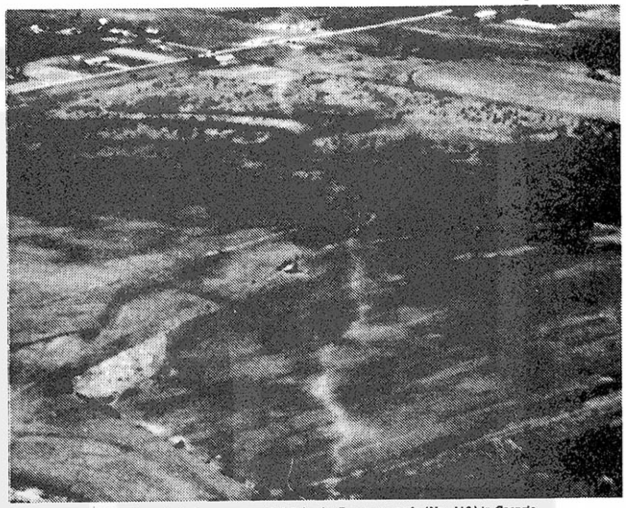

Fig. 14. A single-vortex swath left by the Resaca tornado (No. 119) in Georgia.

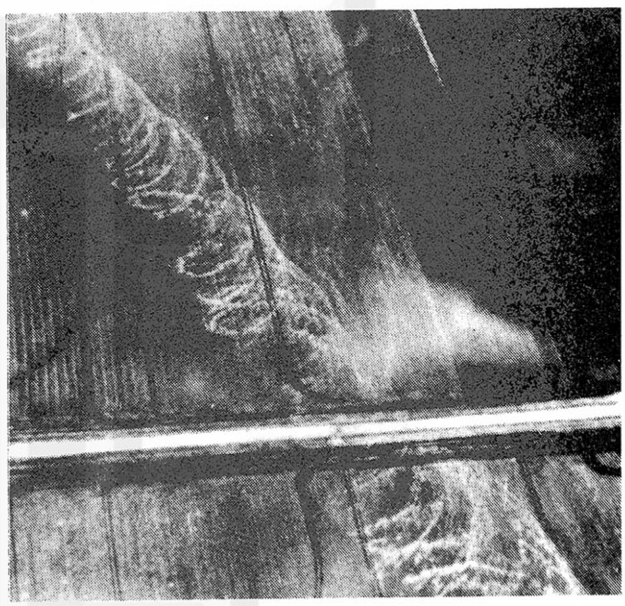

Fig. 15. Small cycloidal swaths of the Anchor tornado (No. 4) in Illinois.

c. Giant cycloidal curves, some with double tracks. The double tracks could be produced by a pair of twin suction vortices rotating around their common centers (see Fig. 16).

Suction vortices in action were filmed during several tornadoes. The Parker tornado (No. 33) had several vortices inside. The Lascassas tornado with suction vortices was also filmed in Tennessee.

Xenia tornado was accompanied by numerous suction vortices like spaghetti, moving around beneath a large funnel cloud which never reached the surface. For a short time, there were a pair of twin suction vortices on the ground, which rotated around each other. The movie revealed that suction vortices exist over a city area despite the argument by some engineers who do not believe the realization of this phenomenon.

Fig. 16. Giant cycloidal swaths of the Homer Lake tornado (No. 10) in Illinois. The double swaths indicate the paths of twin suction vortices.

Reports of multi-funnel sightings by the public had long been disregarded in many cases. Now we suddenly face the realism of multi-vortex tornadoes. How many are multi-vortex tornadoes? Nobody knows the exact answer. However, the author is inclined to think that over 50% of damaging tornadoes are characterized by multi-suction vortices.

7. PHOTOGRAMMETRIC WIND SPEED OF XENIA TORNADO

In an attempt to estimate the maximum wind speed of the Xenia tornado, a super 8 movie taken by Mr. Bruce Boyd was analyzed photogrammetrically. The tornado as shown in Fig. 17 was moving across the Arrowhead section of Xenia where many houses were smashed or blown away. There was no evidence of the condensation funnel reaching the ground.

