SATELLITE & MESOMETEOROLOGY RESEARCH PROJECT

Department of the Geophysical Sciences
The University of Chicago

FEEDER CLOUDS ASSOCIATED WITH TORNADO-PRODUCING MESOCYCLONE OF MARCH 26, 1976

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SMRP Research Paper No. 143
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ABSTRACT

On March 26, 1976 a Learjet was flown in order to photographically study a potential tornado-producing line of thunderstorms. The line extended southwestward to southwestern Missouri, bending nearly southward from that area through western Arkansas. Three tornadoes were spawned near the crest in southwestern Missouri. A weak, short-tracked tornado developed west-southwest of Purdy. Two significant tornadoes moved 42 km from southwest of Sarcoxie through the town of Miller, Missouri. A follow-up damage survey was performed on March 28 to confirm, map, and classify the tornado tracks.

Radar echo motions indicated the existence of a mesocyclone. The parent thunderstorm of the Sarcoxie and Miller tornadoes was located on the eastern portion of the mesocyclone where the greatest convergence existed. The tornado developed west of the 10 db radar echo and gradually moved into the precipitation area before dissipating. The parent thunderstorm was photographed from the Lear at 13,725 m altitude and a distance of 170 km. The 30-second interval pictures indicated feeder clouds moving into the parent storm from the south, giving a visible clue of the mesoscale circulation. Satellite imagery showed overshooting occurring after the tornadoes.

1. INTRODUCTION

Many authors in the past have investigated the problem of tornadogenesis and yet, today, the mystery remains as to what is the actual trigger for the tornado, and what identifies a tornado-producing storm from a non-producing one. The problem, at times, appears to be one of scale. A spring squall line may only produce one tornado, although sometimes many more, and yet one finds it difficult to explain why one storm in the line was, somehow, in an ideal position to produce a tornado. Many meteorologists agree that updraft regions and mesoscale circulations associated with the parent thunderstorm play a role in tornadogenesis. Even if one cannot get good quantitative methods for determining where a tornado will occur, it would still be useful to meteorologists and the general public if identifiable characteristics would alert us to the likelihood of a tornado occurrence. There has been some success in this area and more should be expected, with refinements in the sensing abilities of radar and satellite.

There are several theories on tornadogenesis that have been proposed over the past. Of these, two theories are discussed here: (1) those favoring tornado formation in the main updraft of the thunderstorm and (2) those favoring formation in or near a feeder or flanking cloud.

Danielson (1975) suggests that the mesoscale cyclonic vortex forms preferably in the main updraft and that this is where most tornadoes and hook echoes on radar are observed. This vortex can then become the tornado parent by (1) vortex stretching, (2) horizontal velocity, and (3) mass convergence. Furthermore, if there is a slow down in the growth rate of the cell due to mass loading, then a potential exists for vorticity generation in both the updraft and downdraft. There is an increase in the percentage of mass forced to flow around the cell, enhancing the potential for cyclonic and anticyclonic circulations. Fawbush, Miller, and Starrett (1951) discuss the difficulties in obtaining proximity data to accurately forecast tornadoes. Due to the sparseness of reporting upper air stations, critical data is often missed. They state that once all criteria are met only strong lifting is needed before tornado development occurs. Whiton (1971) makes an interesting observation in that the severest weather usually occurs at the wave crest or slightly southward of the crest. He pinpoints the tornado cyclone as being on the right rear portion of the echo with respect to its movement.

Several authors have felt that the flanking line, or flanking cell, plays an important role in tornado development. The correlation between thunderstorm updraft intensification and tornado is discussed also by Maddox (1973). He further cites, however, that often the flanking cumulus cell closest to the parent thunderstorm is usually the site for tornado formation. Further, it is explained that a circulation already existing in this area is at least partially induced by the gust of the parent thunderstorm. This concept is derived from Bates (1970) who states that the flanking cell formation is the most important part of tornadogenesis. In a specific case, Donaldson (1957) describes a tornado-producing thunderstorm in western Massachusetts. He reported that time-lapsed photographs indicated sudden development of convective activity on the upstream side, followed by damaging winds at the ground. In a report by Foster (1973) radar echo development on the upstream side of a storm was observed. The first flanking echo was observed even after the tornado activity had begun. It is possible that the actual flanking cell without echo return would have been visible earlier.

There could be a correlation between the causes of flanking or feeder cells and cyclic characteristics of tornadoes. Foster (1973) observed many non-tornadic radar echoes and only the storm with a tornado indicated a pulsating growth rate. Fujita (1963), Darkow and Roos (1970), and others have speculated that successive intervals between tornadoes may be cyclic in nature and relate to the intensity and organization of the parent thunderstorm.

2. FORECAST AND FLIGHT PROCEDURE

The general flight program consisted of Learjets and other instrumented aircraft. Flight days are decided upon after a standard forecast procedure consisting of a 48-hour alert and a 24-hour 'go-ahead'. The forecast decision for March 26th was made through conference calls between Edward Ferguson, Director of the Satellite Field Service Station in Kansas City, William E. Shenk from NASA Goddard Space Flight Center, and the author. In both the alert and go-ahead forecasts it was decided that the Missouri-Arkansas area would be the most likely area of tornado activity. Decisions confirming the flights have to be based on the 24-hour forecast due to the fact that the Lears are leased and are, therefore, not literally on-call at all times, and also when the slower instrumented aircraft are participating they must be moved the prior day to the appropriate research flight position. The instrumented aircraft were not used on this research case. Early in the actual flight day it was decided that the northwest Arkansas - southwest Missouri area would be the prime target.

