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STATE OF ILLINOIS
William G. Stratton, Governor

STUDY OF AN ILLINOIS TORNADO USING RADAR, SYNOPTIC WEATHER AND FIELD SURVEY DATA

BY

F. A. HUFF, H. W. HISER and S. G. BIGLER

Department of Registration and Education
Vera M. Binks, Director

STATE WATER SURVEY DIVISION
A. M. BUSWELL, Chief
Urbana, Illinois

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SUMMARY

On 9 April 1953, the development, growth and movement of a tornado echo and its associated thunderstorm echo were observed on the plan-position indicator (PPI) of an AN/APS-15A, 3-cm radar as the storm crossed east-central Illinois into Indiana. The precise location of the tornado funnel which produced the surface damage was not isolated on the PPI; however, the relatively large tornado echo in which the funnel was located was plainly visible on the southwest edge of the associated thunderstorm echo. Detailed photographs of the radar scope presentation were made with a 35-mm scope camera. Employment of an automatic receiver gain control provided definition of echo intensities on the PPI.

Included in this report are: A summary of synoptic weather conditions with illustrative weather charts; a large number of selected radar photographs depicting the history of the tornado echo and its associated thunderstorm echo, with a discussion of interesting features of the echo pattern; and the results of a detailed field survey conducted along the tornado damage path through Illinois for correlation with the radar and synoptic weather data.

The report is largely historical in nature; its chief purpose is to present detailed data for use in tornado research and for the information of those engaged in radar observational programs. It is concluded that radar is capable of detecting tornadic storms under favorable conditions, and that meteorologists have a valuable tool for the investigation of causes of tornado formation.

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The work was performed under the direction of Dr. A. M. Buswell, Chief and the supervision of G. E. Stout, Head of the Meteorologic Sub-Division. The authors are indebted to Dr. H. R. Byers, Water Survey Meteorologic Consultant, for his review and his constructive comments.

INTRODUCTION

Since the advent of radar as a meteorological research and forecasting tool during World War II, there has been considerable speculation among radar meteorologists as to whether or not it would be possible for radar to detect a tornado. Due to the limited size of tornadoes which average about 250 yards in diameter[1], it has sometimes been postulated that such violent storms would occur undetected by radar, especially at long range. Even at short range it has been thought that thunderstorm activity might mask the tornadic activity, or that insufficient reflectivity from the tornado might limit the utility of radar for detection purposes. Observers of radar scopes have reported, however, that unusually large and strong echoes are present when tornado conditions develop,.

During the afternoon of 9 April 1953, the Water Survey was operating its AN/APS-15A (3-cm) radar for the routine collection of rainfall data in conjunction with a research project to determine the utility of radar for the quantitative measurement of precipitation. During the late afternoon, the development, growth, and movement of a tornado echo associated with a thunderstorm echo was observed on the radar scope and photographed in detail. This distinct tornado echo, which was observed near the southwest edge of the associated thunderstorm, contained the tornado funnel which reached the surface and caused about four million dollars damage in east-central Illinois . The actual position of the surface funnel was not visible within the tornado echo on the plan-position indicator (PPI). Although the radar operator, who incidentally was not a meteorologist, recognized the unusual nature of the PPI echo and the possibility of a tornado,, positive identification was not made at the time of the radar tracking.

To the best of the authors' knowledge, this was the first time that such a tornado echo had been observed and photographed in detail, although an interesting radar observation during a tornado situation was reported by the Air Weather Service in 1945[11]. Their set at Maxwell Field, Alabama was on the air at the time a tornado was reported in the area. A precipitation area shaped like a "6" was detected and this shape was maintained during the tornado activity. Unfortunately, radar scope photographs of the storm were not made.

Since the Illinois tornado, there have been other radar observations and photographs made of tornado echoes by several other radar research groups. Consequently, it may be concluded that radar is capable of detecting tornado situations under favorable conditions, and that meteorologists have a new tool for the investigation of the causes of tornado formation. Furthermore, the possibility exists that as more radar tornado data are collected and research progresses, it may be possible to establish radar storm warning systems in tornado areas to reduce loss of lives, and to some extent, property damage.

The purpose of this report is: (1) to present detailed data on the 9 April 1953 tornado for information and use in tornado research; and (2) to make data relevant to the appearance of tornado echoes on the radar scope available to meteorologists, in the hope that it will aid and stimulate interest in radar observational programs to gather more tornado data. Included in the report are: a summary of synoptic conditions with illustrative weather charts; a large number of radar photos showing development and movement of the tornado echo, with a discussion of interesting features; and, the results of a detailed field survey along the tornado path in Illinois for correlation with the synoptic weather data and radar data.

The report is largely historical in nature; conjectures on possible causes of tornado formation have not been included, since it is felt that the available radar data are too inconclusive for such purposes at this time. Since existing theories of tornado formation are amply covered in the literature, they are not discussed in this report.

The maps presented in figure 1 are for orientation of the reader and will be referred to in the ensuing sections of this report. The portion of the tornado damage path through Indiana was obtained from the April 1953 climatological summary for Indiana[4]. Distances throughout this report are expressed in nautical miles to correspond with the range-marker scale employed on the radar PPI, numerous photographs of which appear in the following sections.

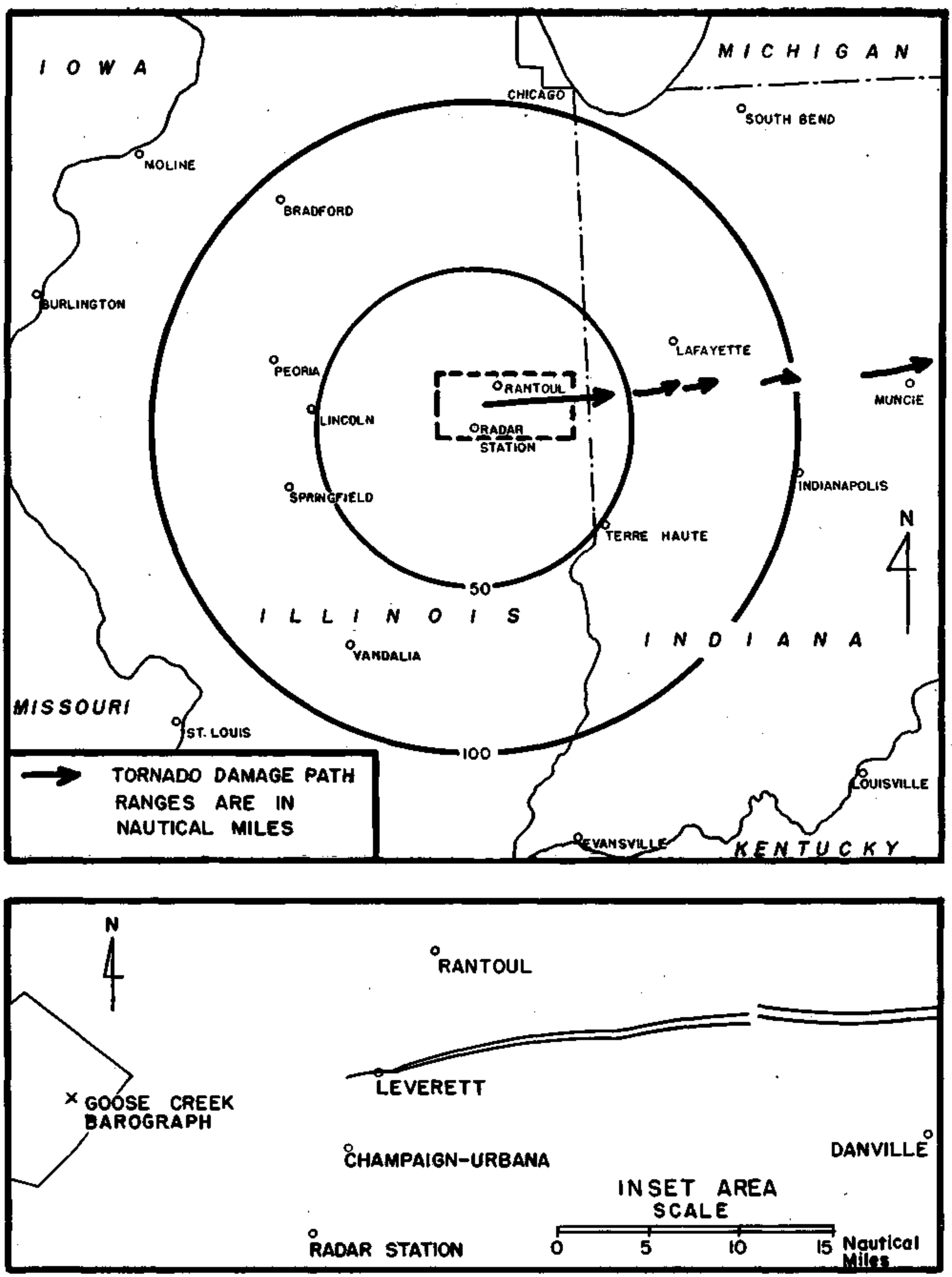


FIG. I ORIENTATION MAPS

SYNOPTIC WEATHER SUMMARY

Surface Conditions

At 0630 CST on the morning of 9 April 1953, the surface map showed a low pressure center over eastern Kansas. This low was moving northeastward at approximately 30 knots and was expected to pass through northern Illinois by late evening. The associated cold front extending southward from the low was expected to pass through Illinois during the afternoon and evening. The warm front extended east-northeastward from the low center through central Illinois. This warm front was moving slowly northward and passed the radar station about 1000 CST. The U. S. Weather Bureau forecast indicated scattered light thundershowers in Illinois during the afternoon, with a few heavy thundershowers associated with the cold frontal passage.

On the 1530 CST weather map (figure 2), the low pressure center was located in west-central Illinois with a cold front oriented south-southwestward from the low. The warm front, which had become nearly stationary, extended east-northeastward from the low center through northern Illinois into northern Indiana. The cold front was moving eastward at about 20 knots and the low center was moving northeastward about 20 knots. There were a few reports of showers north of the warm front in southern Wisconsin, while two reports of light drizzle and fog were recorded to the north and the west of the low center. A weak trough of low pressure extended southeastward from the low, and a weak ridge of high pressure extended toward the low center just to the north of this weak trough. This ridge-trough situation persisted until 1830 CST (figure 2) when the pressure pattern changed in conjunction with a strong squall zone which had developed to the east. The tornado development was on the forward side of this trough. This ridge-trough pattern in the warm sector was similar to that reported by Freeman with the tornado that hit Waco, Texas on 11 May 1953[7]. The hourly surface maps during the period 1530 CST to 1830 CST show that the low pressure center was very active. Pressure falls ahead and pressure rises behind the low were greater than 2 millibars per hour. The maps show an extension of the zero isallobar ahead of the cold front, the extension moving progressively northeastward into the tornado area. About 1600 CST, two small tornadoes occurred in the vicinity of Lincoln, approximately 52 nautical miles west-northwest of the radar station. Since the radar was operating on 30-mile range after 1557 CST, it is not known whether the Lincoln tornadoes were detectable by radar. The tornado echo with which this report is concerned was first detected by the radar approximately 12 miles north-northwest of the radar station about 1700 CST.

Reports of showers to the north of the warm front and reports of rain or fog north and west of the low center continued throughout the afternoon. Radar photographs, to be discussed later, and weather station reports indicated that only a few showers were occurring ahead of this cold front in Illinois prior to the occurrence of the tornadoes. However, by early evening squall zone conditions existed over Indiana and southern Illinois. Selected radar PPI photographs in figure 3 show the distribution of showers during the afternoon and development of the squall zone. It is interesting to note that Brunk[2] has found that tornadoes sometimes occur in connection with squall lines, but usually before the formation of the squall line, or at some distance to the rear.

Figure 4 is a 24-hour precipitation map for central Illinois which shows the distribution of showers and hail as recorded by the U. S. Weather Bureau climatological network. These observations represent 24-hour totals for the period ending either in early evening or at midnight, depending upon the type of reporting station. It can be seen that, except for Rantoul approximately eight miles to the north of the tornado path, the showers were light and scattered. It appears that a hail belt was concentrated to the north of the tornado path. The 0.92-inch rainfall at Rantoul occurred in the thunderstorm with which the tornado was associated. Hailstones as large as 1 1/2 inches in diameter were reported in the Rantoul area. The rainfall in the Effingham area (figure 4) occurred largely during the early evening and was associated with the squall zone. Visual observations of the clouds in the tornado area during the afternoon prior to the tornado development indicated scattered to broken cumulus of small vertical extent.

Pressure jumps were not reported on the hourly weather sequences for Illinois stations during the afternoon. However, there were pressure jump reports from South Bend, Terre Haute, and Indianapolis in conjunction with the squall zone conditions over Indiana during the evening. Barograph traces for Rantoul and for three State Water Survey stations in the vicinity of the tornado are reproduced in figure 5. The locations of these stations are shown on the orientation map in figure 1.

The pressure minimum at the Goose Creek station was about 40 miles in advance of the radar echo, while leveling off of the ensuing rapid rise occurred when the echo was 25 to 30 miles away, although the actual pressure peak was reached as the storm passed over the network. The pressure minimum at Rantoul was recorded about the time the forward edge of the radar thunderstorm echo reached the station, while the following sharp rise and drop (see figure 5) occurred in the thunderstorm shortly before the tornado passed south of the station. At the Champaign-Urbana weather station and the radar station at the airport, the pressure minima occurred about the time the forward edge of the thunderstorm echo passed north of the stations, and ensuing sharp rises leveled off shortly before the tornado passed to the north of these stations. No abrupt pressure drops were recorded by the barographs at the time of the surface funnel passage (figure 5).

The pressure trough or wave initially observed over the Goose Creek network was moving eastward at about 15 knots. By the time of the tornado occurrence, the more rapidly moving tornado-associated thunderstorm had apparently caught up with this pressure trough. Possibly, intensification of convergence in and around the thunderstorm as it moved into the pressure trough area was instrumental in the formation of the tornado.

Upper Air Data

The 850-millibar chart for 0900 CST (figure 7) showed two low centers, one coinciding with the surface low and the other located to the north over central Wisconsin. A pocket of warm dry air was indicated over central Illinois, with moist air to the west ahead of the low and a tongue of moist air pushing northward from the Gulf of Mexico through Indiana. Twelve hours later (2100 CST), the two low centers had merged into a single low over southern Wisconsin and had deepened. The moisture pattern had become more simplified, the two moist areas consolidating into a single moisture tongue with elimination of the pocket of dry air. Flow over the Illinois area during the day was from the southwest.

The 700-millibar chart at 0900 CST (figure 8) showed a trough extending south-southwest from western Minnesota to southeastern New Mexico. A tongue of dry air extended southeastward into central Illinois. By 2100 CST, the trough had moved eastward and was oriented along a line from western Wisconsin to southeastern Kansas. The tongue of dry air had spread eastward into Ohio and southward into Tennessee. Southwesterly flow predominated at this level over Illinois, and steepening of the contour gradient occurred between 0900 CST and 2100 CST.

The 500-millibar chart for 0900 CST (figure 9) indicated strong southwesterly flow over Illinois, with a core of strong winds across central Kansas, northern Missouri and central Illinois. The strong southwesterly flow was still present 12 hours later (2100 CST) over the Illinois area, and the contour gradient had increased considerably.

Figure 10 shows the winds aloft for selected levels at 1500 CST, about one hour before the small tornadoes hit the Lincoln area and about two hours before the large tornado reached the surface at Leverett, about 10 miles to the north of the radar station. The predominance of south-westerly flow and the existence of relatively strong winds over the central Illinois area are shown.

Figure 6 is a wind profile for Rantoul at 1500 CST. As previously mentioned, the path of the Leverett tornado was about eight miles south of

Rantoul. The wind profile shows that the wind veered gradually from 170° at the surface to 240° at 16,000 feet, then backed slightly to 230° at 25,000 feet, and remained from 230° above that level. The wind speed increased gradually from 19 knots at the surface to a maximum of 90 to 100 knots at 30,000 to 40,000 feet.

Selected radiosondes for Columbia, Missouri, and Rantoul are shown in figure 11. At 0900 CST, Columbia occupied a position similar to that of Rantoul at 1500 CST with respect to the surface frontal system. At 0900 CST, Rantoul was just ahead of the warm front moving up from the south; consequently, the sounding is not representative of the air mass within which the tornadoes originated. It is shown merely for the purpose of continuity. While the morning soundings did not appear characteristic of a tornado situation, the Rantoul sounding for 1500 CST closely resembled the mean tornado sounding presented by Fawbush and Miller in 1952[5]. A tabulated comparison of the Rantoul sounding and the Fawbush and Miller mean tornado sounding is given in Table 1.

Although tornadoes occurred across central Indiana during the evening, the 2100 CST radiosonde for Dayton, Ohio did not compare favorably with the mean tornado sounding. Dayton is located less than 100 miles from the eastern end of the Indiana tornado path. Favorable tornado conditions were apparently restricted to a relatively small area.

