Measurements of Radio Frequency Noise from Severe and Nonsevere Thunderstorms[1]

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ABSTRACT

Thunderstorm radio noise measurements at several frequencies in the range 0.01–74 MHz have been made with specially designed remote recording stations in Iowa. The data were recorded during the spring and summer of 1974 when a series of severe storm systems produced a great number of large hail and tornado reports in Iowa. Computer analyses were made of nearly a billion bits of data, corresponding to 170 h of real-time recordings. Careful compilations of surface severe weather reports, hail damage information from insurance companies, and studies on the Des Moines WSR-57 radar echoes were compared with the analyzed radio noise data. The results include the following:

1) In agreement with earlier work, large-amplitude radio noise impulse rates were found to be generally good indicators of thunderstorm severity. Although the majority of the radio energy radiated from major lightning strokes occurs in the 0.01 MHz range, this frequency was found to be a poor indicator of storm severity; the higher frequencies (megahertz range) were considerably better. The character of the noise appears similar at 2.5 and 74 MHz.

2) In at least five cases, tornadic events correlated in time with radio noise count rate peaks. One funnel cloud was reported equidistant at 60 km from two recording stations and coincident with count rate peaks at both stations, lending credence to the idea that the peak was associated with the storm occurrence, rather than with corona or other local effects.

3) No unusual radio noise was recorded during the lifetime of a small, verified tornado at 19 km range. In addition, the count rates for its parent thunderstorm would not have indicated severity.

In spite of inherent atmospheric variableness, the radio noise technique is a useful complementary indicator of storm severity.

1. Introduction

The investigation of the possible detection of severe storms by passive radio techniques has had a long and varied history. The early work was concentrated mainly at frequencies near 10 kHz, where the peak amplitudes are emitted from major lightning-stroke processes. While it was found that thunderstorms could be located reasonably well by direction-finding techniques, further work at these frequencies showed that the VLF range could not reliably distinguish between tornadic and nontornadic thunderstorms. In the 1950's, Jones (1951, 1958) published the results of investigations near 150 kHz. These reports indicated that frequencies higher than 10 kHz were better indicators of tornadic activity. Later, Ward *et al.* (1965) studied radio noise pulse rates at 500 kHz for a number of severe Oklahoma storms. They found correlation with several tornadoes, but also noted that the pulse rates were quite variable with respect to severe weather events, many features in their data not being associated with severe storm reports. Perhaps as a result of the variableness of the latter results, as well as other factors, this area of research suffered a decline in interest for several years. Interest was revived in the late 1960's by accounts of a method for identifying tornadoes with a television set, as described by Waite and Weller (1969).

Reviews of the great amount of work done concerning electromagnetic noise from ordinary thunderstorms have been given by Horner (1964), Oetzel and Pierce (1969), Pierce (1969) and Uman (1969). More recently, results have been reported from several investigations of electromagnetic noise from severe thunderstorms at frequencies above 1 MHz. Among the latter are the recent works by Stanford *et al.* (1971), Lind *et al.* (1972), Taylor (1972, 1973; 1975), Trost and Nomikos (1975) and Grenecker *et al.* (1976).

The present paper reports the results of radio noise measurements at several frequencies in the range 0.01–74 MHz from remote recording stations in Iowa.

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The analyses deal with data recorded during 1974 when a series of severe storm systems produced a great number of large hail and tornado reports in Iowa.

2. Equipment

Four recording stations were designed and constructed in our laboratory. One of the stations was located at the ISU physics building; the other three were in rural locations—a small-town bank (Clarion, Iowa, 90 km north of Ames), a small-town airport (Chariton, 130 km south) and a farm site (Churdan, 80 km west).

a. Antenna

The antenna consisted of a 1 m vertical whip above a ground plane having four 1 m radials secured to a 0.3 m square aluminum base plate. The radials and whip were aluminum tubing. The whip, tipped with a brass ball to reduce corona discharge, was enclosed in a plexiglass cylinder, hermetically sealed to the base plate. An antenna follower, hermetically sealed in a box on the bottom of the base plate, presented a moderately high impedance at the antenna and drove the coaxial cable to the receiver station. At the station, another follower distributed the antenna signal to the various receiver inputs.

b. Receivers

Logarithmic response receivers operating at 10 kHz, 410 kHz and 2.5 MHz were installed in all stations. Two stations also had receivers at 74 MHz. Block diagrams of the receivers appear in Fig. 1. The logarithmic amplifiers (based on solid state differential video amplifiers) had a dynamic range approaching 70 dB. The bandwidth of the 10 kHz receiver was approximately 2 kHz. A 20 μs sine wave calibration pulse at the center frequency of the bandpass was normally used for calibration of the 410 kHz and 2.5 MHz receivers. Bins 16, 12, 6 and 1 (discussed in the next section) corresponded approximately to 0, -20, -40 and -60 dB below a 1.2 V peak-to-peak pulse for both receivers. For the 10 kHz receiver a 200 μs pulse was used. The bandwidths of the 410 kHz, 2.5 MHz and 74 MHz receivers were sharply defined at 6 kHz by a multi-element ceramic filter in the 455 kHz tuned amplifiers. The amplifier stages in all the receivers had low gain such that a 20 mV m^{-1} kHz^{-1} field spectrum in the receiver bandpass would give full detector output. However, the logarithmic amplifiers extended the low-level sensitivity below 10 μV m^{-1} kHz^{-1}. The 10 kHz and 74 MHz systems were about one order of magnitude less sensitive.