We moved from Chicago Midway Airport to a base in Kansas City on the morning of March 26th. By 2120 GMT we were at a height of 13,725 m in our fore-casted area. Unfortunately, the FAA required us to circle several times, delaying the photography that was so essential to our research mission. Due to this problem the research crew members, William E. Shenk and the author, photographed several storms but failed to get the continuity and position necessary to capture a tornado-producing storm in northwest Arkansas. Once photography commenced and we had resumed a reasonable flight pattern, Ed Ferguson informed us at 2210 GMT that the best area now appeared to be 48 kilometers north-northeast of Joplin, Missouri. As discovered later, this position was very close in space and time to the actual tornado touch down which began at 2207. The photographs were taken with two SLR cameras mounted with 28 mm and 50 mm lenses at a height of 13,725 m and a distance of 170 kilometers from the storm. Approximately one hour of 30-second interval photographs were taken with the two cameras of the tornadic storm in southwestern Missouri. The storm was located between Joplin and Springfield, Missouri. An analysis of the tornado and tornadic storm follows.

3. DAMAGE TRACK AND OBSERVATIONS

On March 28 the author performed a damage survey utilizing a Cessna 172. All tornado tracks in southwest Missouri were photographed and mapped using an SLR camera with a 50 mm lens and 7-1/2 minute maps, respectively. Conclusions from the survey are presented here.

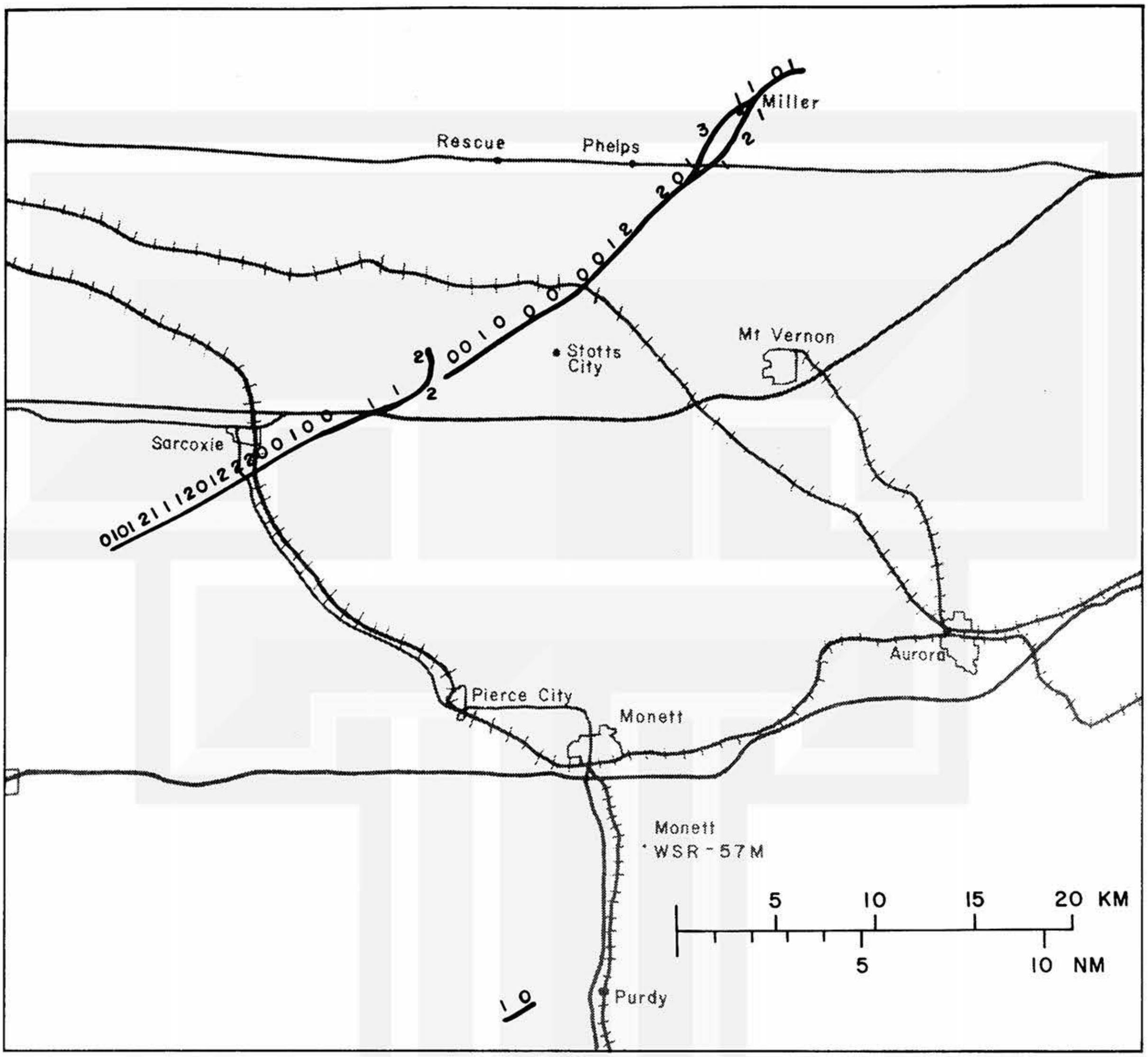

Fig. 1. The Sarcoxie, Miller, and Purdy tornado paths of March 26, 1976; so named due to the proximity to towns which they passed. The F-scale of intensity is indicated along each tornado track.

There were three tornadoes produced. The two analyzed in this paper were in a family. Figure 1 illustrates each of these tornado tracks with the varying F-scale intensity, from Fujita (1971), over each path. For identification purposes, the family will be identified as the Sarcoxie and Miller tornadoes and the other tornado in Fig. 1 will be called the Purdy tornado.

