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RELATIONSHIP BETWEEN TORNADOES AND HOOK ECHOES ON APRIL 3, 1974

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1. INTRODUCTION

One of the largest tornado outbreaks in history occurred on April 3, 1974. Following the outbreak, an intensive damage survey (Fujita, 1975b) confirmed the occurrence of 148 tornadoes. Even more important, the survey brought attention to the periodic production of tornadoes by a thunderstorm, creating a tornado family. It also revealed an occurrence of tornado families whose tornadoes consistently made left or right turns.

Because the damage survey thoroughly documented the location of occurrence of the tornadoes, the opportunity arose to accurately relate thunderstorm features to the tornado life cycle. This paper summarizes three areas of study on this problem: (1) Echo shape is studied as an indicator of the probability of tornado occurrence. (2) Systematic differences in echo movement exist between tornadic and non-tornadic echoes. (3) Thunderstorm-scale features may result in the formation of left- or right-turn tornado families.

2. ECHO SHAPE AS A TORNADO INDICATOR

During the afternoon and early evening on April 3, tornadoes occurred in an area well covered by radar. The sample used to study echo shape included the following radars while they were operating in the 125 n. mi. mode: Marseilles, IL (MMO); Evansville, IN (EVV); Detroit, MI (DTW); Cincinnati, OH (CVG); Nashville, TN (BNA); Athens, GA (AHN); Centreville, AL (CKL); Jackson, MS (JAN). The radar at Champaign, IL (CMI) was also included.

Echoes whose shapes were studied as tornado indicators were defined as "distinctive" echoes. Distinctive echoes included "hook-like" echoes and "spiral" echoes. Since true figure-six hook echoes are only seen at short range, most echoes did not exhibit true hook echoes. Many echoes had appendages on the southwest flank, however. These echoes were called "hook-like" when the orientation of the appendage was at least 40 degrees to the south of the echo movement (i.e., orientation toward 200 degrees or less). Echoes showing rotation, accompanied by a spiral-like distortion in the pattern of nearby echoes, were called "spiral" echoes.

Figure 1 shows the tracks of the distinctive echoes occurring in the sample area. The sample area is outlined. In most cases distinctive echoes could not be distinguished at ranges larger than 100 n. mi. Tornadic and non-tornadic echo paths are shown.

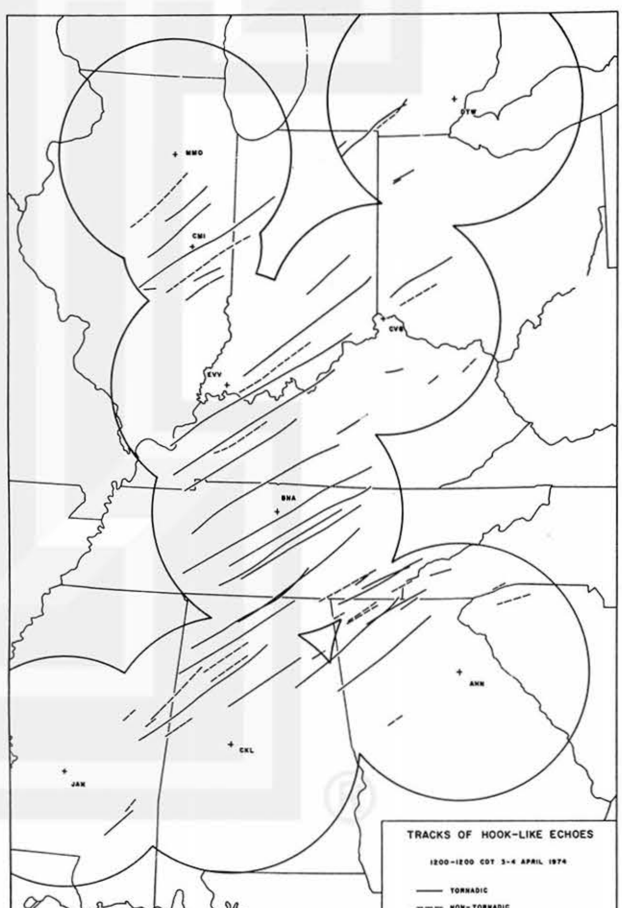

Fig. 1. Paths of distinctive echoes. (See text for definition of distinctive echoes.)