The remote stations were equipped with telephone coupling devices so that a tape recorder (described

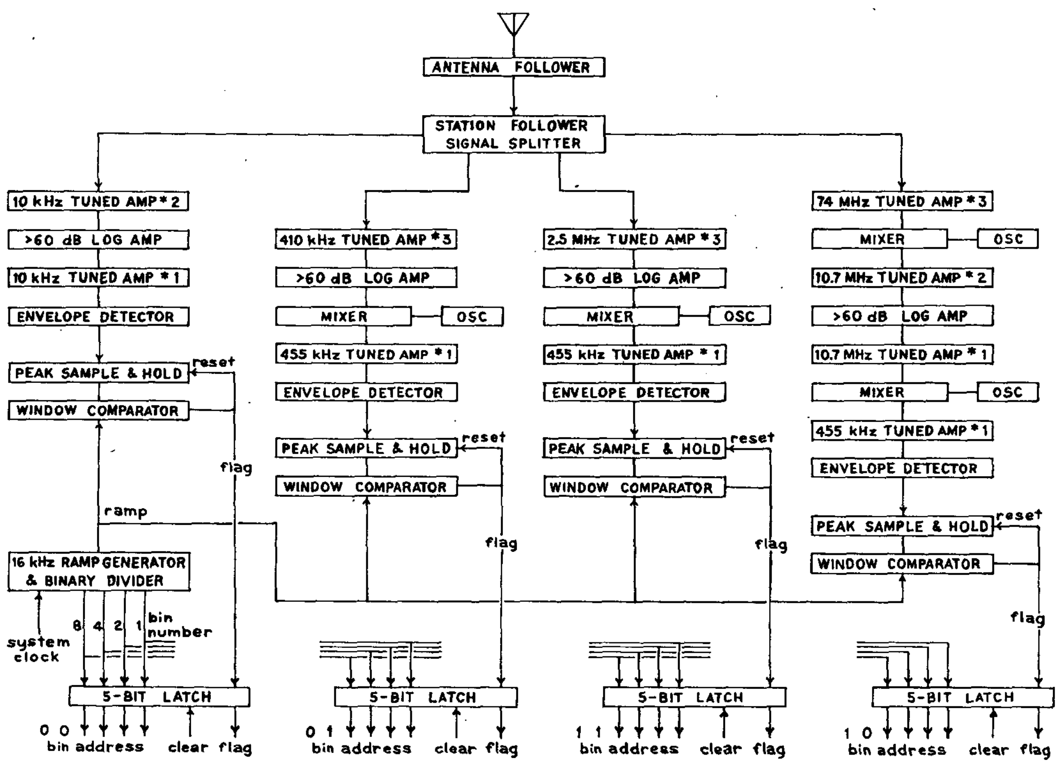

FIG. 1. Block diagram of the remote-station receivers. The number of stages in each tuned amplifier is given by *N, identified by the asterisk.

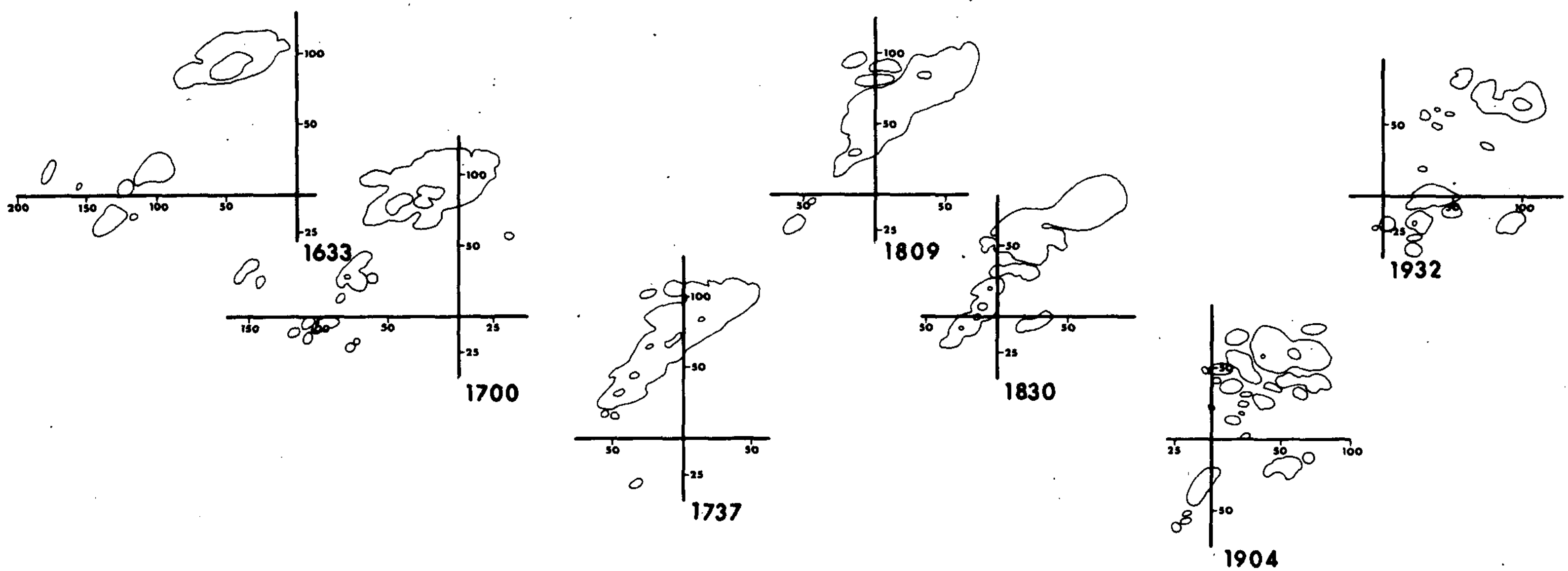

FIG. 2. Storm of 30 May 1974. Radar echo tracings are from WSR-57 radar at Des Moines, Iowa, 133 km south of the recording station at Clarion, Iowa. The intersection of the axes are located at Clarion and the numbers are distances (km) from Clarion. The inner and outer contours are generally at 33 and 0 dB attenuation, respectively. Other available attenuations near 33 dB were sometimes used to supplement time gaps in the availability of 33 dB echo photographs. Even then, the availability of higher attenuation echo data was not always assured; thus an echo tracing without an inner attenuation contour only represents a lack of attenuated data and not necessarily a variation in storm intensity. Times are CDT.