The Sarcoxie tornado began at 2207 GMT, was 18.4 kilometers long, had an average width of 37 meters and was classified as F 2. The tornado moved northeastward through most of its path before turning north and terminating. The Miller tornado which began at 2222 GMT was classified as F 3 and moved in a slightly more north-northeastward direction. It had an average path width of 229 meters, travelled for a distance of 24 kilometers, and at one point was close to 1.2 kilometers wide. The Purdy track was 2.4 kilometers long, and produced F 1 damage at only one point. This tornado occurred at 2215 GMT, or the same time that the Sarcoxie tornado killed two people about .8 km south of Sarcoxie.

There were many visual observations of the effects of the Sarcoxie storm. Through a newspaper questionnaire several responses were received. A few of these elucidate what happened just before and during the tornado.

Bessie Burks--located in Sarcoxie before and during the tornado.

> ... 'I have not seen this in hail before when all were split. They were sort of tan or yellow in color; this too was odd. Hail is generally white ... these hail that were split were not smoothly split, but rather like someone had struck them with an object, cracking them. The odd part was they were all so much alike and not white. The storm that produced the tornado began with heavy rain - pause - hail - pause - and some rain again.'

The above quote, bringing out the color of the hail and the way the hail was all alike, brings the theories of Danielson (1975) and others to light. The color of the hail may have been due to blowing dust over western Oklahoma. The hail size may indicate some type of sorting efficiency of this particular storm.

Further quotes:

Jim Blankenship--driving a car .8 km south of Diamond, Missouri, (21 km west-southwest of Sarcoxie) on highway 71A shortly before 2200 GMT.

'... it started sprinkling (very big drops) and hailing a little (stones were perhaps 1/2 inch (1.27 cm) in diameter). The hail lasted only a few seconds. I noticed that horses in pastures were running wildly about the pastures and nearly hitting the fences... . It began raining as hard as I ever remember seeing rain. This lasted for perhaps five minutes and stopped abruptly.'

His final location was two miles east of Diamond and .8 to 2.4 km north.

Charles Harrison--located northern city limits of Granby, 20 km southwest of Sarcoxie before 2200 GMT.

'The hail was about 1/4 inch (.64 cm) in diameter .... At the time of passing the band of hail we saw little or no lightning but a lot of thunder. But it may have been the tornado forming or passing over us but we could see nothing as at that time we could hardly see the road.'

The Sarcoxie tornado was sighted west of a rain area at 2215 GMT, about .8 km south of Sarcoxie. The funnel was described as being like a vertical pole, more or less like a telephone pole and very narrow. The tornado was destroying a house trailer, at the time of the sighting, killing the occupants.

4. LEARJET AND SATELLITE INTERPRETATION

The tornado-producing thunderstorm was easily visible from the Learjet at 2214 GMT and is labeled by the letter A in Fig. 2. The Learjet flight track was approximately 170 km from the tornado position as illustrated in Fig. 3. From a series of Lear photographs one can observe the parent thunderstorm and the feeder clouds. The feeder clouds are labeled A'.

A movie loop was produced from the aircraft based photographs. During the initial stages of the Sarcoxie tornado, at about 2212, rapid vertical development

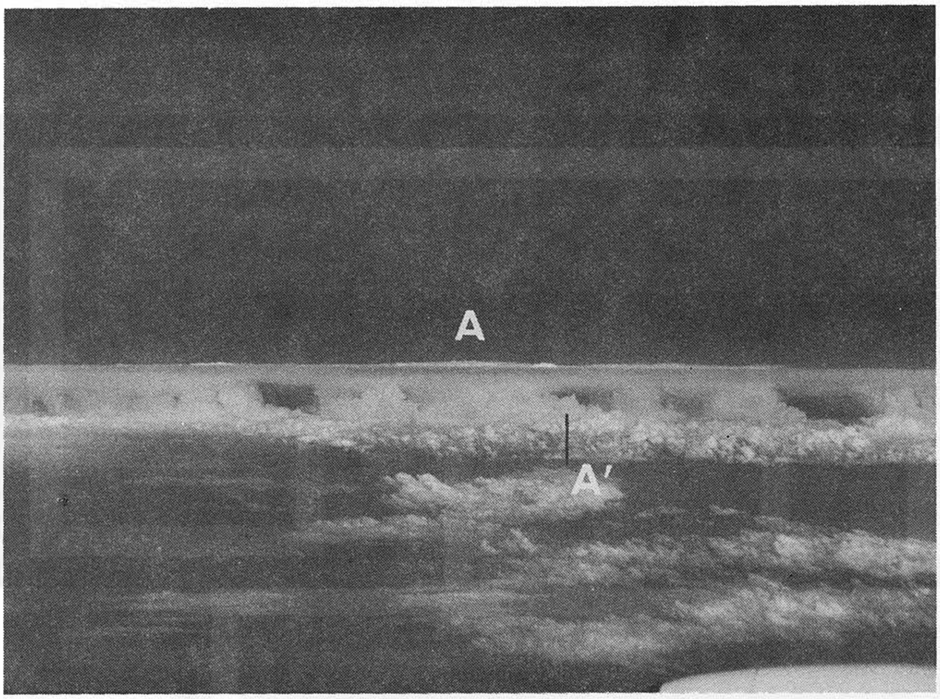

Fig. 2. Photograph at 2214 GMT from Lear of the parent tornadic thunderstorm labeled A and a feeder cloud A'.

