Geophysical Monograph 79

The Tornado:
Its Structure, Dynamics, Prediction, and Hazards

Plainfield Tornado of August 28, 1990

T. Theodore Fujita

American Geophysical Union

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T. THEODORE FUJITA

The University of Chicago, Chicago, Illinois 60637

Shortly before 5 p.m. CDT on Tuesday, August 28, 1990, Chicago radio stations began announcing the occurrence of tornado deaths in the Plainfield area, some 60 km (40 miles) southwest of the University of Chicago. By 5:30 p.m. the casualty figures were upgraded to 20 deaths and 200 injuries, giving an impression that it was a major tornado event. The path length of the tornado, sketchy in nature at that time, was given as 13 km (8 miles). I called for a project meeting before ending the workday, reaching the conclusion that Duane Stiegler of my staff (15 years of survey experience) should go directly to Chicago's Midway Airport next morning to fly over the entire path. We assumed that the survey would take 2 hours.

After completing his initial flight, Duane informed me during refueling that the path of the main tornado extended 27 km (17 miles) from Oswego to Joliet. However, an extensive area of storm damage, possibly by a series of downbursts, extended from Oswego toward the northwest. He decided to fly again on the second day to complete the damage survey and photography of both downburst and tornado areas. I am presenting in this talk the results of my storm investigation, making use of Duane's survey data, along with satellite and radar photographs showing the nature of the violent (F5) tornado which left behind 29 deaths, 300 injuries, and $160 million damage in the southwest suburbs of Chicago.

PHOTOGRAPHIC EVIDENCE OF THE STORM

Aerial and ground photographs taken after the Plainfield tornado revealed that the wind effects of the storm system were very complicated. In studying the nature of the storm, over 600 color photographs covering the 600 km^2 areas of DeKalb, Kane, Kendall, and Will counties were examined in detail.

Found in the extensive cornfields in DeKalb and Kane counties are numerous streaks of high and low winds made visible by damaged and undamaged corn crops. The low-wind streaks, consisting of standing crops, are dark when viewed from the direction of shadows. On the other hand, high-wind streaks, consisting of damaged crops, are light colored because they scatter sunlight, especially when photographed from the favorable scattering angle. In general, low-wind streaks are seen in the downwind of isolated and clumps of trees and the high-wind streaks, extending downwind from open areas (Plate 1).

As has been well known, a slanted roof near the center of a microburst deflects the descending airflow, inducing a jet of high winds which extends downwind from the roof (Plate 2). Although I could not confirm the number of the microbursts, a large number of them were involved in producing the large areas of wind damage located to the northwest of Oswego where the major tornado touched down.

Found and photographed in the downburst areas are four vortex marks, 1–7 km long and 10–30 m (30–100 ft) wide. Because these vortex marks were located beneath the path of a well-defined wall cloud, they were rated as F1 and F2 tornadoes (Plate 3). The major tornado, after its touchdown on the Fox River west of Oswego, failed to produce continuous wind damage; instead, it produced a number of strange ground marks in the cornfields. These are identified as comma-shaped (Plate 4), swirl-shaped (Plate 5), and eye-shaped (Plate 6) marks.

Thereafter, a number of isolated suction vortices formed while the parent tornado intensified to F3 intensity before reaching Wheat Plains. As the vortex diameter increased, a series of suction vortices developed, producing numerous vortex marks (Plate 7) which are clearly visible from the air. Apparently, the tornado reached its peak intensity of F5 upon crossing U.S. Highway 30 (Plate 8) northwest of Plainfield. Because near-ground winds were so strong, bean (Plate 9) and wheat (Plate 10) crops were literally flattened, and some even were pulled out of the ground.

A 20-ton trailer (Plate 11) was blown off U.S. 30 and bounced five times before reaching the final position 350 m (1150 ft) from the highway. While traveling over the cornfield, the core of the tornado, evidenced by the debris deposition band (Plate 8) shrank to approximately 10 m (30 ft) in diameter. Found near the path of the tornado center

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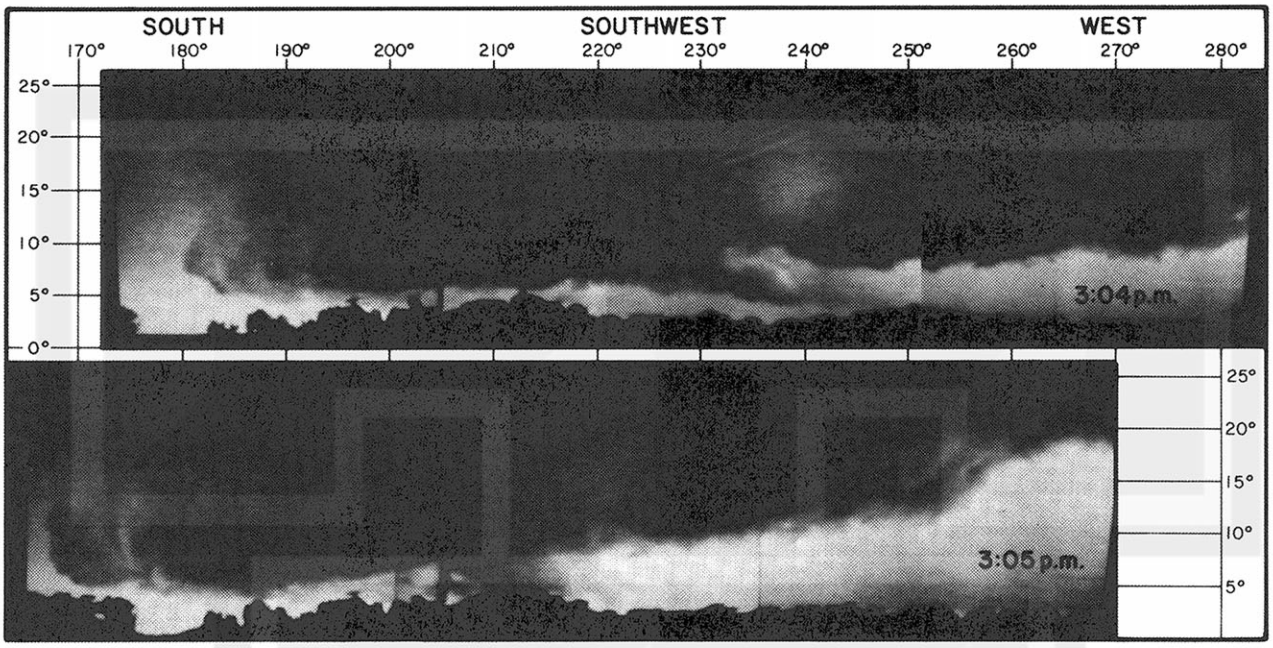

Fig. 1. Two composite video pictures showing the characteristic wall and tail clouds at 3:04 and 3:05 p.m. CDT. The cloud base was as low as 300 m (1000 ft) above ground level, making the visual identification of the large Plainfield tornado very difficult, because it will not be seen as a typical tornado funnel beneath a high cloud base.

was a 25 mm (1 inch) thick plywood board stuck vertically into the ground (Plate 12) where 2 m (6 ft) tall corn crops had existed before the tornado.

F5 Plainfield Tornado

I rated the Plainfield tornado as F5, based on the damage which was comparable to the worst I have ever seen. The damage in the cornfield southeast of U.S. 30 (Plate 8) was entirely different from the damage adjacent to structures affected by the F3 or F4 winds. Some corn crops were stripped of leaves and ears and pushed practically down to the ground. In the worst damage area, corn crops were blown away entirely, leaving behind the remnants of small roots connected to the underground root system.

People often use twisted trees as being the evidence of tornadic winds. What we find in the wake of tornadoes, however, are the results of windshift, rather than windshear. Depending upon the position of the damage site relative to the traveling tornado, a difluence pattern (Plate 13) and a confluence pattern (Plate 14) are commonly seen in the wake of tornadoes. Therefore the patterns shown in these pictures cannot be used as evidence of a tornadic airflow.

St. Mary Immaculate Church in Plainfield was a streamlined quonset structure (Plate 15) affected by F2 to F3 winds. It lost some stained glass without receiving structural damage visible from the air. Crystal Lawns, southeast of Interstate 55, was damaged by F3 to F4 winds. Some houses on Byrum Boulevard were blown off foundations (Plate 16). However, most frame houses were sitting on top of poorly anchored foundations.