below) could be started and stopped by a tone signal sent by telephone. A third tone signal instructed the station to briefly transmit tone-coded count data via telephone back to our laboratory, to check for proper operation.

c. Pulse height analysis and data storage

Each receiver output was fed to the equivalent of a 16-channel pulse height analyzer. An output pulse passed through an attenuation and level shifting stage to a peak-sample-and-hold circuit. The peak voltage was compared to a linear ramp generated from a binary counter. When the voltage difference fell within a "window," a flag pulse reset the sample-and-hold and triggered a 5-bit latch to hold the 4-bit channel or "bin number" (from the ramp generator) plus a flag bit.

The 4-bit number plus a 2-bit receiver number formed a 6-bit bin address for one of 64 binary counters (16 for each receiver) in a 1024-bit memory. A count increment controller cycled through the four receiver data channels, and when a flag bit was encountered, the particular bin count was incremented; then the 5-bit latch was cleared and the controller cycled onto the next flag. Each bin can accumulate $2^{16}-1 = 65\,535$ counts, far more than experimentally required. Atmospheric pulses were counted in 10 s blocks; at the end of each block the count data were transferred (in a few milliseconds) to a 1024-bit shift register. Then, while the next 10 s of pulses were being counted, the count data in the shift register plus a timing sequence number were transferred via a tone code onto $\frac{1}{4}$ inch magnetic tape on a stereo tape recorder modified for reduced speed and remote control. One 7-inch tape reel could hold approximately 20 h of storm data; tapes were replaced when nearly full.

The maximum pulse counting rates were limited by the receiver bandwidths and not by the cycle time of the count increment controller. For the 410 kHz, 2.5 MHz and 74 MHz receivers, the 6 kHz bandwidth (set by the ceramic filters) limited count rates to about 3000 s^{-1}. For a few very strong storms this limitation was reached, but even then only the lowest amplitude pulses were lost. The 10 kHz receiver's 2 kHz bandwidth limited its counting rate to about 1000 s^{-1} and the count totals in its low-amplitude bins showed saturation for many strong storms.

The $\frac{1}{4}$ inch magnetic tapes were returned to Ames and converted to computer-compatible digital tapes for more permanent storage. The ISU IBM-360 computer was then utilized for data analysis and plotting.

3. Severe weather reports

An exhaustive survey was made of all reports of severe weather occurring in Iowa in 1974. The resulting compilation is of interest in its own right and has been published elsewhere (Eshelman and Stanford, 1977). In addition, radar plots were made from the Des Moines' WSR-57 radar and hail-swath damage locations were plotted from data obtained from insurance companies. All these information sources were then used to compare with the results of the analyzed radio-noise data.

4. Results

In spite of technical difficulties (including nearby lightning strikes which destroyed portions of the electronics in two stations), about 200 h of real-time data were recorded. Of these, approximately 170 h of data were eventually selected for detailed computer analysis and study, mostly from the stations at Ames and

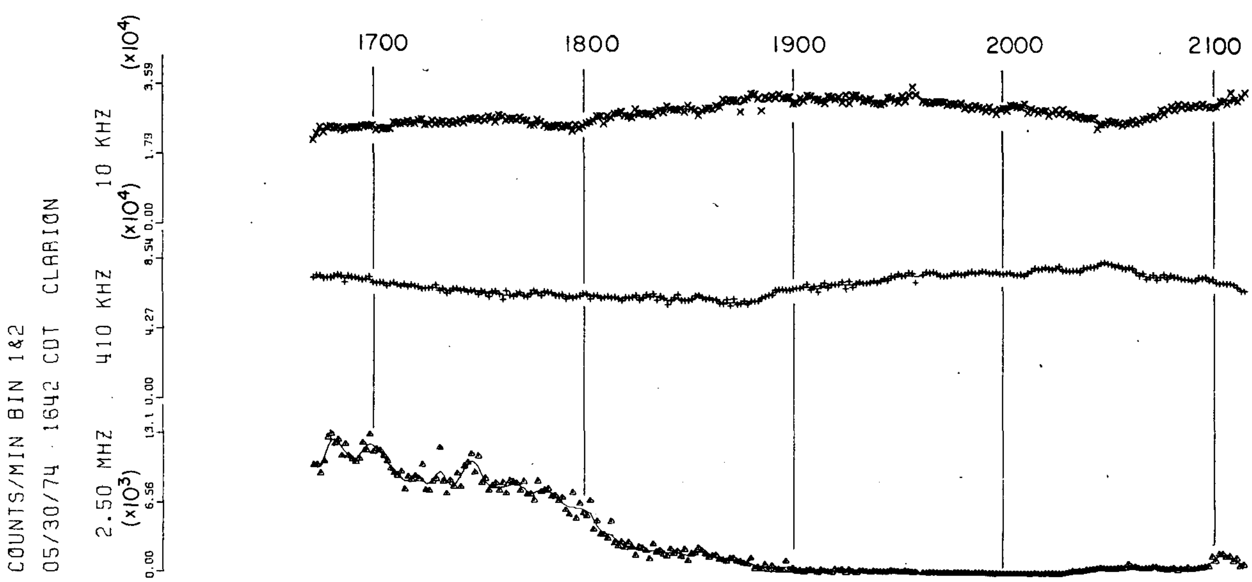

FIG. 3. Radio noise data (counts min^{-1}) for the Clarion station on 30 May 1974 for the lowest amplitude impulses (bins 1–2).