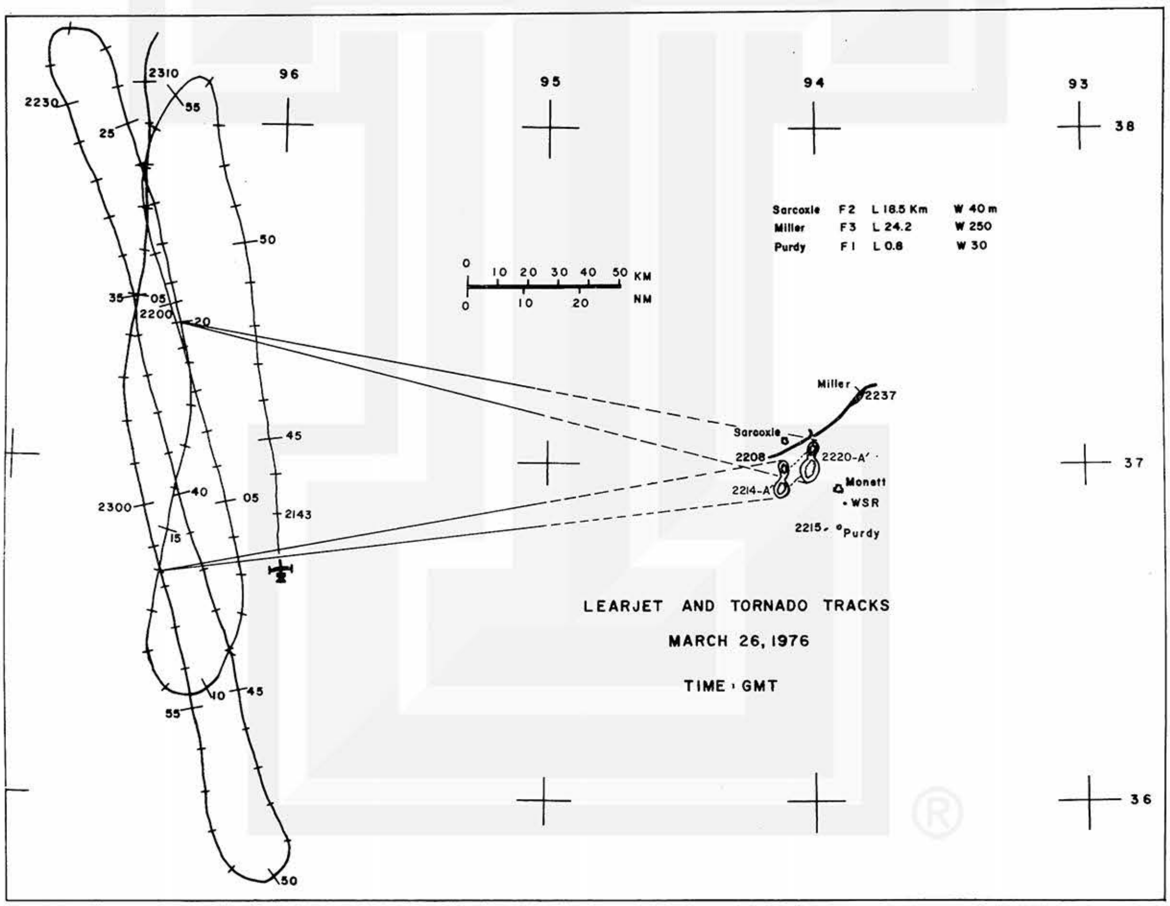

Fig. 3. Learjet flight path relative to the position of the tornado tracks. Time indicated for flight path and tornado tracks is in GMT.

occurs on the southwest flank of the tornado-producing storm. At the same time, a small flanking cumulus is observed southwest of the storm. At 2213 a feeder cloud begins to develop and by 2220 begins to merge, as in Fig. 4, with the parent storm during the initiation of the Miller tornado. Fujita (1958) and Stout and Hiser (1954) both discuss a merging phenomena associated with tornadic thunderstorms. Stout and Hiser show tornado formation at about the time and place where the edges of two merging echoes first touched. Finally, at 2237 an entire merger is completed, coinciding with the end of the Miller tornado, leaving the parent storm with a concave or cooling tower appearance. The rate of growth of the feeder clouds are not rapid at any time and the greatest rate of growth is only 10 m s^{-1}. This rate is based on measuring the top of a feeder cloud using a tilt grid and the 30-sec interval pictures. Individual elements indicate briefly higher growth rates but are not continuously measured due to occasional obscuring of the smaller parcels. The average growth rate was 3 - 4 m s^{-1}. After the initial upward development, the feeder clouds appear to get slowly wider. The feeder clouds merge in the vicinity of the ending point of the Sarcoxie tornado and are likely to be embedded in the flow responsible for the start of the Miller tornado which began at 2222 GMT.

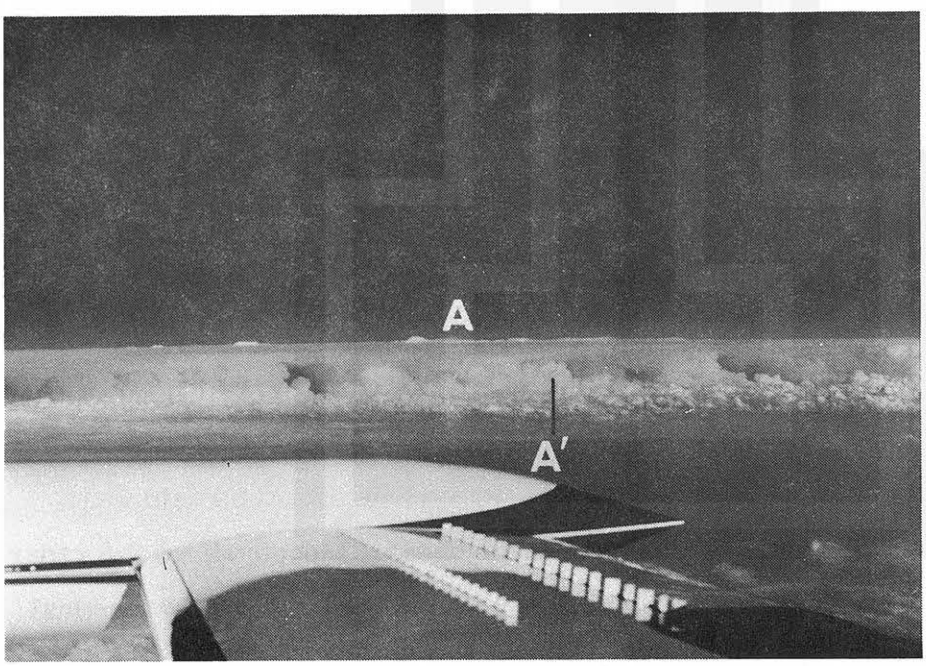

Fig. 4. Photograph at 2220 GMT from Lear of the merging of the feeder cloud A' with the parent thunderstorm A.