The most tragic event occurred at Crest Hill, where two long apartment buildings were damaged by the tornado (Plate 17). The top floors of the apartment complex were sheared off, leaving behind two wedge-shaped structural remnants, with their heights increasing to three stories at the farthest distance from the path of the tornado center. An-

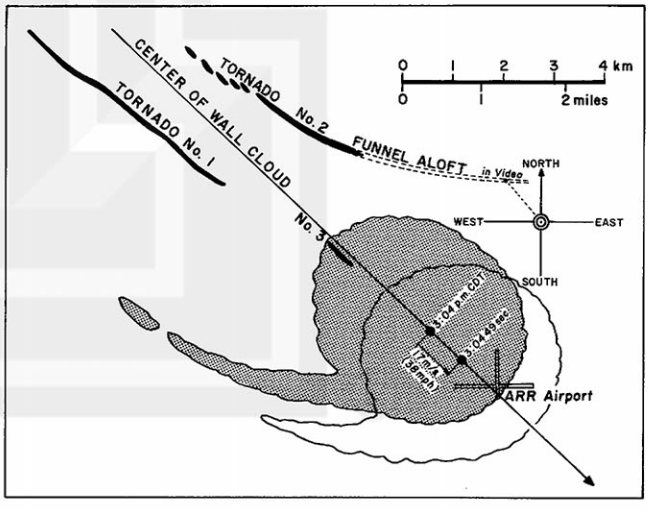

Fig. 2. Tornadoes 1, 2, and 3 in relation to the plan view of the wall cloud shown in Figure 1.

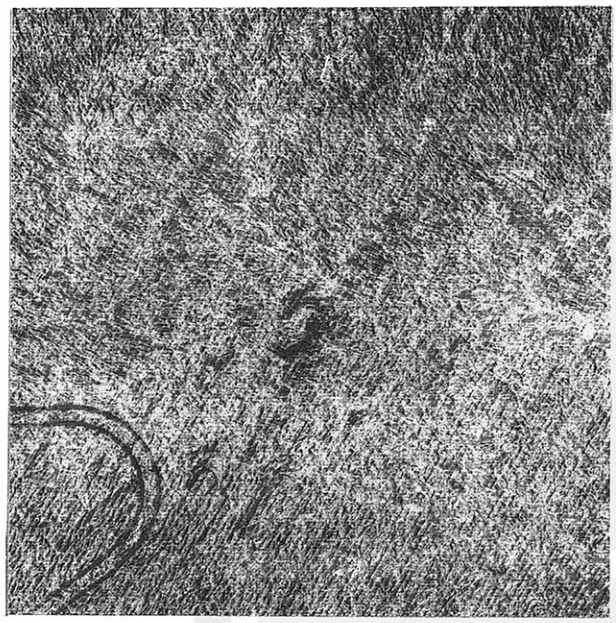

Fig. 3. A close-up aerial photograph of the eye-shaped bare ground inside the core of the Plainfield tornado. (For the location, see Plate 23).

other aerial photograph taken on the following day with identical perspective (Plate 18) shows the removal of corn by the rescue team in search of missing persons.

Mapping the Storm Damage

The area of downbursts on the upwind side of the Plainfield tornado turned out to be much larger than we had estimated. It extended 35 km (22 miles) toward DeKalb, with a maximum width of 19 km (12 miles). The onset time of the downburst winds was 1445 to 1450 CDT. At 1448 CDT, NOAA 11 infrared temperature shows the existence of two cloud tops or "Twin Peaks" over the onset area of the downburst winds (Plate 19).

At 1504 CDT, leaving the downburst storm, Paul Sirvatka, of the College of DuPage, took video photographs, panning his camera through the 160°–270°–350° azimuths. Composite pictures at 1504 and 1505 CDT, 49 s apart (according to the video frame counts), revealed the existence of a well-defined wall and tail clouds (Fig. 1). These clouds are characteristic features of the supercell thunderstorm or mesocyclone clouds. It is estimated that the wall cloud was traveling toward the southeast at 17 m s^{-1}, which is within the computation error of the 20 m s^{-1} movement of the hook echo determined by the Marseilles (MMO) radar imagery.

Aerial photographs revealed the existence of four vortex marks along the path of the wall cloud. In view of the common practice of calling a vortex on the ground beneath a wall cloud a tornado, these vortices were identified as tornados 1–4, all of which occurred inside the downburst area. In fact, a funnel cloud aloft is seen in the video at the extrapolated location of tornado 2 (Fig. 2).

Need for Elevated Scans and Doppler Radar

Marseilles (MMO) radar echoes were depicted by levels 1–6 reflectivity contours (Plate 20) at seven different times, corresponding to the rapid-scan times of the GOES satellite. The result revealed the existence of a hook echo which began forming at 1500 CDT, shortly before the video picture time. Thereafter, the appearance of the echo turned into that of a supercell which could spawn violent tornadoes. The characteristic supercell hook echo was most prominent at 3:11 p.m. CDT (2011 UT) when the weak and narrow tornado 4 was on the ground. When the Plainfield tornado at its F3–F5 intensity was on the ground from 3:25 to 3:40 p.m. CDT (2025–2040 UT), however, the identity of the hook echo was not as clear, in part because of ground clutter.

This evidence and judgment might have been more clear if higher-elevation scans and/or Doppler velocity fields were available for operational use. We expect that the national coverage of the NEXRAD radars and intensive training of storm forecasters will improve the capability for revealing superell-tornado relationships.

Do Tornadoes Grow Upward or Downward?

Like the funnel cloud of a waterspout, a tornado funnel descends from the cloud base, reaching ultimately to the ground. On the other hand, the airflow inside a tornado at the formative stage is predominantly upward. The formation of three isolated rotational winds, comma, swirl, and eye (Plate 21), from F2–F3 intensity presents the following questions: Did they descend from the rotationg winds aloft? Or, did they form on or near the ground first and stretch upward?

I begin to think that the eye (Plate 6) formed near the ground, because it has no sign of the translational characteristics (Plate 3) generated by a fast-moving vortex which descended to the ground. Are comma, swirl, and eye circulations suction vortices? My answer is "yes," because I am hesitant to call them three separate tornadoes. The orbiting suction vortices (Plate 7) probably formed on the ground and stretched upward into the parent tornado, because the aerial photographs suggests that they were slow moving at formation and gained orbital motion thereafter.

While weakening from F5 to F4, the tornado entered Plainfield, passing directly over Plainfield High School (letter S in Plate 22) and St. Mary Immaculate School with its church (letter C). After smashing the community of Lily Cache, the tornado weakened to F2. Then it crossed Interstate 55, injuring six persons in automobiles.

The tornado intensified again while passing through Crystal Lawns, where the Grand Prairie Elementary School (letter S in Plate 22) was damaged by F3 winds. Thereafter, the core diameter shrank while weakening to F2 intensity. In Crest Hill, however, the small-core tornado intensified into F3 while passing across the Cresthill Lake apartments (letter

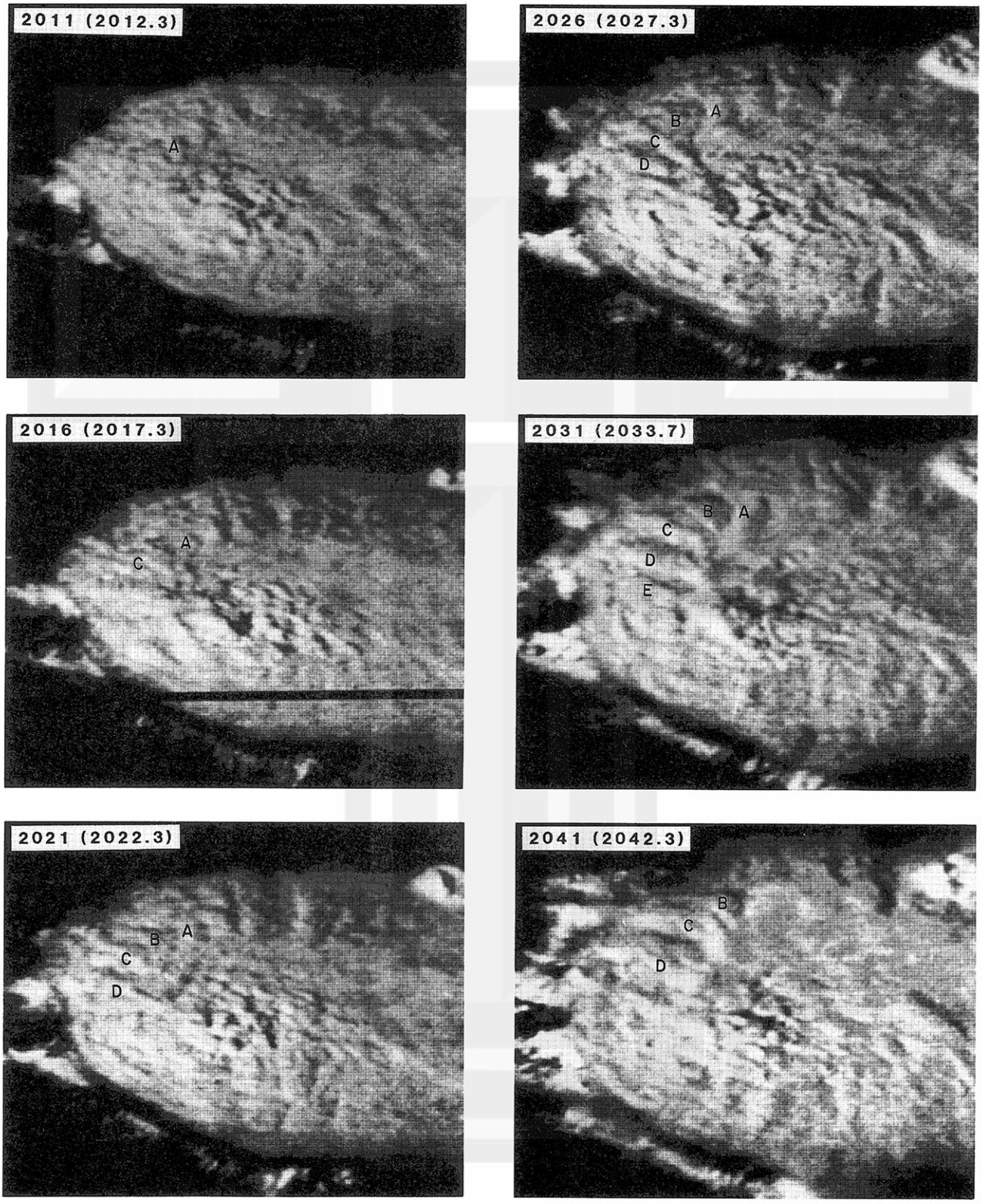

Fig. 4. A sequence of GOES rapid-scan pictures showing fingerlike patterns atop the anvil cloud of the Plainfield cloud. Radar echoes corresponding to these satellite photos are shown in Plate 20.

