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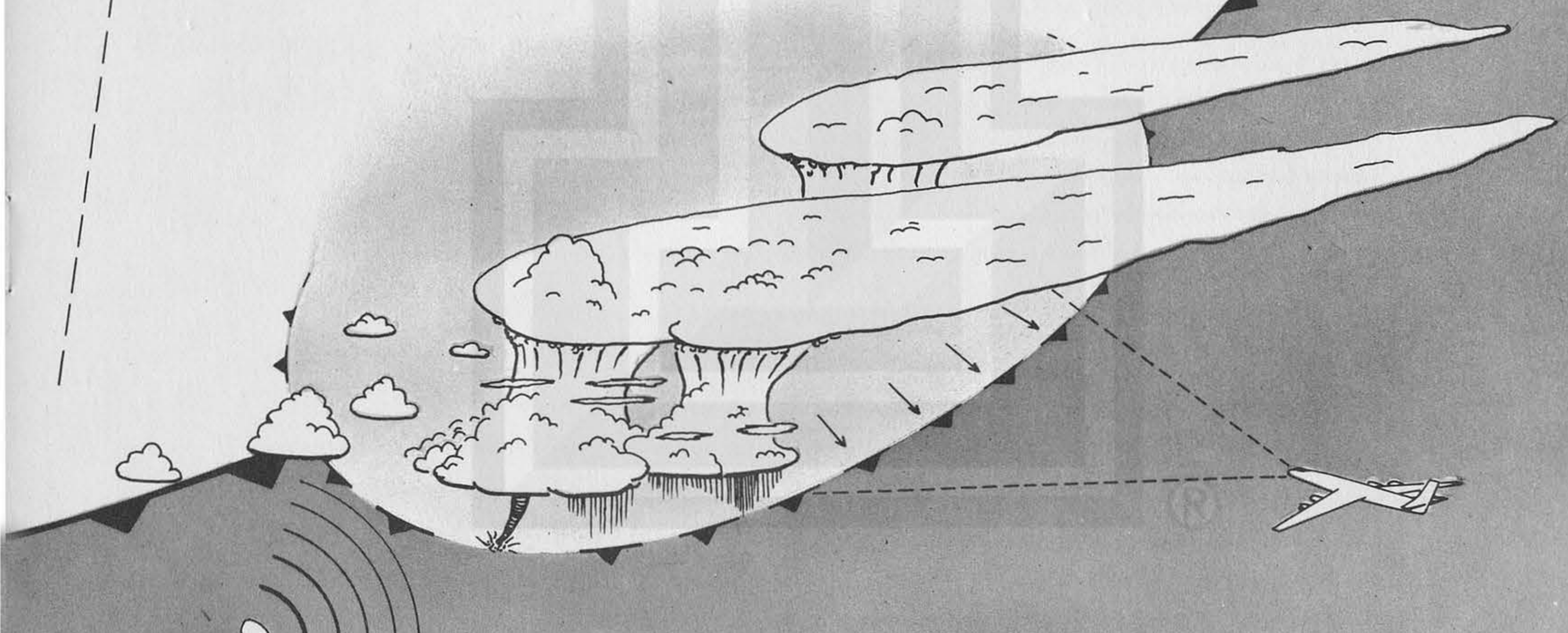
SATELLITE & MESOMETEOROLOGY RESEARCH PROJECT

Department of the Geophysical Sciences
The University of Chicago

CHARACTERISTICS OF ANVIL-TOP ASSOCIATED WITH THE POPLAR BLUFF TORNADO OF MAY 7, 1973

Edward W. Pearl



SMRP Research Paper 119
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CHARACTERISTICS OF ANVIL-TOP ASSOCIATED WITH THE POPLAR BLUFF TORNADO OF MAY 7, 1973

by

Edward W. Pearl
Department of the Geophysical Sciences
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ABSTRACT

Investigation of potential tornado-producing thunderstorms was performed during part of the 1972 and 1973 tornado seasons. Participants for the May 7, 1973 mission included William E. Shenk of NASA and T. Theodore Fujita and the author of the University of Chicago. On this date twenty-one tornadoes were confirmed over southern Missouri, northern Arkansas, and southwestern Illinois. The region was surveyed by high altitude photography performed on a Learjet over the region of reported tornadoes.

