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Close-up View of 20 March 1976 Tornadoes: Sinking Cloud Tops to Suction Vortices

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Cover photo: Mrs. Grace May was alone in her home 30 miles south of Jackson MS when the 29 March 1976 tornado hit. The house was picked up and dropped intact on its side without injuring her. Picture was taken by Fujita on 30 March from Cessna 182.

Huge tornado about 25 miles south of Jackson MS on 29 March 1976 lifted house from foundation and scattered debris at distances of 60 to 180 feet. Damaging winds extended at least one mile in diameter. Tornado moved from right to left across farmstead. Many uprooted trees may be seen in area. Photo by Fujita from Cessna 182 on 30 March 1976.

PRESIDENT FORD'S motorcade from downtown Chicago to the Marriott Hotel was only eight minutes away when a tornado, rated F 2, ripped across the expressway leading to O'Hare Airport on 12 March 1976. Eighteen tornadoes, including one F 4, hit the Chicago area and northwest Indiana, killing six persons and injuring more than 100.

Preceded by an unusually warm February in the Midwest, the tornado season began early this year. One week after this episode, a second and more extensive tornado outbreak was predicted to occur on 20 March in a three-state area: central Missouri, Illinois, and Indiana. Responding to the predicted outbreak, plans for a Learjet mission of tornado truth were finalized at noon on Friday, the 19th.

Background of Learjet Flights

A rotating thunderstorm often spawns multiple tornadoes at fairly regular intervals. Fujita (1963), Darkow and Roos (1970), Darkow (1971), and others reported the amazing periodicity of family tornadoes.

To explain the mechanism of the periodic tornado occurrences, Fujita (1972) constructed a laboratory model of rotating thunderstorms. The subsequent experiment revealed, unexpectedly, the weakening of the tornado when cloud-scale vertical motion is increased. Confirming this result, he found a decrease of the overshooting tops in the ATS satellite pictures associated with three tornadoes on 11 May 1970 near Salina, Kansas.

Supported by both laboratory model and ATS pictures, Fujita (1973) hypothesized that a rotating updraft will store its angular momentum during the overshooting stage and unload the momentum in the form of a twisting downdraft during the collapsing stage. The twisting downdraft, by virtue of its negative buoyancy and rotation, turns into the feeder flow necessary for tornado development beneath the rotating cloud. Thus, the twisting downdraft is recycled into the parent cloud during the tornado-bearing period. His hypothesis was presented in the congressional hearings before the Subcommittee on Space Science and Technology (1973).

To test this hypothesis, a chartered Learjet was flown from time-to-time during tornado seasons since 1972. The results, as reported by Fujita (1973), Pearl (1974), and Umenhofer (1975), confirmed the predicted tendency of overshooting activities in relation to tornadoes.

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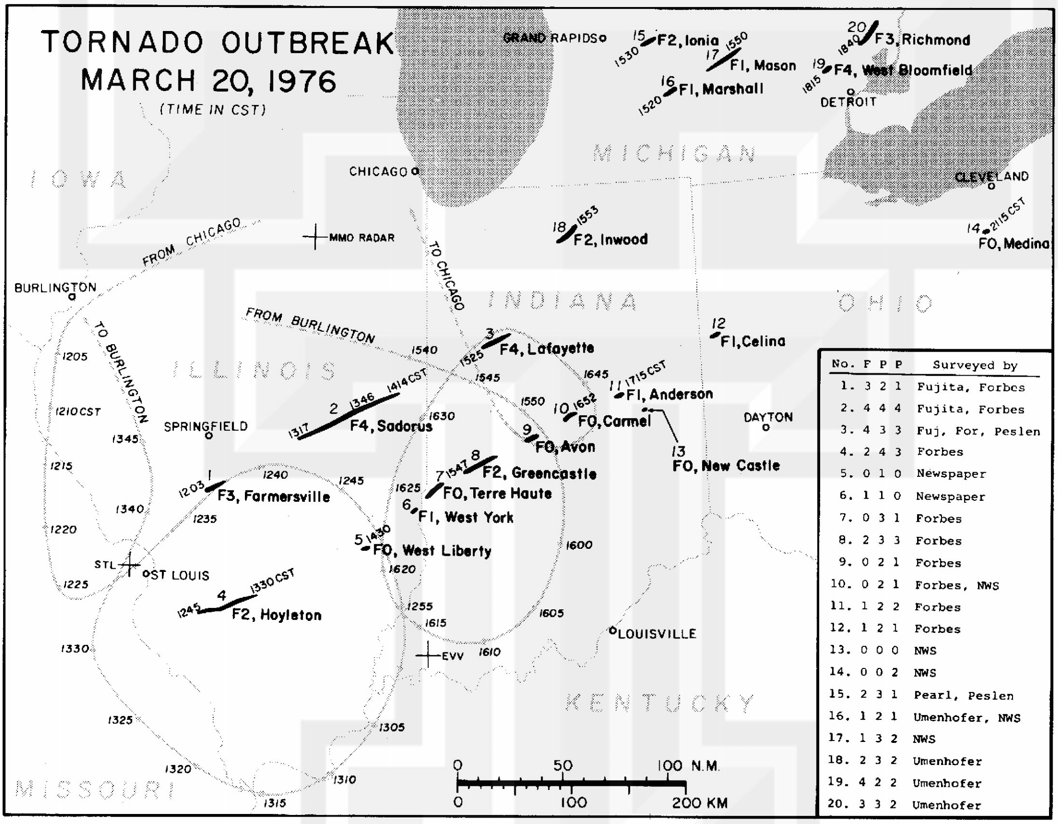

No.	F	P	P	Surveyed by
1.	3	2	1	Fujita, Forbes
2.	4	4	4	Fujita, Forbes
3.	4	3	3	Fuj, For, Peslen
4.	2	4	3	Forbes
5.	0	1	0	Newspaper
6.	1	1	0	Newspaper
7.	0	3	1	Forbes
8.	2	3	3	Forbes
9.	0	2	1	Forbes
10.	0	2	1	Forbes, NWS
11.	1	2	2	Forbes
12.	1	2	1	Forbes
13.	0	0	0	NWS
14.	0	0	2	NWS
15.	2	3	1	Pearl, Peslen
16.	1	2	1	Umenhofer, NWS
17.	1	3	2	NWS
18.	2	3	2	Umenhofer
19.	4	2	2	Umenhofer
20.	3	3	2	Umenhofer

Fig. 1. Flight path of the research Learjet and the location of 20 tornadoes. The paths of the major tornadoes were confirmed by five meteorologists using Cessnas.

Learjet Flew in Proximity of 10 Tornadoes

At 1105 CST on 20 March, a Learjet piloted by Capt. Fred Reed of American Jet Aviation took off from Chicago Midway Airport and climbed to 45,000 ft while flying toward Burlington, Iowa. The three meteorologists on board were Ted Fujita for mission control and movies, Tom Umenhofer for close-up color photography, and Dave Johnson for wide-angle photography.

Due to the relatively low tropopause at 40,500 ft, the Learjet at 45,000 ft could top the anvil except where overshooting domes and jumping cirrus were high. Two flights were made over eastern Missouri, Illinois, and Indiana with a refueling stop at Burlington, Iowa (Fig. 1).