As mentioned before, eyewitnesses reported heavy rain and small hail preceding the Sarcoxie tornado. Whereas, the outer edge of the parent thunderstorm was visible to ground-based observers during the Sarcoxie tornado, the Miller tornado as it approached Miller was encompassed by the merger of the feeder clouds and the southern portion of the parent storm and was not visible due to heavy rain surrounding the tornado.

The author first became interested in the feeder cloud phenomena from pilot reports and a previous unpublished case study. Pilots indicated that under and near feeder clouds there was strong shear and overturning and described it as possibly being more dangerous than crossing under portions of the main thunderstorm. The case study was on May 29, 1975 where a large thunderstorm southeast of Amarillo, Texas was photographed by the author and William E. Shenk of GSFC in a Learjet at an altitude of 13,725 m. The storm was more or less isolated from large areas of severe weather and a series of feeder clouds were produced over a several hour period. An NSSL chase team which traveled in automobiles into northern Texas gave eyewitness as well as photographic accounts of many funnels protruding from this storm. Later, Gregory S. Forbes, a graduate student at the University of Chicago, performed a damage survey from a Cessna aircraft and produced photographic evidence of tornadoes as well as the mapping of seven tornado tracks. Even though these were considered weak tornadoes, they did occur in open country and stimulated the author's interest. The periodicity, if it can be called that, of six consecutive flanking-cells in this case averaged 42.5 minutes and may have an effect on the cyclic nature of tornadoes reported by Darkow and Roos (1970).

The feeder cloud environment is likely to be in a zone of high shear both horizontally and vertically in the low-levels. The horizontal shear can at least in part be induced by outflow from the parent storm and the associated mesoscale feature and the feeder cloud is simply located in an area where the outflow lifts the warm and moist air from the south and southeast and creates the shear. Monett where the radar film and soundings were taken is within 30 kilometers of the tornadoes. The vertical shear was found in the Monett sounding at 1200 GMT, not shown here, where winds at the surface were at 170^{o} at $3.5\ m\ s^{-1}$ and at 800 m more at 213^{o} at $27\ m\ s^{-1}$. At

2400 GMT, slightly over one hour after the tornadic event the surface winds were 220° at 5 m s^{-1} and 261° at 16 m s^{-1} at 800 m. At 700 millibars the sounding is very dry in the morning and nearly saturated in the evening whereas the reverse is true in the lower few hundred meters.

The Learjet photo at 2214 GMT, previously shown in Fig. 2, indicates the parent thunderstorm shown by the letter A. The initial stages of one of the feeder clouds which merges at 2220 GMT is shown by the letter A'. At this time the Sarcoxie tornado is in progress and the Purdy tornado is about to touch down. The Purdy tornado is located under the first large cell to the right (south) of the flanking cell and is not analyzed here. The parent thunderstorm is seen at 2240 GMT in Fig. 5. The feeder clouds have previously completed merging, the parent thunderstorm is shown by the letter A. The overshooting top on cell A is somewhat obscured from the Learjet view by the cirrus spreading further westward from the parent than had been the case at 2214. Cells B, C, D, E, G and G' are labeled here for identification purposes.

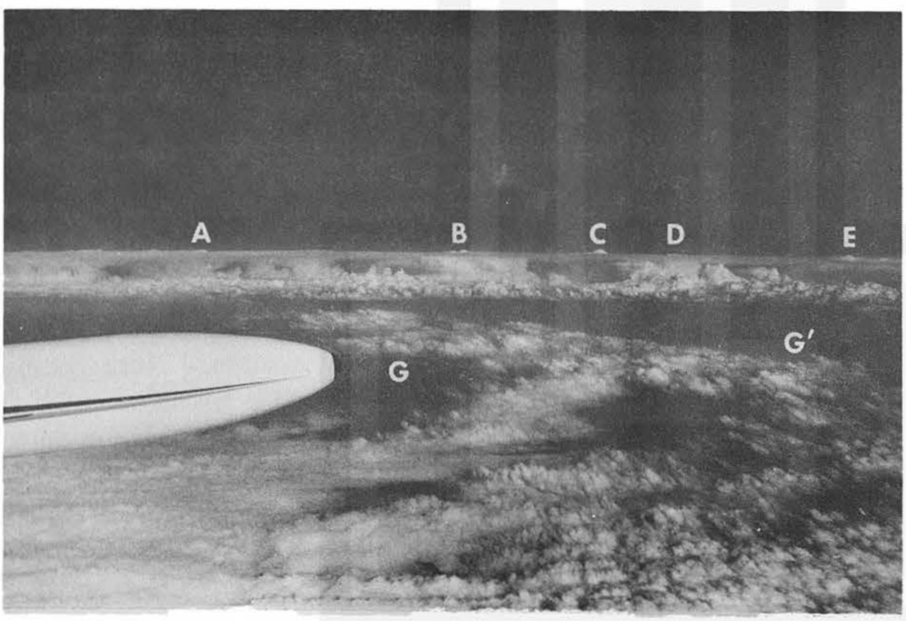

Fig. 5. Lear photograph at 2240 GMT of the final stages of the Sarcoxie-Miller parent storm A. The Miller tornado has just ended. Note concave appearance of the wall of the thunderstorm.