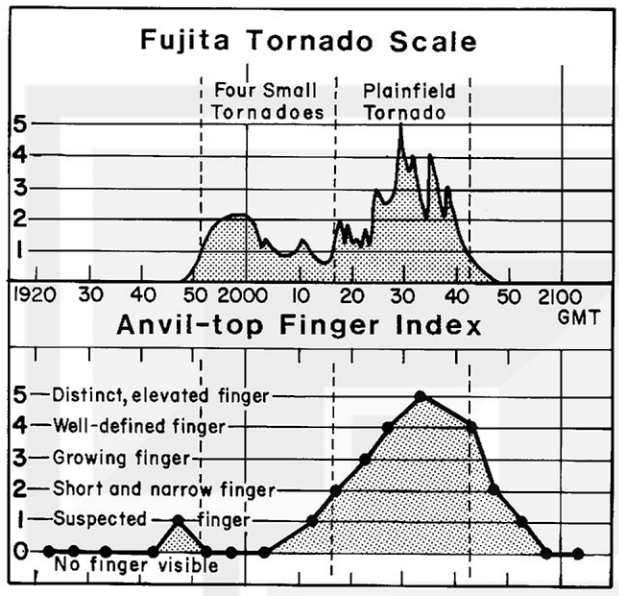

Fig. 5. Variation of anvil-top fingers rated by index 0–5. These fingers are closely related to the F scale variation of the Plainfield storms consisting of tornadoes and downbursts.

A in Plate 22), consisting of two long buildings separated by a 10-m wide pathway. When the tornado crossed the 250-unit apartment complex, several persons were thrown into the cornfield to the southeast (Plate 17). By the morning of August 30 the cornfield was cleared (Plate 18), recovering seven bodies, including a 5-week-old infant. Two persons perished in cars parked by the apartment. Thereafter, the tornado weakened rapidly and disappeared after crossing Larkin Road in Joliet.

What Happened in F5 Winds?

The only location where I estimated F5 winds, based on the corn damage, was to the southeast of U.S. 30 (Plate 23). Prior to the highway crossing of the tornado, its core diameter, evidenced by the width of the debris deposit (Plate 8), shrank from 70 m to 10 m. Meanwhile, the storm intensified up to F5 intensity. Six automobiles were blown into the cornfield. After traveling over the field for about 400 m, the core diameter began increasing again, reaching 100 m.

A series of exposed ground, free from corn crops, was left in the field during the increasing stage of the core diameter (Plate 24). Meanwhile, the corn damage to the southwest of the exposed ground was rated as less than F2, suggesting the existence of an extremely large wind shear, characterized by strong anticyclonic vorticity. Did it induce a series of anticylconic suction vortices on the right-hand edge of the tornado? Another interesting piece of evidence is that the large-core tornado induced a number of orbiting cyclonic suction vortices shortly thereafter. Aerial photographs also showed an eye-shaped vortex mark consisting of exposed ground (Figure 3) at the location of the eye in Plate 23.

Four persons were killed when automobiles were blown off U.S. 30. A northbound tractor-trailer left two separate impact marks (Plate 25) on the shoulder, indicating that the tractor and trailer had been separated before they were blown off the highway. The tractor flew 100 m before plowing into the debris deposit. Apparently, the tractor left the highway moments after the tornado core crossed the highway. The trailer, after losing most of its scrap metal cargo, bounced in the cornfield five times before resting in the field at position E (Plate 23).

A passenger car, after being blown off the highway, traveled at very low altitude, as seen by the shearing and clipping off of corn crops along its 720-m (2350-ft) flight path. Apparently, the car looped around the core of the tornado before coming to rest at position C (Plate 26) in the right-side-up position with four passenger seats remaining intact. One passenger was reported killed after being thrown out of the car. It is remarkable that a car could fly such a long distance in a violent tornado without either tumbling or bouncing.

Cloud-Top Features by Satellites

Both polar orbiter (NOAA 11) and geostationary GOES satellites were in operation on August 28. The former, with 99° orbital inclination, scanned the storm cloud only once at 2:48.8 p.m. CDT (1948.8 UT) during the northbound orbit from 851 km altitude over southeast Iowa. The latter obtained 5-min rapid-scan data from 1:00 p.m. to 4 p.m. CDT (1300–1600 UT) from above the equator at 97.7°W longitude.

GOES infrared (IR) temperatures at 30-min intervals were contoured and superimposed upon MMO radar echoes and the location of downbursts and tornadoes (Plate 27). Meanwhile, NOAA 11 IR data with 1-km resolution were analyzed with 1°C isotherms below the −50°C cloud-top temperature (Plate 28). Because NOAA 11 isotherms are capable of depicting individual cold tops, they were superimposed upon the isoecho contours of the MMO echo at the same time. Two significant cold tops, identified herein as the "Twin Peaks" (Plate 29), with their coldest temperatures, −67.6°C of the West Peak and −61.5°C of the East Peak, coincided with the high-reflectivity cores of the MMO echo. These peaks were located above the onset area of the downburst winds just to the east of DeKalb, Illinois (Plate 19). The high-temperature ring encircling the Twin Peaks is an interesting feature, but its physical and dynamical meanings are not known at this time.

Fortunately, the 5-cm radar of United Airlines northwest of O'Hare Airport made RHI scans of the Twin Peaks area, obtaining the RHI cross section at the top of Plate 29. It is suspected that the West Peak was in the early sinking stage while the East Peak was in the downburst-inducing stage when its strong echo was already on the ground (Plate 19). It is premature to make a conclusive interpretation of such findings from this case study.

In this particular case, several distinct, elevated fingers extended from above the tornado toward the northwest. On

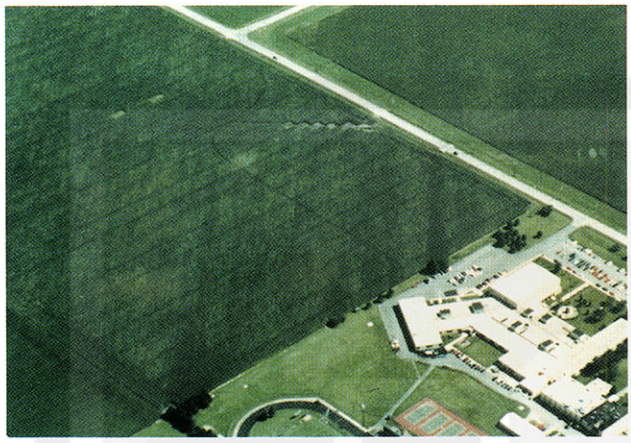

Plate 1. High- and low-wind streaks seen in the vast area of downbursts.

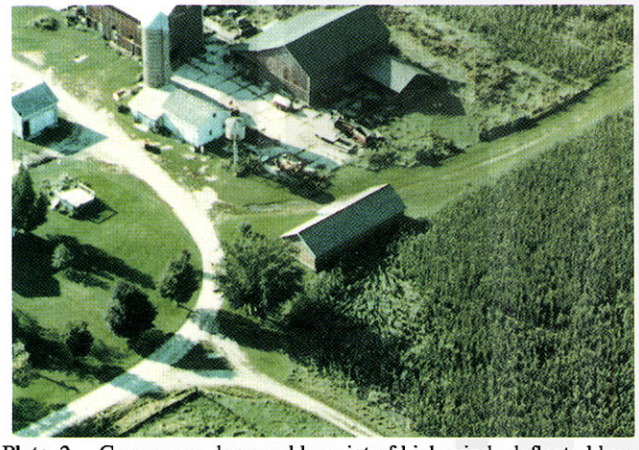

Plate 2. Corn crops damaged by a jet of high winds deflected by a slanted roof.