Each of the two storms in this report were chosen from aircraft observation with the guidance of ground and radar reports. A series of photographs were taken of a tornado producing cloud. An analysis of the activity before and during the tornado is made. Most noteworthy were changes detected in the growth and collapse of overshooting domes above the anvil. Suggestions are included for a comprehensive study.

1. INTRODUCTION

Inferences have been made as to the thunderstorm characteristics which signify tornadic activity. In the early sixties Fujita (1962) discussed a possibility that a 45-minute interval existed between consecutive tornado touchdowns. Darkow (1971) further supported this concept by his study on long-lived parent thunderstorms. Once again the periodicity was found to exist.

Research was performed to recognize elements of the thunderstorm that may cause such an effect. Bonner and Kemper (1971) showed that in the central U.S. there was a significant dependence of hail production with the height of the echo top and yet little dependence was found in relation to tornadoes. Fujita (1972) discovered the relationship that tornadoes may be occurring during the pausing or declining stage of the cloud top.

The motion of the overshooting top of a thunderstorm was analyzed by Newton (1963). The overshooting dome or turret (Fujita 1974) travels into an area with a stable lapse rate and hence will collapse back into the cloud. Newton computed that if the overshooting top were to reach 1500 m then a downdraft velocity of 30 m sec^{-1} could be obtained at the anvil level.

Many of the overshooting domes were greater in size than one kilometer. On previous flights, including the one of May 7, it has not been uncommon to find domes greater than several miles in diameter. Individual turrets usually compose the dome structure. Battan and Theiss (1969) suggest that the most common eddy sizes are in the order of one kilometer. These turrets approach the Brunt-Vaisalla frequency of oscillation as described by Fujita (1974). When many of these turrets are close together and form the dome structure it appears as though the environment may be disturbed. Evidence to that effect has been found by the extreme cold near the anvil tops.

The flights of the past two years have been directed to understanding the cloud-top motions. It has been found that in order to get an accurate correlation between cloud-top activity and surface phenomena one must include a damage-truth survey and on-time observations at the cloud base. Hopefully, this will be included in future flights.

Hair-like clouds have been observed on some of the previous flights. Further research may find the cause and the relation of this type of cloud element to the rest of the thunderstorm.

2. INVESTIGATION OF DOMES OF SEVERE STORMS

A detailed discussion will be given here of a rather small, tornado-producing thunderstorm with an oscillating top. This cell also indicated inflow by bands of stratocumulus curved counterclockwise into the base of the cumulonimbus. The discussion would not be complete if it were not also mentioned that on the same day another anvil was photographed. In this case only a widespread, slowly changing overshooting top was observed.

May 7 began with thunderstorms scattered from Louisiana and Mississippi to Iowa and Illinois. The storms were along and ahead of a weak surface cold front. The mission began at San Antonio, Texas. At first, we were not sure of the location for the most severe activity. After observing the thunderstorms over Louisiana and Mississippi, the decision was made to move northward. We positioned the aircraft in an area covering northern Arkansas and southern Missouri. The choice was excellent since there were twenty-one tornadoes confirmed in this area and a portion of southwestern Illinois.