Figure 6 is a satellite picture for 2237 GMT. The same cells seen in Fig. 5 of the aircraft photos at 2240 can be readily identified. The grid indicated in this satellite picture is not properly aligned and a rectified longitude and latitude grid was constructed using landmarks as a reference. This grid is not shown here but was the only available means, independent of radar, to show that the tornado occurred at the southwest edge of the parent thunderstorm.

In Fig. 5 the tornado had just ended south of the overshooting top A under the cirrus canopy. The satellite pictures did not show the feeder clouds before the merger but indicated a rather flat top on the parent thunderstorm. Only after the feeder clouds penetrate or that other growth occurs above the anvil in the storm does it become evident that there was vertical development below the anvil top. In the future, cloud-top temperatures, vertical soundings and the use of microwave sensors may help us to solve some of the problems of tornado cell identification. In this case there is so much cirrus that a clear view of the cell is not possible.

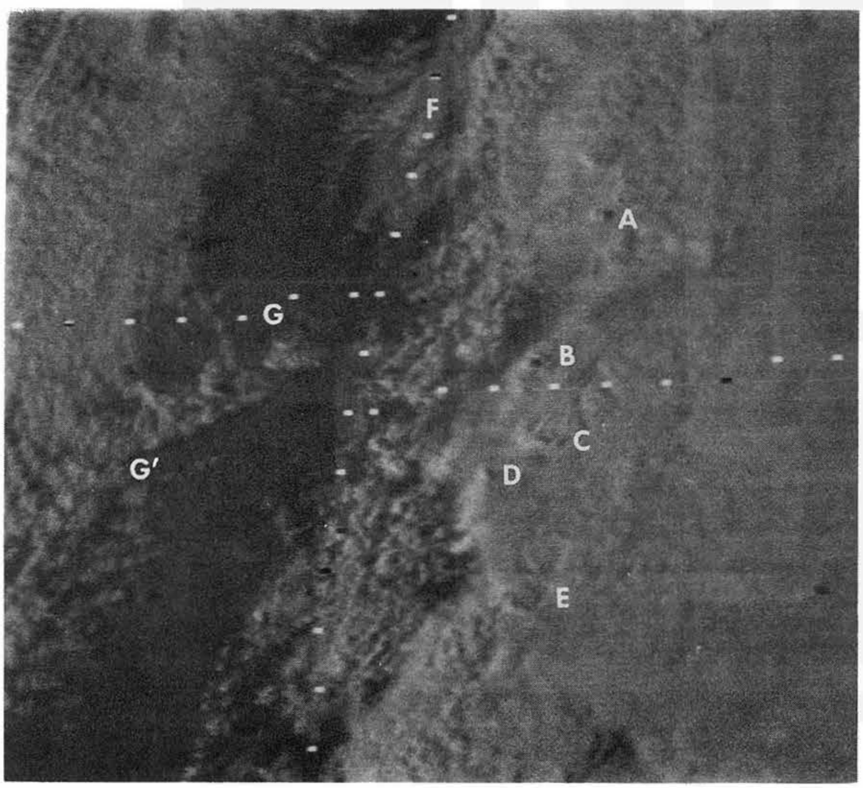

Fig. 6. Satellite photograph at 2237 GMT of similar area as shown in Fig. 5. Overshooting labeled A in the parent thunderstorm. Note other visible features such as G and G' seen in both satellite and Lear photos.

It is interesting to note that cell A is on the southwestern border of a northeast-southwest line of thunderstorms. Another line extending north-northeast to south-southwest extends from that point. Therefore, the Sarcoxie-Miller tornadoes were actually located at the southernmost edge of a line of thunderstorms and near the intersection of the two lines. Inflow from blowing sand and dust over part of Oklahoma may have been responsible for the tan-colored hail but could not be readily identified by satellite or Learjet views. It is possible that another source under the storm was responsible, such as a mesoscale circulation.

5. RADAR

The radar located near Monett, Missouri, only about 30 kilometers from the furthest tornado touch down point, was an ideal tool for identifying the tornado-producing storm. Also the other storms previously lettered in the satellite and Learjet prints were easily identifiable except for cells F, G, and G' which were non-precipitating clouds.

In Fig. 7a only the parent storm is outlined with the tornado position and direction indicated. The letters A, B, C, D, and E are labeled to trace identifiable elements of the echo. At 2222 the southern portion of the storm echo increases in diameter. This expansion occurs at the same time as the merger of the flanking cell with the parent storm as identified by the Learjet photos. Unfortunately, ground clutter and a blacked-out portion in the radar viewing area obstruct any other view of the feeder clouds or the cell which produced the Purdy tornado. The motion of the echo indicated the mesocyclone circulation.

Figure 7b shows the movement of the identifiable echo elements. The southernmost element close to the mesocyclone moved slower and at 30-deg to the right of the other elements. This appears to indicate the influence of the mesocyclone. It is easy to see why the feeder cloud gradually moved into this southern portion of the parent storm.