TABLE I

	Rantoul	F-M
Depth of Moisture Layer	155 mb	175 mb
Top of Moist Layer	824 mb	825 mb
Top of Inversion or Isothermal Layer	798 mb	780 mb
Level of Free Convection	790 mb	660 mb
Zero isotherm Level	659 mb	620 mb
Mean R.H. of Moist Layer	75 %	85 %
Minimum R.H. in Moist Layer	61 %	65 %
R.H. at Base of Inversion	81 %	85 %
R.H. at Top of Inversion	50 %	30 %
R.H. at 700 Millibars	39 %	30 %
R.H. at 500 Millibars	M	40 %

Discussion of Existing Criteria For Tornado Formation

Fawbush, Miller, and Starrett have devised a method for forecasting tornadoes based upon the existence of certain synoptic conditions a few hours prior to tornado formation[6]. Briefly summarized, the synoptic conditions which must be fulfilled are:

1. A layer of moist air near the surface must be surmounted by a deep layer of dry air.

2. A distinct moisture wedge or ridge must be present in the moist layer.

3. The winds aloft must exhibit a maximum of speed along a relatively narrow band at some level between 10,000 feet and 20,000 feet, with the maximum speed exceeding 35 knots.

4. The vertical projection of the axis of wind maximum must intersect the moisture ridge axis.

5. The temperature distribution of the air column as a whole must indicate conditional instability.

6. The moist layer must be subjected to considerable lifting.

Fawbush and Miller amplified these forecasting criteria with the presentation of a mean tornado sounding in 1952, which was mentioned earlier. Reference to the various surface and upper air charts and the Rantoul radiosonde for 1500 CST indicates that the Fawbush and Miller criteria were generally satisfied in east-central Illinois at the time of the tornado formation.

Tepper has indicated that the intersection of two pressure jump lines is a preferred location for tornado development[10]. Except for those shown in figure 5, barograph records for Illinois and Indiana stations were not available for a pressure jump analysis. As previously mentioned, pressure jumps were not reported by Illinois stations on hourly sequences during the afternoon, although there were several jumps reported in Indiana in conjunction with the evening squall zone.

Showalter has presented both a thunderstorm stability index and a tornado index, both of which may be used to indicate the probability of tornadoes[8]. These indices are based upon thermodynamic considerations, the details of which will not be repeated here. Showalter states that a zero or negative tornado index indicates probable tornadoes when associated with a zero or negative thunderstorm stability index. He points out that experience to date indicates a very high probability of tornadoes in any warm sector that shows negative values of -4 or greater on both the stability index and the tornado index. The Rantoul radiosonde for 1500 CST indicated a -1 for the tornado index and -5 for the thunderstorm stability index. The thunderstorm stability index for Columbia at 0900 CST was +1, while the tornado index was +2. Columbia was the nearest station to the central Illinois area which was in the warm air mass at that time.