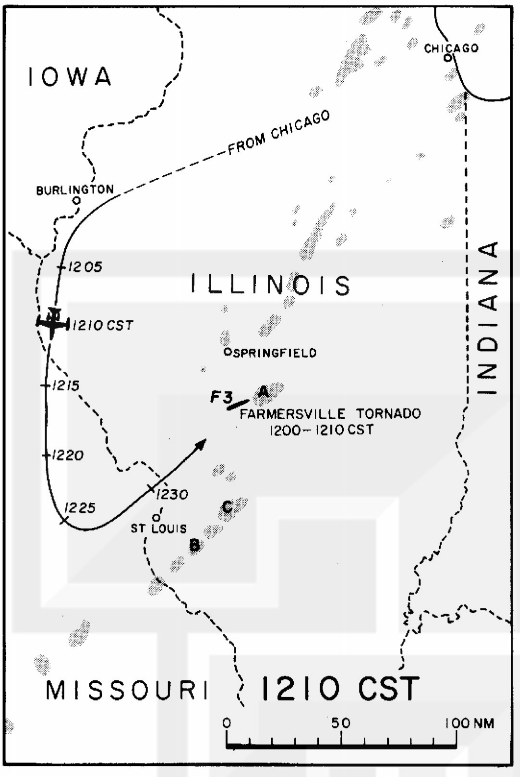

Fig. 2. Composite echoes at 1210 CST, 20 March 1976, based on STL, EVV, and MMO radar pictures. The Learjet flew toward cloud "A" which had spawned the Farmersville tornado.

Upon returning to Chicago, the time and location of tornadoes in the SELS (Severe Local Storms) Log were received from Allen Pearson of the National Severe Storms Forecast Center (NSSFC) over the phone. By 0130 on the 21st, about 70 tornadoes in the SELS Log were mapped. After a short night's sleep, Fujita and Forbes departed from Midway by Cessna 182 to survey the Sadorus and Lafayette tornadoes.

Three Cessnas were flown concurrently on the next two days for taking pictures of fresh damage and ground marks. Fifteen tornado paths were surveyed. Five more tornadoes were confirmed by the National Weather Service offices and/or local newspapers. It turned out that the Learjet had flown around 10 tornadoes including two F 4s and one F 3. (For the F P P tornado scale, refer to *Weatherwise*, April 1973, page 58.)

Excitement of Over-Anvil Flight

The following is an account of the events of the flight as recalled by Fujita who controlled the tornado-hunting mission:

"Upon reaching 45,000 ft, I could see the entire length of the squall line extending from Chicago to St. Louis. Of the numerous overshooting tops, the ones near St. Louis were very high and active. I told the pilot to

Fig. 3. Farmersville tornado at 1210 CST photographed by Mr. Zimmerman looking north.

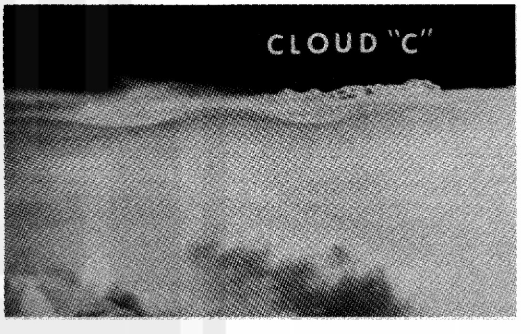

Fig. 4. Cloud "C" located 40 nmi to the southeast of the Learjet at 45,000 ft. The obstacle effect of the overshooting dome was inducing wake waves on the anvil surface.

maintain a 180° magnetic heading while I talked to Edward Ferguson of the National Environmental Satellite Services (NESS) through ARINC, a communication network. He informed me that SELS had received a report of a tornado south of Springfield, Illinois. The aircraft heading was changed quickly to 40° to fly toward the tornado (Fig. 2). We learned a few days later that the Farmersville tornado was on the ground at this time (Fig. 3).

"There was an active overshooting cloud, 'C,' to the right of our aircraft. Umenhofer and Johnson had been taking pictures of this cloud at 30-sec intervals. Apparently, cloud 'C' acted as a giant obstacle to the anvil-level flow, inducing wake waves somewhat like those from a moving ship (Fig. 4).

"The echo of tornado cloud 'A' on airborne radarscope increased in size as we approached from the southwest. Although there were some overshooting activities reaching 43,000 ft, we flew over the top without encountering any turbulence (Fig. 5).

"Then I requested a right turn of the aircraft and started circling around clouds 'B' and 'C' in order to give the other researchers the best photographic perspective. We learned later that the Hoyleton tornado was on the ground while we were circling around 'B' (Fig. 6).

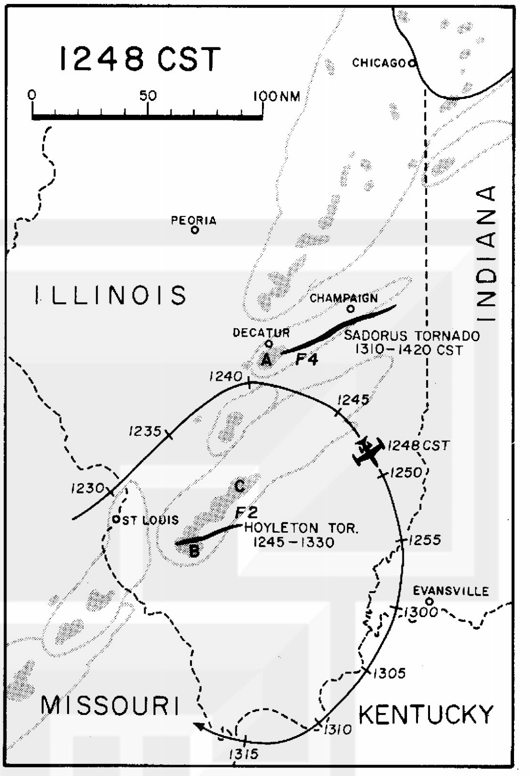

Fig. 5. Composite echoes at 1248 CST and anvil boundaries from SMS picture. After flying over cloud "A," the Learjet circled around cloud "B" while Hoyleton tornado was in progress.

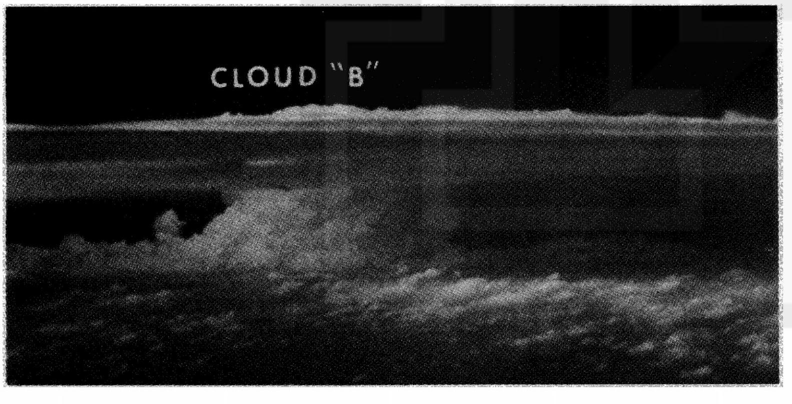

Fig. 6. Cloud "B" at 1315 CST located 80 nmi to the north-northwest. The Hoyleton tornado was on the ground.