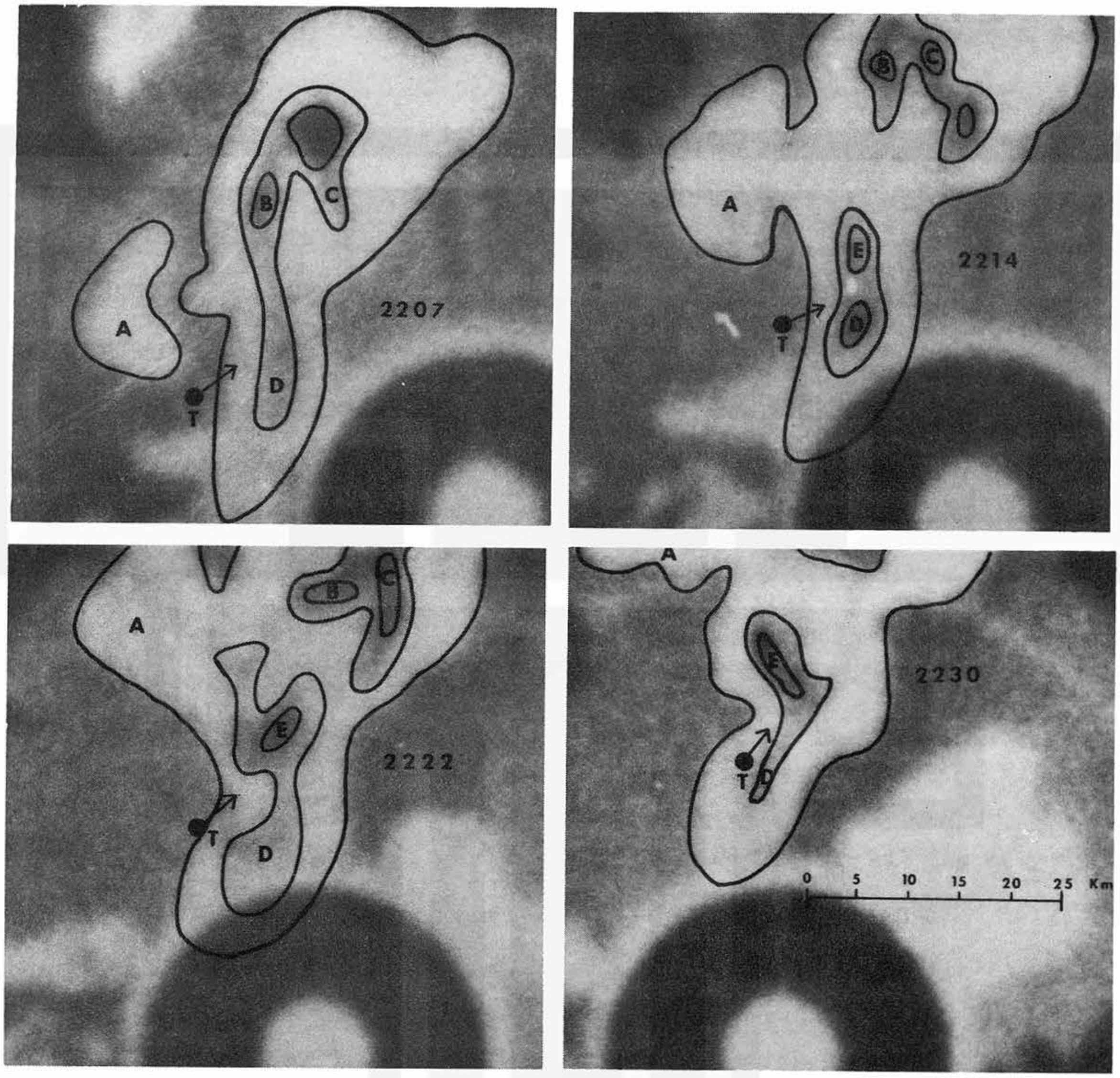

Fig. 7a. Radar illustration depicting echo appearance and tornado position from 2207 through 2230 GMT. Radar used was the WSR-57M located near Monett, Mo.

The author has found from previous Learjet experience, as well as from this case, that most severe storms do not have feeder clouds. This event appears to set aside some tornado-producing systems from those storms not producing tornadoes. Although this may not be true in every case, it certainly should be a feature to be studied, especially with F 2 or stronger tornadoes.

The tornado at 2207 and 2214 GMT is outside of the precipitation area and

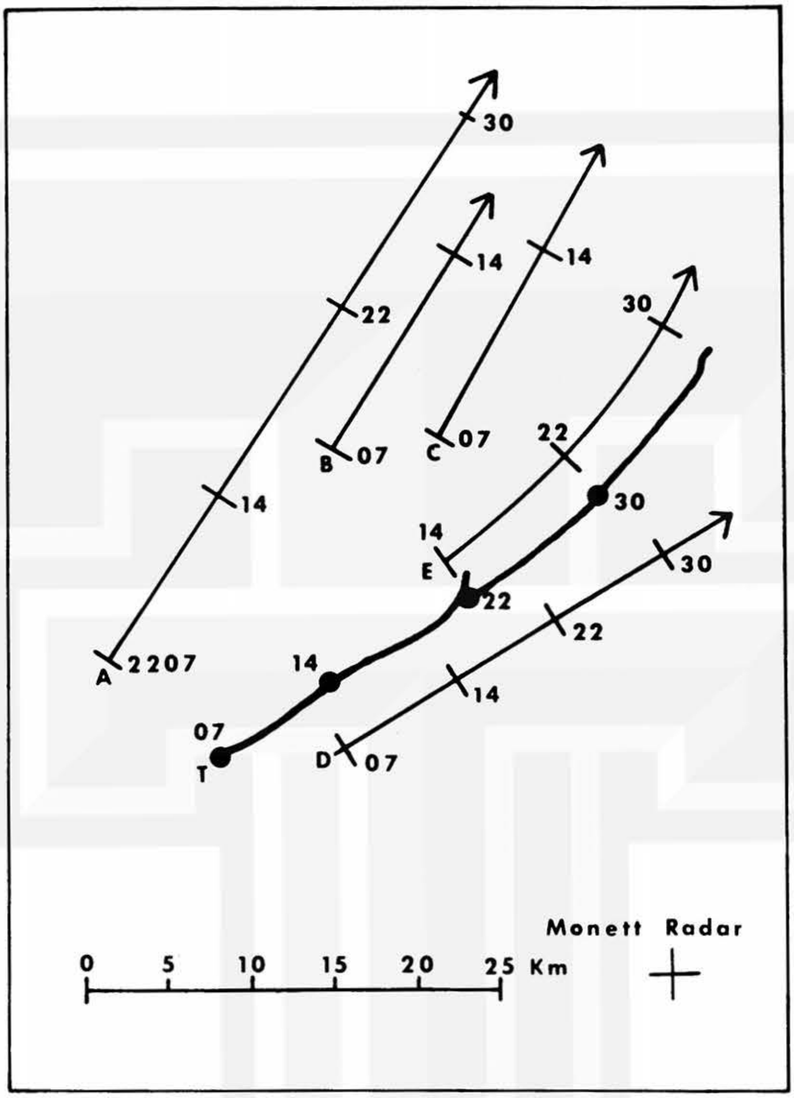

Fig. 7b. Motion of individual intense echo regions. Mesocyclone moved to the right.