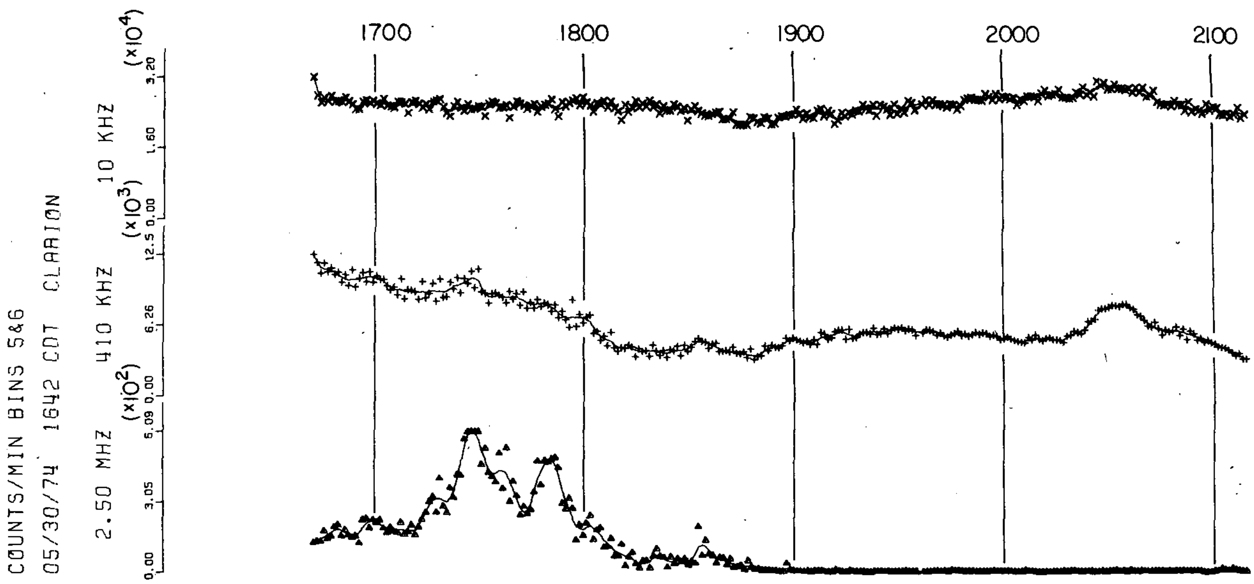

FIG. 4. As in Fig. 3 except for intermediate amplitude impulses (bins 5–6).

Clarion. The results are presented here for several major severe storm systems. In Section 5, the results for non-severe storms will be discussed and compared with those from the severe cases.

a. Storms of 30 May 1974

On this date a thunderstorm complex moved from northwest to southeast. The remote station at Clarion was the closest to the activity. The radar echo tracings are given in Fig. 2. As the storm approached the Clarion station, it intensified around 1730 as shown by the radio noise data (Figs. 3–5) and comparison of the radar plots at 1700–1737 and 1809[6]. The radar plot at 1904 shows that the storm was breaking up.

At about 1820 a small tornado was observed near Goldfield, 19 km west of the Clarion station. This was a well-authenticated tornado, picking up dust in a plowed field and reported by a civil defense worker. The width of the tornado was estimated as 30 m on the ground. The tornado lasted for perhaps 10 min. About 2–3 min prior to seeing the tornado, the observer's CB radio began to "shriek." This may have been due to antenna corona discharge since our equipment did not record anything significant at this time; conversely, low-level RF signals from the tornado cannot be entirely ruled out due to the sensitivity range of our equipment.

At 1920–1930 a law enforcement officer reported spotting a funnel cloud 24 km southeast of the station at Clarion. The funnel tail did not touch the ground. At 2030 a funnel was reported by the police 60 km southeast of Clarion. It apparently did not touch down.

It is quite interesting to compare these funnel cloud and tornado reports with the radio noise data recorded during these times. Figs. 3–5 show the Clarion radio noise data for low, intermediate and higher amplitude impulses (bins 1–2, 5–6 and 11–12, respectively). The lowest amplitude impulses (Fig. 3) are received from storms at both close and longer range and do not fully correspond to the larger amplitude count rates (Figs. 4 and 5). It is apparent that little if any significant noise was recorded at the time of the tornado (19 km range) at 1820–1830 in any of the amplitude bins. Likewise, the funnel cloud (24 km range) at 1920–1930 does not exhibit noticeable radio noise.

In contrast, the funnel cloud at about 2030 does coincide with an enhancement in radio noise count rate in Figs. 3–5. A strong peak in the data at this time in Fig. 6, recorded in Ames, lends credence to the postulate that this funnel (or its associated thunderstorm) produced the recorded noise peak: the funnel cloud was approximately equidistant from both recording sites at 60 km range.

b. Storm of 3 June 1974

The radar tracings and radio noise data for this storm are shown in Fig. 7 for the closest station, Clarion. The severe events measured from Clarion were as follows (all tornadoes moved toward northeast or east-northeast):

1749	hail (2.5 cm diameter), 47 km NNE
1830	funnel cloud, 50 km WSW
1835	tornado (6 km path length, damaged 3 farms), 110 km NE
1850	funnel cloud, 107 km NE
1900	6–8 cm rain, hail damage, 45 km NW
1900	hail (2.5 cm diameter), 50–70 km E

[6] All times CDT.