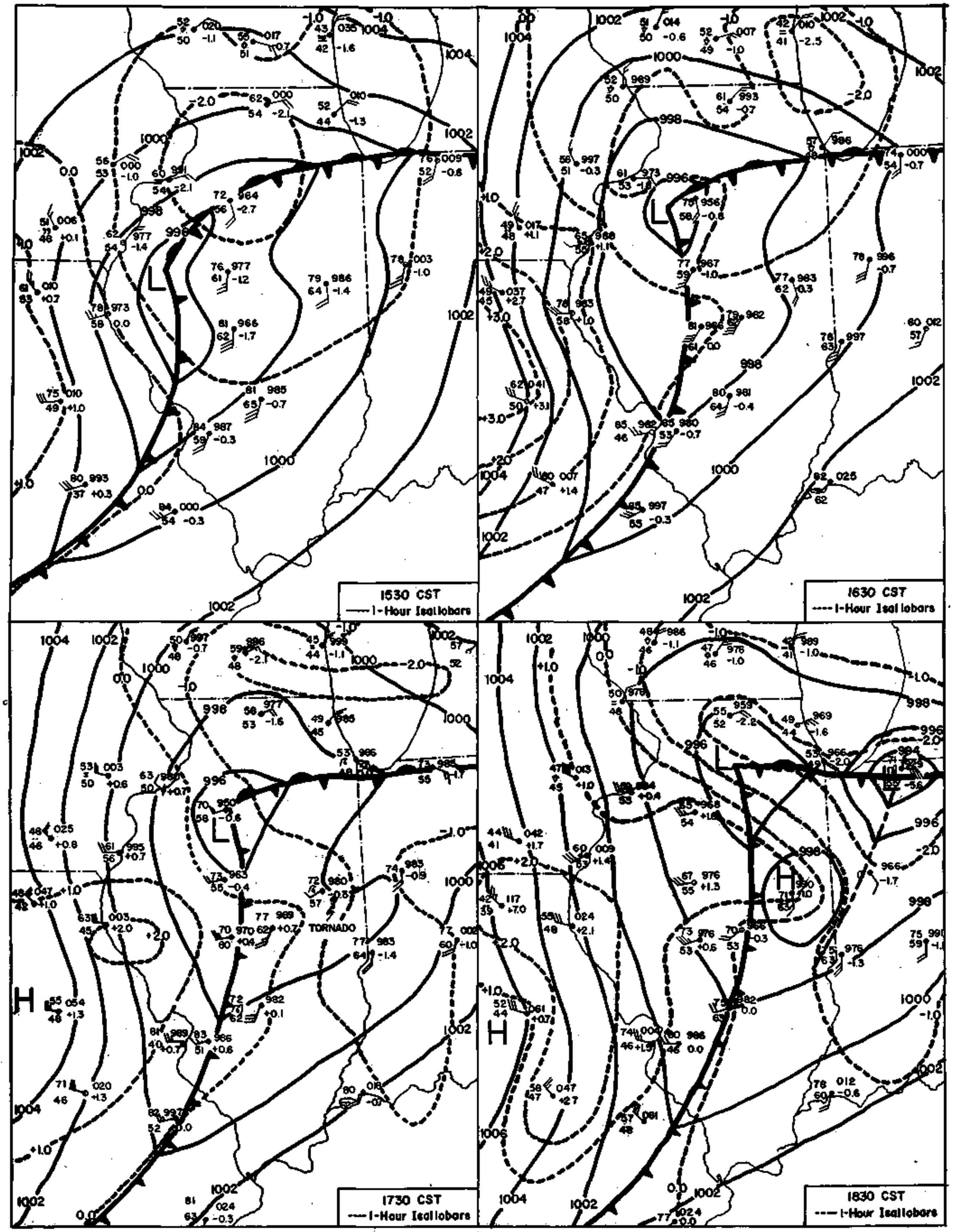


FIG 2

ONE-HOURLY SURFACE MAPS FOR 9 APRIL 1953

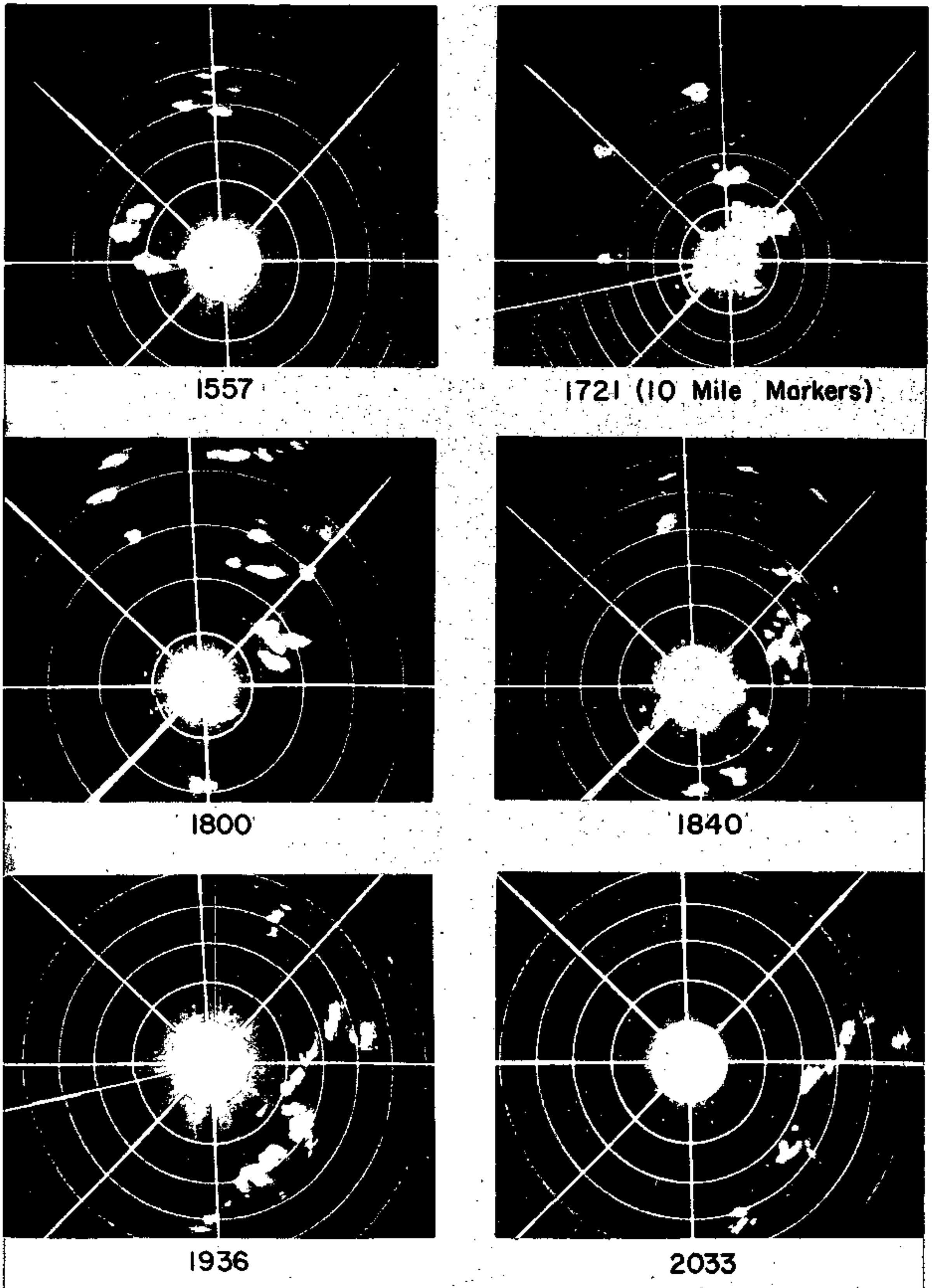


FIG. 3 PPI PHOTOGRAPHS INDICATING SQUALL ZONE DEVELOPMENT

Maximum Gain

20 Mile Markers Unless Noted

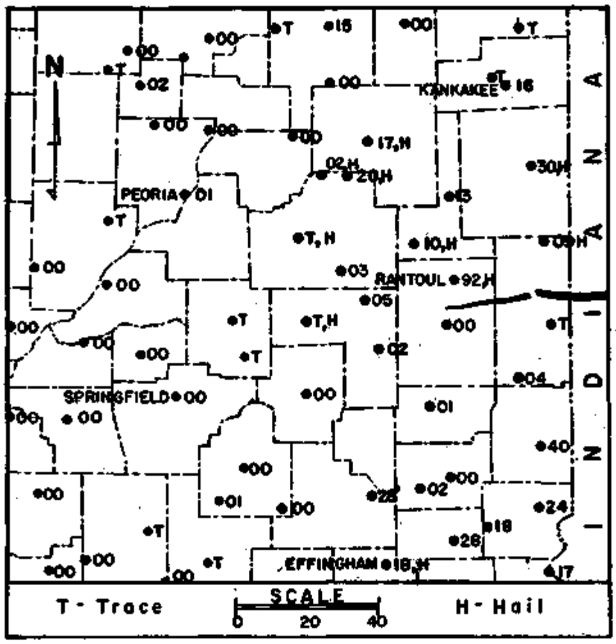


FIG. 4 24-HOUR PRECIPITATION IN HUNDREDTHS OF AN INCH FOR 9 APRIL 1953

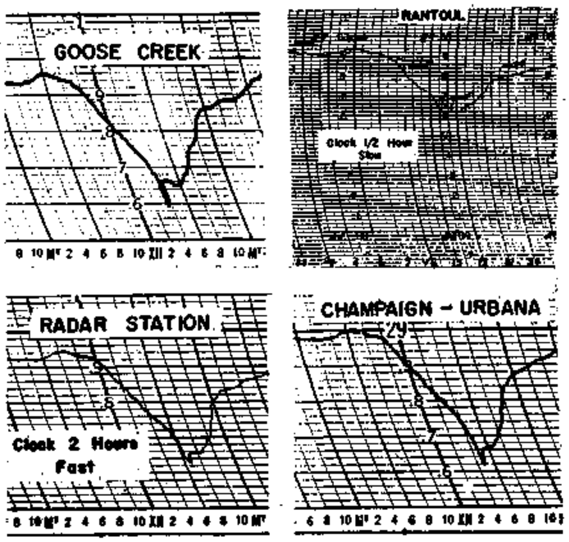


FIG. 5 BAROGRAPH TRACES FOR 9 APRIL 1953

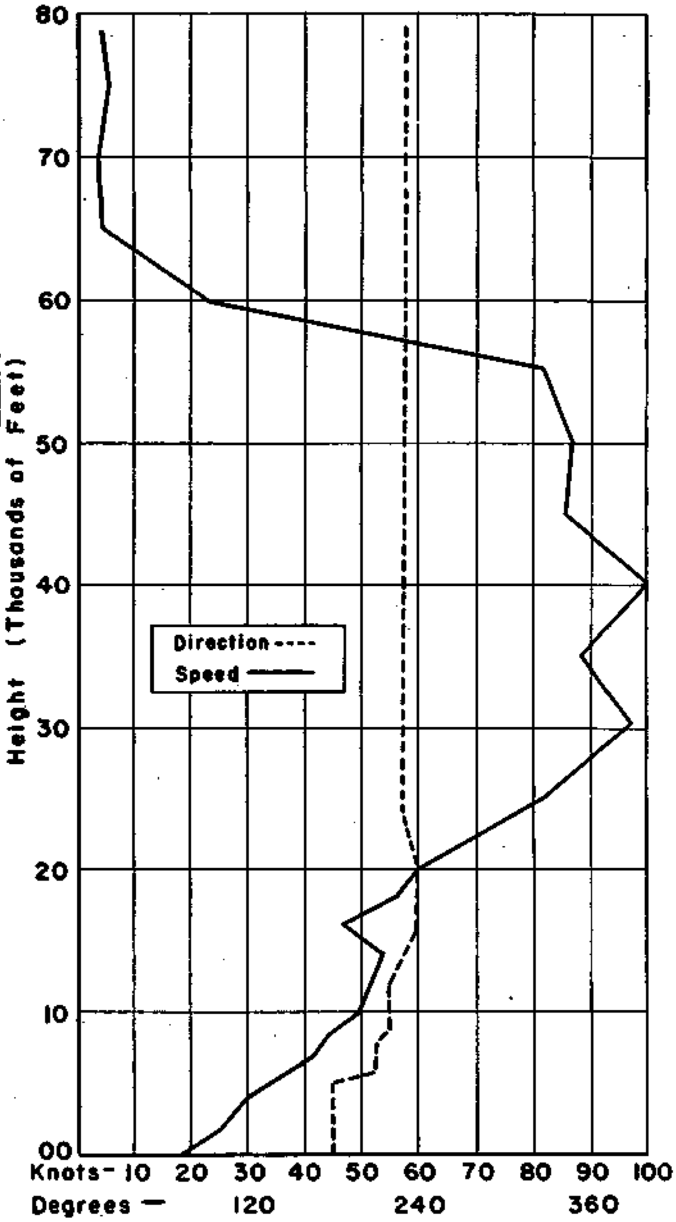


FIG. 6 WIND PROFILE FOR RANTOUL FOR 1500 C.S.T., 9 APRIL 1953

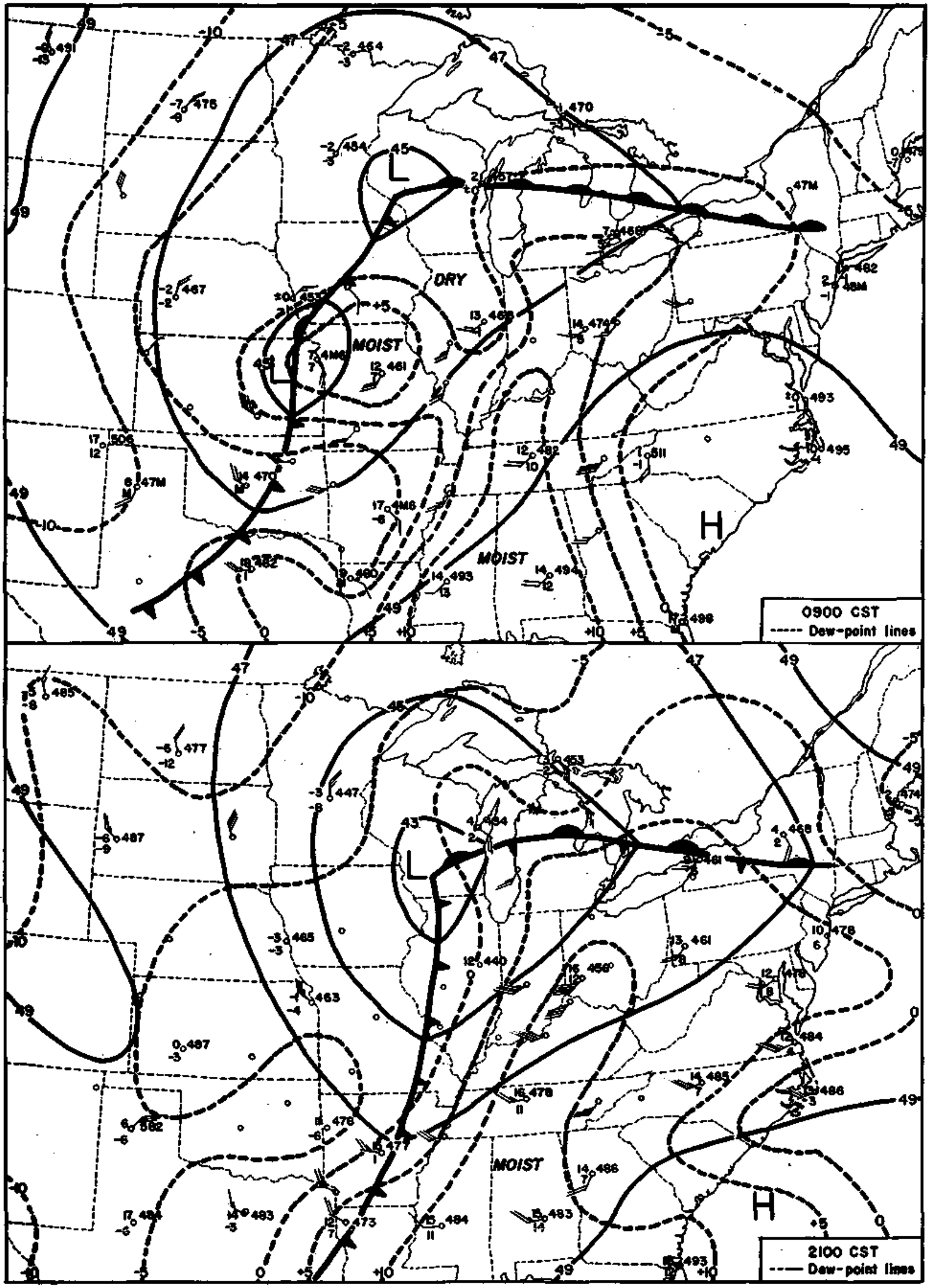


FIG. 7 850 - MB LEVEL CHARTS FOR 9 APRIL 1953

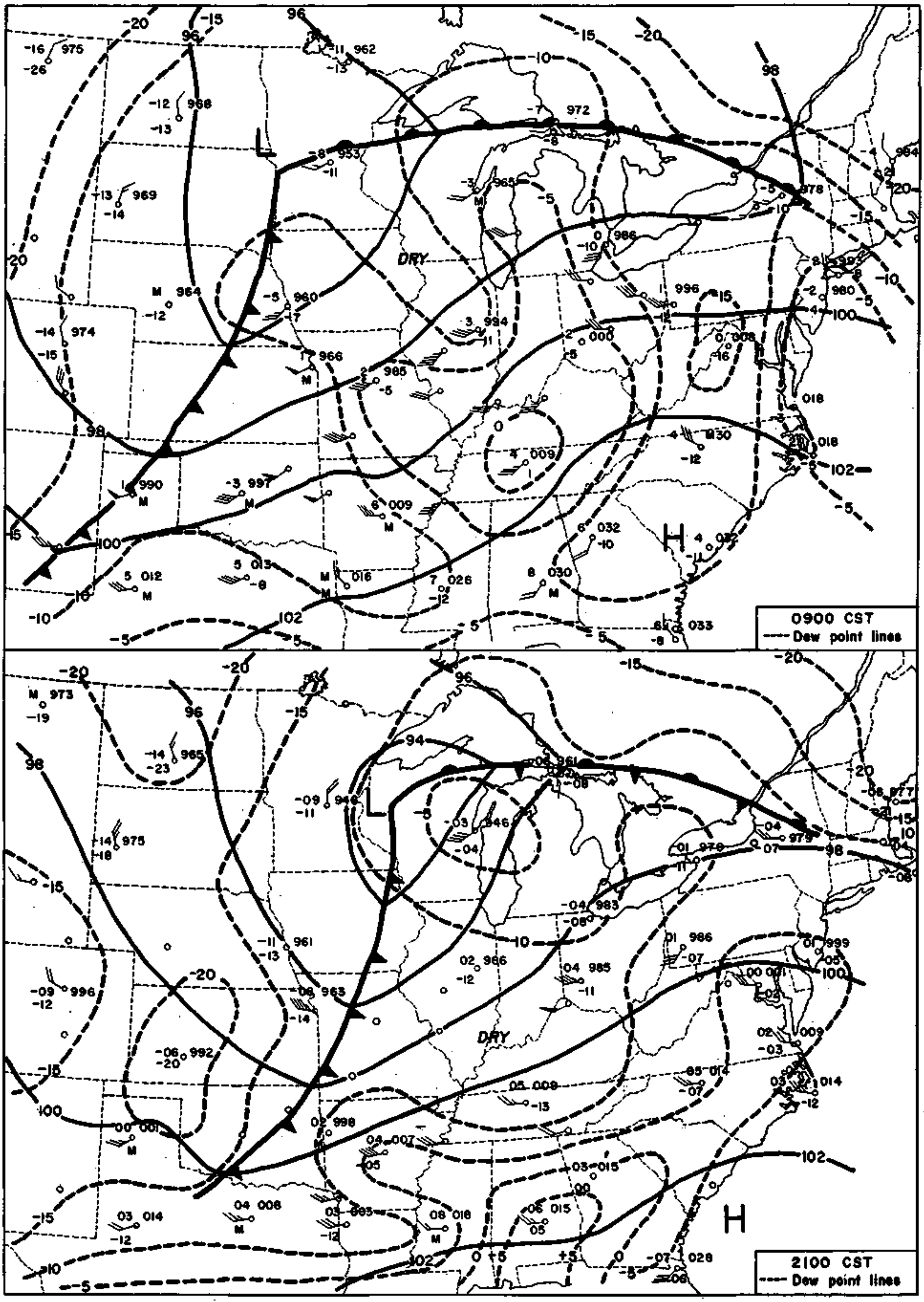


FIG. 8 700-MB LEVEL CHARTS FOR 9 APRIL 1953

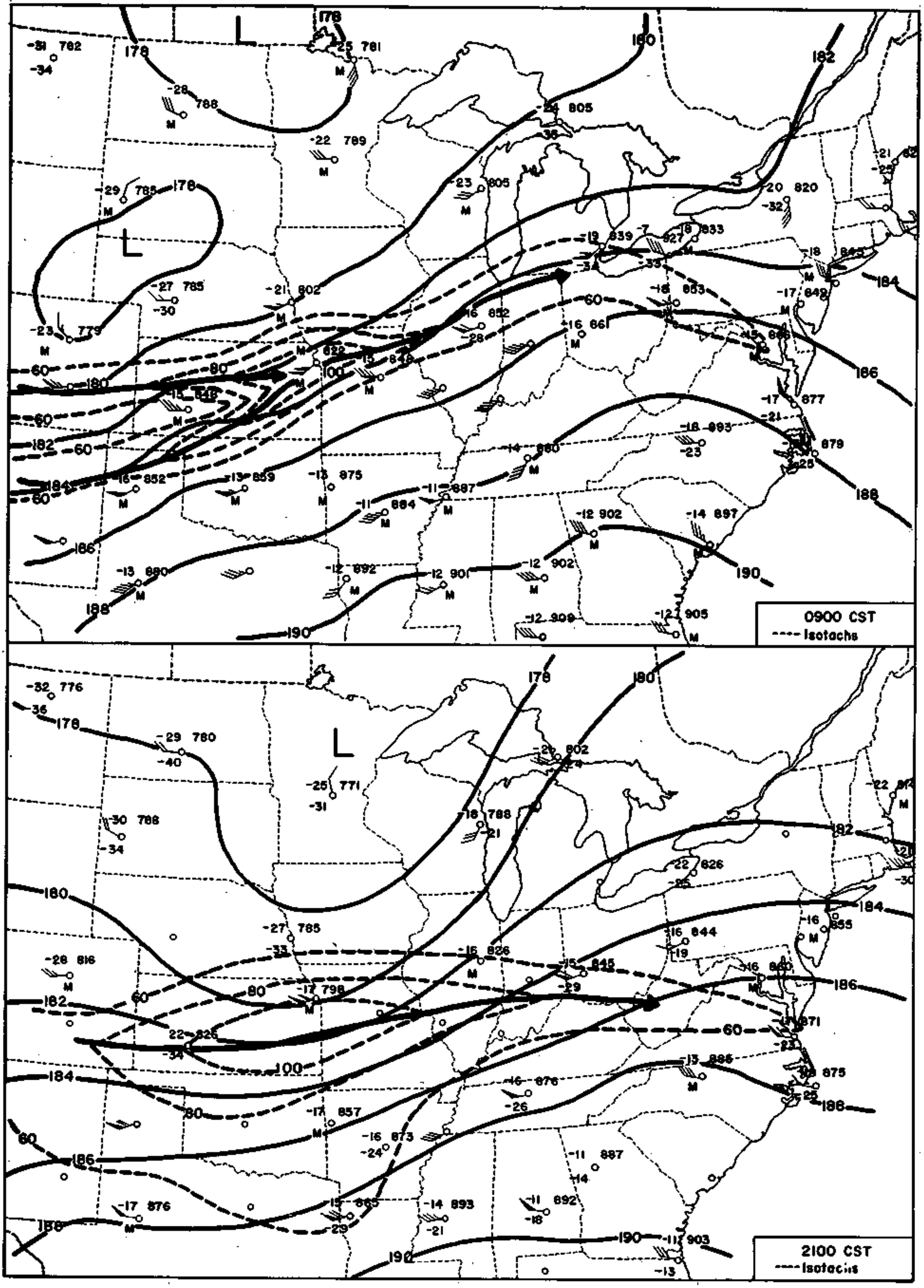


FIG. 9 500 - MB LEVEL CHARTS FOR 9 APRIL 1953