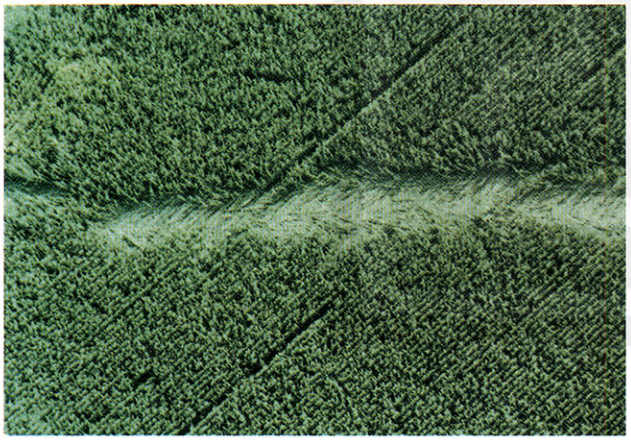

Plate 3. Path of an F2 tornado located inside the area of downbursts.

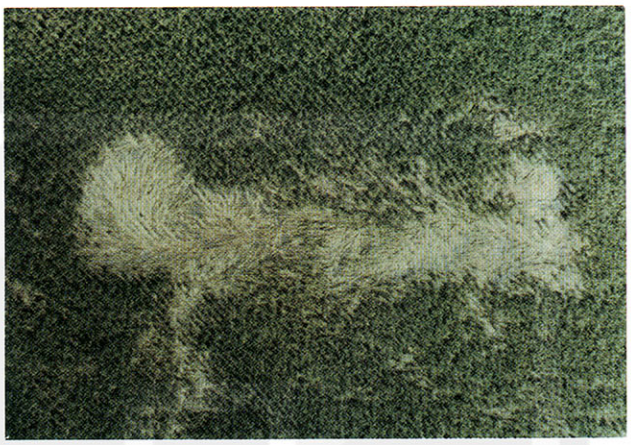

Plate 4. Comma-shaped damage. The tornado was moving left to right.

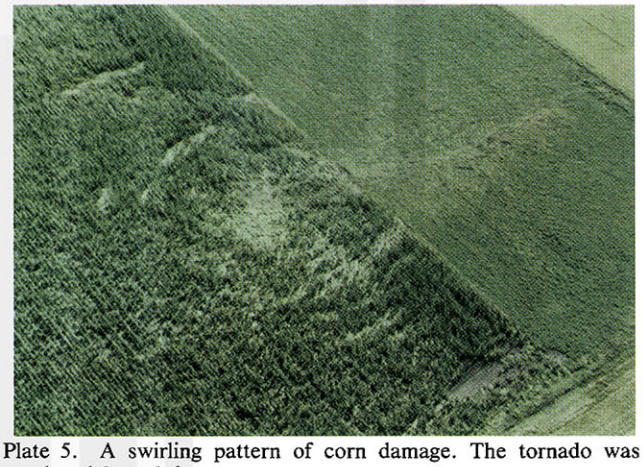

Plate 5. A swirling pattern of corn damage. The tornado was moving right to left.

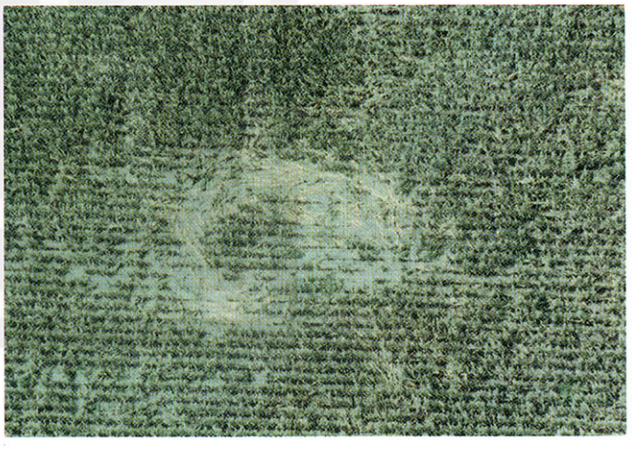

Plate 6. Eye-shaped corn damage. The tornado was moving from top to bottom.

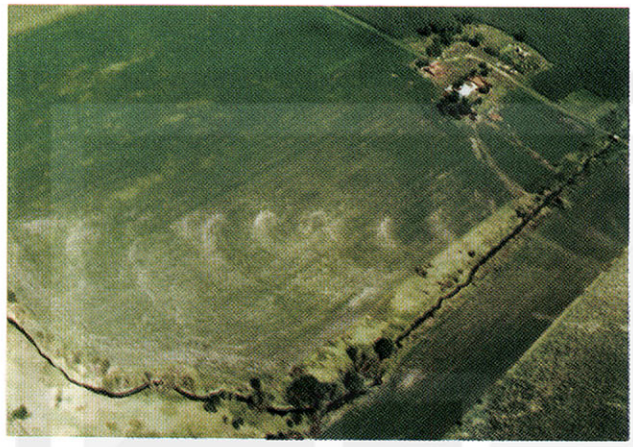

Plate 7. Suction-vortex marks near Whisky Road, looking northeast.

Plate 10. Spring wheat flattened inside the F4–F5 area.

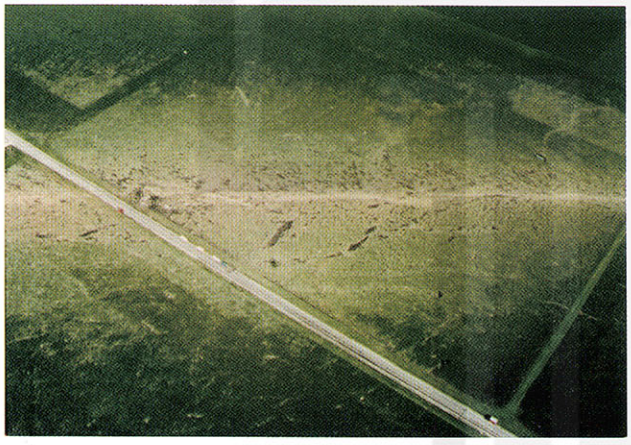

Plate 8. The F5 damage to the southeast of U.S. Highway 30.

Plate 11. A 20-ton trailer blown off U.S. 30. It bounced five times.

Plate 9. A close-up view of bean crops in the F4–F5 area.

Plate 12. A plywood board stuck vertically into the ground in the F4 area.

Plate 13. A difluence pattern produced by the wind shift in the tornado.

Plate 16. Frame houses with weak foundations blown off by F3–F4 winds.

Plate 14. A confluence pattern produced by the wind shift in the tornado.

Plate 17. The Cresthill Lake apartments on August 29 with damaged cornfield.

Plate 15. St. Mary Immaculate church, which lost the cross on the steeple.

Plate 18. The apartment complex on August 30 with cleaned-up cornfield.