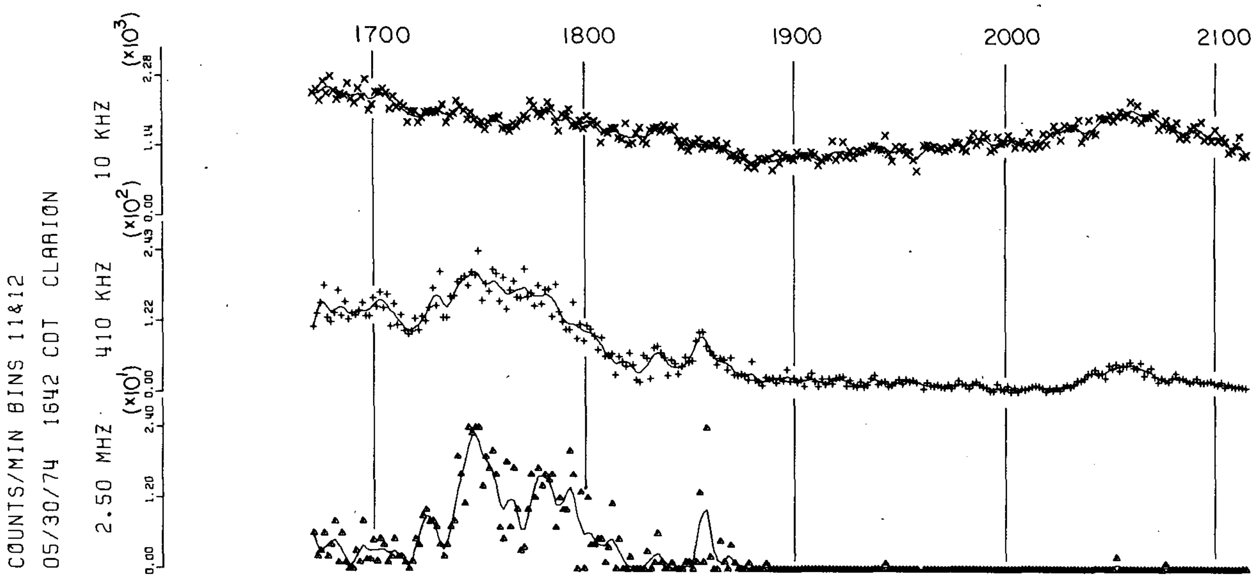

FIG. 5. As in Fig. 3 except for higher amplitude impulses (bins 11–12).

1915 funnel cloud, 50 km NE
1954 tornado, 47 km E, 15–20 m wide, lasted 3–4 min
2000 wind damage, 25 km NE
2030 funnel cloud, 65 km ENE
2100 funnel cloud, 65 km NE.

c. *Storm of 14 June 1974*

Fig. 8 shows the radio noise data for 14 June 1974 from the stations at both Clarion and Ames, along with the radar tracings.

The radio noise peaked shortly after 1600 from the Clarion station and is seen to correspond to the passage of that station by the line of thunderstorms. No severe activity was reported during this time in this area. The peak in the radio noise data at 1654 in the Ames station data in Fig. 8 occurred just prior to the arrival of the line of thunderstorms at Ames. A small 33 dB radar echo was still 7–11 km northwest of the station at this time. On other occasions, simultaneous visual and real-time radio noise count rate observations indicate that the highest count rates usually occur just prior to passage of the heavy precipitation area by the station.

The later peak a few minutes after 1700 in Fig. 8 apparently occurred as the storms intensified as they