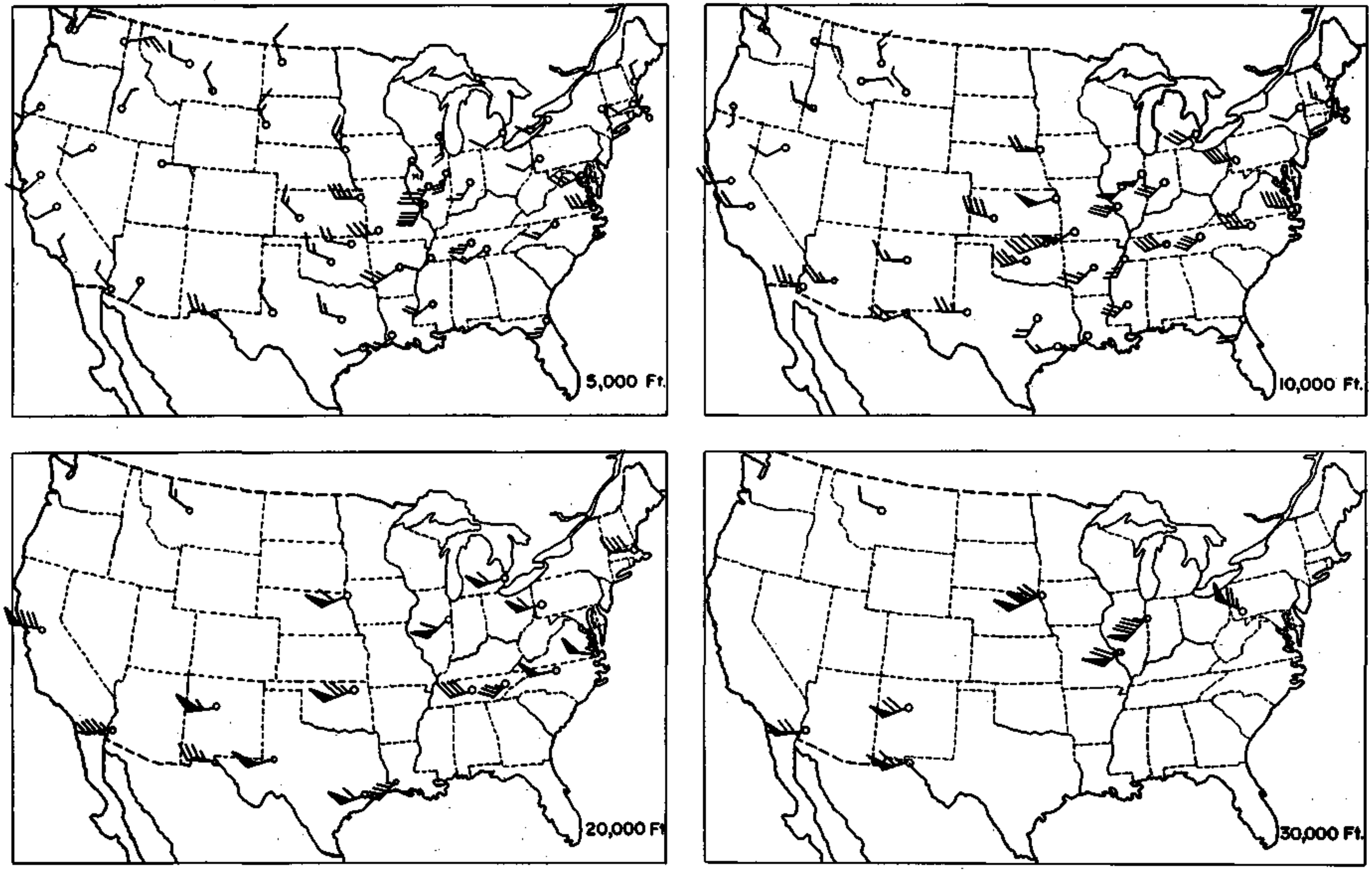


FIG. 10 WINDS ALOFT CHARTS FOR 1500 CST, 9 APRIL 1953

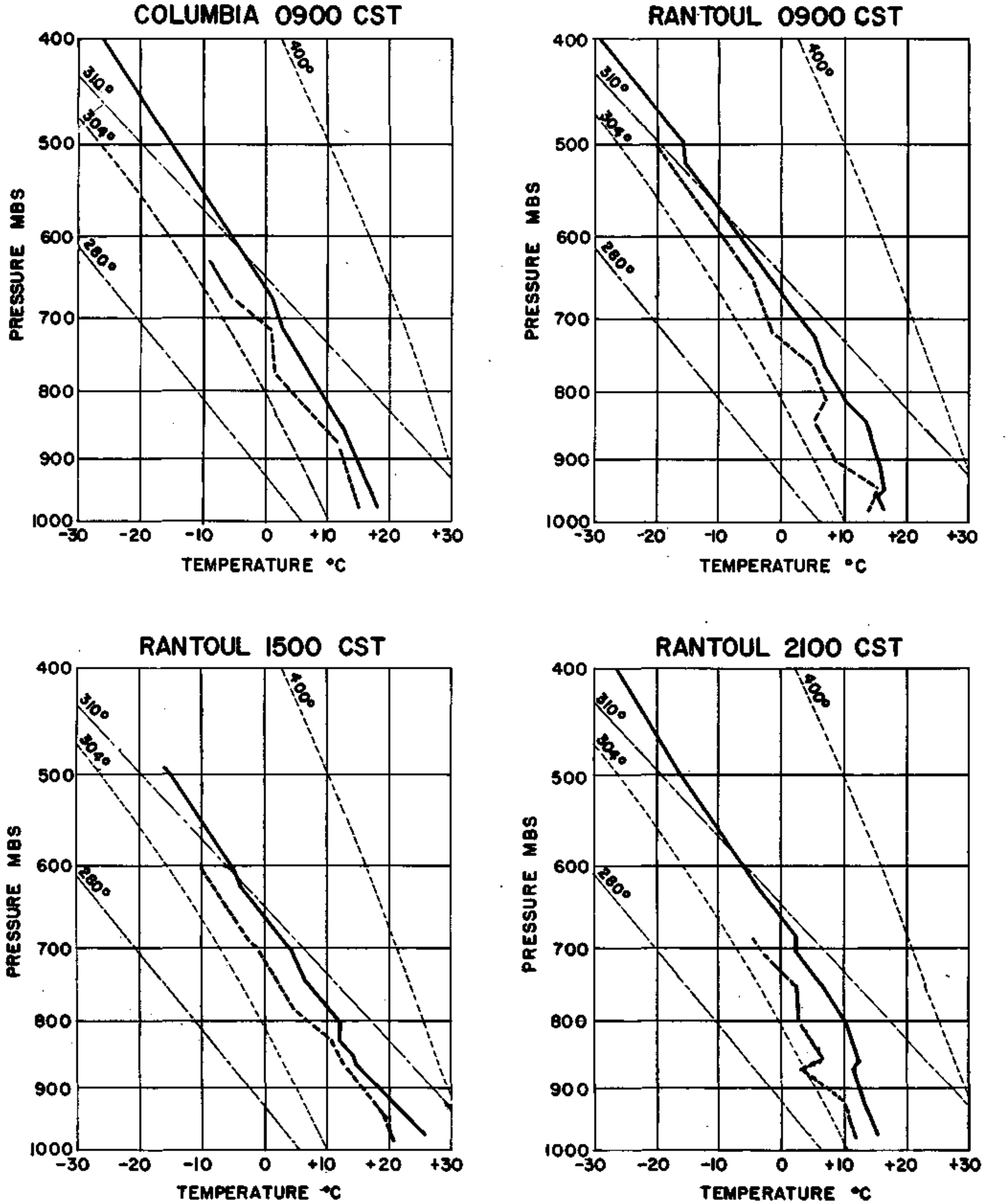


FIG. 11 RADIOSONDE OBSERVATIONS FOR 9 APRIL 1953

(— Dry Bulb Temperature; ---- Wet Bulb Temperature)

DISCUSSION OF RADAR DATA

Equipment

The radar data were obtained from a modified AN/APS-15A. This is a 3-cm set which has a 3-degree beam width and a pulse length of two microseconds. The plan position indicator (PPI) is photographed by a Navy type A scope camera using 35-mm film. Pictures of the scope are taken each scan. This set has also been equipped with an automatic gain reduction device which reduces the receiver gain with each antenna sweep. A maximum of 10 gain steps is available and a timer limits the rate of photography to one series of steps each minute.