Table 1 summarizes the distinctive echoes of Fig. 1. Of the 60 distinctive echoes, 62% produced at least one tornado.

Not all of the 148 tornadoes were included in the sample area. Tornadoes occurring outside the sample area, and those occurring while echoes were undetectable due to inoperational radars, were excluded from the statistics. Table 2 shows that the sample included 93 tornadoes. 81% of these were produced by distinctive echoes. It is clear that some echoes produced several tornadoes.

Table 3 relates tornado intensity (in terms of Fujita-scale, Fujita and Pearson, 1973) to distinctive echo occurrence. It is of interest to note that tornadoes produced from distinctive echoes were stronger than those from other echoes. Very few weak tornadoes were produced by distinctive echoes. In fact, because many distinctive echoes produced tornado families, every tornadic distinctive echo produced a tornado of scale F 1 or higher. All of the F 4 and F 5 tornadoes in the sample were produced by distinctive echoes.

Hook-like echoes	58	
Spiral echoes	2	
Total, distinctive echoes	60	
Tornadic	37	62%
Non-tornadic	23	38%

Table 1. Characterization of "distinctive echoes".

Tornadoes produced by distinctive echoes	75	81%
" " " other echoes	18	19%
Number of tornadoes in sample	93	

Table 2. Classification of tornado origin.

-Percentage of tornadoes produced by distinctive echoes-		
F 0	29%	
F 1	75%	
F 2	72%	
F 3	88%	
F 4	100%	
F 5	100%	
-Probability of a distinctive echo producing a tornado-		
F 1 or greater	62%	
F 2 " "	57%	
F 3 " "	45%	
F 4 " "	30%	
F 5 " "	8%	
-Mean F-Scale of tornadoes-		
produced by distinctive echoes	F 3	(172 mph)
" " other echoes	F 1	(109 mph)

Table 3. Distinctive echoes and tornado intensity.

This study reveals very important statistics on hook-like echoes. It indicates that (1) a majority of hook-like echoes produce tornadoes; (2) hook-like echoes are often associated with tornado families; (3) tornadoes from hook-like echoes tend to be stronger than those from other echoes. It must be remembered that these absolute statistics are for one unusual day. It is difficult to infer the generality of the statistics except in a qualitative sense.

The generality of the probabilities in Table 3 is particularly in doubt. The mean F-scale of the tornadoes in the sample was a weak F 3. Based upon Fujita and Pearson (1973), the mean F-scale of all tornadoes for the years 1965, 1971, and 1972 was F 1. Only 8% of those tornadoes reached F 3 or stronger. Since the probability of producing the mean tornado on April 3 was 45%, it may be more appropriate to infer that, in general, with mean tornadoes having intensity F 1, the probability of a distinctive echo producing a tornado of intensity F 1 or higher is about 45%.

In terms of real-time forecasting of tornadoes based upon hook-echoes, the statistics were inconclusive. The hook-like echo usually appeared before the first tornado formed, but could appear up to 48 minutes after or even 126 minutes before the first touchdown. As shown in Fig. 2, the variance was large, even though the mean appearance time was 25 minutes before the first tornado.

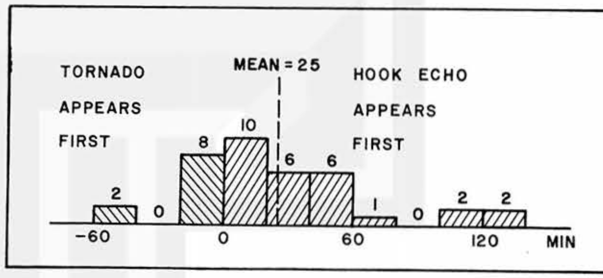

Fig. 2. Time interval between appearance of hook-like echo and first tornado touchdown. Negative values mean that the tornado occurred before appearance of a hook-like echo. Based upon the echoes of Fig. 1.

3. ECHO MOVEMENT AND TORNADO OCCURRENCE

The outbreak was interesting in that tornadic echoes tended to be relatively isolated large cells, or at least distinct hook-like cells within a line of echoes. Figures 3 and 4 are radar composites for 2200 GMT and 0000 GMT on the evening of April 3. Tornadic echoes are stippled.

In Fig. 4, it can be seen that from Alabama to Kentucky the tornadic cells are in advance of the ordinary squall line. Fujita (1975c) has named this a "tornado line". The tornado line originated from a squall line, becoming separated from it due to differential echo movement. The separation process is beginning in Fig. 3.