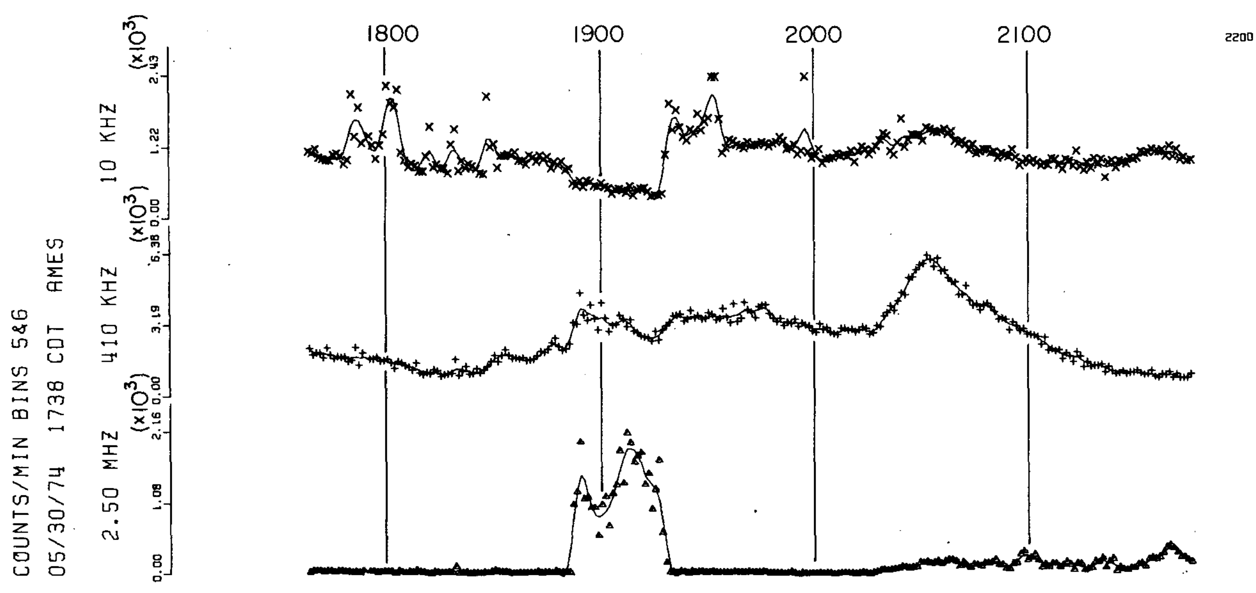

FIG. 6. Radio noise count-rate data for the Ames station on 30 May 1974 for intermediate amplitude impulses (bins 5–6).

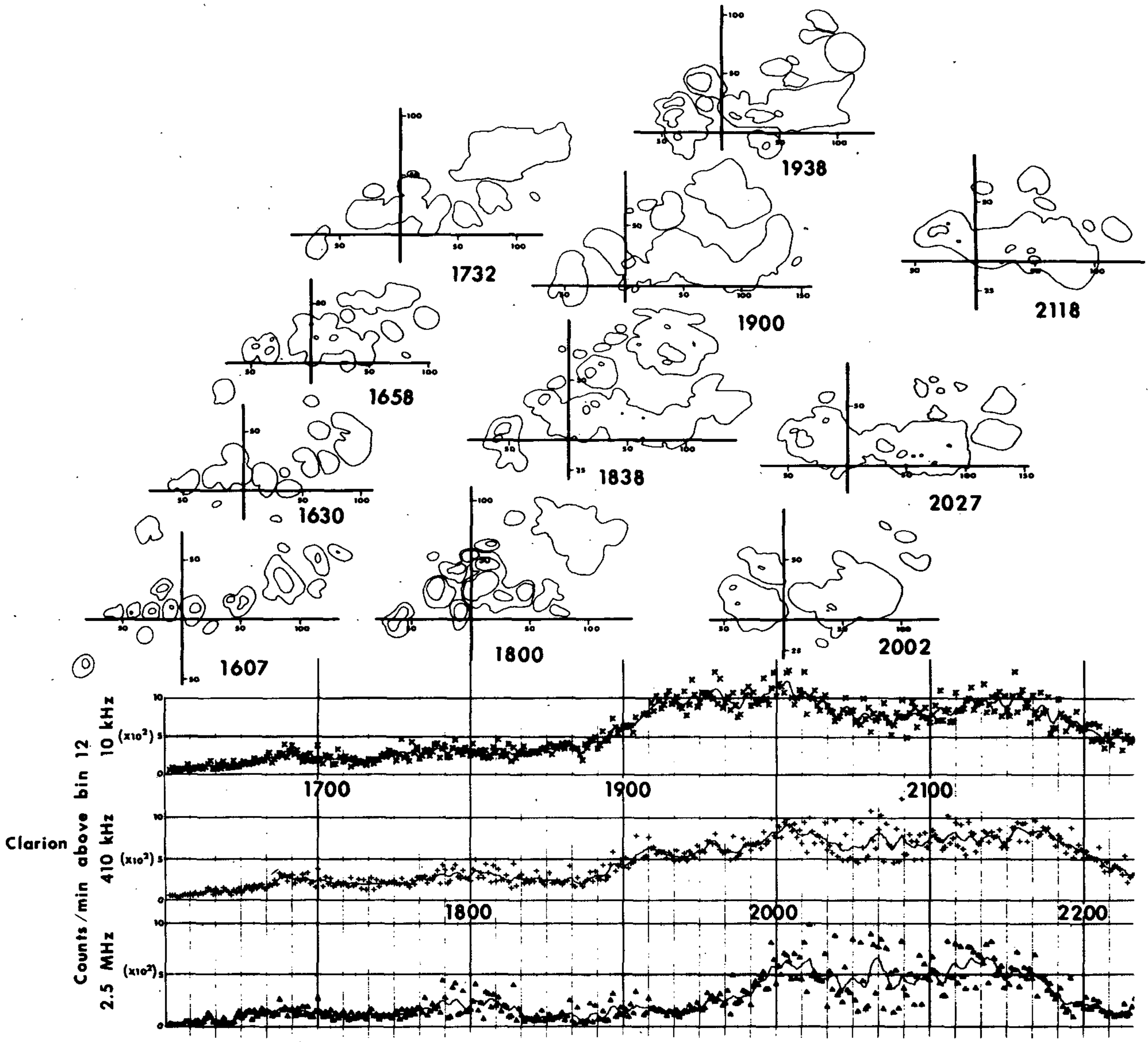

FIG. 7. Radar echo tracings and radio noise data for the Clarion station on 3 June 1974. Radar axes intersect at Clarion; distances are in km.

moved southeastward. At 1725, two funnel clouds were reported by a patrolman 27 km south–southwest of Ames. The funnels then touched down briefly with a path length 200 m long by 100 m wide. Ten minutes later two funnels were observed further southeast and shortly afterward dissipated. Shortly after this, baseball size hail fell for about 5 min at a location 35 km south of Ames. The electromagnetic noise from this storm is apparent in the data tracings from the Ames station. At the high-impulse amplitudes depicted in Fig. 8, both the 2.5 MHz and 410 kHz receivers show a plateau or a slowly decreasing count rate during the time of the storm intensification, approximately 1700 to 1730. The low-amplitude impulses, typified by the count rate from bin 3 shown in Fig. 9, clearly show the intensification of the storm at the time of the tornado (1725). The peak in Fig. 9 at 1720–1730 occurs at the time of the tornado at 27 km and also about the time that detailed hail-swath analysis shows very intense hail damage was occurring to crops in the same area. Also evident is the peak slightly before 1700 when the storm passed Ames.