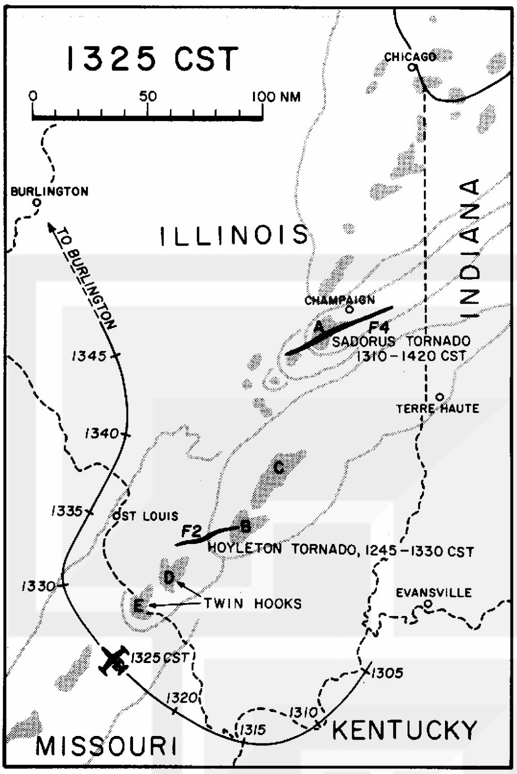

Fig. 7. Composite echoes and anvil boundaries at 1325 CST. The Learjet flew by twin hooks, "D" and "E," which produced no tornadoes.

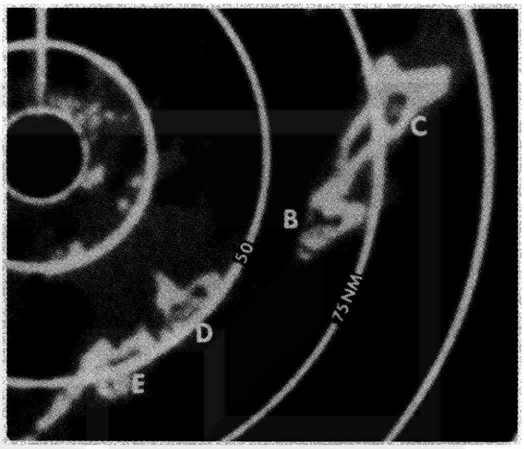

Fig. 8. Twin hooks photographed by the NWS St. Louis radar at 1326 CST.

"At 1313 CST, we found a low spot on the anvil top. I asked the pilot to change the heading gradually to 310°. Very soon, two hook-shaped echoes appeared on the radarscope. They are identified as clouds 'D' and 'E,' each with a pointed echo tip like the beak of a bird (Fig. 7).

"An enlargement of a 16-mm radar film from St. Louis shows also that they were bird-shaped twin hooks (Fig. 8). During our approach to the "twins," I asked Johnson and Umenhofer to take close-up pictures of 'D' and 'E,' respectively. Cloud 'D' had sustained overshooting while 'E' collapsed for a short time as we were flying by. Based upon statistics by Forbes (1975), I expected the formation of one or more tornadoes from these twin hooks. Neither the SELS Log nor

Fig. 9. A panoramic view from 45,000 ft at 1340 CST, northeast through southeast. The Sadorus tornado (F 4) was on the ground beneath cloud "A."

Fig. 10. **The Sadorus tornado at 1340 CST. One frame of a movie taken by Mr. Wilson.**

Fig. 11. Composite radar echoes and anvil boundaries at 1548 CST. After refueling, the Learjet flew by the Lafayette tornado cloud and began circling cloud "B."

the NWS St. Louis or Springfield offices confirmed tornadic activities in the proximity of the hooks.

"At 1340 CST, shortly before we began descent for refueling, Johnson took panoramic pictures of clouds 'A' through 'E.' 'C' was the most active overshooter followed by 'D,' 'B,' and 'E' (Fig. 9).

"Cloud 'A' showed the least overshooting characteristics of all, but it was the cloud which spawned the Farmersville tornado between 1200–1210 CST. During our descent for refueling, to Burlington, Iowa, I thought that the cloud had weakened and was in the dissipating stage.

"While on the ground at Burlington, Ferguson informed me that SELS had received reports of tornadoes between Decatur and Champaign, Illinois. That is the general location where I had witnessed cloud 'A' without overshooting tops. I asked myself, 'Does a rotating thunderstorm sink beneath the anvil cloud during the tornado-bearing stage?'

"We decided to chase cloud 'A' immediately after the refueling. It was a proper decision for our mission, because we learned the next day that a huge tornado was on the ground beneath cloud 'A' at 1340 CST. It was the Sadorus tornado, rated as F 4 (Fig. 10).

"Because of congested air traffic below 40,000 ft, the FAA told us to climb to 45,000 ft in clear air, then to proceed over to the squall line. After this unexpected delay, I selected a 110° heading toward Lafayette, Indiana. From the cockpit all I could see in the direction of Lafayette was a slightly elevated anvil with a very flat top at about 40,000 ft, with no overshooting tops whatsoever. Now I regret that I did not fly over this flat top. There was an F 4 tornado on the ground, beneath the flat anvil, northeast

Fig. 12. Overshooting tops and anvil boundaries from SMS picture at 1648 CST. The Learjet flew around the holes on the anvil when the Carmel tornado was on the ground.

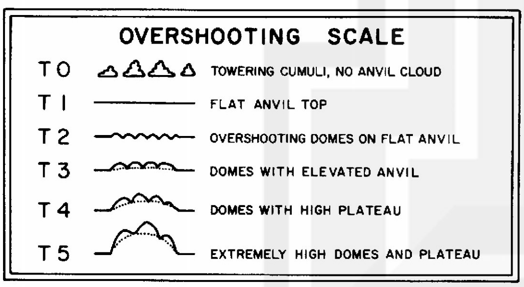

Fig. 14. The overshooting scale for assessing the cloud-top characteristics.

of Lafayette only 20 to 30 miles to the left of our Learjet (Fig. 11).

"An F 2 tornado was on the ground near Greencastle, Indiana, when our Learjet circled around cloud 'B' (Fig. 12).

"While we were flying toward Lafayette, cloud 'B' started sinking rapidly, giving the impression that we could safely fly over the top. I told the pilot to fly southeast and wait for a chance to fly over. At 1648 CST, a decision was made to make a right turn to inspect the region of the sinking top from the closest possible distance. At 1650, we saw a number of depressions and holes on the anvil some 10 miles to the north of the aircraft. I shot a continuous movie for about two minutes and Johnson took a series of unique pictures (Fig. 13).

"A few minutes after the completion of our fly-by mission I looked back toward the southeast, to the sinking-top area. There I saw a splash of cirrus topped with a hat of pileus cloud."

The Overshooting Scale

The top of a strong updraft overshoots into the stratosphere due to the inertia of the violently rising air. The topography of overshooting tops is a reflection of the vertical air currents beneath the anvil surface. This phenomenon is similar to an underwater spring which gives rise to a bulge of the water surface.

The overshooting scale was devised for the purpose of classifying the features of thunderstorm tops into six categories, T0 through T5. The letter "T" stands for the Top (Fig. 14).

The T-scale classification can be made by observing thunderstorm tops from a high-flying aircraft or by examining the high-resolution satellite pictures taken by SMS, Nimbus, etc.