The antenna elevation does not have a precise control or indication system so can not be set accurately to 0° elevation. An analysis was made of ground target return and storm echo reflectivity on reduced gain. This analysis indicated that the storm echo pattern, as observed on maximum gain, may have been an integration of return from the ground to a maximum elevation of about six degrees above the horizon. Consequently, an accurate calculation of the vertical extent of echo contained in the radar beam at various times could not be made.

The effect of attenuation on 3-cm radar scope presentations is considerable and deserves brief mention before proceeding with the discussion of the radar scope data. Attenuation of the radar transmitted signal is proportional to the rate and depth of rainfall; consequently, the true intensity and areal extent of the echo presented on the PPI is reduced, and the echo shape is distorted as the attenuation increases. Since there was no intervening rainfall (echoes) between the radar station and the tornado in this case, conditions on the near side of the thunderstorm echo and the tornado echo, located on the southwest corner of the associated thunderstorm, should have been accurately presented. However, since heavy rainfall was reported in the thunderstorm as it passed over the Chanute Air Force Base Weather Station at Rantoul, Illinois, scope echo presentations of the far side of the thunderstorm were subject to considerable attenuation effects.

Early History of Associated Thunderstorm

In the following discussion frequent reference will be made to PPI photographs appearing in figures 12-20. Figures 12-18 are scope photographs made with maximum receiver sensitivity (step 1), and show the maximum areal extent of the echoes as presented on the PPI. Figures 19-20 were taken on reduced gain at step 3. They illustrate the appearance of the echoes when the lighter, less significant portions of the echoes are eliminated. Steps 1 and 3 correspond to receiver sensitivities of 97 and 89 decibels below one milliwatt, respectively (see Table II). North is to the top of the photographs, and range markers are at intervals of 10 nautical miles unless otherwise noted.

TABLE II

Receiver Sensitivity 9 April 1953
(Decibels Below One Milliwatt)

Step	Db.	Step	Db.
1	97	5	81
2	93	6	75
3	89	7	69
4	87	8	63

The thunderstorm echo with which the tornado to the north of the radar station was associated was first detected about 55 miles west-southwest of the station at 1525 CST. At 1541 (figure 12), two groups of echoes were discernible, one located 80 to 100 miles north-northwest of the radar station, and the other located 50 to 60 miles to the west. The tornado, which reached the surface about ten miles north of the radar station about 1713 CST, occurred in conjunction with the most southerly of the western group of echoes. The echoes were moving in a northeasterly direction at this time. The camera trigger is responsible for the small blank sector appearing to the west-southwest.

At 1557 CST (figure 12), the echo pattern was essentially the same except for the dissipation of one echo to the southwest. However, there had been a general increase in intensity, as the echoes continued to move northeast at about 45 knots. The radar range was reduced to 30 miles at this time to present a more detailed view of the most southerly echo as it passed over the Goose Creek raingage network, which encompasses about 75 square nautical miles and is centered 18 miles west-northwest of the radar station (figure 1).

About 1600 CST, two small tornadoes occurred in the vicinity of Lincoln, 52 miles west-northwest of the radar station. The damage paths of these storms were in a southwest to northeast direction, lying between the middle and southern echo as shown by the radar at 1557 CST (figure 12). Whether they were associated with either of these echoes could not be positively determined. If such was the case, the true areal extent of the associated echo must have been considerably greater than was indicated by the radar. Another possibility is that the tornadoes were associated with another cloud behind the southern echo which was not detected by the radar. Because of the reduction to 30-mile range, no PPI photographs of the Lincoln area were obtained after 1557 CST.

Two small appendages on the southern side of the middle echo and another on the southwest edge of the northern echo were discernible in the original PPI photographs for 1557 CST; however, most of the detail has been lost in the reproductions of figure 12.

Light rainfall was recorded on the Goose Creek raingage network between 1615 CST and 1650 CST as the thunderstorm echo passed over the area (figure 1). Amounts recorded by gages ranged from 0.0 to 0.23 inch. Gain step 8, corresponding to 34 db below maximum sensitivity (Table II), was required for extinction of the echo. Normally, considerably heavier rainfall occurs when such a gain step is observed. However, hail was reported with the storm over the network, and it is quite likely that high reflectivity from the hail (water-coated ice) caused the abnormally strong radar return observed with the light surface rainfall.

The echo, which later was associated with the large tornado, came into full view again at 1630 CST (figure 12). Note that the echo at 23 miles to the west-northwest is a ground target and not an appendage on the thunderstorm. By this time, the direction of movement had veered slightly to the right. After formation of the surface tornado, the echo followed a 250-degree to 275-degree course. The Rantoul Rawin for 1500 CST indicated the mean wind from 2000 to 20,000 feet was from 217 degrees at 45 knots, with the winds above 20,000 feet moving from 230 degrees. Other echoes on the scope moved in a direction very near to the mean wind. The echo associated with the tornado was somewhat larger than the average thunderstorm and was oriented in an east-west direction. Note the appearance of another echo on the edge of the scope to the northwest at 1636 CST (figure 12), indicating that the radar beam was not completely attenuated in passing through the large thunderstorm echo, although some parts of the cloud are probably not seen. Also observe the sharp cutoff on the western side of the large echo.

The echo had moved well on to the 30-mile range scope by 1636 CST (figure 12) and was beginning to enter the fringe of the ground pattern. The ground targets produced by Leverett and Thomasboro are very distinct; both are at 20 degrees, Leverett just inside the ten-mile marker and Thomasboro at 13 miles. The tornado later passed directly over Leverett.

The Tornado Echo

At 1653 CST (figure 13), a small, weak echo appeared at the southwest edge of the thunderstorm echo. About 1658 CST (figure 13), an appendage appeared on the northwest edge of the thunderstorm echo; however, this appendage dissipated about 10 minutes later. By 1700 CST (figure 13), the echo at the southwest edge of the thunderstorm had developed and expanded southward. The surface tornado developed a few minutes later from this echo, which will henceforth be referred to as the tornado echo. The tornado echo extended three to four miles beyond the edge of the thunderstorm echo. A flat "V" began forming on the north side of the associated thunderstorm echo about this time. This was probably due to attenuation. At 1705 CST (figure 14), Rantoul (RAN) was on the edge of this "V", and a surface observation taken at that time indicated a heavy thunderstorm and heavy hail in progress. Reduced gain observations indicated that the heaviest precipitation was occurring a few miles south of Rantoul. An apparent appendage can be seen on the cloud at the north edge of the scope at this time (figure 14). However, no tornadoes were reported with this cloud at this time or later, although heavy hail did occur with it. Note the sharply defined edge of the thunderstorm echo near the tornado echo, indicating the presence of a strong moisture gradient. Reference to the reduced gain photographs in figure 19 shows a separation between the tornado echo and the thunderstorm echo in the early stages of the tornado development, indicating the presence of a separate core or cell in the tornado circulation.

The tornado echo continued to develop, and about 1713 CST (figure 14), the tornado reached the surface west of Leverett at a point approximately ten miles north of the radar station. At this time, the tornado's surface position was at the southern end of the tornado echo appearing on the PPI. At the time of the first surface damage, the tornado echo was about four miles long and just beginning to develop cyclonic curl. This curl developed at a rate of about 60 knots.

The tornado echo was plainly visible for at least 10 minutes before the tornado reached the ground. Six to seven steps (gain reductions) were required to extinguish the tornado echo during this time, indicating the presence of appreciable water, either in the liquid or solid state. These steps are 22 and 28 decibels below the maximum receiver sensitivity of 97 decibels (Table II).

It is of interest at this time to summarize the observation of Major Carl D. Mitchell, a Chanute Air Force Base Weather Officer, who observed the formation of this tornado from his home on the north side of Urbana, about three miles south of the surface path. Prior to the formation of the tornado, he observed five or six projections, apparently tornado funnels, from the bottom of the thunderstorm cloud. He estimated that they each lasted for about 15 seconds and dissipated. They appeared to extend only a few hundred feet below the cloud base and were much paler than the thunderstorm cloud. When the tornado formed, it appeared to reach the ground in the form of a column rather than a funnel. It appeared to be a vertical column with oscillation of the base near the ground. Major Mitchell indicated that the thunderstorm cloud was the only cloud with strong development in the area just prior to the tornado formation.

Figures 14 and 15 show the growth and development of the tornado echo as it moved eastward at about 40 knots. Continued development of the cyclonic curl can be seen in these photographs. Between 1720 CST and 1725 CST (figure 15), the cloud mass changed rather abruptly into a "T" shape as a portion rapidly developed on its north side. This too may have been the result of attenuation since the cloud movement was gradually bringing this portion into better position for viewing. On the original PPI photographs, a weak spot or "eye" appeared in the tornado echo about 1720 CST; however, details of this "eye" have been obscured in the photographic reproductions of figures 15 and 16.

As the thunderstorm and tornado echoes moved eastward, the tornado echo grew at the expense of the associated thunderstorm. This is illustrated in Table III where the areas of the thunderstorm echo and tornado echo are compared for steps 1 and 5.

As the tornado and thunderstorm echoes progressed across Illinois, steps 6 to 7 were required to extinguish the tornado echo until 1720 CST, after which steps 7 to 8 were required. The thunderstorm echo disappeared on steps 7 to 8. Prior to 1740 CST, no observations of precipitation were reported along the funnel path, although the field survey revealed an observation of a few hailstones less than one mile north of the surface damage path and heavy hail was reported approximately two miles north of the path. One farmer reported large hail immediately in advance of the funnel at about 1740 CST. Since the tornado echo extended four to five miles southward from the associated thunderstorm echo, it appears

TABLE III

Radar Echo Areas

Time (CST)	Area, Sq. Nautical Mi. Step 1			Area, Sq. Nautical Mi. Step 5		
	A*	B	A+B	A	B	A+B
1710	179	8	187	83	3	86
1714	171	6	177	80	3	83
1718	185	13	198	74	4	78
1723	164	14	178	75	6	81
1727	172	16	188	70	8	78
1731	134	22	156	67	10	77
1735	152	40	192	69	13	82

* A - thunderstorm echo, B - Tornado echo.

that hail was associated with the tornado echo as well as with the thunderstorm echo. The relatively high reflectivity from the tornado echo may have been largely due to the presence of hail.

No large differences in intensity were observed between the tornado-associated thunderstorm echo and other echoes viewed on the scope prior to or during the passage of the tornado through Illinois. In general, one more step was required to extinguish the thunderstorm echo associated with the tornado.

Between 1725 CST and 1730 CST (figures 15-16), the combined echo mass developed a spiral appearance. This spiral development can also be seen in the reduced gain photographs of figure 20. The presence of the "eye" in the tornado echo is also discernible in these reduced gain photographs.

The continued spiral development and the presence of the tornado "eye" are illustrated in figure 16 and figure 20. Note the echo approximately eight miles east-northeast of the radar station at 1738 CST (figure 16). This echo moved northeastward at about 60 knots, merging with the tornado echo about 1805 CST (figure 17).

The maximum surface damage in Illinois occurred after the development of the spiral appearance. The maximum width of moderate to heavy surface damage as revealed by the field survey was about one mile. The surface tornado path, as reconstructed from the field survey, was at first near the southern edge of the tornado echo "eye"; by 1800 CST, however, the surface path's axis was more than one mile south of the southern edge of the "eye" (figures 24-25).

<u>Indiana Tornado Path</u>

Since the echo was beginning to move out of the 30-mile range, the radar range was increased to 100 miles at 1740 CST (figure 17). Figures 17-18 show the development of a squall zone which passed through Indiana and southern Illinois during the evening. U. S. Weather Bureau reports[4] indicated tornado damage along an east-west path through central Indiana to the vicinity of Albany during the evening. The time of occurrence of the Indiana tornado damage and the damage path were such that the Indiana damage could have been caused by the same tornado which passed through Illinois. However, by 1830 CST the Illinois tornado echo had lost its identifying characteristics, partly due to range and precipitation attenuation effects and partly due to changes taking place in the thunderstorm echo patterns in the vicinity of the original echo.

The arrows in figure 18 show the radar echoes with which the Indiana tornado damage was apparently associated. The echoes were identified from damage locations and tornado occurrence times provided by the Indianapolis office of the U. S. Weather Bureau. In the PPI photograph for 2032 CST, note the appearance of an appendage on the south side of the echo at 80-90 miles. No tornado was reported with this storm. As indicated by the arrow, the Indiana tornado was associated with the echo at 120 miles.

Figure 21 illustrates the movement of individual storm echoes during the period of the Illinois and Indiana tornadoes. The echoes in the tornado area were moving in a nearly easterly direction, while those to the north and south of this area were moving in a northeasterly direction, in agreement with the winds aloft. As pointed out earlier, the Rantoul Rawin for 1500 CST indicated a mean wind from 217 degrees at 45 knots between 2000 feet and 20,000 feet. Above 20,000 feet, the wind was from 230 degrees (figure 6). The Rantoul upper winds were in agreement with the general flow pattern as shown by the winds aloft map for 1500 CST (figure 10). It is apparent that the movement of the tornado echo (or echoes) was not in agreement with the upper wind flow as revealed by PIBAL and RAWIN observations.

Summary of Radar Observations

The thunderstorm echo with which the tornado was associated was first detected about 1525 CST approximately 55 miles west-southwest of the radar station. At this time the echo appeared to be moving northeastward at about 45 knots; however, by the time of the tornado occurrence its movement had veered to a nearly easterly direction. The tornado echo which contained the surface tornado became distinctly discernible aloft by 1700 CST, and was located at the southwest edge of the associated thunderstorm echo. The tornado reached the surface around 1713 CST about 10 miles north of the radar station. At this time, the tornado's surface position was at the southern end of the tornado echo as revealed on the PPI. The tornado echo and its associated thunderstorm continued to move in an easterly direction at approximately 40 knots, the tornado echo developing a cyclonic curl and growing at the expense of the thunderstorm echo. By 1730 CST the combined thunderstorm and tornado echoes had developed a spiral appearance and a weak spot or "eye" had developed in the tornado echo area. The surface damage was initially concentrated near the southern edge of this weak spot in the tornado echo; however, the damage path was more than a mile south of the "eye" by 1800 CST. The maximum surface damage in Illinois was experienced after the development of the spiral appearance. The easterly movement of the tornado echo was not in agreement with the winds aloft which were from a southwesterly direction; however, other echoes to the north and south of the tornado area moved in close agreement with the upper wind flow. A definite squall zone had developed over Indiana and southern Illinois by 1830 CST, but the radar photographs did not show well-defined squall zone conditions prior to or during passage of the tornado through

Illinois. Apparently the tornado occurred during the developing stage of the squall zone over Illinois.

U. S. Weather Bureau reports indicate that tornado damage occurred along a west-east line through central Indiana during the evening. Times of occurrence and the path of the tornado damage was such that the tornado damage in Indiana could have been caused by the same echo that passed through Illinois. However, due to radar range and precipitation attenuation effects and changes in cell patterns taking place in the tornado area over Indiana, it is not known whether the Indiana damage was caused by the same tornado that passed through Illinois. The total length of the Illinois-Indiana damage path was approximately 140 miles.