Figure 5 shows the differential echo movement involved in forming the tornado line. The large rotating tornadic echoes seen on Nashville radar moved from 240 degrees at 49kt while the other echoes moved from 227 degrees at 62 kt. The right-moving thunderstorms were thus able to move ahead of the squall line, forming a tornado line.

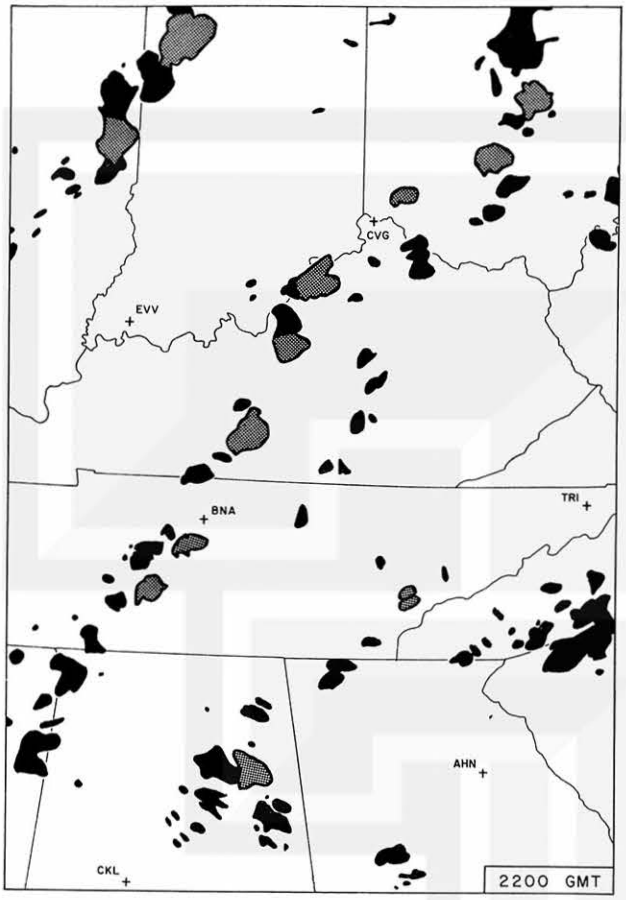

Fig. 3. Radar composite for 2200 GMT, April 3, 1974.

Figure 6 shows three hook-like echoes in the squall line at 2000 GMT, before formation of the tornado line. The echoes are aligned so that the weak echo regions (WER) of echoes A and C are in advance of the WER of echo B. It appears that this orientation favored development of echoes A and C into tornadic echoes. The large-scale surface flow shown by an arrow was apparently impeded from reaching echo B because of the position of echo C. Echo B lost its hook-like appearance and weakened. Echo A later produced the Louisville tornado family. Echo C later produced the Elizabethtown tornado family.

4. RADAR STUDIES OF TORNADO FAMILIES

It has been seen that some thunderstorms tend to periodically produce tornadoes, forming a tornado family. Some light has been shed on determining which echoes are likely to produce tornadoes and tornado families. It also would be helpful to understand the tornado formation process of such thunderstorms and to be able to deduce from the radar echo when the tornadoes will form.