Cloud Top Sank Before Violent Tornadoes

The super-cell thunderstorm which produced the family of the Farmersville (F P P = 3, 2, 1), Sadorus (4, 4, 4), and Lafayette (4, 3, 3) tornadoes were photographed by the National Weather Service St. Louis radar from 1030 to 1330 CST and by the Marseilles radar from 1120 to 1620. After the first hook-shaped echo was depicted 30 nmi northeast of the St. Louis radar at 1105, the tornado-producing cell travelled 221 nmi in 5.3 hours at a mean speed of 42 kt (48 mph or 77 kph).

The combined duration of the three tornadoes was 1 hour and 55 minutes which corresponds to only 37 percent of the life of the parent thunderstorm after the first hook formation.

Twenty-seven pictures taken by SMS satellite revealed that the overshooting top at the tornado time was very low or practically nonexistent (Fig. 15).

Five figures of the tornado-producing storm were prepared to show the variation of cloud features in both radar and satellite pictures. These pictures reveal that the overshooting activities decreased prior to the touchdown of violent tornadoes. During the Sadorus tornado (F 4) at 1325, the anvil top was relatively flat and slightly dark, showing an apparent swirl pattern about 25 nmi in diameter (Figs. 16 and 17).

Between the times of the Sadorus and Lafayette tornadoes, the overshooting activities intensified (Fig. 18). No overshooting or swirl pattern was seen in the satellite picture at 1548 when the Lafayette tornado (F 4) was on the ground. The anvil top observed from the Learjet at 1540 was simply flat, without a sign of overshooting (Fig. 19). Apparently the storm's top regained its altitude after the tornado, showing a sign of overshooting at 1618 (Fig. 20).

Cloud "B" which traveled from southern Illinois to central Indiana produced nine tor-

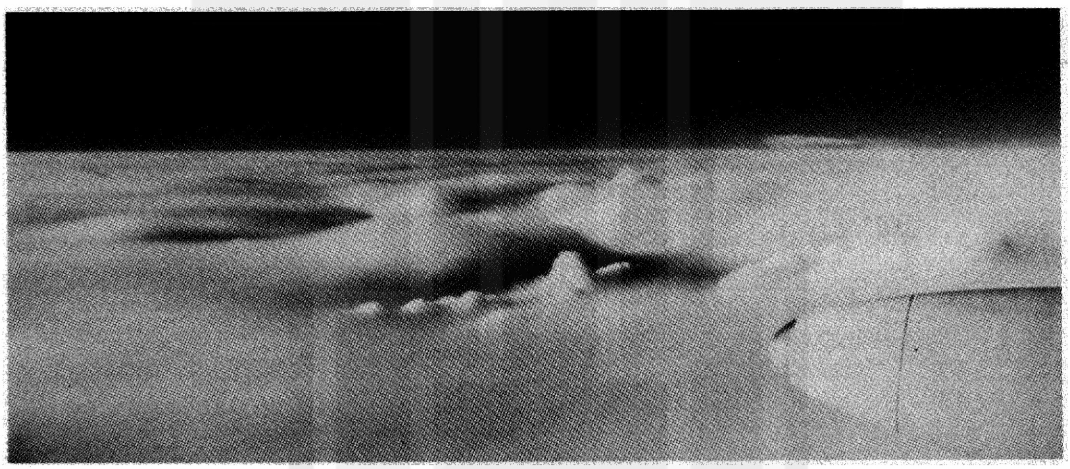

Fig. 13. Holes and depressions on the anvil above the Carmel tornado at 1652 CST.

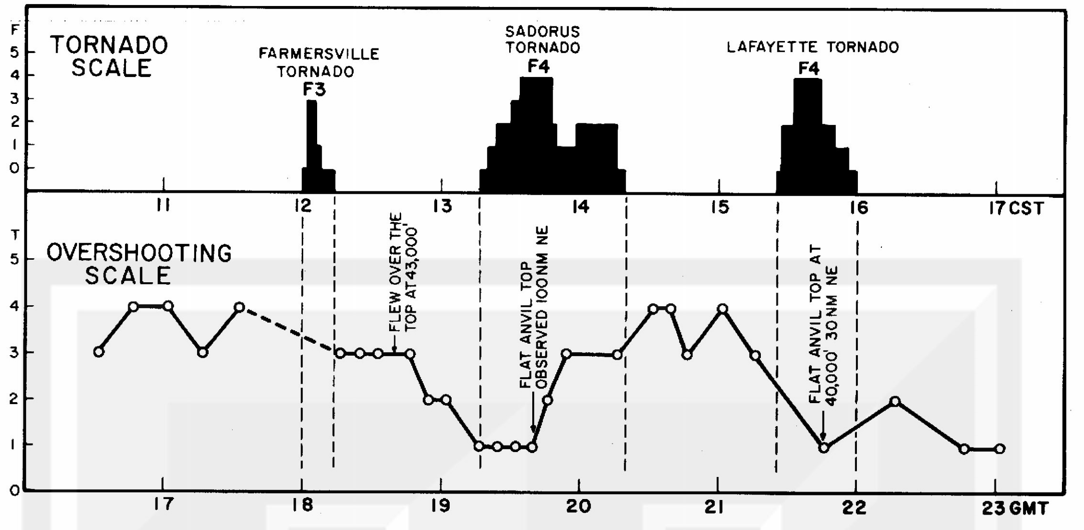

Fig. 15. Change in the overshooting scale in relation to the intensity of tornadoes spawned by cloud "A."

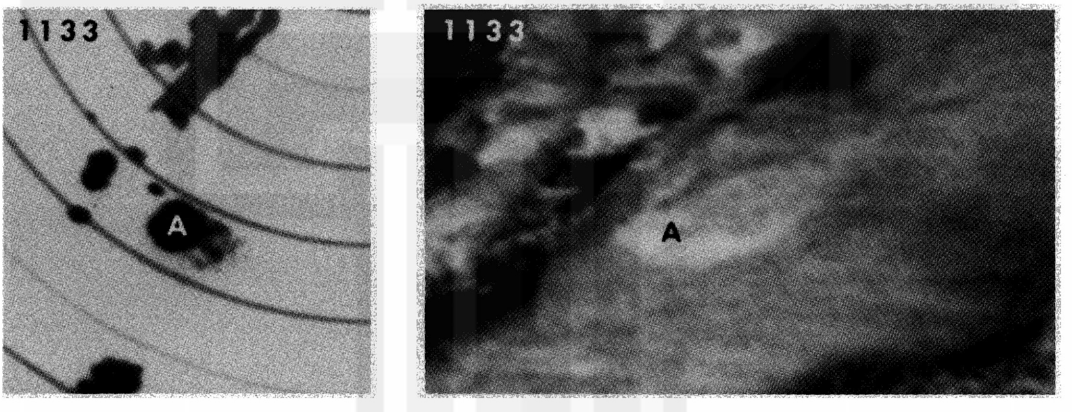

Fig. 16. Radar and SMS views of cloud "A" at 1133 CST, 30 min before the onset of the Farmersville tornado (F 3).