At 1730 a possible tornado was reported approximately 50 km southeast of Ames. As these storms moved further southeast, a number of cases of 5 cm diameter hail were reported from 1800 to 1830. The storms were apparently still quite intense after 1730, but the radio noise recorded at the Ames station decreased in intensity rapidly after that time. The 410 kHz receiver at Clarion recorded the storm intensification around 1700–1730, but the 2.5 MHz channel did not. Clarion was evidently in the 2.5 MHz skip zone from the storms at 1730.

d. Storms of 18 June 1974

On this date a very large number of severe weather events were recorded in central Iowa, including many reports of very large hail and at least a dozen tornado touchdowns. These data are extensively tabulated in Eshelman and Stanford (1977) and we report here only those events within useful range of our recording equipment. Fig. 10 shows the radar tracings and the radio noise count rates recorded in Ames. As this intense storm system swept across Ames, power was lost at the station from 2054 until 2217. However, the data that were obtained are quite interesting and the station came back on prior to the destructive tornadoes that struck Ankeny, Iowa, at approximately 2230.

The severe weather events in the vicinity of the Ames station after it began recording at 1910 are as follows (unless otherwise noted, all distances and direction refer to the recording station in Ames):

1946 Two funnels were reported at distances of 20 and 30 km NW.
1955 A tornado touched down briefly and destroyed a barn on a farm 20 km NNE.
2025 A funnel was sighted approximately 8 km N.

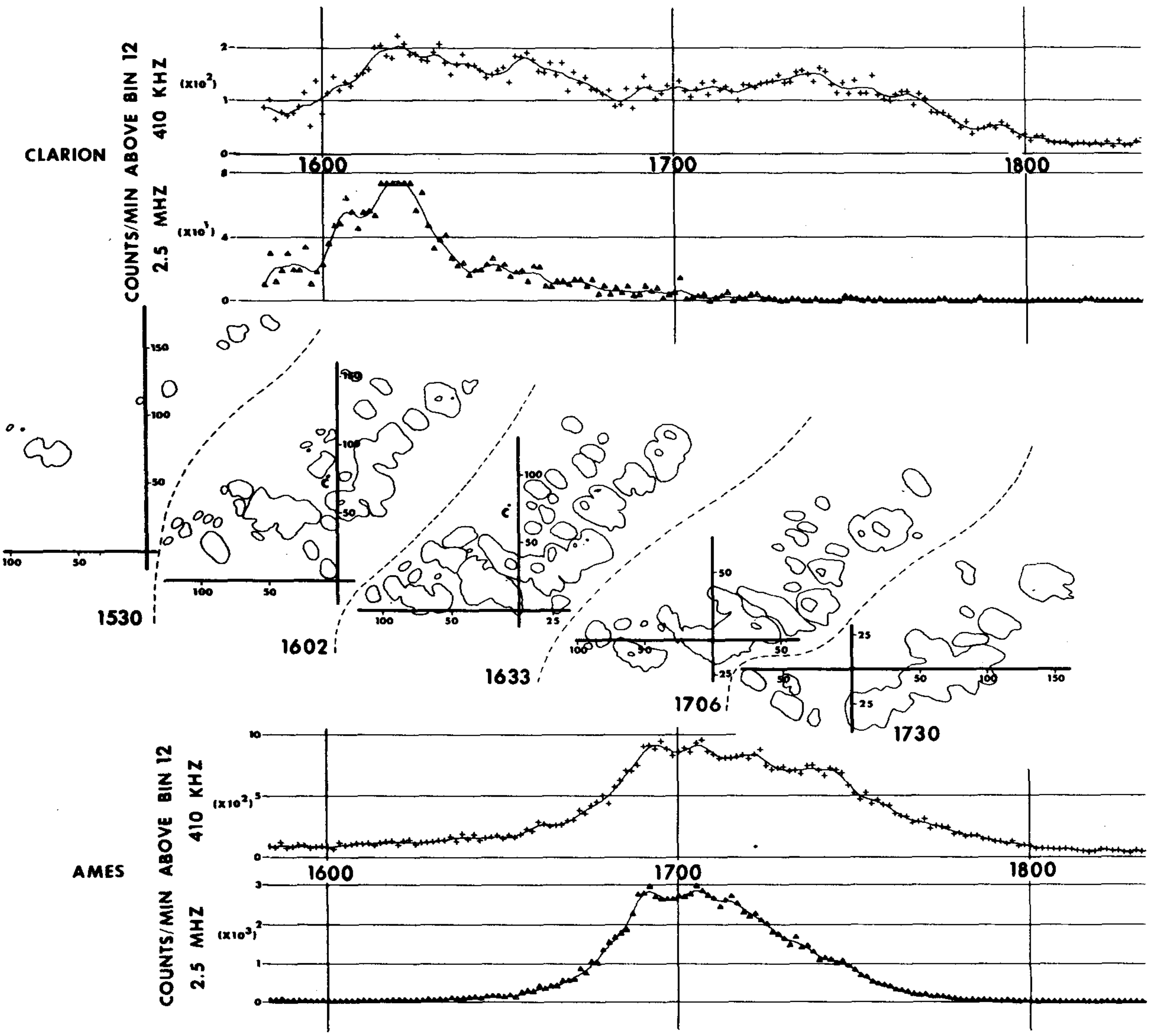

FIG. 8. Radio noise data for high-amplitude impulses for the Clarion and Ames stations of 14 June 1974. The axes of the radar plots intersect at Ames; the location of Clarion is designated by C; distances are in km.