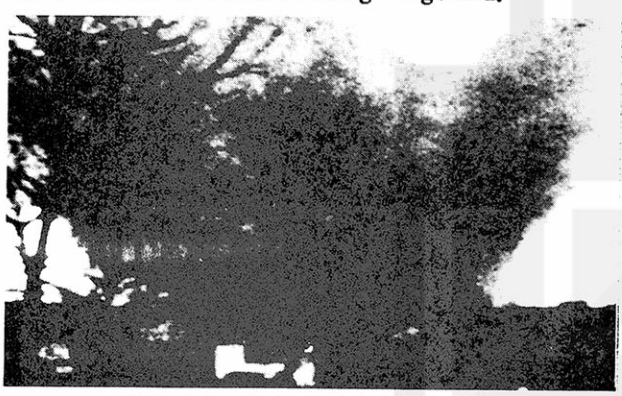

Fig. 17. One frame of the Super-8 movie taken by Mr. Bruce Boyd.

The apparent dust motion shown in Fig. 18 was computed by tracking clusters of dust clouds. The range to each cluster was computed assuming that the cluster is located on the outer edge of the swirling dust cloud.

Since the dust-cloud motion was characterized by a significant radial motion, away from the tornado center, the distance/horizontal-speed diagram as

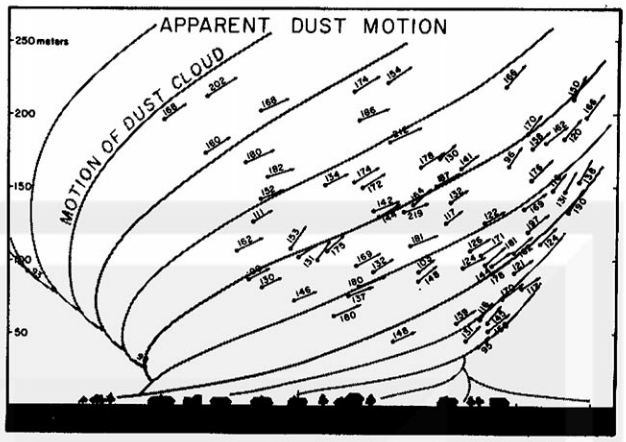

Fig. 18. Motion of dust cluster in the plane of the image (apparent dust motion) in mph. Five scenes over the Arrowhead section were combined.

shown in Fig. 19 was used in determining both radial and tangential speeds. The diagram reveals that the isoline of the horizontal speeds plotted against the distance from the tornado axis is an ellipse. Unless a dust cloud is on the tornado axis the horizontal speed does not represent the tangential speed. This figure, however, will permit us to perform a reasonable correction to the speed of dust clusters located off the center axis of a tornado. The correction which may be called the "off-center correction" is necessary in computing the tangential speed from the apparent horizontal speed.

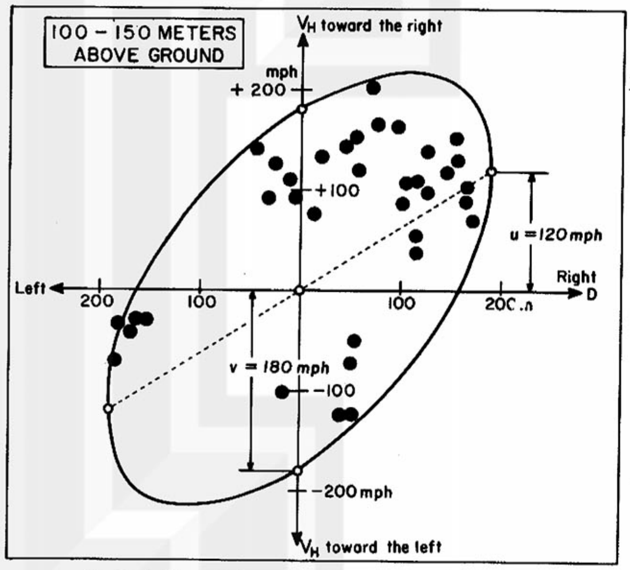

Fig. 19. An ellipse on the distance/horizontal-speed diagram. The "off-center correction" can be made by this diagram.

The tangential speeds relative to the tornado center, after the off-center correction, were plotted against the height above the ground (Fig. 20). The heavy line represents the uppermost boundary of the tangential speeds of dust clouds.