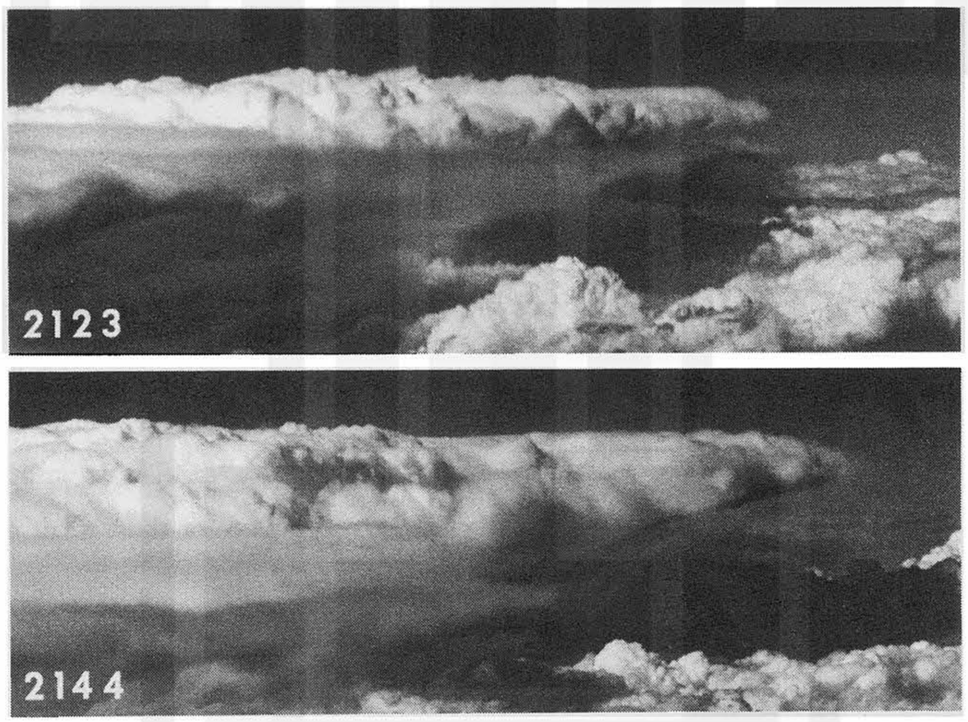

Fig. 1. Large dome showing little change in a twenty-one minute period. First flight of May 7, 1973.

The weak, widespread overshooting thunderstorm was approached on this first of two flights. We continuously photographed the cell for a fifty minute period. It became obvious that there was little variance in the amount or height of the overshooting dome above what could be considered the anvil surface. One may question whether or not the entire dome may be considered a raised anvil top. Our position relative to the cloud changed considerably throughout the flight. Figure 1 shows this cell twenty-one minutes apart. The first photograph was taken at 2123 Z and the second at 2144 Z, indicating little change.

The pictures indicated a massive overshooting dome. The individual turrets, see Fujita (1974), indicated up and down motions but the dome as a whole varied only slightly. A cloud of this magnitude would likely be seen from present day satellites, however it would probably be difficult to distinguish the actual anvil from the dome.

It was interesting that there were not any confirmed tornadoes with this cell. We are, of course, basing this on the state-of-the-art of the present Storm Data publication. A survey of the sight would have been desirable to confirm such a report.

James Purdom was located at NSSFC in Kansas City for the purpose of supplying the valuable up-to-the-minute forecasts. Utilizing ATS photographs and ground based reports, he emphasized the necessity for the second flight. He informed the research team of several unconfirmed reports of tornadoes. Therefore, although it was late in the day and the photographic mission would be limited, it was decided to go forward with the second flight.

Shortly after takeoff for the second flight for May 7, the author and the other researchers observed a few cells surrounded by a clear, almost cloud-free area. One of the cells in particular indicated a pulsating growth and collapse of a small dome at the top of the anvil. The author was aware that bands of stratocumulus clouds were curved in a counterclockwise manner into the base of the storm as in figure 2.

The photography commenced shortly after 2326 Z and continued for several minute intervals until 0015 Z or about forty-nine minutes later. There were a number of times when no pictures were taken due to the difficult maneuvers that were necessary in order to photograph. A position close to the cloud was disturbed by

Fig. 2. Indication of cyclonic flow seen as bands of stratocumuli move toward base.

the anvil of a nearby thunderstorm. The last fifteen minutes were used in a maneuver to fly over the cell in order to obtain a good view of the rear edge of the anvil.

3. CORRELATION OF DOME OSCILLATION WITH SURFACE DAMAGE

The tornado-producing cell indicated that the maximum heights of the overshooting dome occurred at approximately 232945, 233830, and at 234300. The dome at 232945 is shown in figure 3. After the last significant overshooting dome of 234300 there was a gradual collapse and the top became much less active as shown in figure 4. The author discovered later that during the slow cessation of overshooting activity a tornado was spawned by this thunderstorm. The tornado was confirmed in Storm Data. It was described as originating at Poplar Bluff at 2350 Z and continuing in a skipping path for fifty miles northeastward. The tornado was intense enough to designate the damage as F 3 according to the Fujita scale (Fujita 1971).