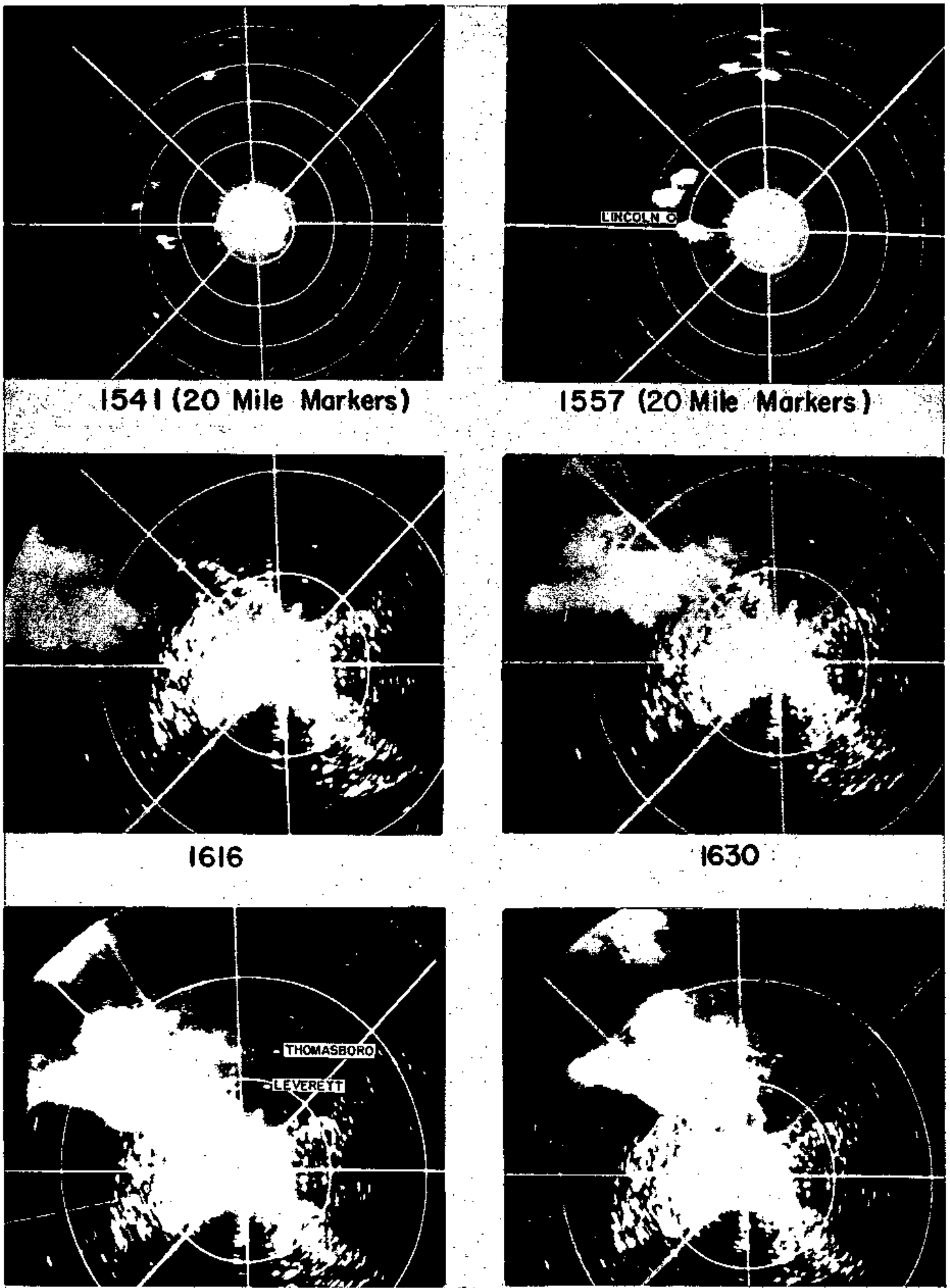


FIG. 12 PPI PHOTOGRAPHS ON 9 APRIL 1953

Maximum Gain 10 Mile Markers Unless Noted

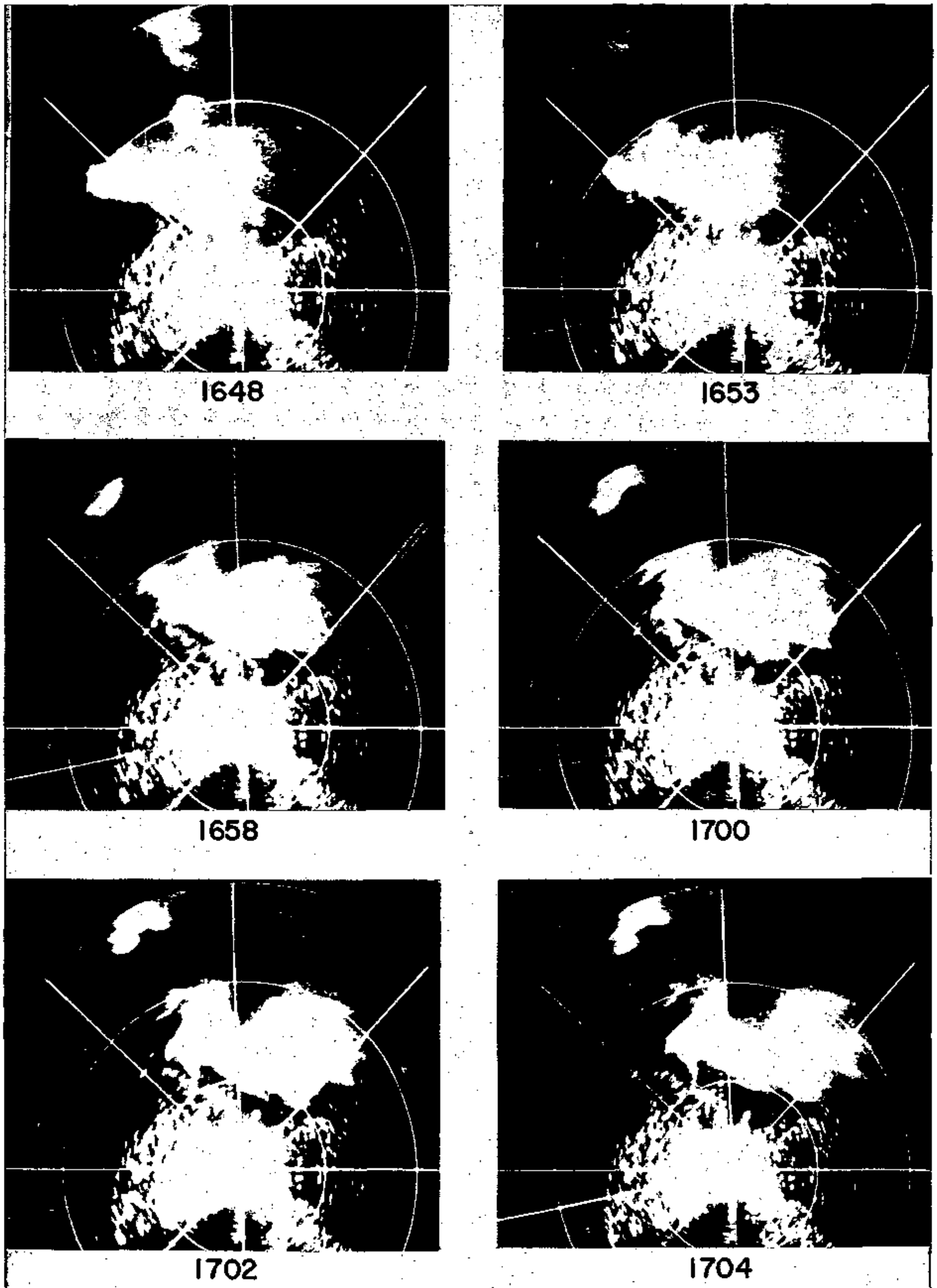


FIG. 13 PPI PHOTOGRAPHS ON 9 APRIL 1953

Maximum Gain 10 Mile Markers

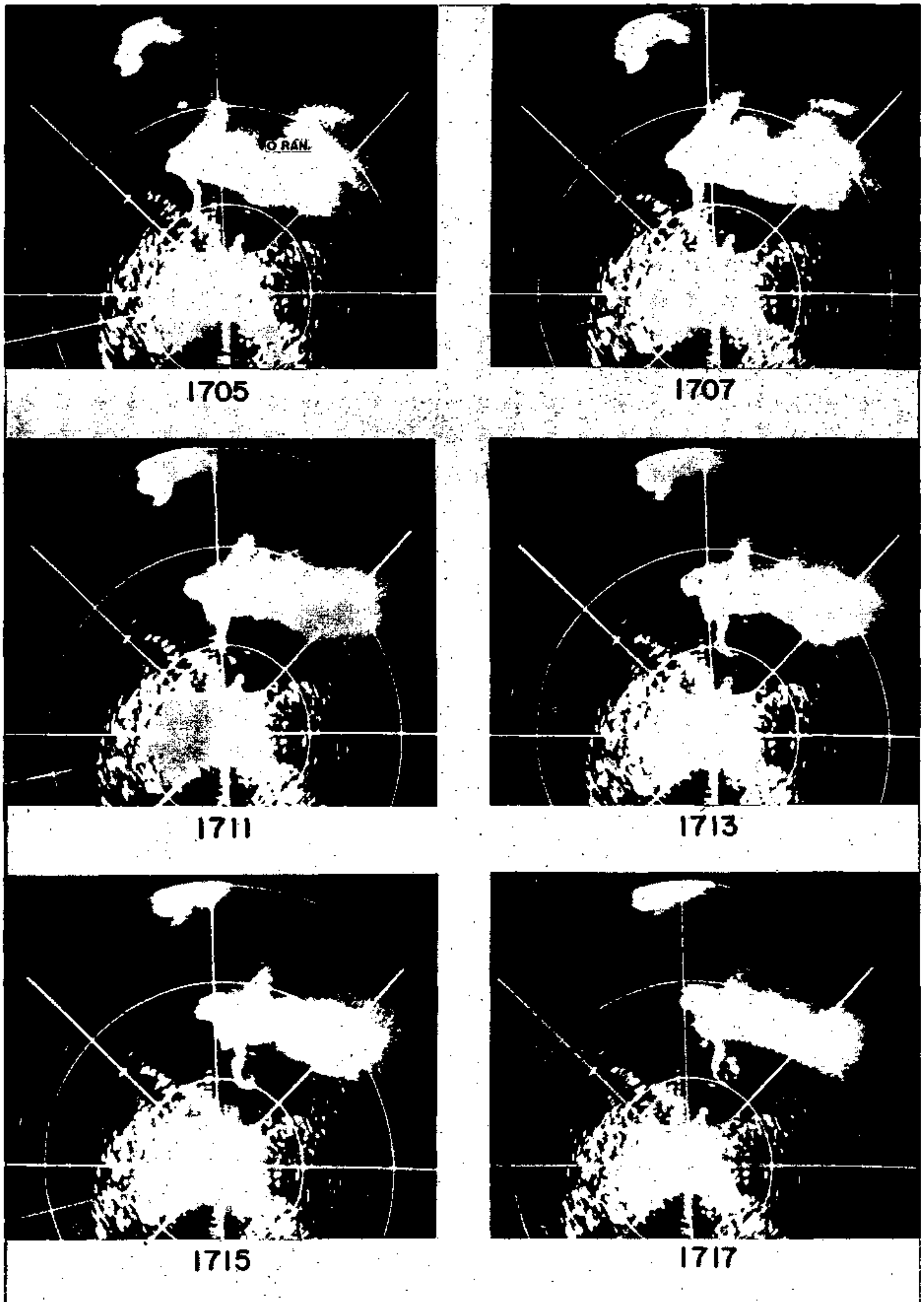


FIG 14 PPI PHOTOGRAPHS ON 9 APRIL 1953

Maximum Gain   10 Mile Markers

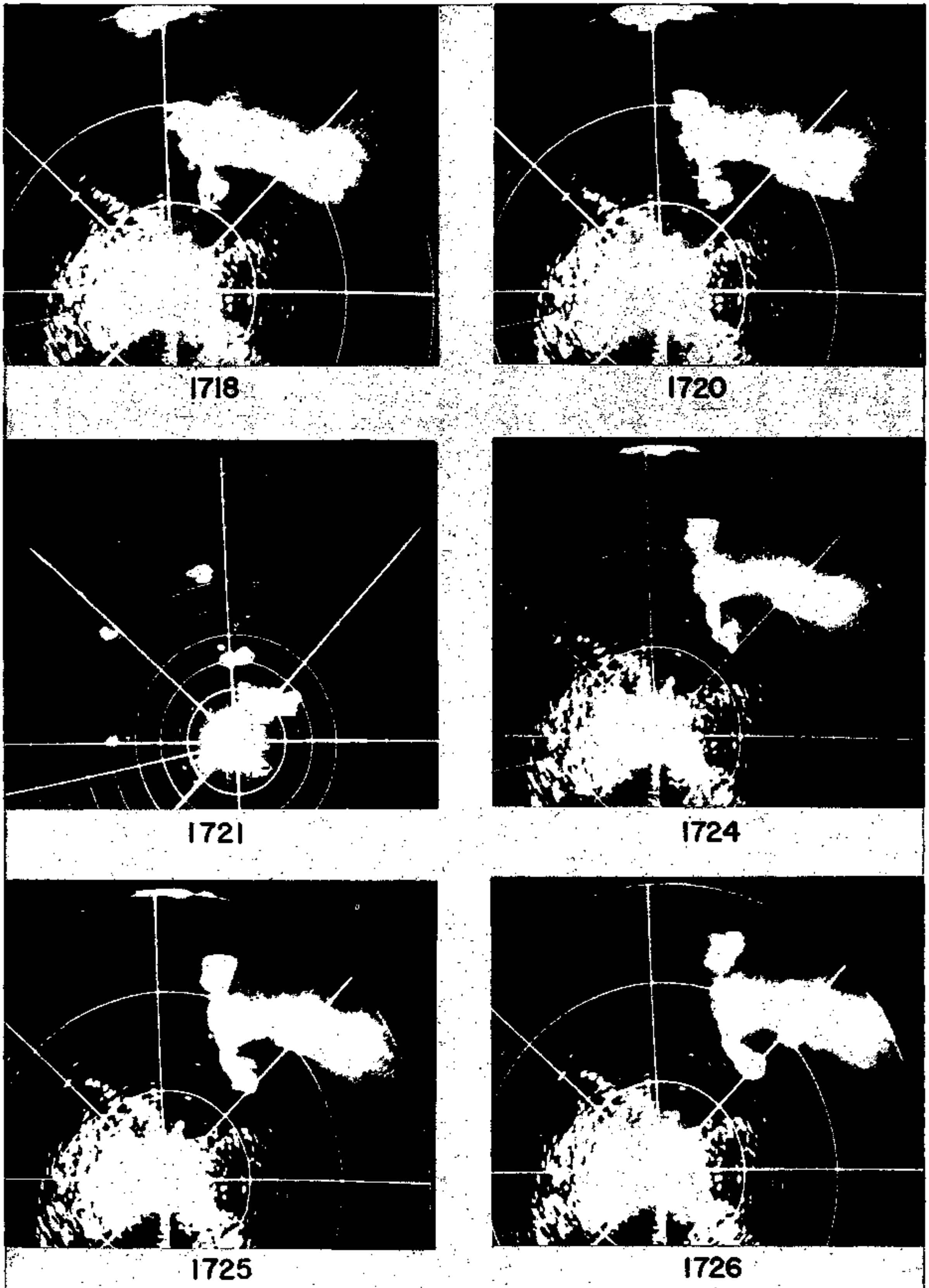


FIG 15 PPI PHOTOGRAPHS ON 9 APRIL 1953

Maximum Gain 10 Mile Markers

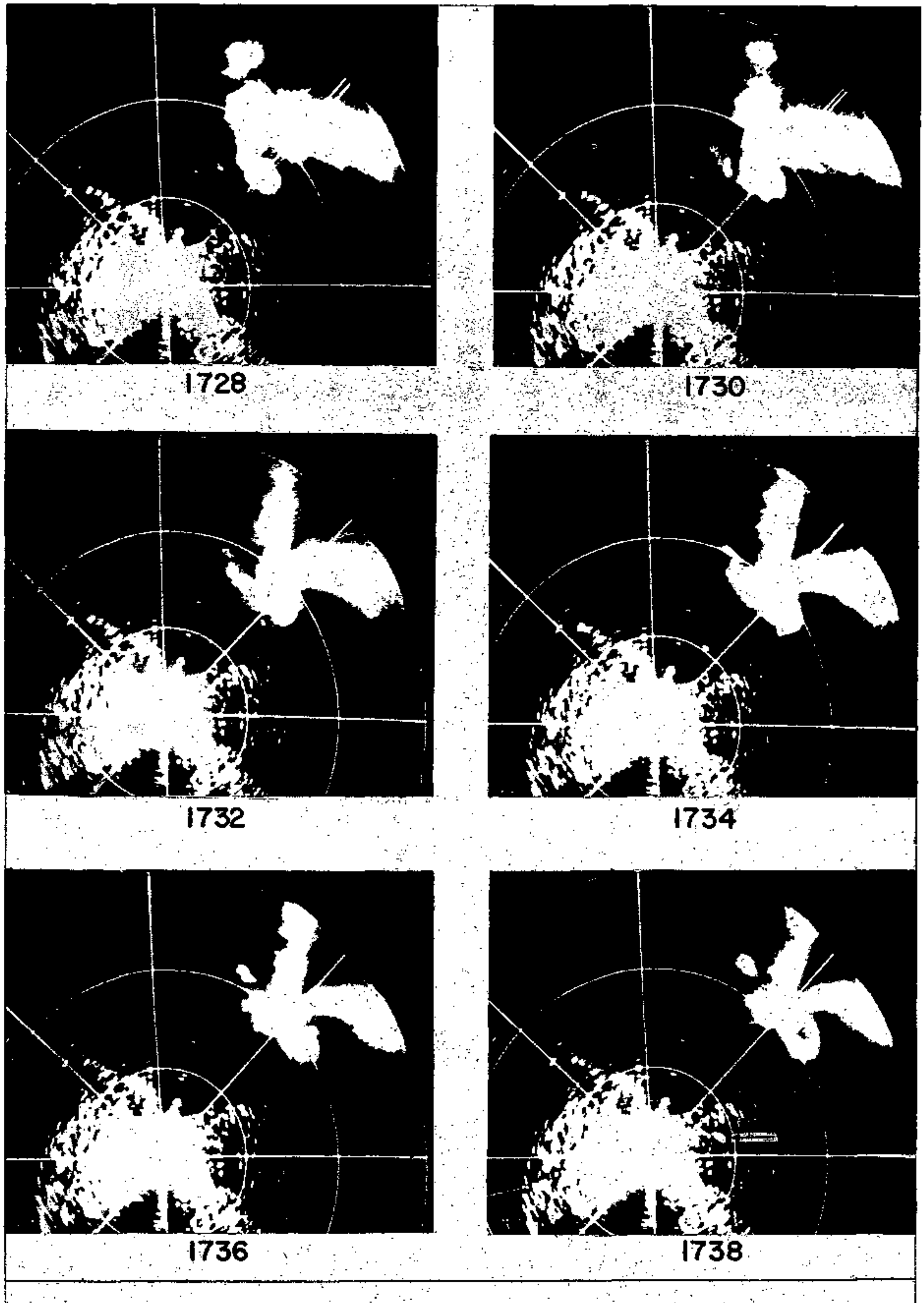


FIG. 16 PPI PHOTOGRAPHS ON 9 APRIL 1953

Maximum Gain 10 Mile Markers

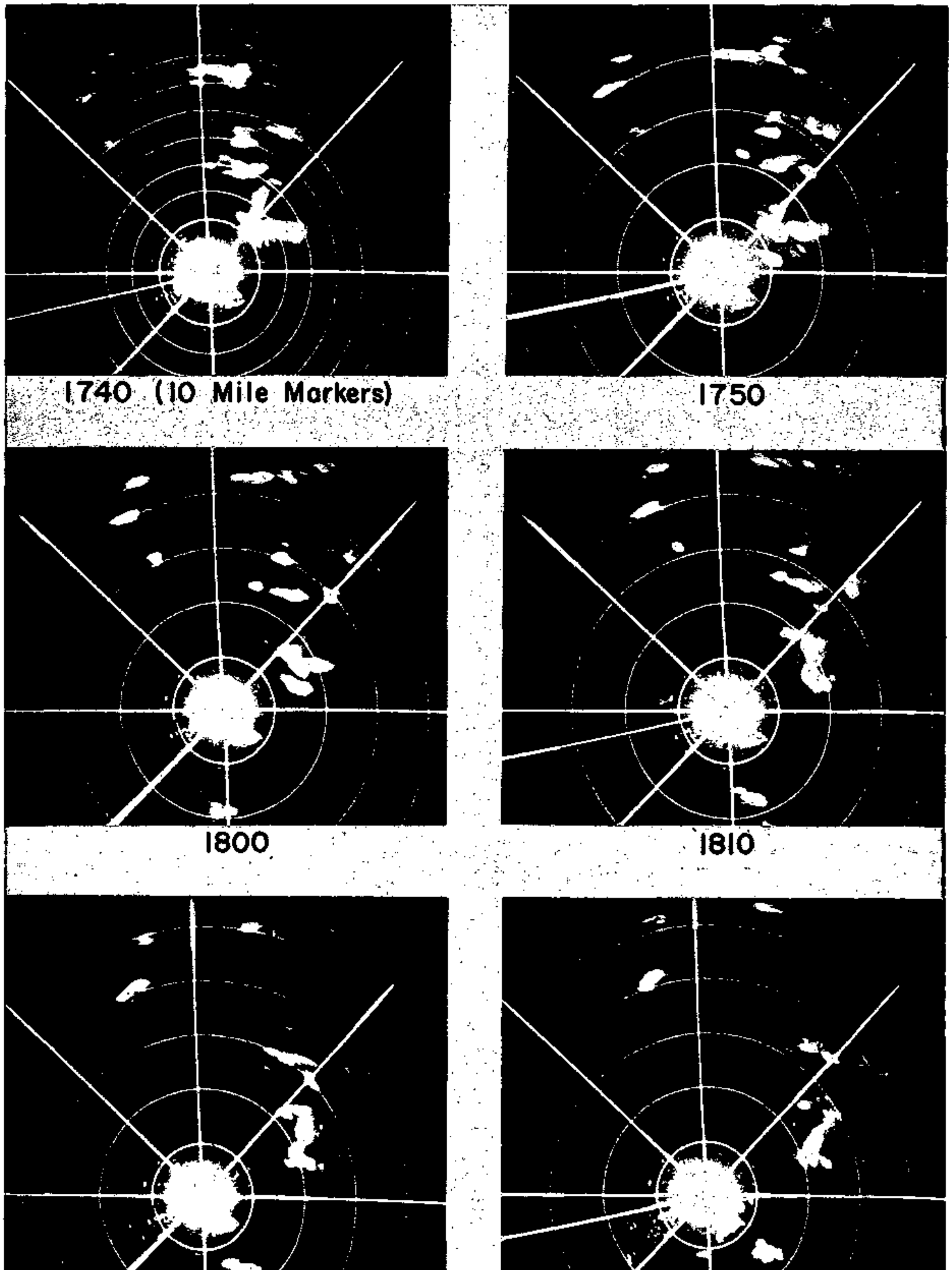


FIG 17 PPI PHOTOGRAPHS ON 9 APRIL 1953

Maximum Gain 20 Mile Markers Unless Noted

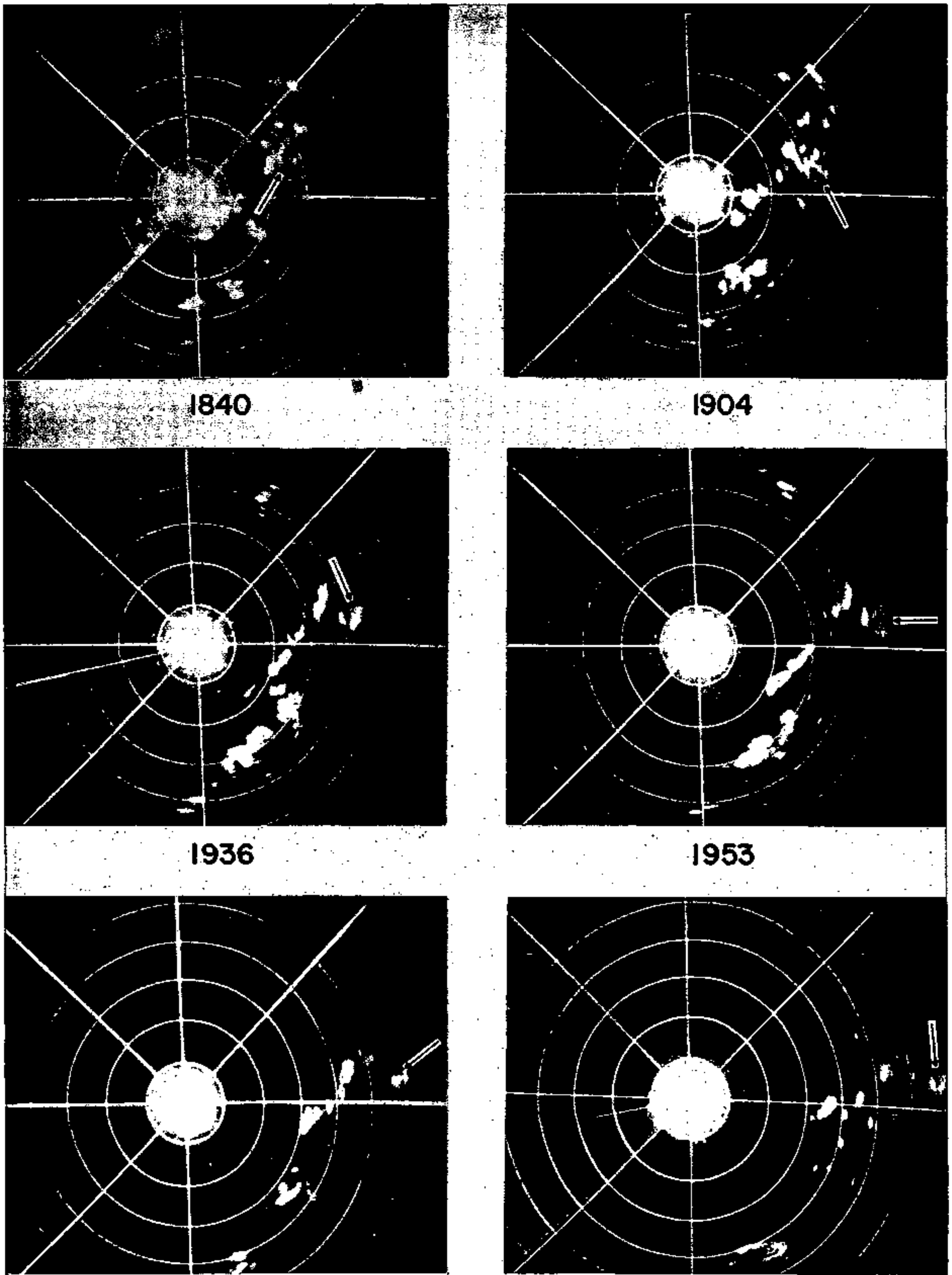


FIG 18 PPI PHOTOGRAPHS ON 9 APRIL 1953

Maximum Gain 20 Mile Markers

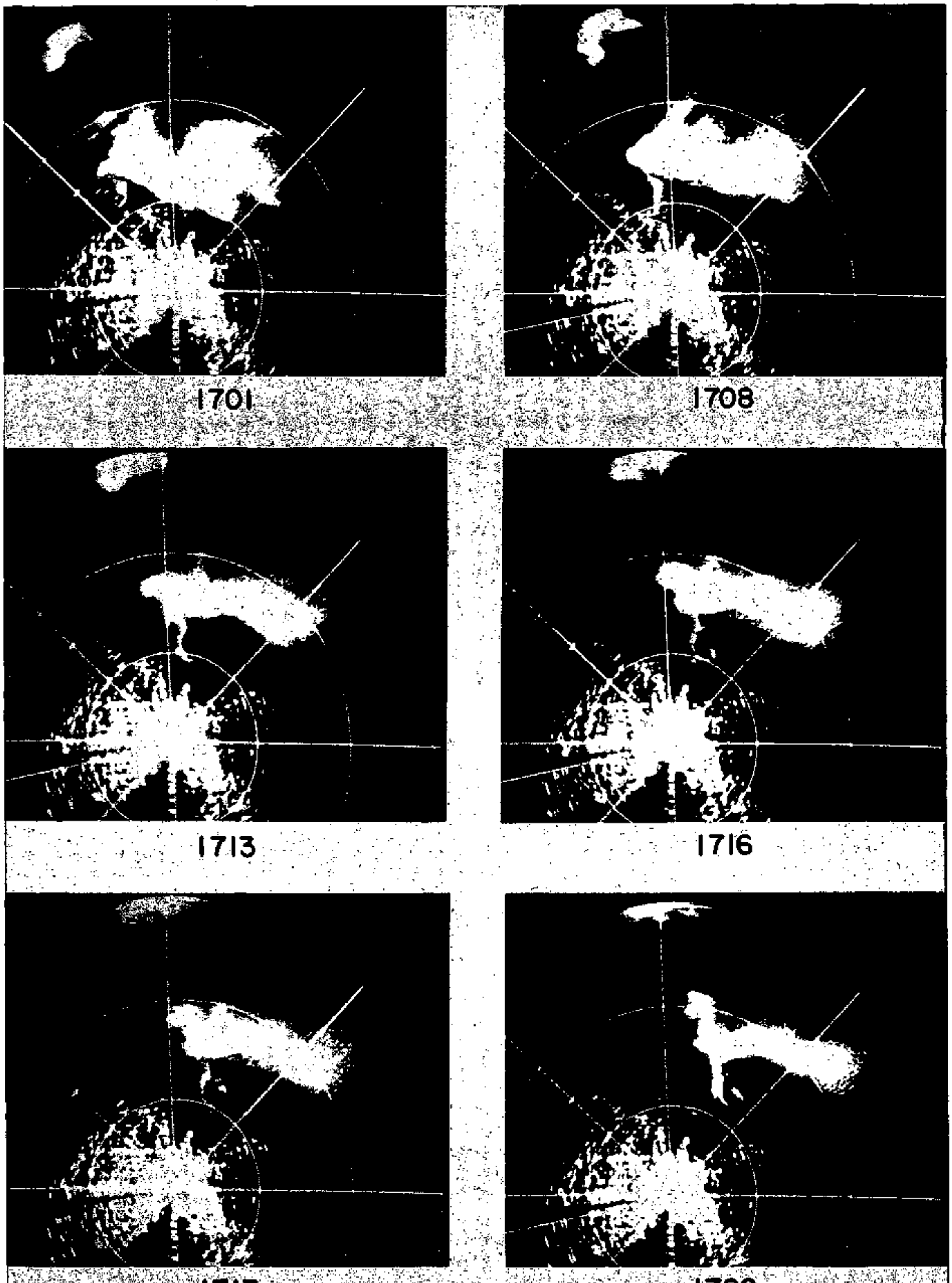


FIG 19 PPI PHOTOGRAPHS ON 9 APRIL 1953

Reduced Gain 10 Mile Markers

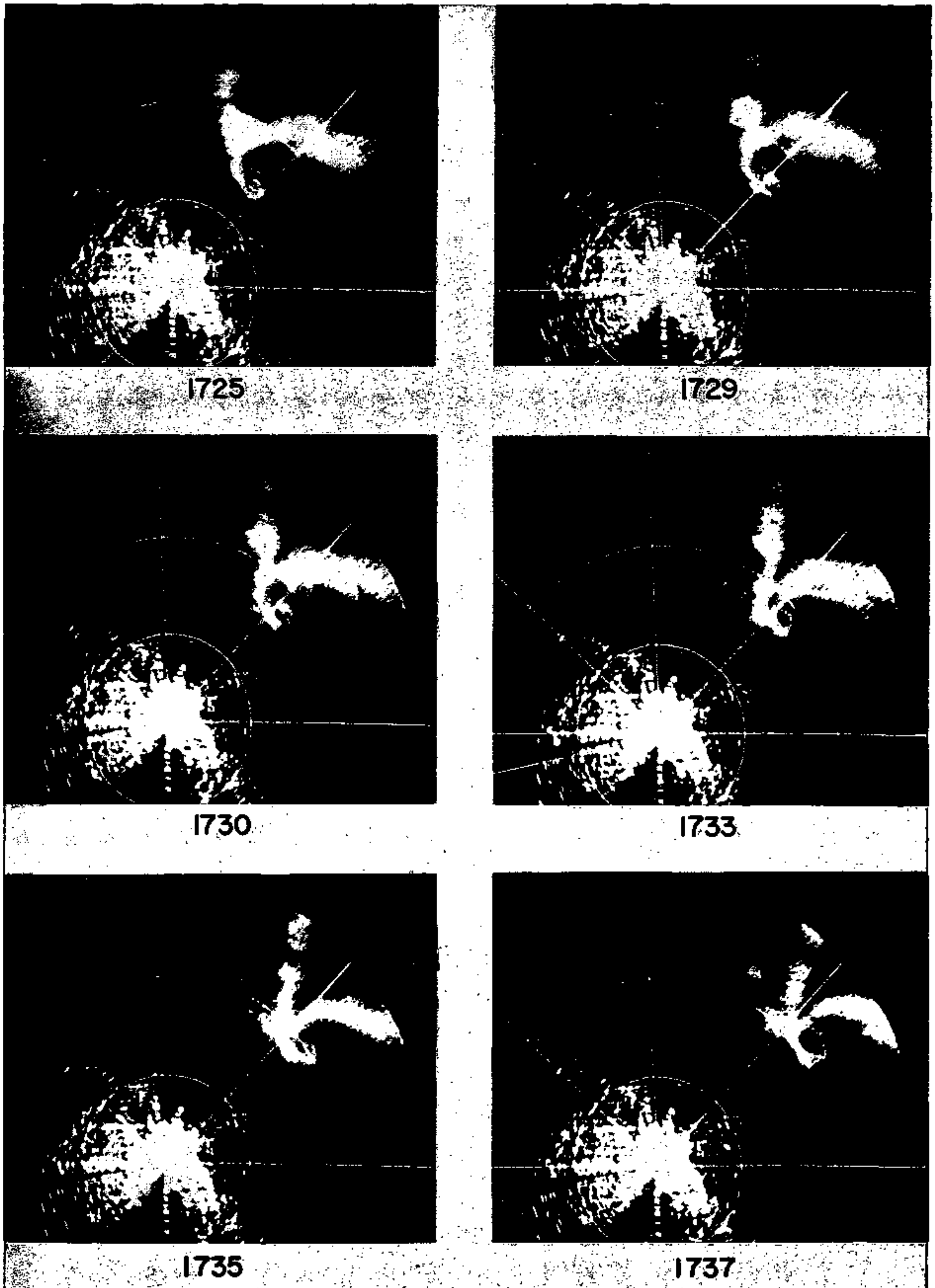


FIG 20 PPI PHOTOGRAPHS ON 9 APRIL 1953

Reduced Gain   10 Mile Markers

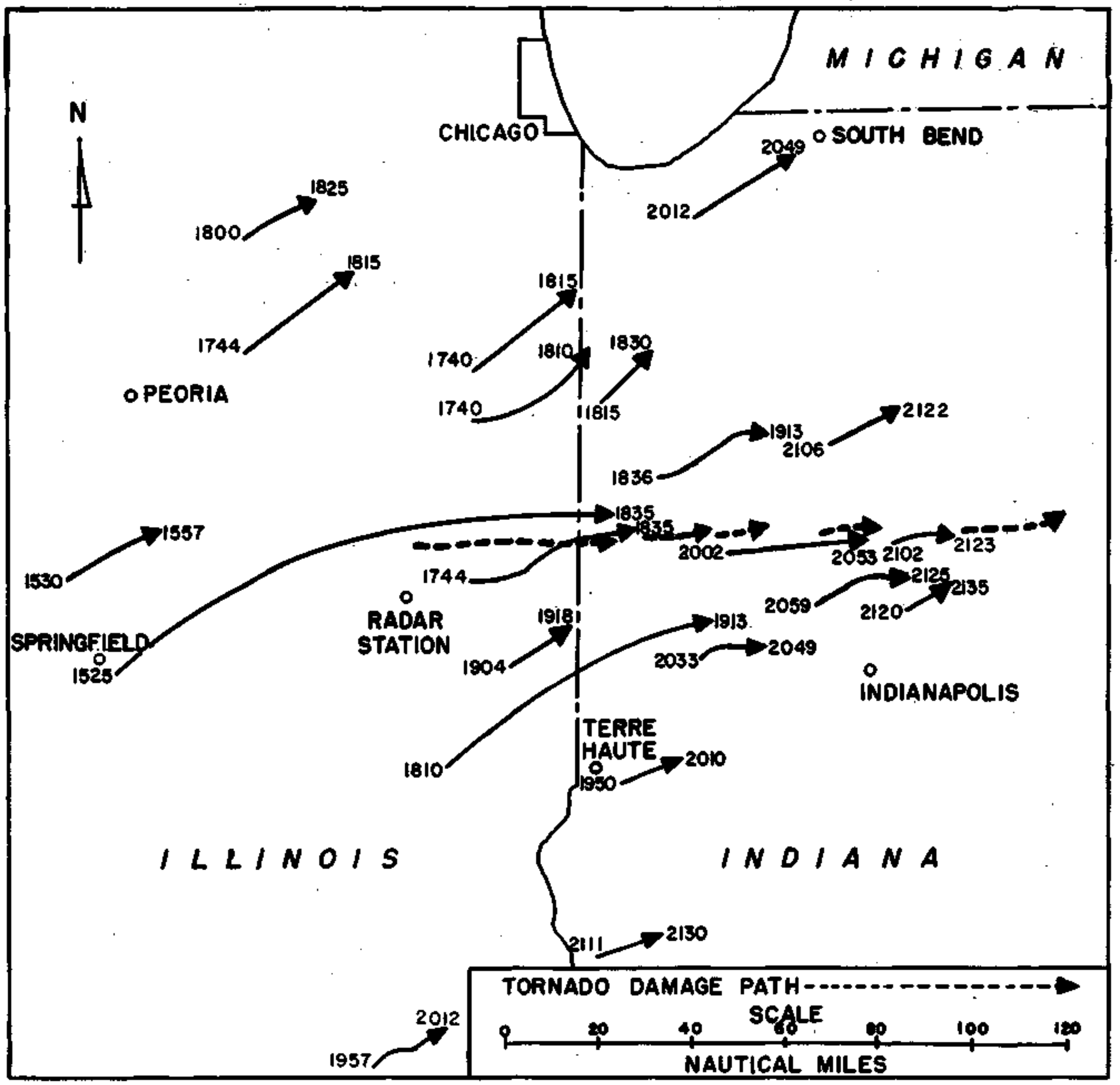


FIG. 21 PATH OF MOVEMENT OF SELECTED RADAR ECHOES
(LENGTH OF PATH DOES NOT INDICATE LIFE SPAN)

FIELD SURVEY OF DAMAGE PATH

Introduction

A field survey of the tornado damage path was made immediately after the storm. Subsequent checking was done from 1 1/2 miles west of Leverett, Illinois eastward to the Indiana-Illinois state line. On 14 April, air photographs were taken of the damage path from its origin west of Leverett, Illinois, to a point north of Linden, Indiana, about 33 miles east of the Illinois border.

Selected points of damage are shown in figure 25. The following code is used to describe the extent of damage to farmsteads on the map.

L - light damage - trees, roofs, and small buildings destroyed or damaged.

M - moderate damage - most trees and farm buildings destroyed except the strongest (usually the house).

H - heavy damage - all farm buildings totally destroyed or severely damaged.

Because of the great path width and the apparent gradation of damage across it, the space between a group of farm buildings was less significant than in tornadoes in which abrupt changes are found at the edges of a narrow path.

Discussion of Damage Path

Evidence indicates that the tornado funnel touched the ground in open fields about two miles west of Leverett, Illinois, around 1713 CST. However, the first reported damage was farther east at a point 1 1/2 miles west of Leverett (figure 25). The first damage consisted of the removal of asphalt shingles from one side of a barn roof and damage to the corner of a machine shed constructed of concrete blocks. One mile farther east, a four-room house was almost totally destroyed at 1715 CST (figures 22a and 25, #1). The foregoing times were established from stopping of an electric clock in the destroyed house and interview of Leverett residents.

The damage path indicates that the storm moved from about 250 degrees during this first part of its course. It then shifted to a 270-degree course through Leverett and to a point approximately one mile east of this town, where it again pursued a course of about 250 degrees. Several empty grain storage bins were destroyed at the Leverett elevator and were strewn over a widening path extending nearly one mile down-wind from their source. A corn crib and machine shed and numerous trees were destroyed along the path about one mile east of Leverett. After this, the funnel moved across open fields. The destruction of several billboards gave an indication of where it crossed U. S. Highway 45 (figure 25).

The next damage evidenced was quite severe (see figure 25, #2 and figure 22b). All of the farm buildings which were situated west and southwest of the house were completely destroyed, and the debris was blown northeastward against the house, leaving it badly scarred. Again the tornado passed over open fields with the only evidence of its path being wind-swept corn stalk fields and debris-laden fences. For the next seven miles, on a course from 250 degrees, the observed damage to farm buildings was slightly less severe than shown in figure 22b, but was continuous and was found over an ever widening path.

At No. 3 (figure 25), the damage began to show signs of an increase in severity as well as in extent of path width. The degree of observed damage reached a maximum in Illinois about the time the funnel crossed Illinois route 49. The damage path then began to curve toward the east on a course from 265 degrees. The maximum of continuous damage produced by the tornado in Illinois was found over a five-mile stretch beginning one mile west of Illinois route 49, about 18 miles east of the point of first damage. Portions of this severe damage are shown in the aerial photographs in figure 26. Ground photos (figure 22c-d) also show some of the damage to farm buildings. The tornado probably attained equal degrees of destructiveness at other points farther east; however, its course at the time of maximum observed damage followed an east-west road so that numerous consecutive farmsteads were almost totally destroyed. The left photograph in figure 23 shows a portion of a north-south woven-wire fence which was twisted to the size of a steel cable. The right photograph shows a similar undisturbed eight-strand fence for purposes of comparison.