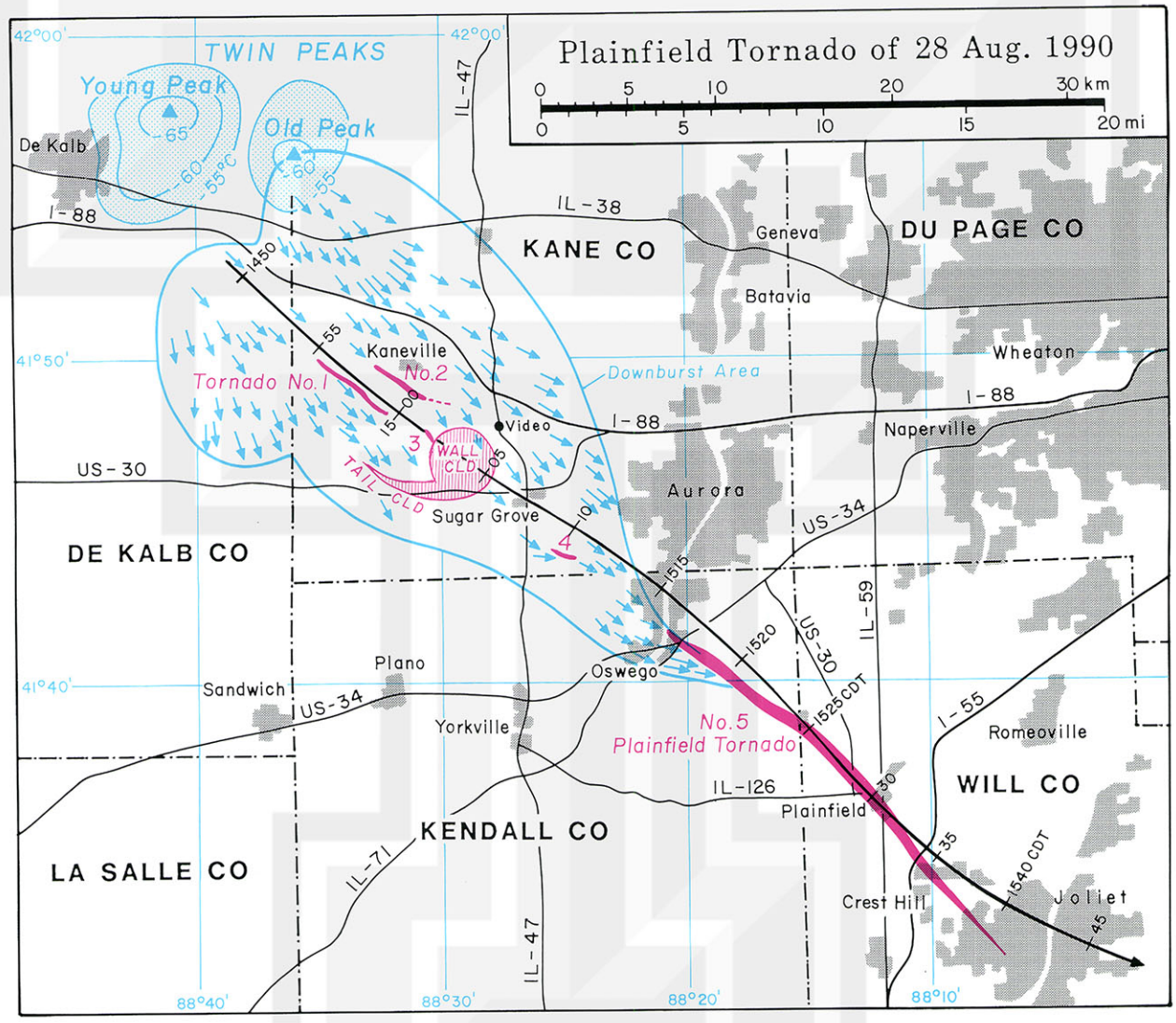

Plate 19. Damage maps of the Plainfield storm. Downburst winds are shown by blue arrows and tornadoes by red areas. The wall cloud depicted in video was located to the northwest of Sugar Grove. The path of the wall cloud center, with 5-min time markers, was estimated by the shape of the MMO radar echoes.

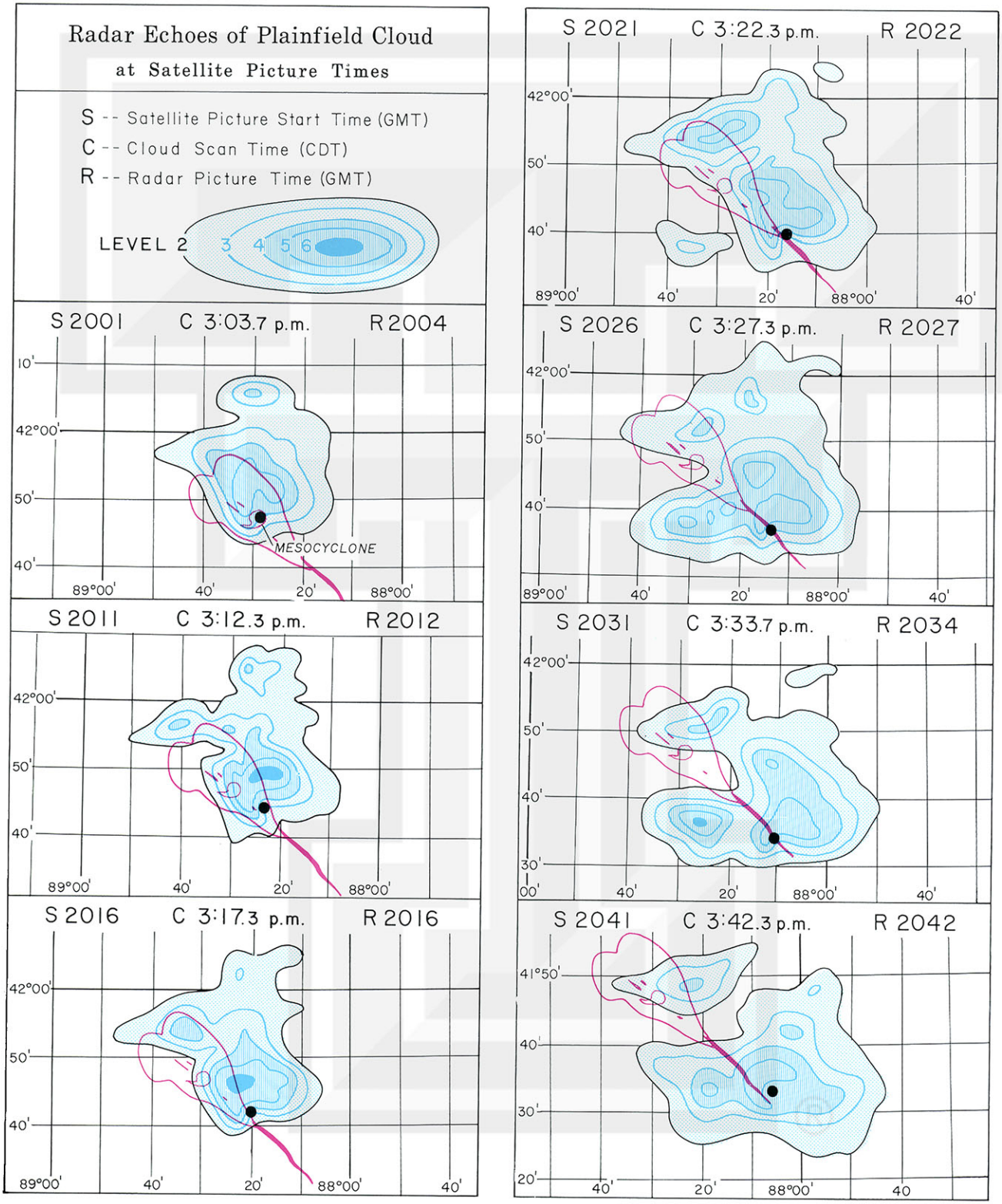

Plate 20. Reflectivity contours of the Plainfield storm with superimposed positions of the hook-echo centers and damage areas. The hook was most pronounced at 3:12 p.m., shortly after the video pictures were taken.

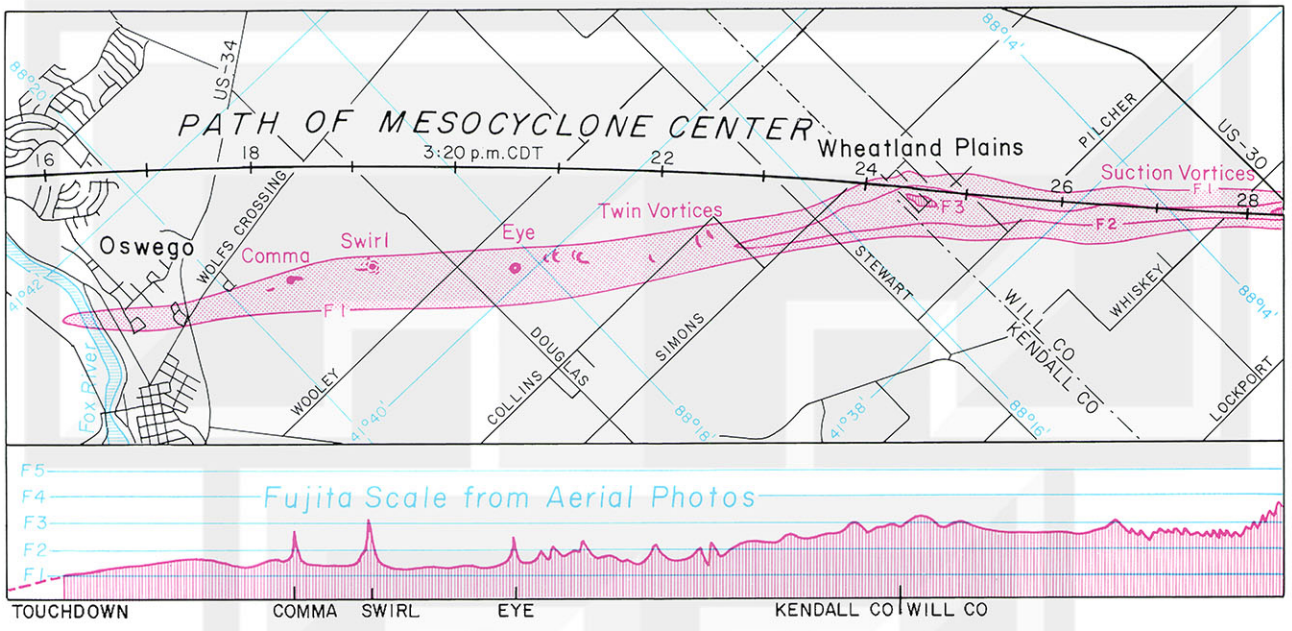

Plate 21. The first half of the damage area of the Plainfield tornado. Variation of the F scale was determined by aerial photographs of cornfields, trees, and structures.