The oscillation of the dome could only be described in scalar quantities as used in figure 5. The reason for the scalar value is due to the great variation of distance and especially in the height of the aircraft in relation to the anvil top. The

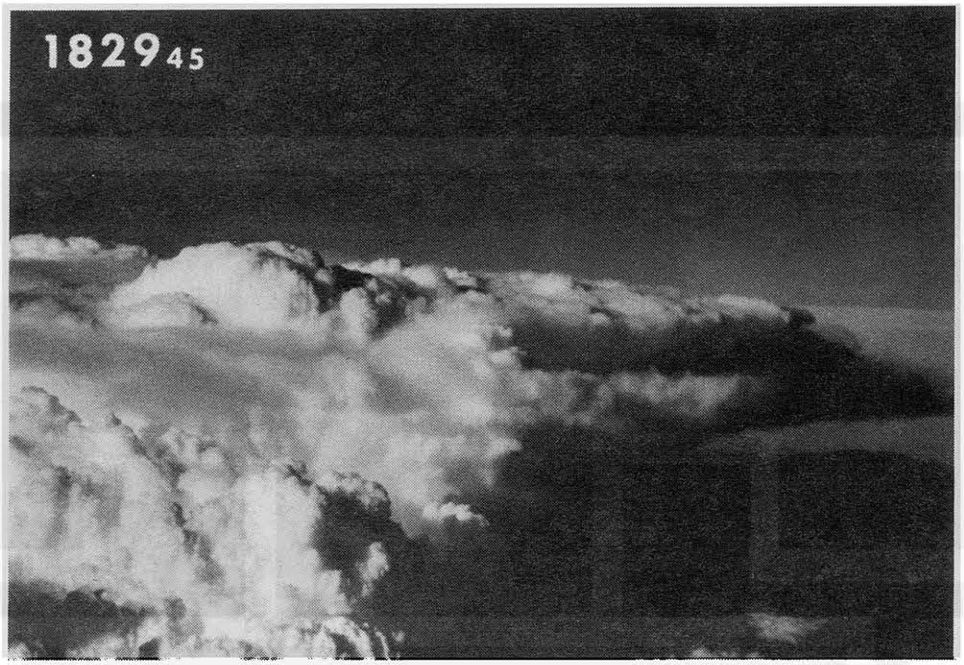

Fig. 3. Maximum dome height is reached.

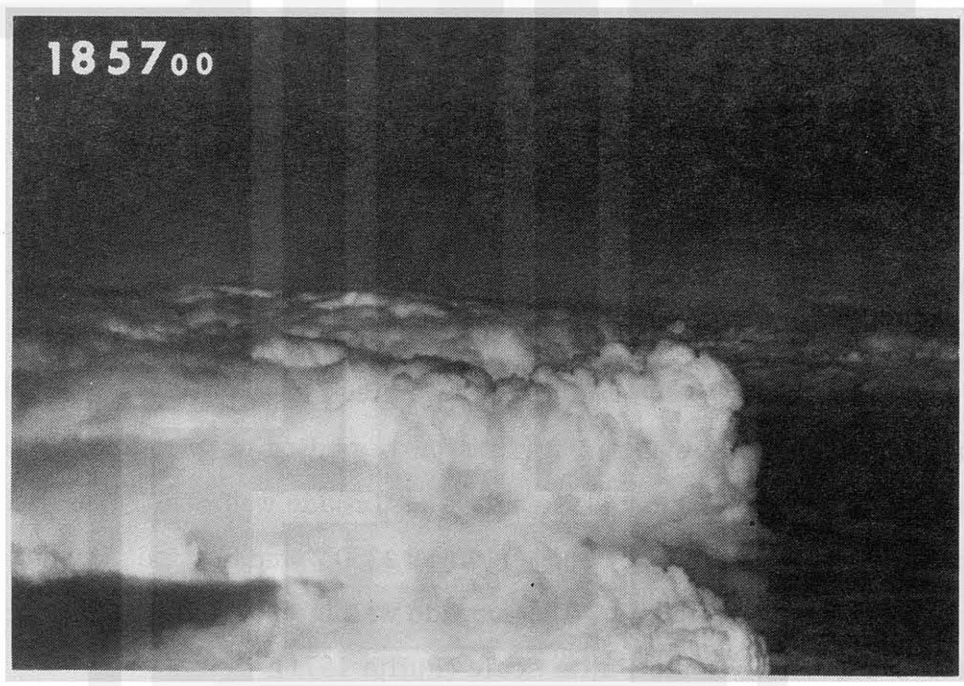

Fig. 4. Activity subsides as tornado is produced.