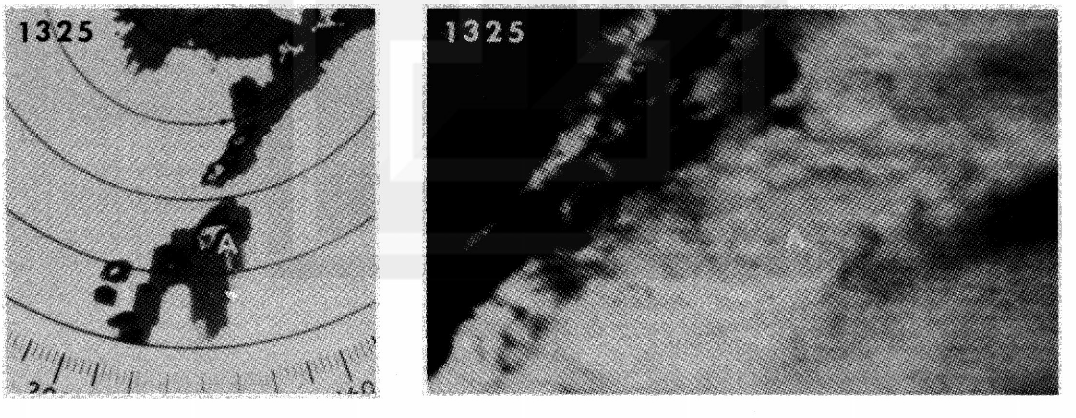

Fig. 17. A swirl of a dark anvil cloud was visible when the Sadorus tornado (F 4) was on the ground at 1325 CST.

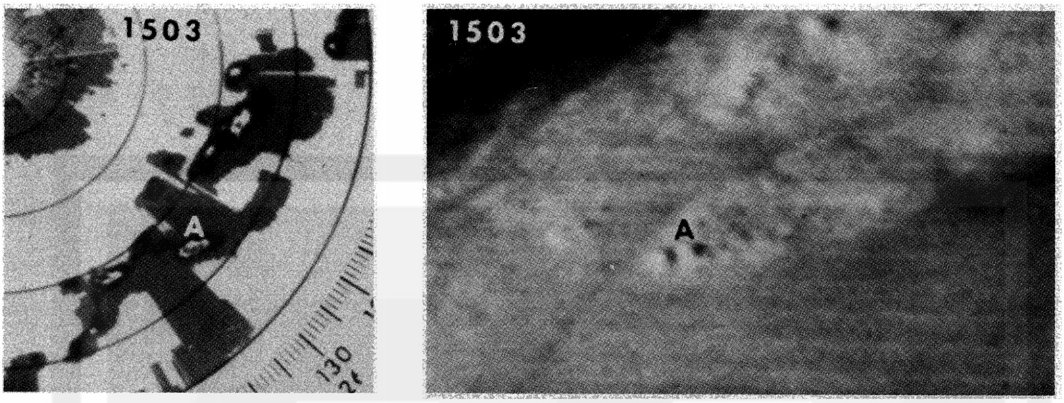

Fig. 18. Radar and satellite view of cloud "A" at 1503 CST, the time between the Sadorus and Lafayette tornadoes.

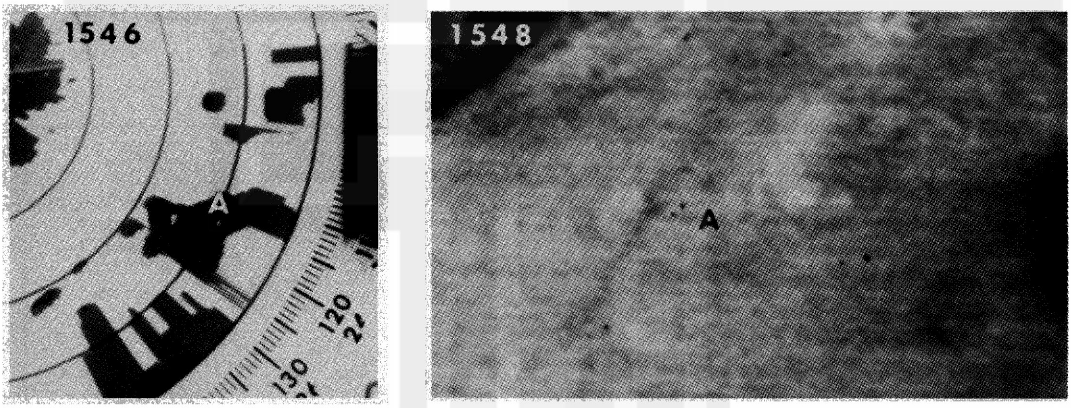

Fig. 19. The flat anvil top at 1548 CST when the Lafayette tornado was on the ground. The Learjet flew 30 nmi southwest of cloud.

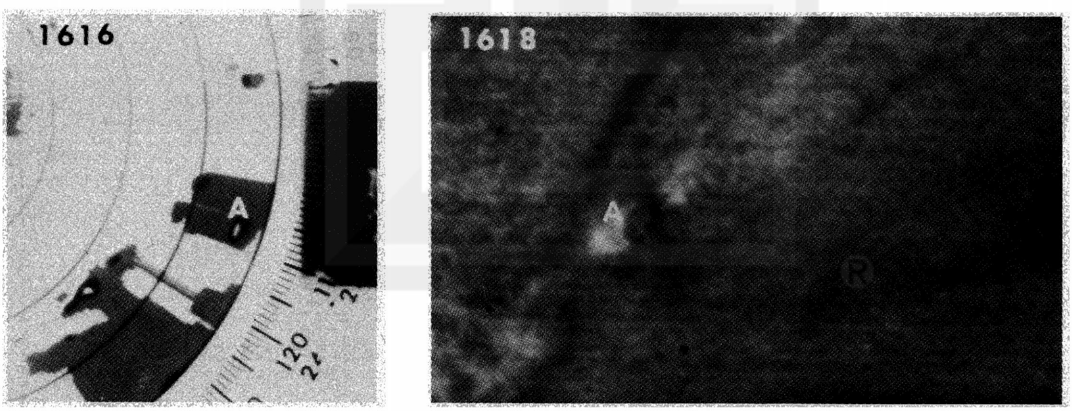

Fig. 20. An overshooting top re-appeared in the SMS picture taken after the Lafayette tornado.

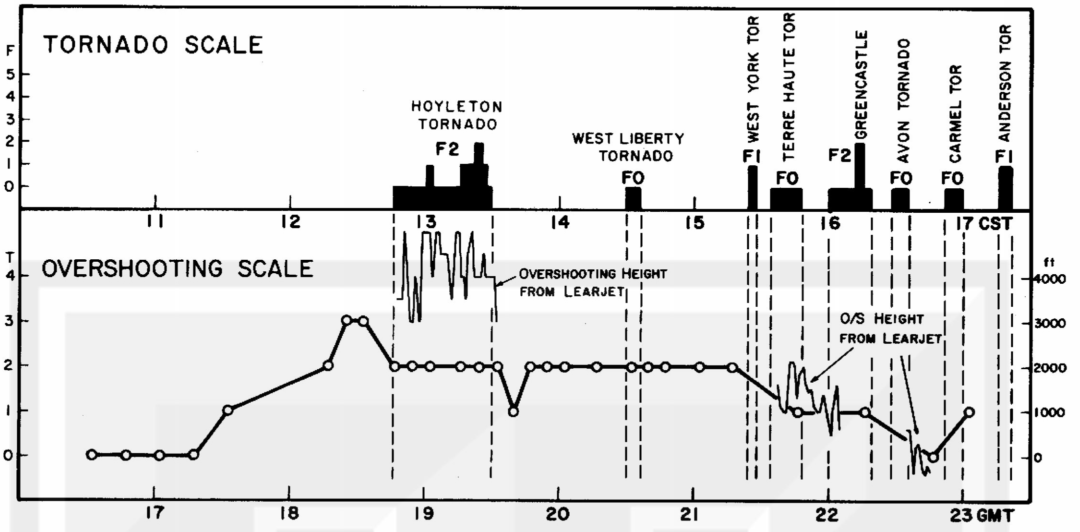

Fig. 21. Changes in the overshooting top during the life of cloud "B" which produced nine weak tornadoes.