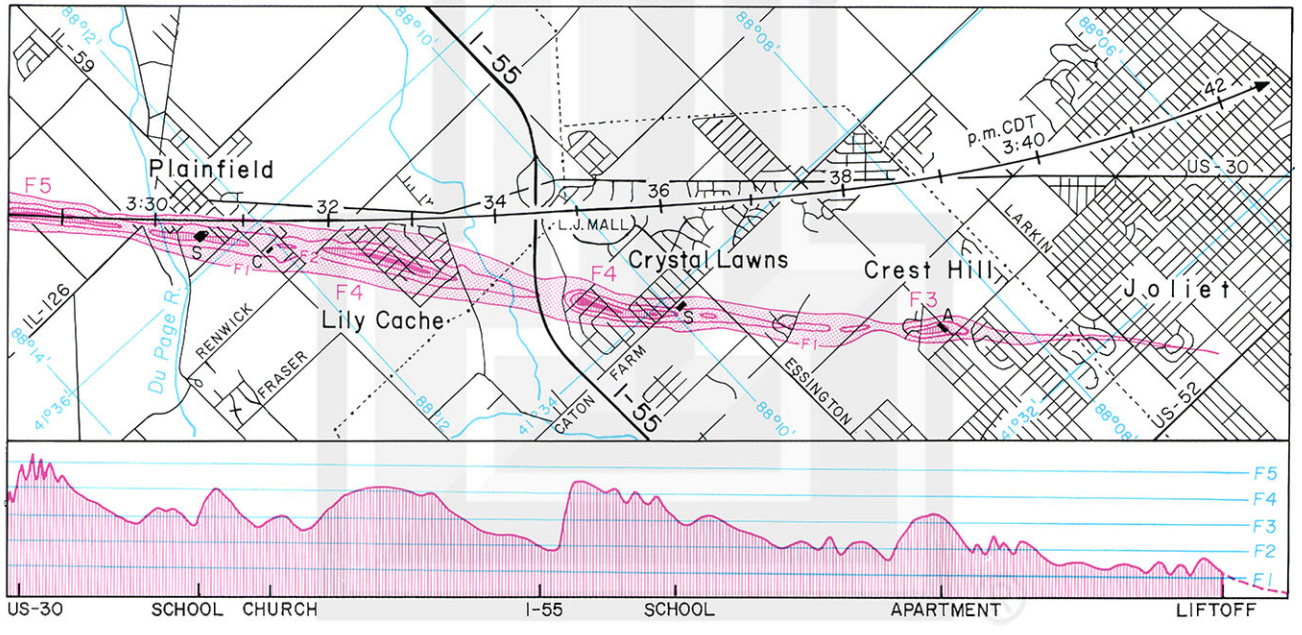

Plate 22. The second half of the damage area of the Plainfield tornado. The tornado at touchdown was 1.7 km to the right of the mesocyclone (hook) center. As the F scale increased to F5, both tornado and mesocyclone axes became close to each other.

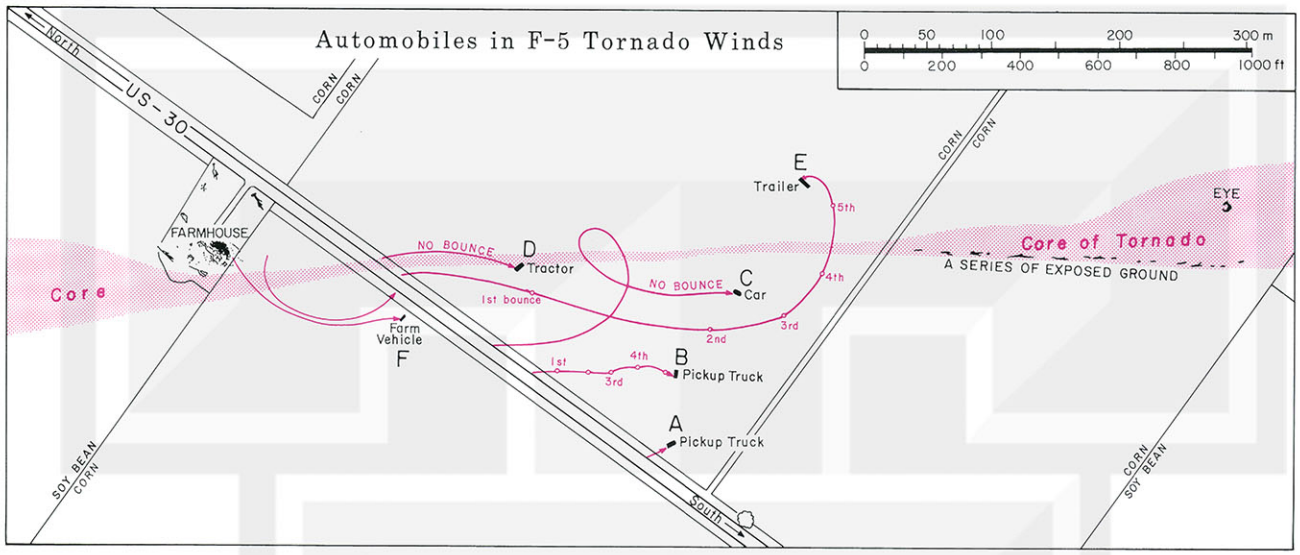

Plate 23. The F5 area of the Plainfield tornado where the core diameter shrank from 70 m to 10 m and increased again to 70 m. When the diameter was increasing, a series of suction vortices formed on the right-hand side of the core, pulling out corn crops and exposing the bare ground.

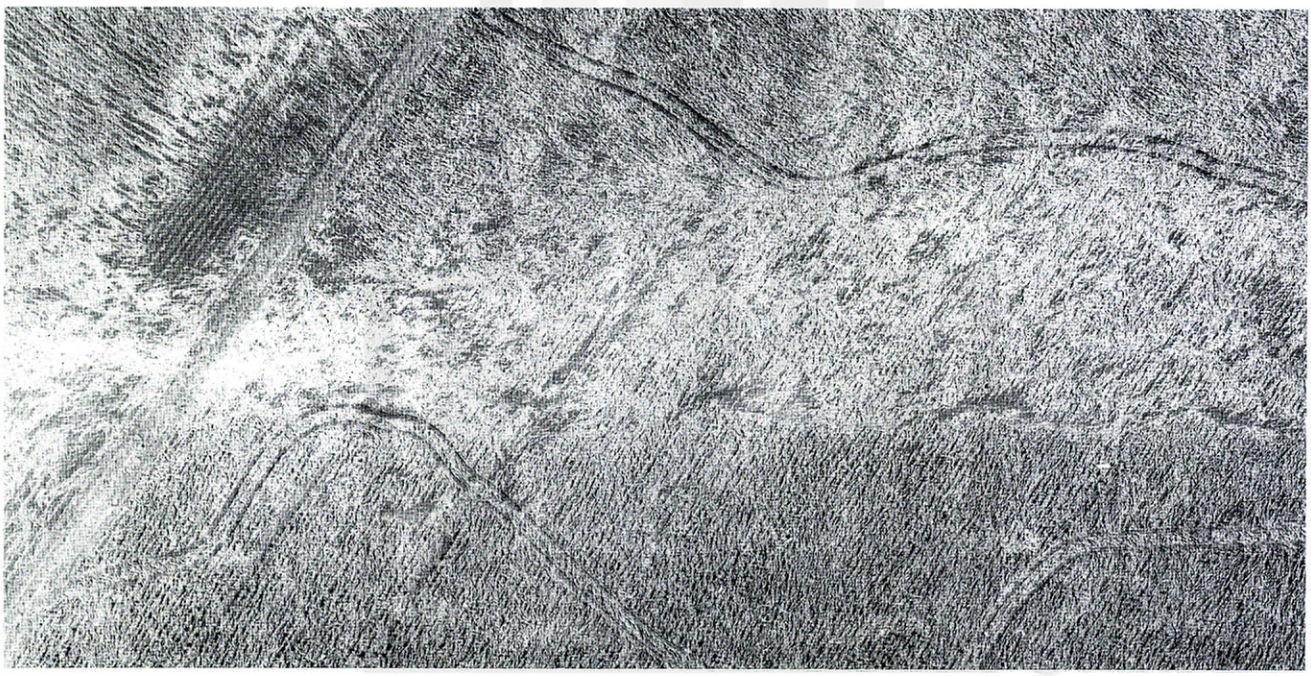

Plate 24. An aerial photograph of a series of exposed ground. Relatively light damage on the southwest side of the core suggests the existence of extremely large anticyclonic wind shear at the core boundary.