The vertical speeds computed as the vertical component of the apparent dust motion in Fig. 17 are presented in the scatter diagram of Fig. 21.

The measured values of the four basic speeds, tangential, vertical, radial, and translational, are presented in Fig. 22. Since the obstruction prevented us from tracing clusters of dust below about 30-m level, the speeds at low levels are given by dashed lines.

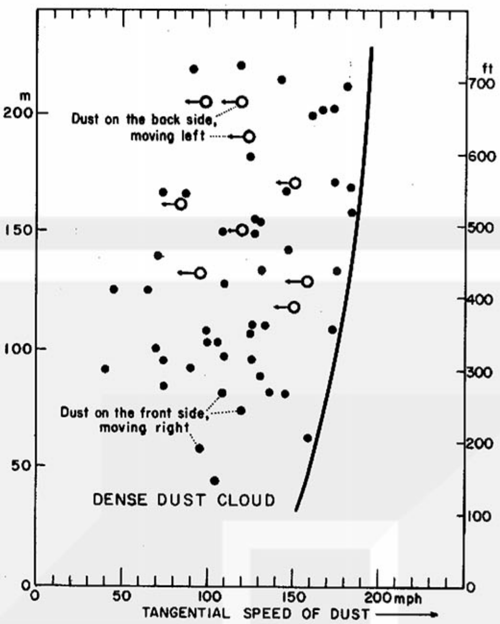

Fig. 20. Vertical distribution of the tangential speed of dust clusters.

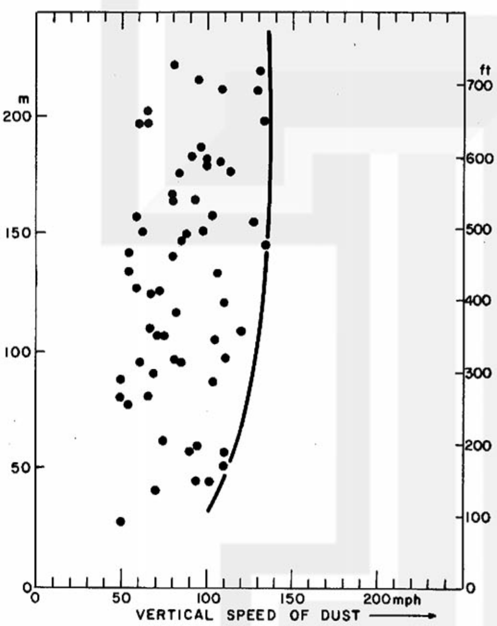

Fig. 21. Vertical distribution of the vertical speed of dust clusters.

The total speed was computed by adding the four basic speeds vectorially. Although the chance of finding the maximum value of each speed at one location is remote, we should not rule out such a possibility. Since suction vortices at higher levels are diffused, the total speed above 100 m or 300 ft is likely to include the effects of suction vortices.

As the height decreases the dust swirl inside and outside of the suction vortices should be significantly different. The high swirl speed of suction vortices is likely to penetrate way down to the structure level or even to the ground. Outside the vortices, the total speed is likely to decrease rapidly, thus keeping damaging winds above the structure level.

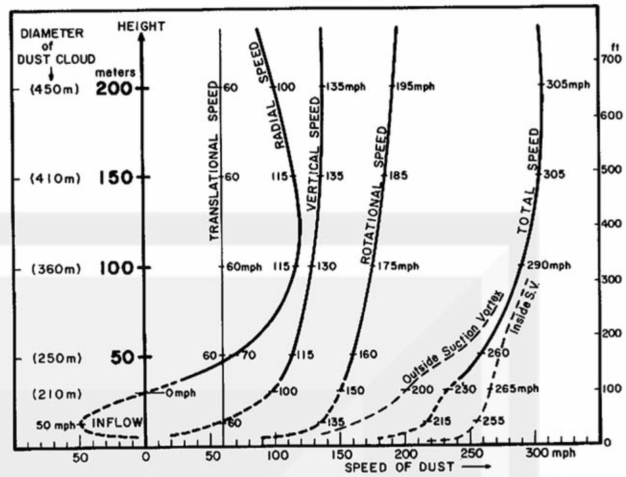

Fig. 22. Vertical distribution of four basic speeds and the total speed computed from them.