During this and later periods of the tornado's history, excellent evidence of low level convergence of the winds into the storm center was found in the damage pattern, as shown by the arrows on the aerial photographs of figures 26 and 27. Figure 26a shows a farm house located at No..4 on the damage map, on the north side of the damage path, which was lifted from its foundation, rotated, and carried about 50 feet to the south. Also, this photograph shows trees toppled to the south and a small poultry house in the foreground which was moved south. One tree in the foreground, toppled to the southeast, had been cut down prior to the tornado. Figure 26b shows trees along the east-west road at No. 5 in figure 25, in the center of the damage path, toppled to the east; while those 1/4 mile to the north, at the left portion of the photograph, were all toppled to the south indicating winds converging toward the center and rotating cyclonically. Some of the farm houses on the north edge of the path in this vicinity had fine mud spray driven against their north sides indicating strong north winds. The mud spray must have been formed by an airborne mixture of dust and fine rain droplets because the ground was dry and little or no rain reached the ground in the tornado path.

Figure 27a shows an aerial view of the wooded valley of the Middle Fork of the Vermillion River, where a discontinuity in the tornado damage path occurred. As the tornado entered the valley from the foreground there is evidence of convergence as before. Trees to the north and south of the path were toppled inward toward the center. Up to this point nearly all debris was strewn toward the east, and most of the trees and buildings evidencing the convergence also showed an eastward component of motion. As the storm crossed this valley a sudden change in the damage pattern occurred. The most obvious thing is the lack of damage directly across the valley in the background in the aerial photograph. The field survey showed that the damage path suddenly shifted to the north about 3/8 mile (figure 25), and the direction of debris scatter was reversed, taking on an east to west orientation. This debris scatter is not shown in figure 27a but lies to the north (left) of the view shown. About 75 trees in a 30-acre tract of land, just east of the stream and north of the previous line of tornado damage, were toppled toward the west. Also, the west wall of a concrete block garage was blown out to the west, and a farm house was shifted on its foundation toward the west.

Farther east beyond the stream, the damage path veered slightly to the southeast over a course about six miles in length. About one mile west of the North Fork of the Vermillion River it again shifted to an easterly course. The first 1 1/2 miles of the six-mile course beyond the Middle Fork of the Vermillion River lay mostly over open fields and not much evidence was obtainable (see background in figure 27a). Beyond this, moderate to heavy damage to farmsteads was again in evidence and continued into Indiana with a predominant eastward toppling and scatter of debris.

The aerial photograph in figure 27b shows damage along the path after the course changed to east again. This photograph shows the North Fork of the Vermillion River near Bismark, Illinois (figure 25). Here there is evidence of convergence and a trend of debris toppling and scatter toward the east, as was found much earlier in the storm's history before the discontinuity in damage at the Middle Fork of the Vermillion River.

During the latter half of the tornado's traverse in Illinois, covering the expanse from Illinois route 49 eastward to the Indiana border, the average width of the path of moderate to heavy destruction was about 0.6 mile. By the time the tornado reached the Bismark area, its width of damage had increased considerably. Moderate to heavy damage was found over a path 0.6 to 1 mile wide, and light damage was noted over a path up to about 2 miles in width. Light damage was found in Jamesburg and Bismark north of the path (figure 25) and on farmsteads south of the path.

This tornado, or another originating in the same group of radar echoes, continued in a general eastward direction to the vicinity of Albany, Indiana, giving a total destructive path length of about 140 nautical miles (160 statute miles). The Water Survey did not conduct a survey of the path in Indiana. The U. S. Weather Bureau's map[4] of that portion of the tornado path is shown in figure 21.

The total storm damage in Illinois produced by this tornado was estimated at about 4 million dollars , mostly to farmsteads but some to livestock and to grain in storage.

Summary of Survey

Results of the damage path survey indicate the tornado pursued an east-northeasterly to easterly path across Illinois, beginning in the vicinity of Leverett. U. S. Weather Bureau reports indicate the same tornado, or another originating in the same storm area, moved in an easterly direction across central Indiana to the vicinity of Albany. The total length of the Illinois-Indiana destructive path was about 140 nautical miles.

Evidence of cyclonic rotation was found after the storm had reached a maximum of intensity in Illinois and the path had widened sufficiently to include moderate to heavy damage over a distance up to 1 mile. The maximum level of destruction in Illinois occurred after the tornado had progressed about 18 miles from its point of first damage.

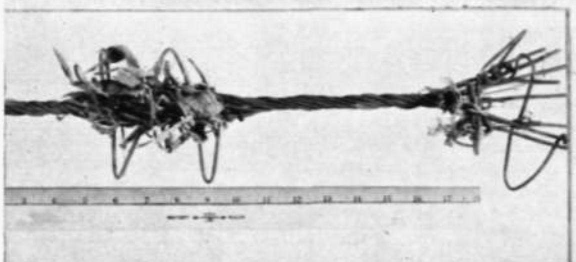
a. First House Destroyed ½ Mile West of Leverett