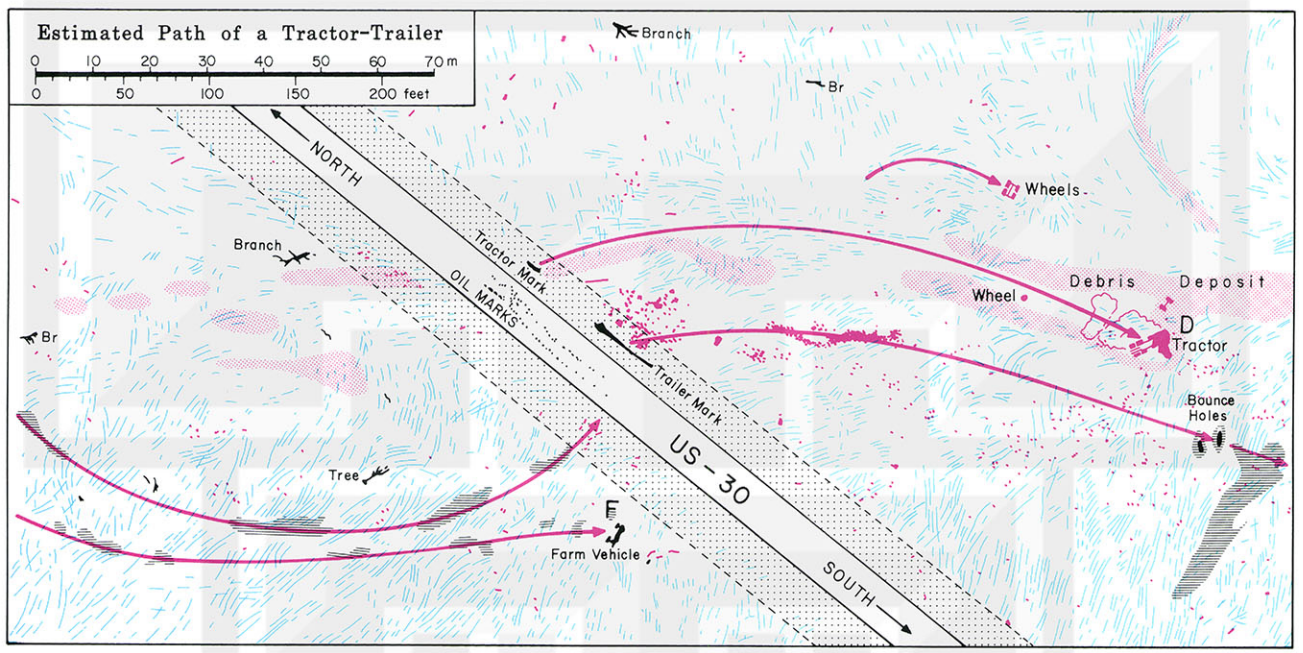

Plate 25. Various ground marks on U.S. 30 and adjacent fields left behind by the Plainfield tornado at its F5 intensity.

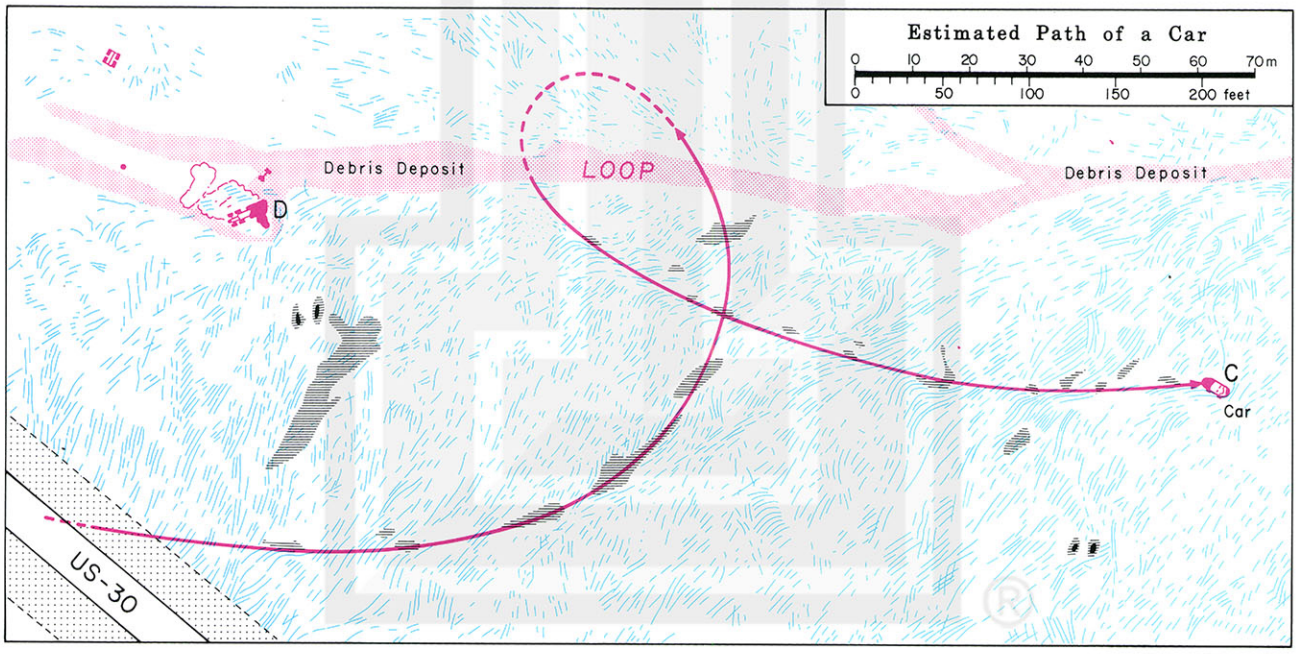

Plate 26. The path of a car which circled once around the small core of the tornado. The car, resting at C with four passenger seats inside, traveled less than 1 m above the ground, probably on the cushion of laminar rising air.

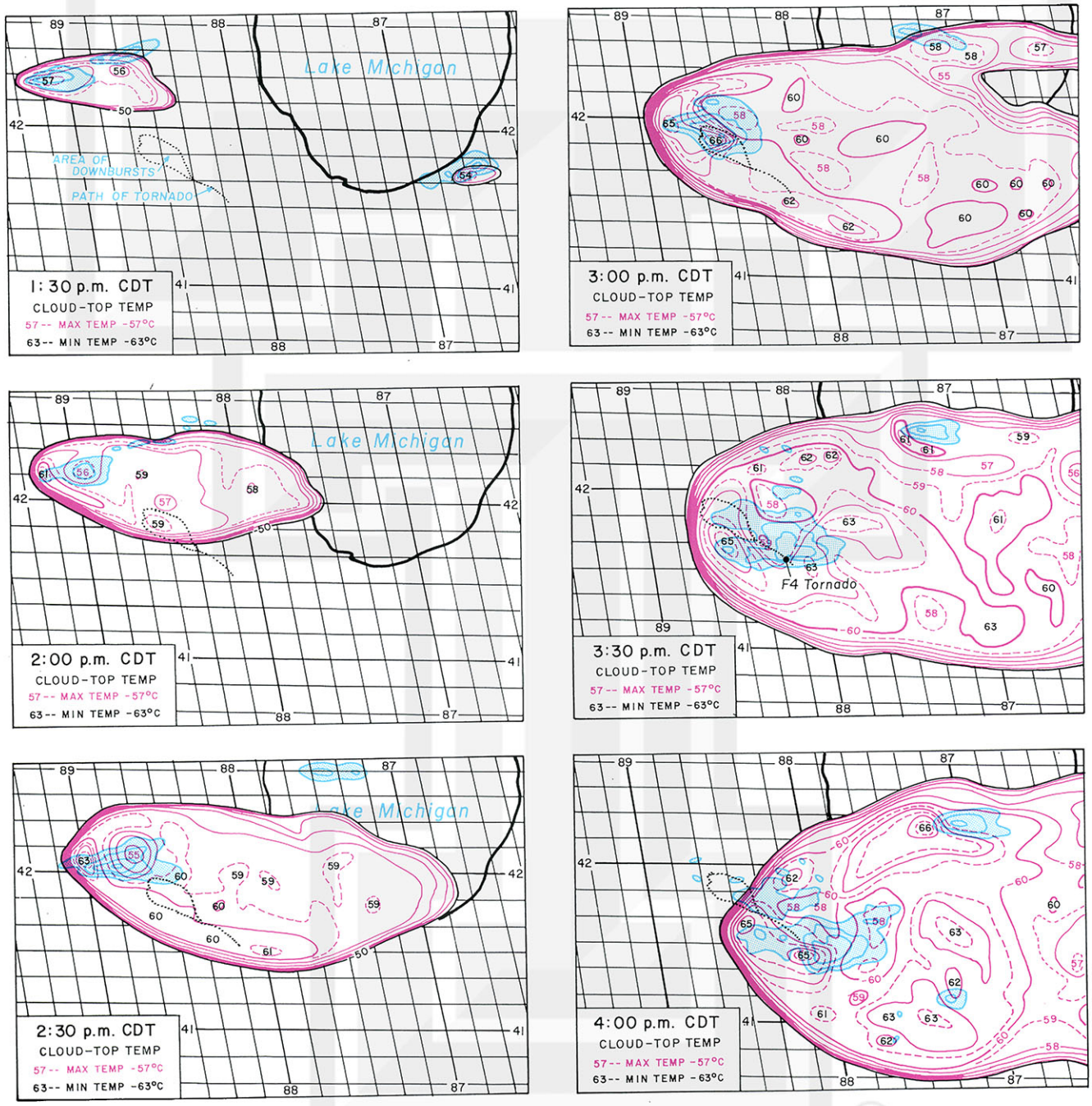

Plate 27. Growth of the Plainfield cloud depicted by 1°C isotherms of the cloud-top temperature. It should be noted that the horseshoe-shaped upwind edge was not characterized by radar echoes of comparable horizontal dimensions.