Six out of 148 tornadoes of April 3-4 were classified as being F 5. In view of the photogrammetric measurements, it is likely that an F 5 wind near the ground may be experienced only inside the suction swaths on the right side of a tornado. Thus, an F 5 wind will last for an extremely short time (probably less than 2 seconds) in a very narrow swath (probably less than 20 m). A portion of a house could be sheared off while leaving the other portion practically untouched. A large structure is very unlikely to respond precisely to the peak wind generated by a suction vortex.

Numerous debris flying in tornado winds seem to be moving differently from the cluster of dust. Shown in Fig. 23 are the vectors of apparent debris motion. Most of them are rising but some are descending. Their mean speed is far less than that of dust clouds.

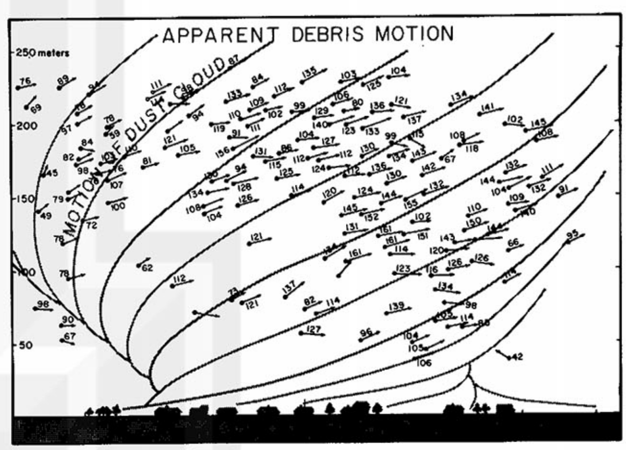

Fig. 23. Apparent motion of debris superimposed upon the flow pattern of dust clusters.

The analysis presented herein does create a number of questions, i.e.,

*The motion of debris is different from that of dust clusters. Do clusters of dust move with winds?

*Different sized structures and objects should respond to a specific mean wind averaged in both time and space. What kind of mean winds are necessary to initiate the damage or flight of following objects? Power plant, brick structure, suburban house, mobile home, passenger car, garbage can, human, dog, chicken, telephone book, letter, cancelled check, a piece of straw, dust particles, spray of water, raindrops, newly condensed water droplets, air molecules.

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--TO BE PUBLISHED--

DETAILED ANALYSIS OF SAYLER PARK TORNADO
-Life History and Ohio River Crossing-
by
James W. Carter, II and T. Theodore Fujita

The Sayler Park Tornado was the only tri-state tornado spawned during the Superoutbreak. A sequence of 19 pictures by Carter and other pictures and movies are analyzed photogrammetrically. Features and dimensions of the tornado as it moved along the path are related to the aerial pictures taken after the tornado. The variation of the tornado as it crossed the Ohio River is investigated in detail. (November 1975)

PHOTOGRAMMETRIC CHARACTERISTICS OF PARKER TORNADO
-From Single, Twin, to Multiple Vortices-
by
Gregory S. Forbes and T. Theodore Fujita

A detailed analysis of the motion of dust cluster and condensation funnels of the Parker tornado is made to infer wind speeds of the multi-vortex tornado. During its life cycle, the tornado went through a process, changing from single- to multi-vortex structure. For a short time it was a twin-funnel tornado. Each stage of the tornado is combined with the aerial photograph taken after the storm. (December 1975)

STRUCTURE AND FLOW CHARACTERISTICS OF XENIA TORNADO
by
T. Theodore Fujita

The Xenia tornado provides us with important information regarding the four scales of motion: tornado cyclone/hook echo, tornado, suction vortex, and its split into twin vortices. Motion of dust clusters and debris around both tornado and suction vortices are determined photogrammetrically. (December 1975)

ONE HUNDRED FORTY EIGHT TORNADOES
by
T. Theodore Fujita

Before the memory of the extensive damage survey of the Superoutbreak tornadoes fades away, characteristics of all tornadoes are described by using local maps and photographs. A 500-page book with 8 color pages is being prepared. The book will include chapters on: Restless tornado alley, Birth and death of tornadoes, Ranking tornadoes in F PP scale, Suction vortices, Tornadoes airmail checks, Where and how people survived or perished, State-by-state account of tornadoes. (February 1976)