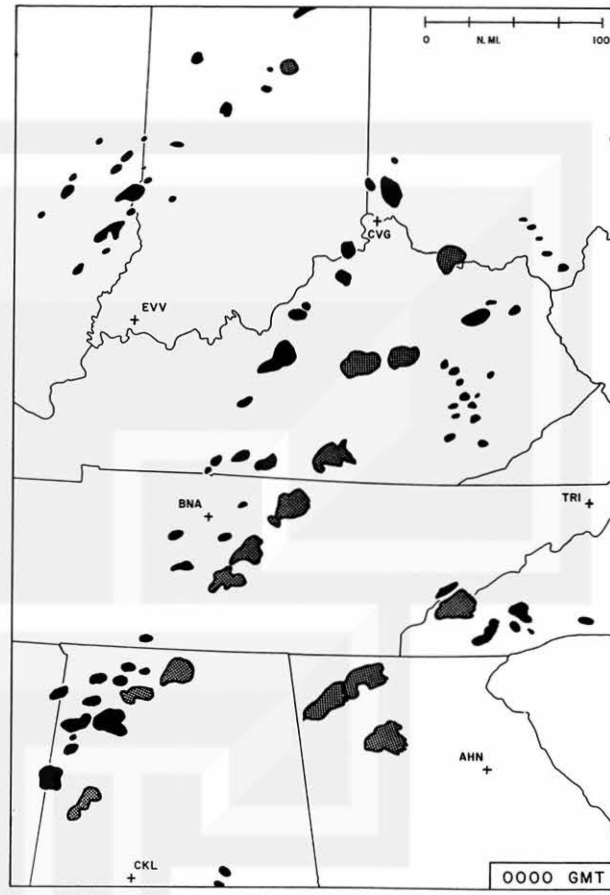

Fig. 4. Radar composite for 0000 GMT, April 4, 1974.

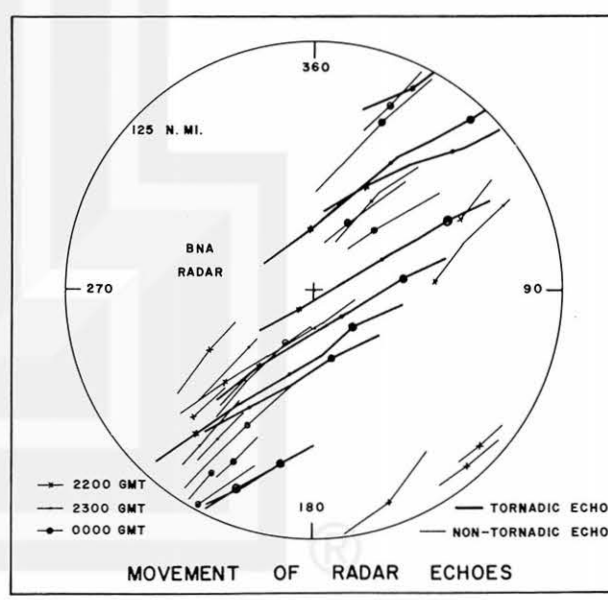

Fig. 5. Differential echo movement between tornadic and non-tornadic thunderstorms.

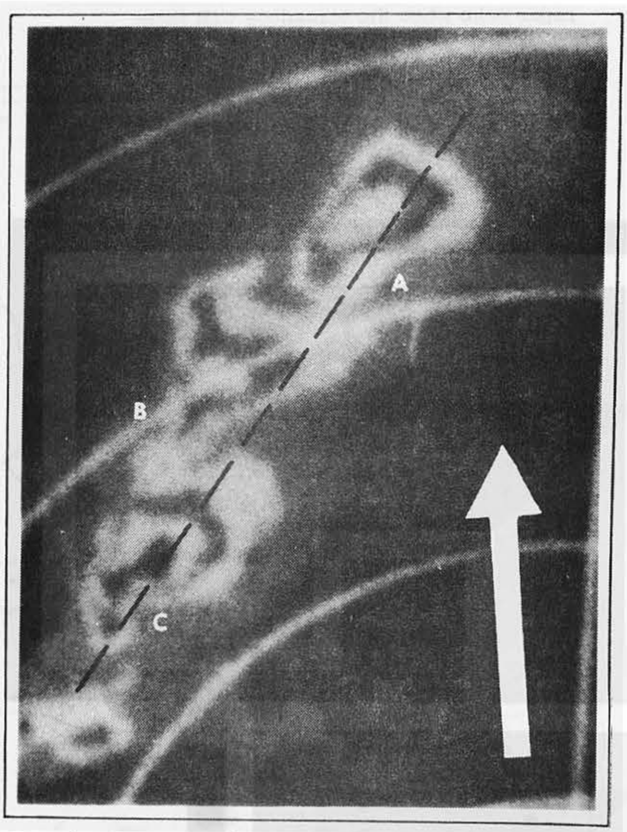

Fig. 6. Preferential echo development. Because of their position and orientation, echoes A and C were favored for development into tornadic thunderstorms.

Using Cincinnati and Nashville radar echoes, several hook-like echoes were studied. Echo area was calculated at numerous time intervals to determine if echo area underwent a periodic fluctuation. There was no indication that echo area underwent a cycle related to tornado production.