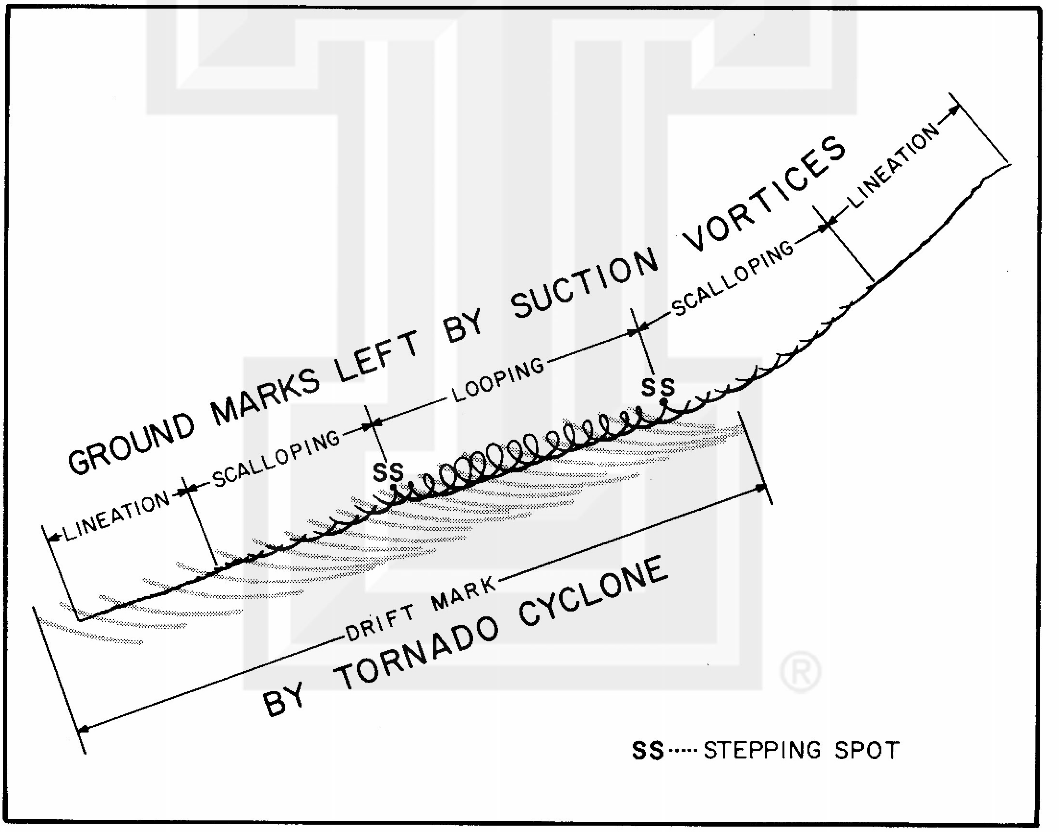

Fig. 22. Typical ground marks showing the three scales of motion.

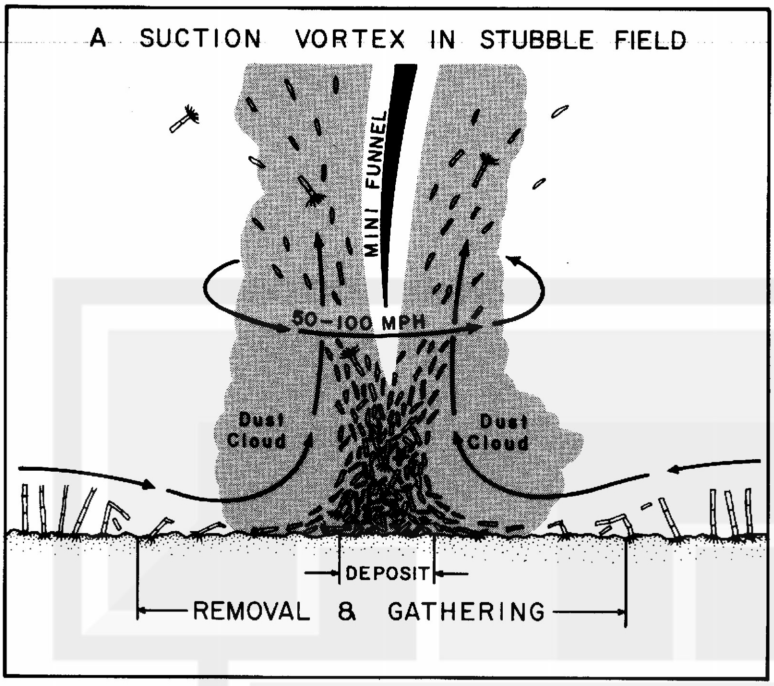

Fig. 23. A model of a suction vortex in stubble field.

nadoes during its six-hour life. All tornadoes in this family were relatively weak, consisting of two F 2s, three F 1s and four F 0s. The cloud-top variations in relation to the tornado periods were insignificant, although the top subsided somewhat prior to the touchdown of F 2 tornadoes (Fig. 21).

Close-up View of Ground Marks

Tornadoes are like criminals who cannot get away without leaving behind their fingerprints at unexpected locations. Important signatures of tornadoes are frequently found in open fields.

A detailed examination of the ground marks left by a large tornado indicates that the marks cannot possibly be produced by a tornado acting alone. It must be accompanied by the tornado cyclone, the parent cyclone which spawns tornadoes, and also by the suction vortices that swirl around inside a large tornado.

The tornado cyclone was described by Brooks (1949) and the initial concept of localized suction spots was proposed by Fujita (1967). The combined effects of these three scales of swirling motion produce the ground marks familiar to experienced tornado surveyors (Fig. 22).

Fast-Spinning Suction Vortex

A suction vortex is small, usually less than 30 ft (10 m) in diameter, but it spins fast. While in the field it removes small objects on the ground and gathers them around the center (Fig. 23).

Although the accumulated debris is continuously thrown upward, a traveling suction vortex cannot carry away all debris. It leaves behind a litter line along the path of the

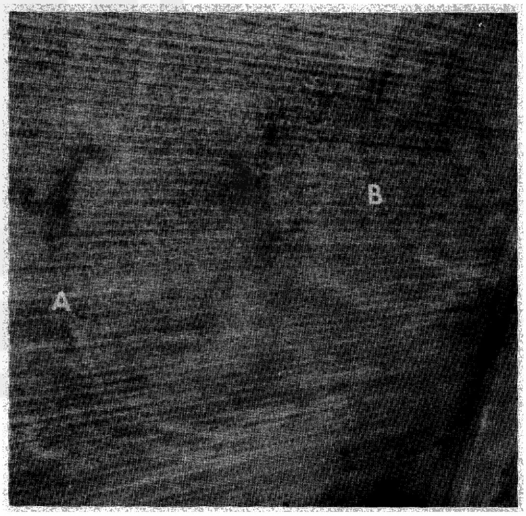

Fig. 24. Removal and deposit lines of debris left by the suction vortices in the Lafayette tornado.