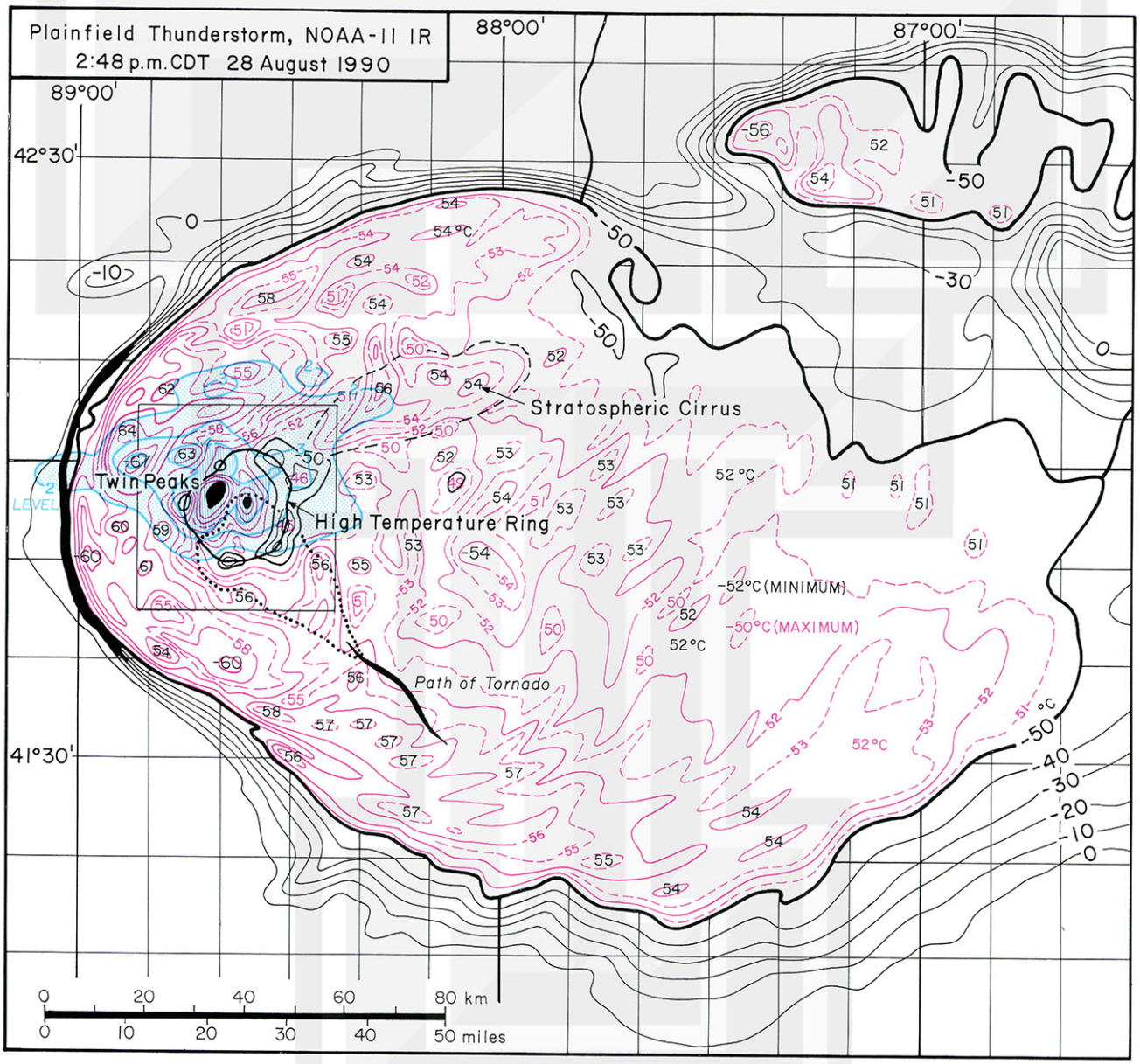

Plate 28. Infrared temperature of the Plainfield thunderstorm obtained by contouring the NOAA 11 data with 1°C resolution. The boxed area near the west edge of the cloud is enlarged in Plate 29.

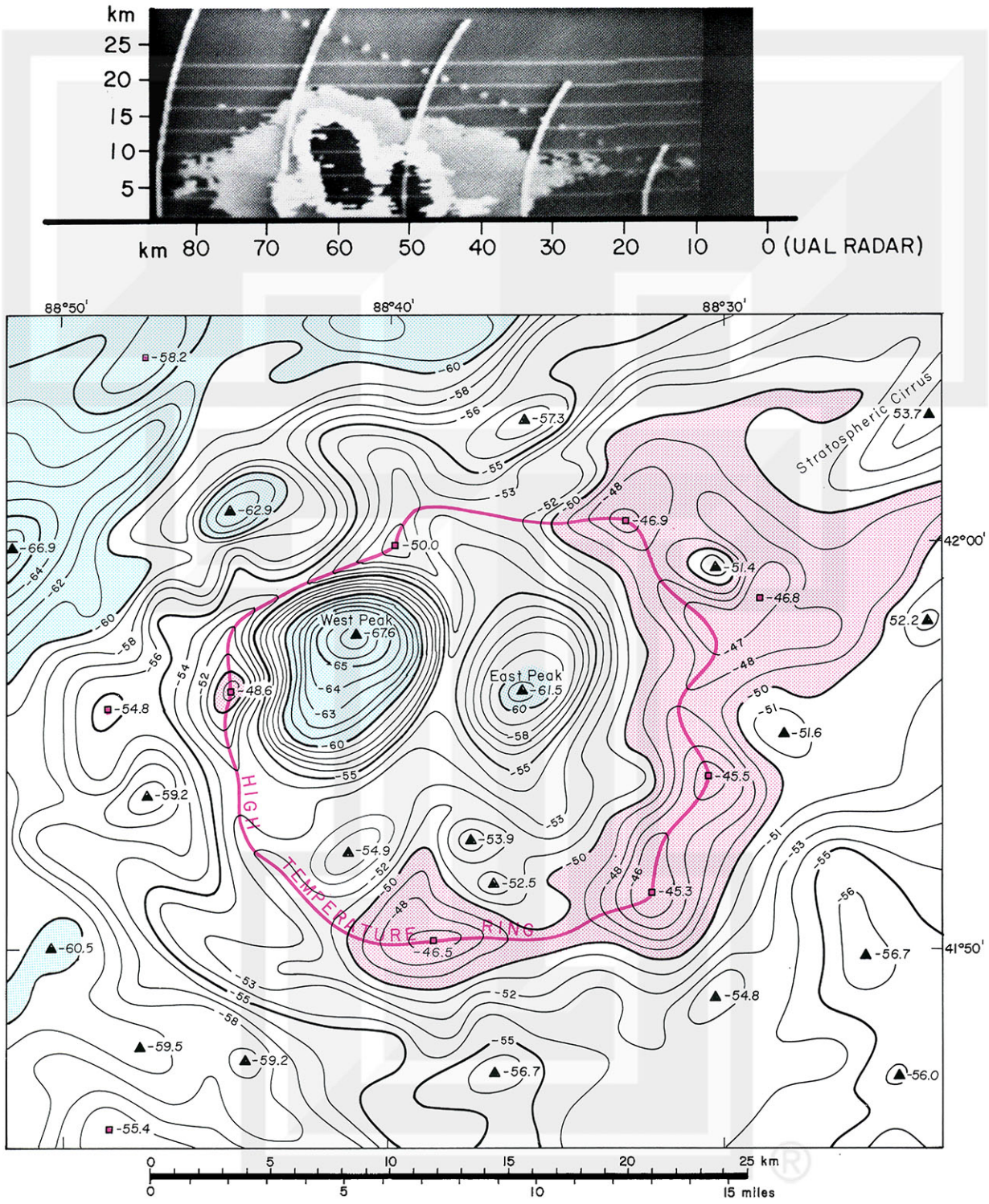

Plate 29. High-resolution isotherms showing two cold-temperature tops identified as the −67.6°C West Peak and the −61.5°C East Peak. An RHI picture of these two peaks by United Airlines radar is shown at the top.

the basis of my Lear Jet experiments in the 1970s (Fujita [1974*a*, *b*], to be published in color in 1992), I am assuming that these fingers consist of the anvil material pushed outward from the highly convective region of the cloud. The time-dependent analysis of the cloud top features (Fig. 4) in relation to the temporal F-scale variation resulted in a positive correlation between the F scale and a so-called cloud-top finger index (Fig. 5).

It was an honor to have had an opportunity to present my research on the Plainfield tornado at the banquet of Tornado Symposium III. As in this research case, an investigation of a complicated phenomenon often leads to additional studies, making use of both new data and advanced techniques. This particular tornado was, no doubt, a very complicated one. I hope that this presentation will stimulate a number of questions and studies for the next generation of tornado researchers.

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References

Fujita, T. T., Overshooting thunderheads observed from ATS and Lear Jet, *SMRP Res. Pap. 117A*, 29 pp., Univ. of Chicago, Chicago, Ill., 1974*a*.

Fujita, T. T., Overshooting tops of severe thunderstorms revealed by Lear Jet, satellite, and radar observations, *SMRP Res. Pap. 117B*, 48 pp., Univ. of Chicago, Chicago, Ill., 1974*b*.