New evidence was obtained through a study of the Monticello tornado family, however. This family of eight tornadoes was interesting in several respects. As seen in Fig. 7, the family consisted of several right-turn tornadoes as well as a long no-turn tornado. Also it was associated with one of the spiral echoes mentioned previously.

It was fortunate that an important portion of the Monticello family life was documented by radar, both at Marseilles and Champaign, Illinois. Although both were 10 cm radars, the CMI radar showed more detail. The MMO radar provided coverage of the entire line of thunderstorms.

Figure 8a is a time sequence of the spiral echo using CMI radar. The hook visible at 1557 is near the center of the tornado cyclone, but tornadoes formed on the east periphery of the echo. The Homer Lake tornado is in progress at T.

At 1605 the spiral nature of the echo is seen. The curved echo to the south of the main echo mass is along the gust front. The tornadoes formed at the intersection of this front with the main echo. The Homer Lake tornado has lifted at t. The Bismarck tornado began at T at 1615 and lifted near t at 1625. At 1633 the Rainsville tornado is in progress.

By 1641 the large echo begins to break down into several portions. The easternmost portion of the echo begins to take on a more typical hook-like shape. This echo produces the Monticello tornado, beginning at t. The Rainsville tornado is about to lift at T.

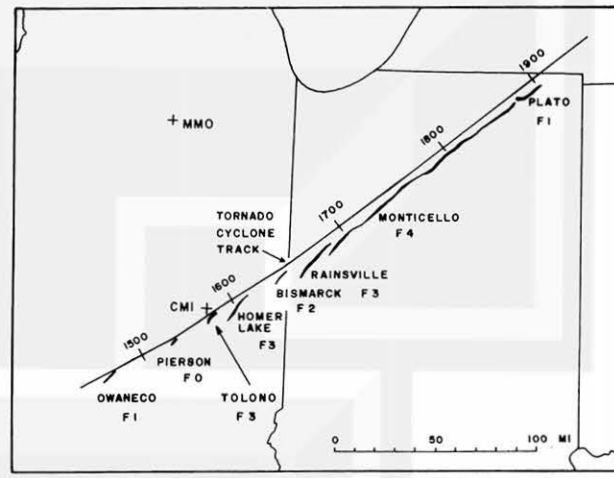

Fig. 7. Monticello tornado family. Names of individual tornadoes are given below and to the right of each track.

Figure 8b shows selected radar photos from the MMO radar. The sequence shows that the rotating echo was moving ahead of the rest of the squall line. The town of Monticello was hit approximately at 1715, with the tornado occurring along the SE edge of the spiral pattern at T.

Figure 9 is a mesoanalysis for 1557 CDT. The arrow points to the mesolow associated with the Monticello family. The gust line is evident south of the main echo. The right-turn tornado family is explained as follows. The tornadoes formed in the shear along the gust front, as proposed by Fujita (1975a). The tornadoes moved northeastward along the eastern periphery of the main echo until they encountered the outflow from the main echo. At this point the northward movement ceased and they were pushed eastward, making a right turn and dissipating. The movement relative to the main echo is shown schematically in Fig. 10. The dot indicates the tornado position at 1615, approximately at time of touchdown.

The echoes of the gust line appeared to play an important role in formation of the right-turn tornadoes. After this line weakened, at 1641, the Monticello tornado began in association with the southeast portion of the main echo. The Monticello tornado was essentially a no-turn tornado, probably remaining in a stationary position with respect to the echo.

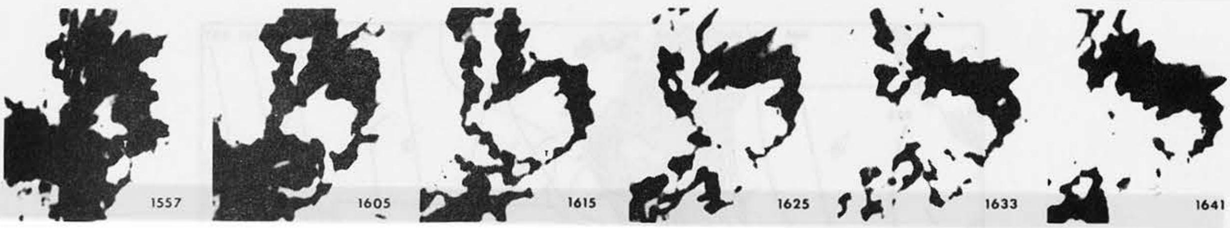

Fig. 8a. Echoes of the Monticello family, from Champaign, Illinois radar. Elevation angle was 0.4 degrees. Distance scale is given in Fig. 8b. Times are in CDT. T represents tornado location. t represents interpolated position of forming or just-dissipated tornado. Photos courtesy of Illinois State Water Survey and R. C. Srivastava, The University of Chicago.