scale was made such that O indicates the anvil itself; 5, the greatest height reached by one of the domes; and every other value between is a proportionate amount. In other words, if a value of one were given then the dome would be one-fifth of the height of the highest dome observed on this flight. A negative value was given when a dome dropped below the anvil top. We were able to verify this since our altitude was such that the surface of the anvil was observable; however, the amount of departure below the anvil was unknown.

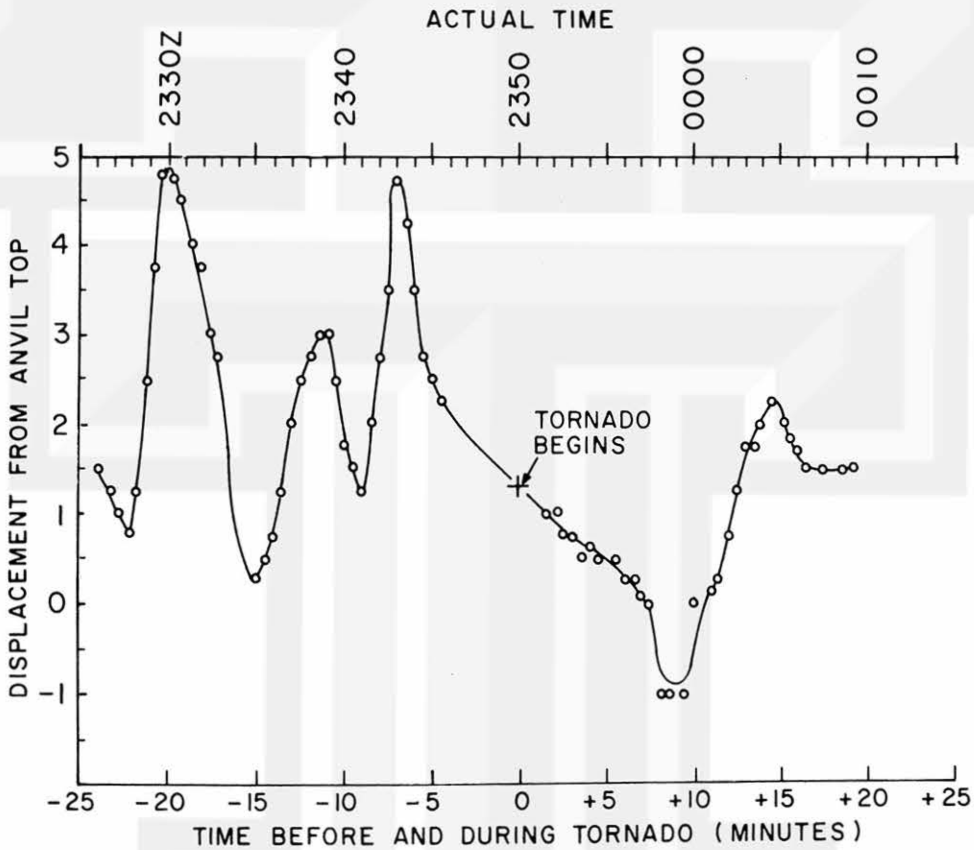

Fig. 5. Oscillation of dome as a function of time.

Figure 5 shows the change in height of the dome as a function of time. There were three periods of overshooting prior to the tornado. It is evident that the tornado began during a quieting of the overshooting activity. Shortly after the tornado began the dome actually dropped below the anvil top. Only a small oscillation with a maximum value slightly over two was observed over fourteen minutes after the tornado began.

4. SIGNIFICANCE OF RADAR ECHOES

Radar indicated that the cells investigated by the Learjet team had significantly smaller echoes than a large group of cells located about twenty-five miles to the east. The crew of the Learjet were aware of these cells and one is clearly visible during one pass at 2356 Z as shown in figure 6. Strangely enough, these larger cells did not produce any tornadoes during the time of our flight.