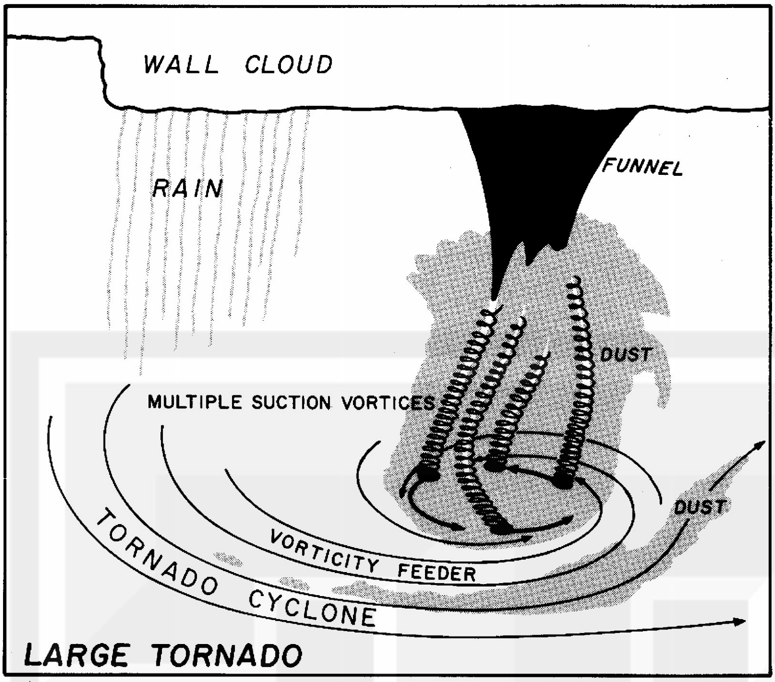

Fig. 25. A model of a large tornado with multiple suction vortices and the vorticity feeder.

Fig. 26. Looping marks of suction vortices left by the Sadorus tornado. Tornado moved at 45 mph while suction vortices circled around its center.

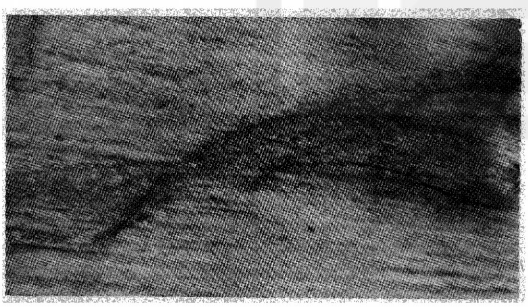

Fig. 27. Scalloping marks of suction vortices to the west of Sadorus.

vortex center. Sometimes a litter line is seen inside a dark band of bare ground (Fig. 24).

Multiple Suction Vortices

A large tornado is often spawned and guarded by a tornado cyclone which continuously feeds the vorticity to its baby, the tornado (Fig. 25).

Suction vortices hidden inside a huge column of dust cloud are rarely seen by man. The swirl marks, the footprints of these vortices, uncover secrets: the number of vortices, their speed, sizes, etc. (Fig. 26).

When the revolving speed of suction vortices around the tornado is slow, scalloping marks are left on the ground (Fig. 27). As the revolving speed increases, the suction vortex starts moving along a looping path. Shortly before it starts looping, the vortex stops momentarily on the left side of the tornado. There, the suction vortex removes the ground objects around its stationary center, creating a circular bare spot on the ground similar to one produced by a person spinning on his heel (Fig. 28).

When a tornado is small, it acts like a single suction vortex (Fig. 29). Thus, a small tornado is likely to produce a single litter line along its path. Moments after the formation of the litter line the tornado cyclone wind blows over the open field. But it fails to wipe out the litter line because the height of the litter extends only a few inches above the ground (Fig. 30).

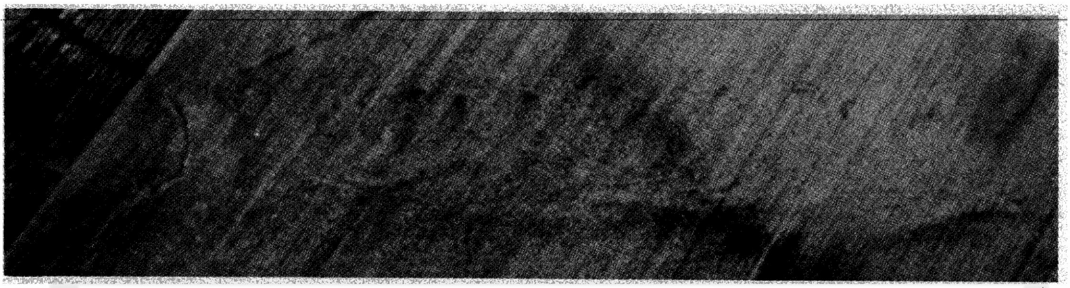

Fig. 28. Stepping spots left by the Lafayette tornado. Suction vortices pause temporarily at these spots and remove corn stubble.

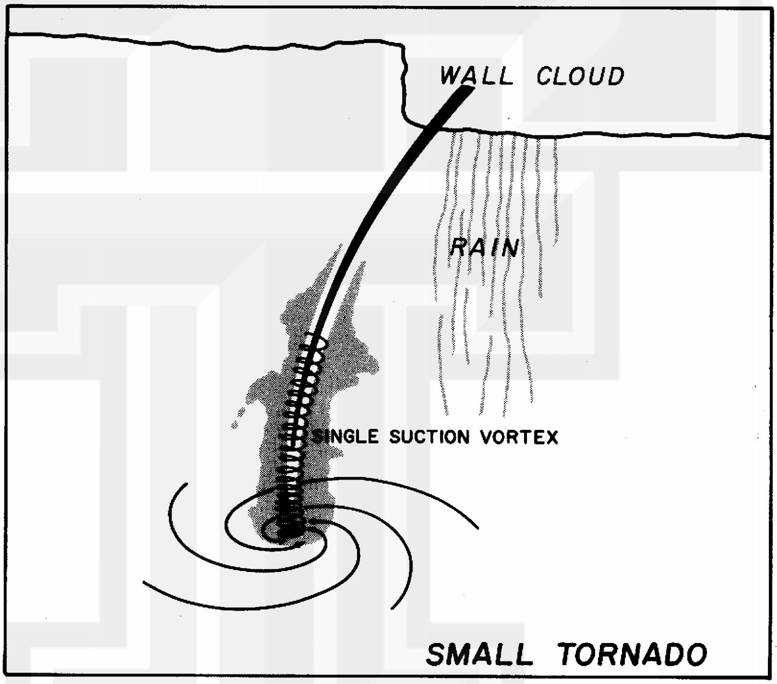

Fig. 29. A model of tornado with single suction vortex.