therefore the tornado is understandably visible to ground-based observers. By 2230 the tornado is embedded in the precipitation echo. People indicated that as the tornado approached Miller at 2237 they had no warning due to the visual obstruction by precipitation. Furthermore, the tornado passed through in a shield of precipitation. There is sufficient evidence by radar that this was the situation as a strong radar echo surrounded the forward half relative to the tornado's movement.

6. SUMMARY AND CONCLUSIONS

The analysis of the parent storm that produced two of the three southwest Missouri tornadoes required the use of satellite, radar, and Learjet photos to clearly define both the position and character of the storm. The satellite identified the overshooting top at 2237 GMT even though the aircraft photographs did not easily show this characteristic. The radar was extremely useful in the initial stages of identifying individual storms and also in detecting the mesoscale feature associated with the tornadoes. The aircraft photographs followed the entire feeder cloud development and merger. This was easily seen in a movie loop produced from the still photographs. These photographs were also an excellent means of interpreting the satellite and radar images. A schematic model of the mesocyclone and tornado relationship is shown in Fig. 8.

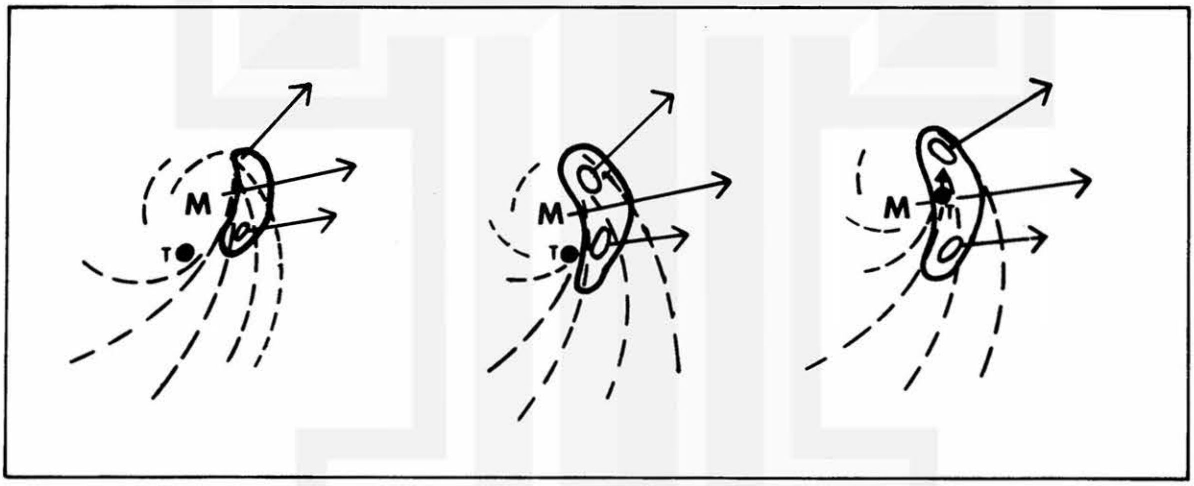

Fig. 8. A schematic model of mesocyclone, echo motion and tornado.

The mesocyclone in this case is the most important element of this tornado-producing thunderstorm. The feeder cloud merges at the time of and south of the position of the initial stage of the Miller tornado where there is strong convergence. The parent thunderstorm is located in this strong convergence area on the eastern side of the mesocyclone. Furthermore, the southern portion of the storm moved 30-deg to the right of the storm. The tornado first occurred west of the 10 db echo and gradually moved into the precipitation area before dissipating.

It is possible that in some cases the feeder cloud and the parent thunderstorm work in unison to produce a tornado, and in particular types of storms a hook echo may be the manifestation of their interaction. In other words, the precipitation-related outflow from the parent storm and the updraft in the feeder cloud draw precipitation from the parent storm and leave a hook-like appearance on radar. There will not be a hook if there is only an interplay between non-precipitating outflow and the updraft. Therefore, the possibility exists of a weak or moderate tornado occurring in a region that would be nearly echo free. If the feeder cloud suspends precipitation-sized droplets in the updraft, there may be an individual echo as though there is a cell outside of the parent thunderstorm. Finally, if the cell merges entirely with the parent thunderstorm one may not detect the potential for tornado development at all, although a contoured or Doppler radar would likely show evidence of the circulation.

The dense cirrus canopy of early spring outbreaks makes the use of a variety of satellite sensors difficult. There are a few visible characteristics that should continue to be closely studied. These include the overshooting tops, intersecting lines of storms, arc clouds, and feeder clouds. The use of satellite and radar together appears to be the best method for forecasting and at the present state-of-the-art for analyzing individual cases as well. Perhaps, with further developments, both for satellite and radar one will be able to pinpoint where tornadoes will occur with a far greater accuracy than is now presently possible. Through future studies of the mesocyclone and feeder cloud phenomena on the upwind side of tornado-producing thunderstorms as well as the environmental conditions in and near the thunderstorm, one may find the answers and be able to put the results to use operationally.

ACKNOWLEDGEMENT

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