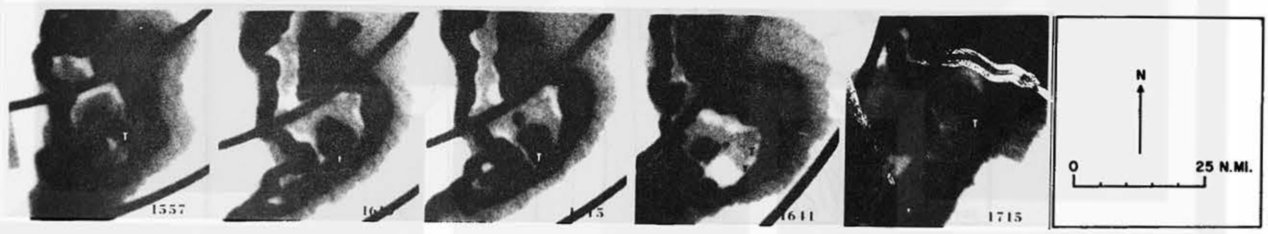

Fig. 8b. Echoes of the Monticello family, from Marseilles, Illinois radar. Elevation angle between 0.2 and 0.4 degrees.

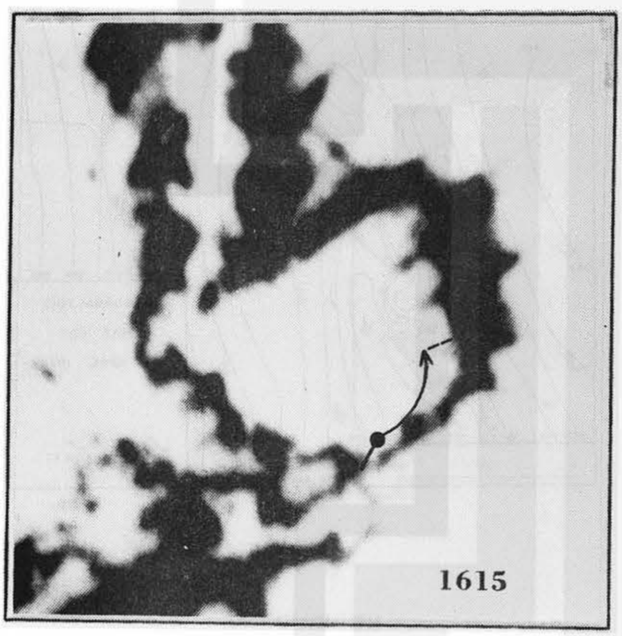

Fig. 10. Schematic representation of tornado formation, movement, and dissipation in relation to the Champaign radar echo.

It appears that the Louisville tornado, also a right-turn tornado, did not form along the gust front shear line, however. Rather it formed within the hook echo and was blown out. The mechanism for such an occurrence appears to be a pulsating downdraft. As the downdraft reaches the ground, a jet of momentum blows the tornado out of the hook to eventually dissipate and establishes a new eddy to the east. The new eddy becomes the next tornado of the family.

Research is continuing on the pulsating downdraft and the tornado family. Fujita (1975c) presents additional studies on radar and visual cloud relationships between downdrafts, hook echoes, and tornadoes.

5. SUMMARY

Statistics show that hook-like echoes are a good but not foolproof indicator of tornadic thunderstorms. Most strong tornadoes and tornado families occur with hook-like echoes. The statistics for the April 3 outbreak were impressive, but may lack generality.

On April 3, 1974, hook echoes produced 81% of the 93 tornadoes in the sample studied. 62% of the hook-like echoes produced at least one tornado. All of the F 4 and F 5 tornadoes were produced by hook-like echoes. The tornadoes produced by hook-like echoes had mean intensity F 3, while the other tornadoes had mean intensity F 1.

The tornadic hook-like echoes moved to the right of the non-tornadic echoes forming a tornado line in advance of the squall line.