b. All Buildings Destroyed Except House One Mile East of U.S.45

c. All Buildings Destroyed Except Barn ½ Mile East of Ill.49

d. All Farm Buildings Destroyed One Mile East of Ill.49

FIG. 22 EXAMPLES OF TORNADO DAMAGE



a. Portion of Woven Wire Fence Twisted by Tornado

b. Portion of a Similar 8-Strand Fence

FIG. 23 TORNADO-TWISTED FENCE

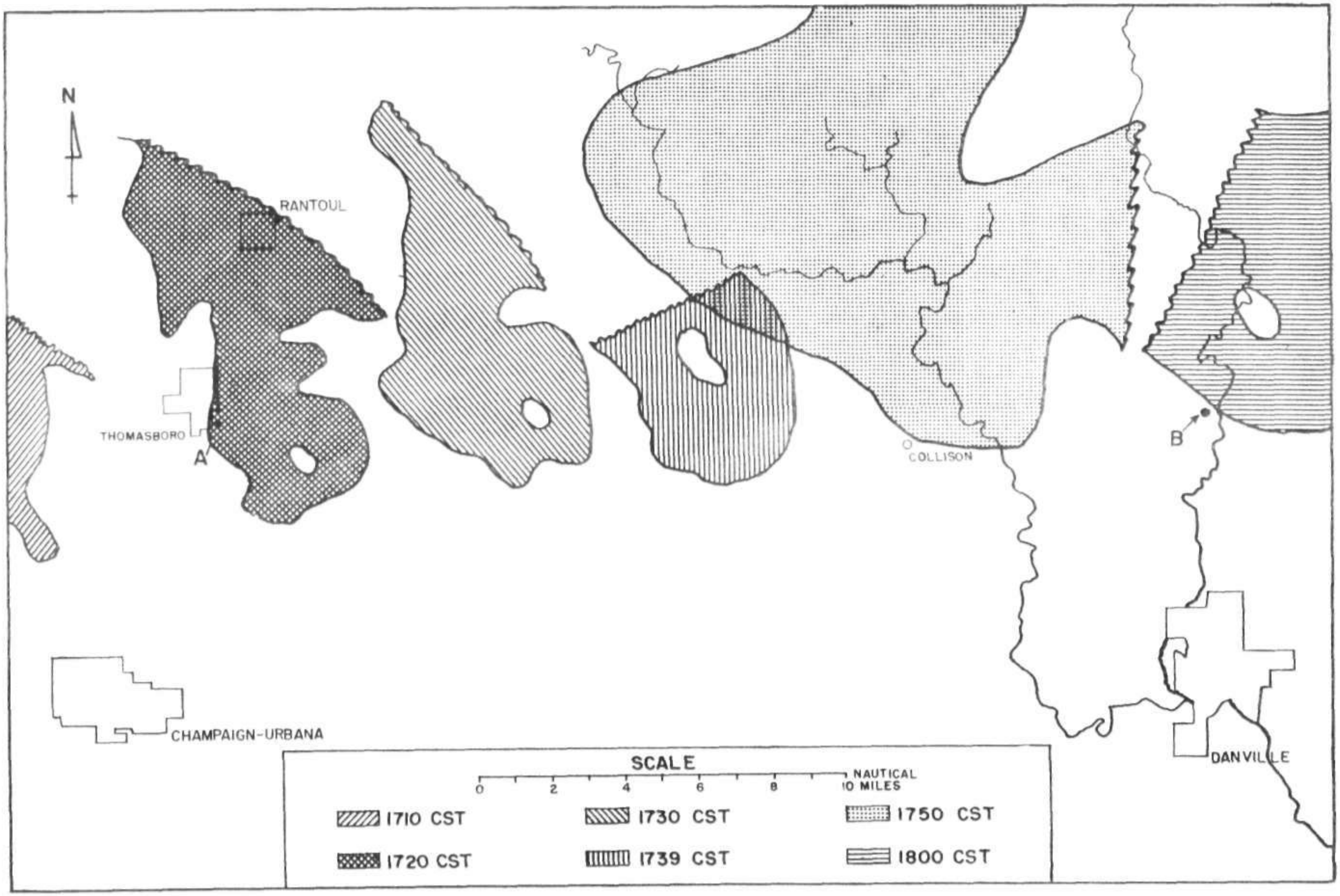


FIG. 24 POSITION OF TORNADO ECHO AT SELECTED TIMES

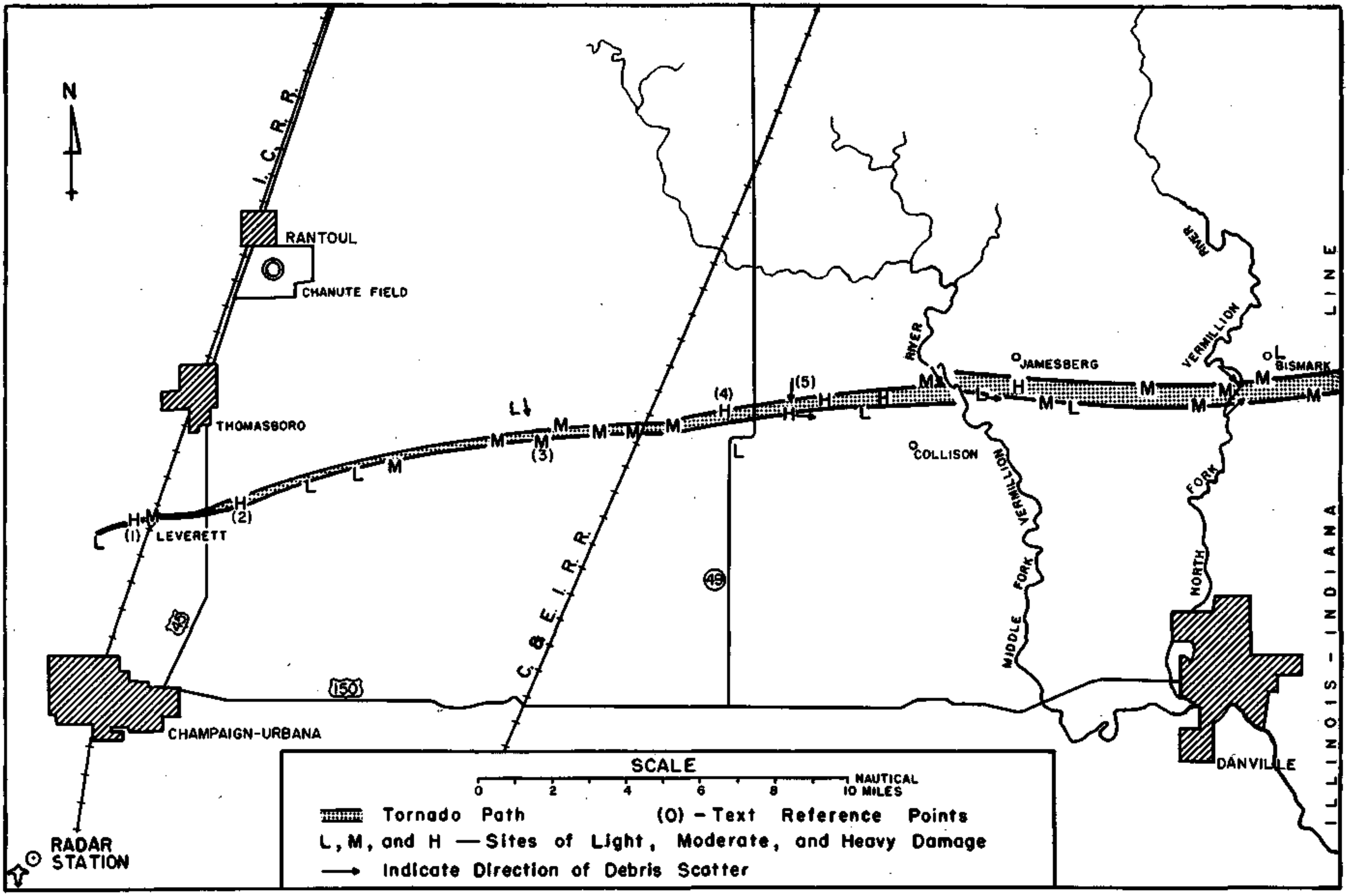
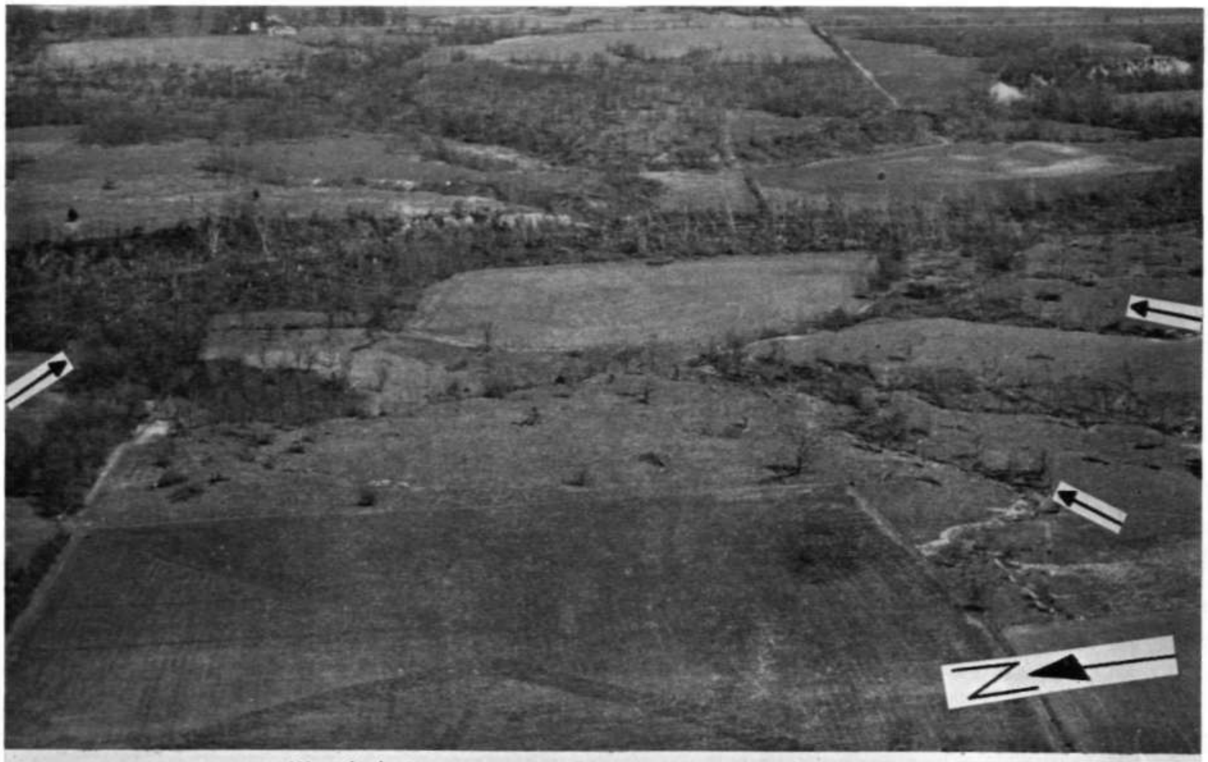


FIG. 25 TORNADO DAMAGE PATH MAP

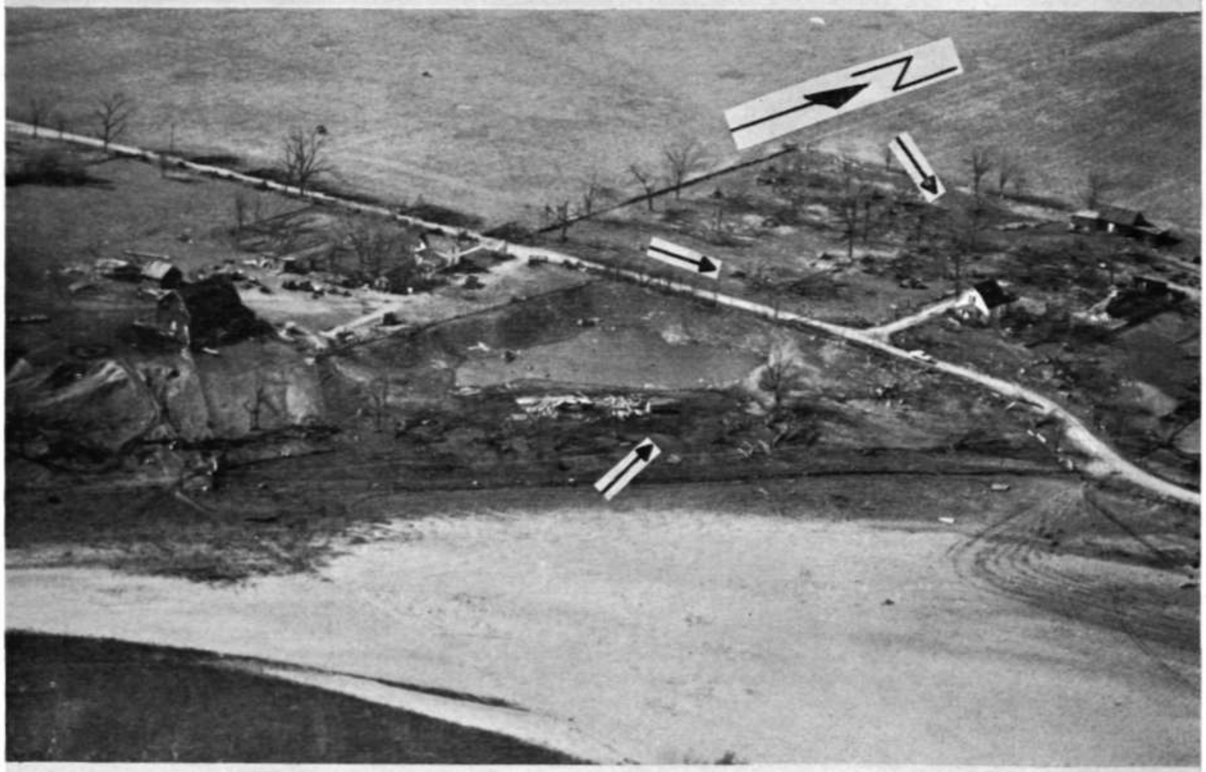
a. Farmstead, One Mile West Illinois Highway 49, North Edge Of Damage Path

b. Farmsteads, One and One Fourth Miles East Of Illinois Highway 49, Near Center Of Path

FIG. 26 AIR PHOTOGRAPHS WITH ARROWS INDICATING DIRECTION OF DEBRIS SCATTER



a. Wooded Area Along Middle Fork Of Vermillion River, Damage Path Shifted To Left Across Stream Valley



b. Farmsteads Along North Fork Of Vermillion River Near Center Of Path

FIG. 27 AIR PHOTOGRAPHS WITH ARROWS INDICATING DIRECTION OF DEBRIS SCATTER

PHYSICAL ASPECTS OF TORNADO

Comparison of Radar Presentation With Surface Path

The position of the tornado echo at 10-minute intervals between 1710 CST and 1800 CST is shown on the overlay in figure 24. This overlay, which has the same scale as figure 25, facilitates comparison of the damage path and tornado echo data. Only the significant portion of the tornado echo, as indicated by the jagged cutoff line, has been shown to avoid overlapping in successive plottings of the echo position.

The tracing at 1710 CST shows the position of the tornado echo about three minutes before the first significant surface damage occurred. By 1720 CST, the tornado had become well developed, and the next two plottings show the tornado echo position when it appeared to be at a peak intensity during its traverse of Illinois.

The weak spots or "eyes" shown in the tracings in figure 24 were located by using some photographs on lower gain, usually step 3 on the radar. Field survey evidence of the damage path indicates that this weak spot or "eye" in the radar echo does not represent the actual center of the surface tornado funnel, For this reason, some of the irregularities in the path of the "eye" do not necessarily represent shifts in the actual path of the surface tornado. The "eye" is probably a manifestation of a larger circulation aloft rather than the lower extremities of the funnel, as will be discussed in connection with figures 28 and 29. The most significant feature is that the "eye" of the radar echo remained north of the damage path.

Figures 28 and 29 show the tornado as observed from points A and B of figure 24. The motion picture used in assembling figure 28 was taken by Capt. John H. Yancy, while the photographs in figure 29 were made by Mr. Paul Meradith. In figure 28, the approximate width of the visible funnel is 5500 feet and the height of the main cloud base is about 2900 feet. These values were computed trigonometrically by use of parameters of Capt. Yancy's 8-mm Revere "Ranger" movie camera and the known distance from the observer to the damage path of the tornado. The small marks on the photographs in figures 28-29 indicate where measurements used in computation of the funnel width were made.

The radar tornado echo on step 1 at 1720 CST was about three miles in diameter or approximately three times that of the visual funnel in figure 28. This can be attributed mainly to radar return from upper portions of the cloud, although some effects of beam width and pulse length "stretching" of the echo are also present. In scanning across a target, beam width effects cause the PPI echo width to be slightly greater than the actual width of the reflecting target; likewise, the length of the pulse adds slightly to the true depth of the target. Assuming the radar was receiving return to an elevation of six degrees above the horizon (see radar section), the top of the beam would have been at about 6000 feet at the range of the tornado echo at 1720 CST. Figure 29a gives a good overall picture of the clouds above and beyond the visible funnel, portions of which probably were detected by the radar.

All of the following computed cloud widths from the photographs in figure 29 were made by using parameters of Mr. Meradith's 35-mm Leica camera, image sizes, and the estimated distances from the photographer to the tornado. The estimates of distance from the photographer to the tornado were made from two considerations: the intercepts of the damage path with the azimuth along which the photographs were taken, and the approximate times at which the photographs were taken. The results are less reliable than those for figure 28, in which the distance was more definitely established.

The photograph in figure 29a was taken about 1745 CST shortly after the tornado crossed the Middle Fork of the Vermillion River, where a shift in path and a decrease in extent of damage were noted. By 1745 CST, the radar echo of the tornado was more than four miles in diameter. Figure 29a shows a broad funnel or protrusion from the cloud, 10,400 feet in diameter, extending some distance below the main clous base;"a much smaller funnel, 1500 feet in diameter, extends from the flat base of the broad portion to the ground. Measurements were made across the darkest portion of the funnel as shown in figure 29. The radar at this time was probably getting a high percentage of its return power from the broad upper portions of the funnel and the main cloud. The indication that the lower extremity of the funnel is smaller in figure 29a than it was earlier in figure 28 may be related to the change in extent and direction of the damage path which had just occurred at the Middle Fork of the Vermillion River.

Figures 29b and 29c were taken about 1752 CST. In both of these photographs the lower portion of the funnel is about 2200 feet in diameter, wider than in figure 29a but still narrower than shown in figure 28. The path of moderate to heavy damage at this time was about 0.6 mile in width. This width of damage might be explained by a whipping motion of the funnel, or strong winds outside the dark portion of the funnel.

Figures 28, 29a and 29b show light sky to the west and south of the tornado where scattered clouds existed. Figure 29c shows a dark cloud mass approaching from the south (left in the photograph) which may be a part of the large echo that developed east of Urbana about 1738 CST and slowly converged with the tornado shortly after 1800 CST (figure 17). This echo to the south is not shown in figure 24 since it did not merge with the tornado echo until a later time than is presented in the sequence. As the Urbana echo approached the tornado echo a change in the direction of the damage path occurred. This change in direction took place about one mile west of the Middle Fork of the Vermillion River (figure 25). The actual merger of the converging echo with that of the tornado took place east of this point; however, the two incidences may still have been related.

<u>Precipitation and Clouds Accompanying Tornado</u>

The associated thunderstorm cloud was producing rain and hail north of the tornado echo during the early stages of surface damage. Observations of hail in the tornado echo, 1 to 2 miles north of the damage path, were made around 1730 CST. About 1740 CST, heavy hail was reported along the actual damage path with the approach of the funnel. By this time the radar tornado echo had grown to such an extent that it enveloped most of the southern portion of the parent cloud. Mud deposits on buildings, where little or no rain occurred, indicated that there must have been large quantities of suspended rain drops in the tornado funnel which were mixed with blowing dust and wind-driven against the buildings. There were no raingages along the damage path.

The clouds in both figures 28 and 29 have a billowing or mammatus appearance. This agrees with observations by experienced weather observers at Champaign and Chanute Field. Capt. Yancy, who took the movies used in figure 28, reported that the clouds overhead, at point A on the map in figure 24, indicated tremendous turbulence by their boiling motion. He also reported the occurrence of some rain and light hail about 1710 CST; at this time, his position was near the southern edge of the associated thunderstorm echo. No unusual electrical activity was reported with the tornado.

FIG. 28 TORNADO AS OBSERVED FROM POSITION "A" BETWEEN 1715 AND 1720 CST LOOKING SOUTH

a. Funnel Approximately 7 Miles Away

b. Funnel Approximately $2\frac{1}{2}$ Miles Away

c. Funnel Approximately 2 Miles Away

FIG. 29 TORNADO AS OBSERVED FROM POSITION "B" BETWEEN 1745 AND 1800 C.S.T. LOOKING WEST-NORTHWEST

CONCLUSIONS

1. Radar is capable of detecting and tracking tornado-producing echoes under favorable conditions, thus providing a valuable tool for tornado research.

2. The appearance of an appendage on a precipitation echo is not a rare occurrence and does not necessarily denote the presence of a tornado. For example, appendages were observed on several echoes outside of the tornado area on 9 April. Also, there is insufficient evidence at present to conclude that tornadoes occur only in conjunction with an appendage or a parasite echo (tornado echo) along the associated precipitation echo. Observations and photographs appearing in the literature indicate that tornadoes may also originate from within the associated cloud. Furthermore, when a tornado echo is present, attenuation due to range and intervening precipitation may appreciably reduce the effective detection range of the tornado echo. This is especially true with 3-cm radar where precipitation attenuation may be significant.

3. However, the Illinois observations and others made later in 1953 show that well-defined tornado echoes do sometimes occur. The continued growth of a parasite echo or appendage with development of cyclonic curl and/or an "eye", such as in the Illinois tornado, may be a positive indication of a tornado. However, more data are needed before the utility and limitations of radar in tornado detection can be defined. Possibly large tornadoes, such as the tornado cyclone mentioned by Brooks , are typified by the Illinois tornado while small tornadoes originate from within the associated thunderstorm cloud. (Large here refers to tornado size and not necessarily the associated property damage).

4. Although radar is capable of detecting a tornado-producing echo and its associated thunderstorm echo, the present data do not indicate that the exact position of the surface tornado funnel can be visually observed within the tornado echo mass on the radar scope. The radar integrates the echo mass within the volume of its beam, and in the case of the 9 April tornado, the areal extent of the surface funnel was much less than that of the tornado-producing echo, although the size of the surface funnel was considerably greater than the average for tornadoes. However, as more data are collected, some means of positioning the surface funnel within the echo mass may be revealed.

5. The use of radar having both plan-position indicators and range-height indicators is desirable for the collection of tornado research data, so that a three-dimensional picture of the storms can be obtained.

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