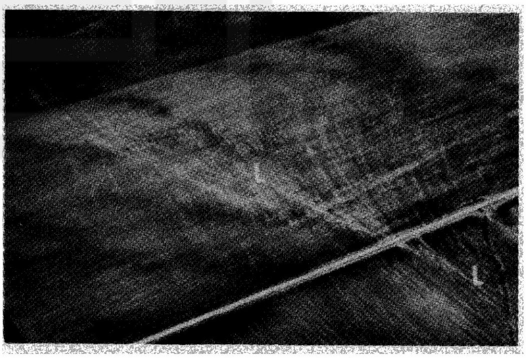

Fig. 30. Drift of debris by the tornado cyclone winds which came after a suction vortex had produced the lineation mark L–L. Photo was taken over the field east of Decatur, Illinois.

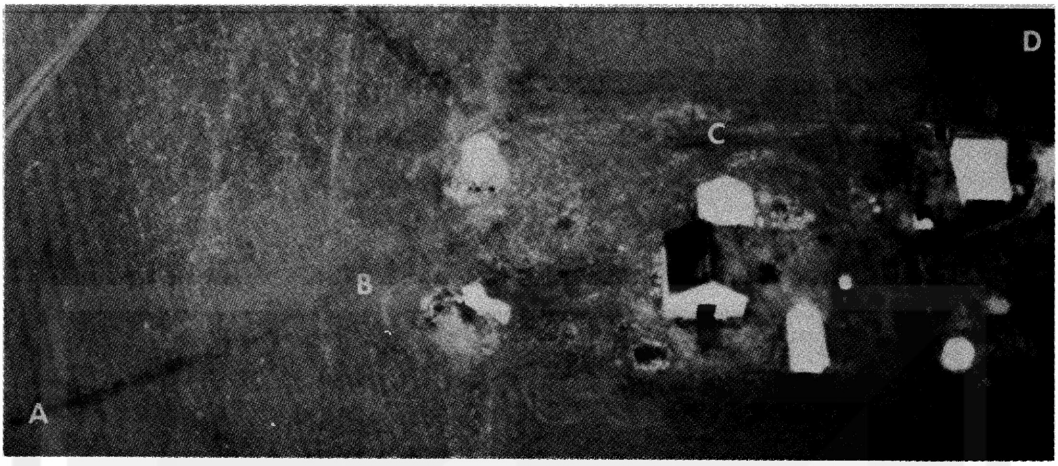

Fig. 31. A lineation mark A–D across the Jordan Farm. The apparent damage near B is a junk pile.

Fig. 32. A ground view of the Jordan Farm. The dashed line denotes the tornado path.

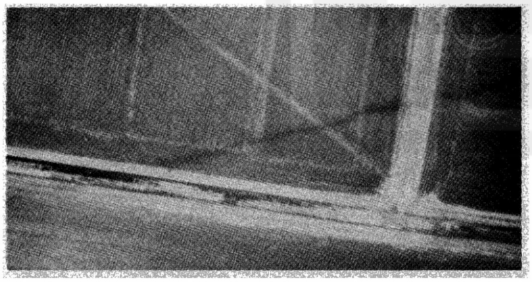

Fig. 33. The lineation mark which extended beyond the Jordan Farm.

Small Tornado Crosses Jordan Farm

When our Learjet was flying toward cloud 'A' a tornado swirled through the Jordan Farm south of Springfield, Illinois. A black lineation mark or a litter line extended through the northwest corner of the farm (Fig. 31).

The small tornado was the final stage of the Farmersville tornado spawned from cloud 'A.' It moved through a 150-ft space (46 m) between a metal silo and a barn without damaging either of them (Fig. 32).

After the farm, the lineation mark extended more than 0.5-mi (0.8 km) across the field and roads. The width of the black line was narrower than 10 ft (3 m) (Fig. 33).

Fortunately, the tornado in action was photographed by Messers. Fesser and Weber from two opposite directions (Fig. 34). One of the closest shots shows that the tornado was not as weak as the lineation mark implies. Its dust column was 200 ft across and 400 ft tall (61 and 122 m). The tip of the mini funnel, 10 ft (3 m) in diameter, was hidden by the dust cloud (Fig. 35).

Conclusions

The tornado flight mission on 20 March 1976 has shown several important characteristics of tornadoes:

1. Active overshooting existed prior to the onset of tornadoes. However, the scale of the overshooting was comparable to other active thunderstorms which did not produce tornadoes.

2. No overshooting existed during the two F 4 tornadoes. The Sadorus tornado cloud was topped by an apparent swirl of dark anvil. The top of the Lafayette tornado cloud was simply flat.

3. Collapse of cloud "B," which spawned nine F 2 or weaker tornadoes, was less significant. Prior to the Carmel tornado (F 0), however, the top sank rapidly resulting in holes and depressions on the anvil top.

4. The SELS Log and the NWS offices at St. Louis, Illinois, and Springfield, Missouri, recorded no tornadoes along the paths of the twin hooks with sustained overshooting.

5. Ground marks of large tornadoes showed evidence of three scales of motion typical of a tornado cyclone, tornado, and suction vortex.

Acknowledgments

While the Learjet flight was in progress, we received continuous advice from Messrs. Edward Ferguson of NESS and Allen Pearson of NSSFC in their Kansas City offices. Without their professional guidance, we could not have completed this mission successfully.

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Fig. 35. The tornado at A in Fig. 34 photographed by Mr. Fesser standing 340 m (1000 ft) away. No structure was damaged at the Jordan Farm.

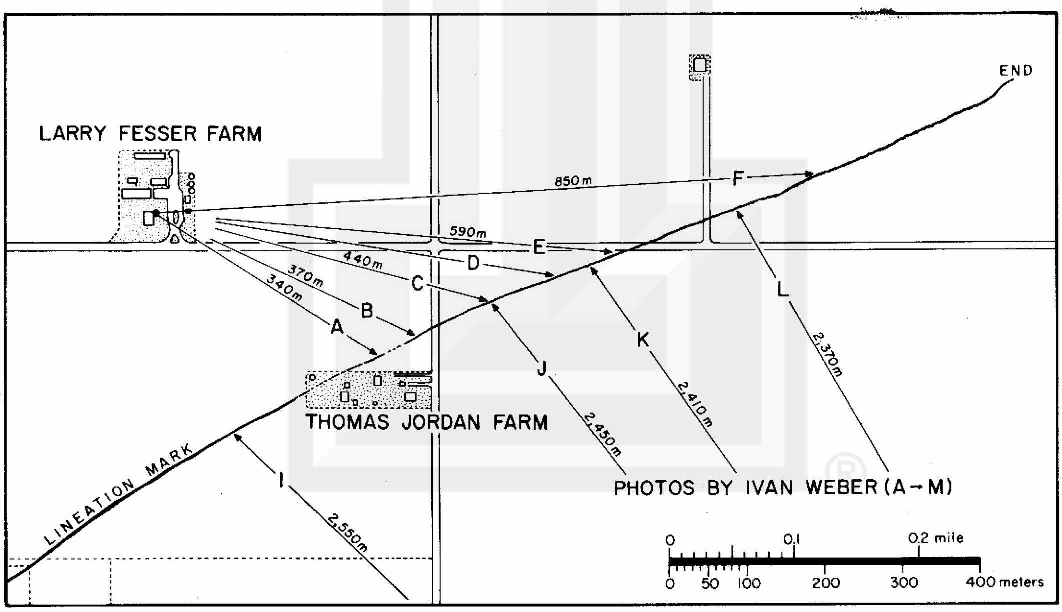

Fig. 34. Location of pictures taken during the final stage of the Farmersville tornado.

Tornadoes (*Continued from page 131*)

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