The Monticello family was associated with a spiral-like echo pattern. The right-turn tornadoes formed along the gust front south of the main echo. When the echoes along the gust front weakened, the Monticello tornado formed near the main echo and apparently remained stationary in that position relative to the echo. Overall, the Monticello tornado followed a fairly straight path.

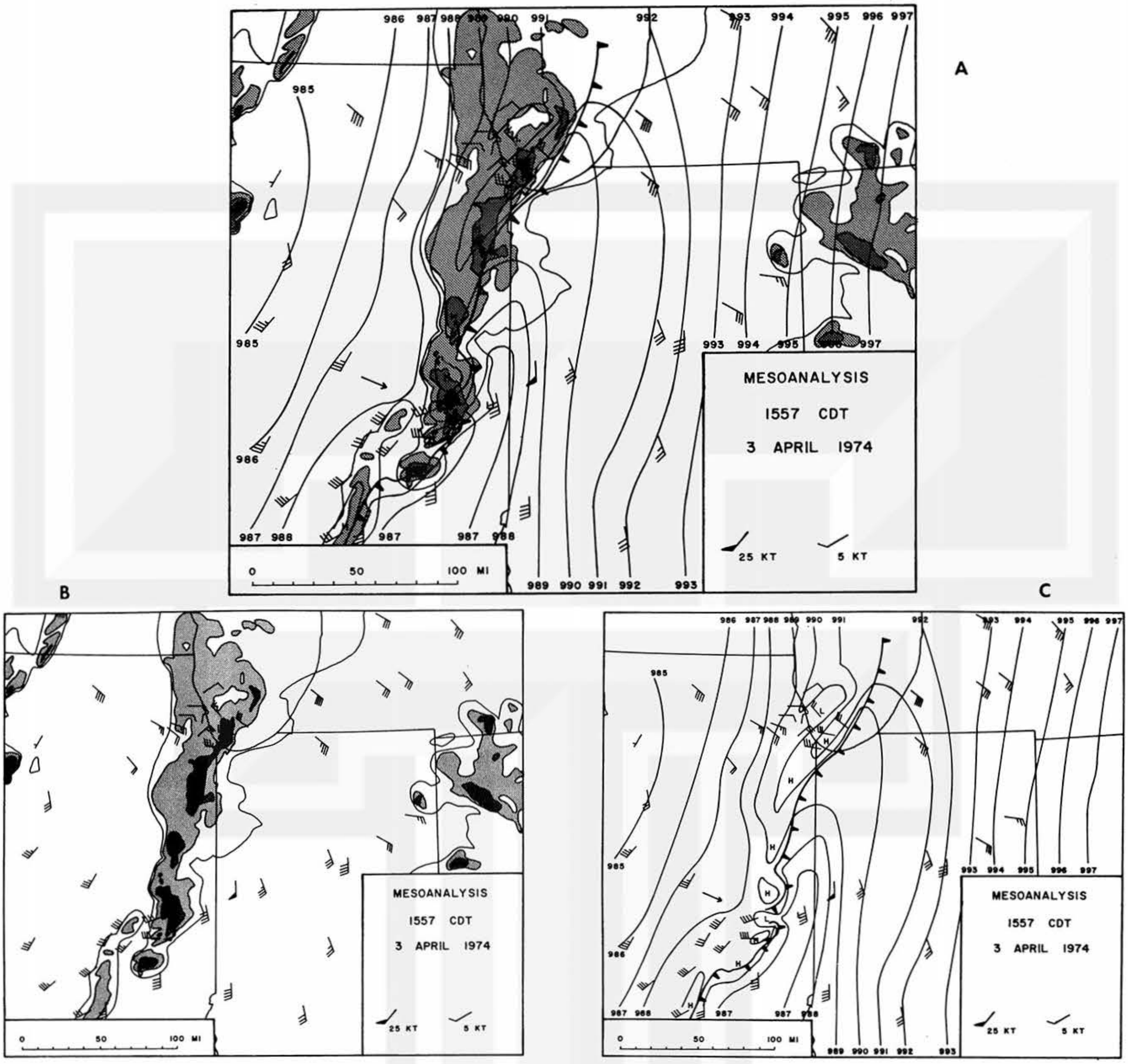

Fig. 9. Mesoanalysis for 1557 CDT, 3 April 1974. The radar composite includes four intensity levels.

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