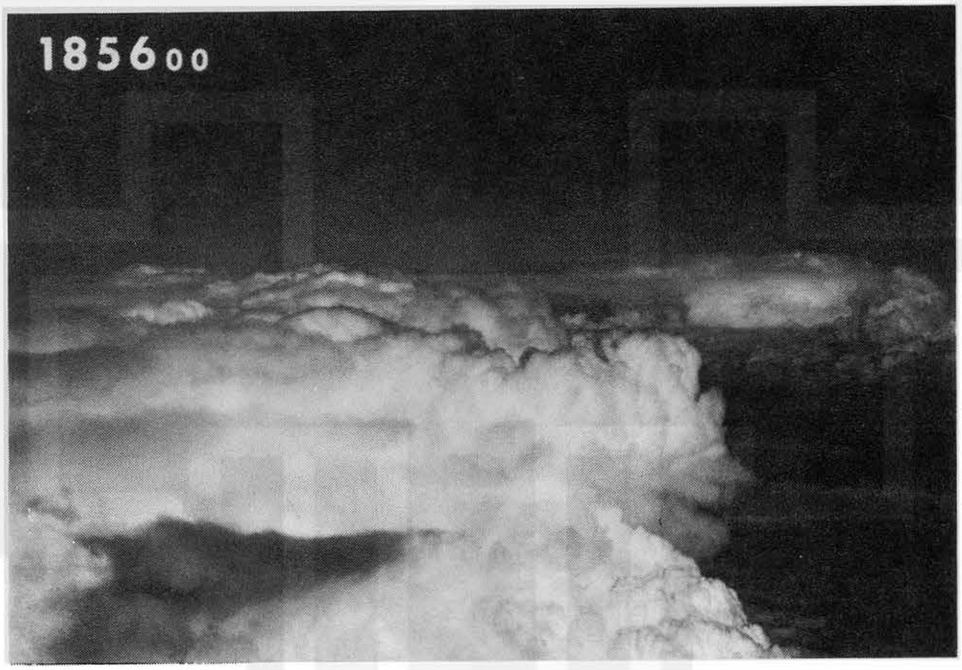

Fig. 6. Larger storm seen twenty-five miles to the east.

The tornado-producing echo was not easily identified on radar. The echoes, unfortunately, were almost at the limits of three radar stations in the area: Little Rock (LIT), Memphis (NQA), and St. Louis (STL). Therefore, there was some difficulty due to attenuation and height of the radar beam. Further problems were encountered, not the least of which was a broken timer on the St. Louis radar. The Memphis radar indicated a much greater definition of the echoes and especially of the echo producing the tornado.

The echoes at 2350 Z are shown in figure 7 along with the flight track of the Learjet covering the entire period of photography. Central Daylight Time in five minute intervals was used on the flight path.

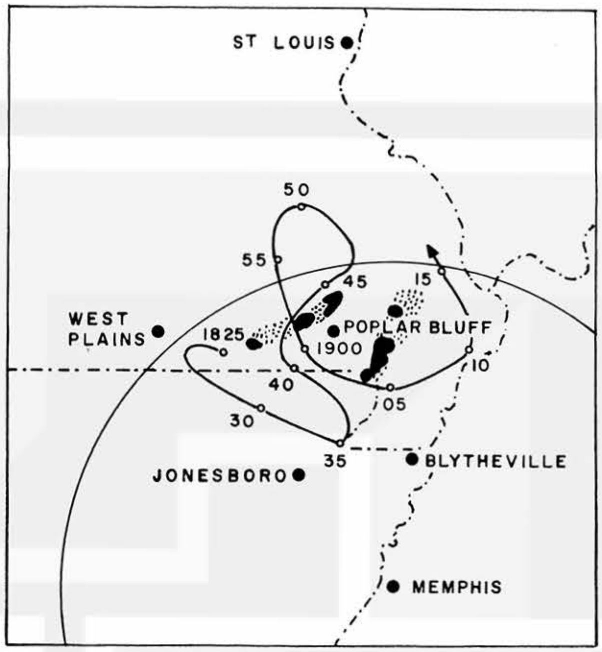

Fig. 7. Track of Learjet and echo location at 2350 Z (1850 CDT).

5. FLIGHT TRACK IN RELATION TO THUNDERSTORMS

The flight track in the last figure shows that the Learjet was not in a good position for photography all of the time. Although the flight was very successful there is room for improvement in the future.

The flight path close to a thunderstorm may obscure interesting large scale details of a thunderstorm. It is possible to determine that turret motion approaches the Brunt-Vaisalla frequency at a close distance (Fujita 1974). Although of interest scientifically, the fact may be impractical from a standpoint of satellite photography applications.

There is a likelihood that we were too close to the tornado-producing cell. Fortunately, we were able to observe the dome of the tornado-producing thunderstorm. Still it would have been desirable to have seen the relation of this cell to the others in the vicinity. Secondly, when studying the radar film, many problems are eliminated if a one-to-one relation can be easily found between the echo and the observed storms. Also, at a greater distance the researchers could have observed more than one cell at a time and thereby increase the probability of observing a tornado-producing thunderstorm.

The author and the other researchers have decided that a greater distance is needed for applicability towards the future satellite programs. It is the author's opinion that a distance slightly greater than 100 nautical miles would be appropriate depending on the atmospheric conditions. At a greater distance from the cloud the aircraft would not likely be in the vicinity of other severe storms. Therefore difficult maneuvers with the aircraft could be avoided. The maneuvers that were required during the May 7 flight caused periods of time where no photographs were taken. The continuity is therefore somewhat disturbed.

6. CONCLUSIONS AND SUGGESTIONS

The storm discussed in this report is the first tornado-producing one that was photographed before and during a tornado by the use of a Learjet. There may be great significance in the fact that the top of the storm showed a decrease in activity associated with the production of the tornado. Further evidence must be gathered before any final conclusions can be made.

Fujita (1974) points out that there appears to be a relation between the vertical mass transport and the spreading rate of the anvil. Purdom (1971) indicated that it is when the spreading rate slows or temporarily stops that tornadoes often occur. It could be deduced that when the vertical transport of mass slows or comes to a halt the chance of a tornado increases.

Figure 8 shows the last picture taken of the cell. There is a definite anvil overhang on the upwind side close to where the overshooting is taking place. Fujita (1974) describes the likelihood of a meso-high structure at the top of the anvil with overshooting domes. The high induces a modification in the tropopause and an outflow of cold air spreads outward from the vicinity of the cold dome.

Damage-truth surveys and on-time observations should be run in order to augment the results in the future. Storm Data cannot possibly verify every tornado that occurs. For instance, if there is a sparse population in a particular area, the tornado may go completely undetected. A detailed investigation could be accomplished by the use of Cessna aircraft and automobiles. Also, similar vehicles could be used to photograph or at least record any peculiar activity at the base of the storm.

Fig. 8. Anvil lip shown on upwind side.

Further research concerning the relation between a cessation of overshooting activity and tornado production is needed. Forecasting of tornadoes with the present skill of the Learjet aircraft or future use of satellite photography depends on the determination of a one-to-one relation between what occurs at the anvil top to what is occurring at the base of the cloud.

All flights performed should have guidance as to where the most severe activity is to occur. Radar, as shown in this paper, may not be enough for proper directives. It is a combination of surface and aircraft observations as well as an analysis of current ATS photographs that would lead to a smoothly controlled project.

A greater distance between the storm and the Learjet has been found to be necessary. The enlarged field of view enhances the possibility of photographing a tornado-producing thunderstorm. Therefore the large details of tornado-producing storms should be visible.

Acknowledgements:

The Learjet mission could not have been successfully completed without the full cooperation of those involved: Mr. James Purdom who prepared the forecasts for and aided in the guidance of the aircraft through the use of the facilities at NSSFC in Kansas City; Messrs. Vincent J. Oliver and Edward Ferguson who gave helpful advice when it was most needed; the pilot, Clyde Alber, and the co-pilot, Ray Miller, who carefully took the aircraft wherever and whenever they were asked; the researchers, William E. Shenk of NASA and T. Theodore Fujita from the University of Chicago who jointly worked with the author.

Special additional commendation should be given to the pilot and co-pilot for their careful notetaking which allowed us to reconstruct our flight track.

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