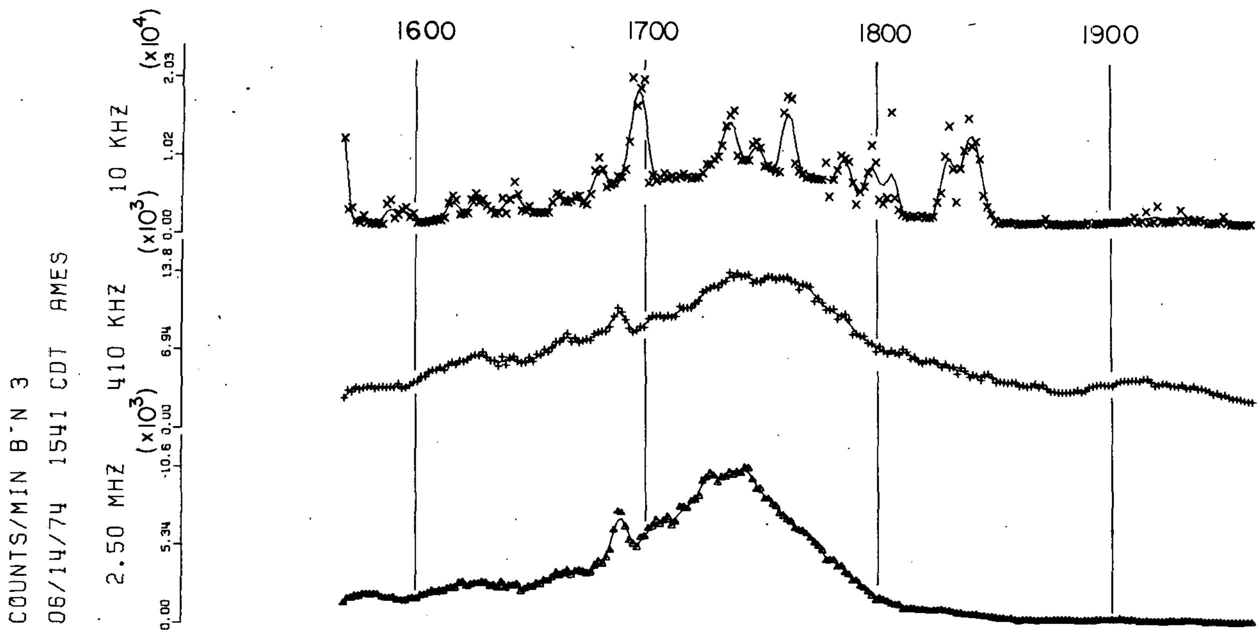

FIG. 9. Low-amplitude impulse rates from the storm of 14 June 1974.

It may have possibly touched down because some damage was reported.

2030 A tornado was reported 5 km NE, but no damage was reported.

2045 Wind damage was reported 5 km N.

Shortly after 2100 the storm struck Ames with high winds and a great deal of large hail. Baseball size hail fell for 10 min, causing extensive damage to homes in the area.

2115 A tornado reportedly destroyed a barn approximately 8 km S; its path was reported as 3 km long and 200 m wide. At the same time, a funnel was reported ~13 km SE. A policeman reported sighting seven funnel clouds over the period 2120 to 2210 at a location 30 km S.

2132 A funnel was reported 30 km S.

2200 Two funnel clouds were reported 50 km SE.

2203 A funnel was reported ~5 km NW and later, probably the same funnel, 1.5 km SE at 2215. All the storms on this evening were traveling toward SE or SSE.

2207 A funnel was reported 60 km SE.

2210 Hail 2.5 cm in diameter was reported 16 km E.

2217 The Ames recording station came back on the air.

2220 A funnel was reported 5.6 km SE.

2220 A patrolman spotted a tornado on the ground 3 km NW of Ankeny, Iowa, about 30 km S of Ames.

2230 Ankeny (33 km S) was hit by at least two tornadoes. The same tornado or tornadoes from the same parent thunderstorm caused damage across a 35 km path in a south–southeasterly direction. Two people were killed in Ankeny.

2315 The tornado was reported at a location 65 km SSE of Ames.

2325 The tornado was reported at a location 72 km SSE. It apparently dissipated near this point.

From an examination of the radio noise data (Fig. 10) it may be seen that the funnel or tornado 8 km north of the recording station at approximately 2025 to 2030 correlates well with the peak in the radio noise data at this time. Fig. 11 shows a tracing of the radio noise recorded on the 74 MHz receiver located in Ames. The peak at approximately 2030 is particularly evident. The sensitivity of this higher frequency receiver was considerably less than that of the other receivers so that useful data were obtained only for nearby storms. Where the data permit, however, the 74 MHz receiver shows results similar to those from the 2.5 MHz receiver. Whether the noise peak at 2030 is from the tornado (which was 5–8 km from the receiver) or from electrical processes in the parent thunderstorm, cannot be ascertained. This noise peak lasted about 20 min.

The very rapid rise in count rate prior to the power failure at 2054 seen in Fig. 11 can be ascribed to the very intense storm which hit Ames shortly after 2100. When the power came back on, as shown in Fig. 10, the 410 kHz and 2.5 MHz data appear to be saturated for several minutes. However, this was due to the analysis scheme; when a more careful analysis was performed, as shown in Fig. 12, the actual count rates were found to be falling off rapidly. This rapid fall-off

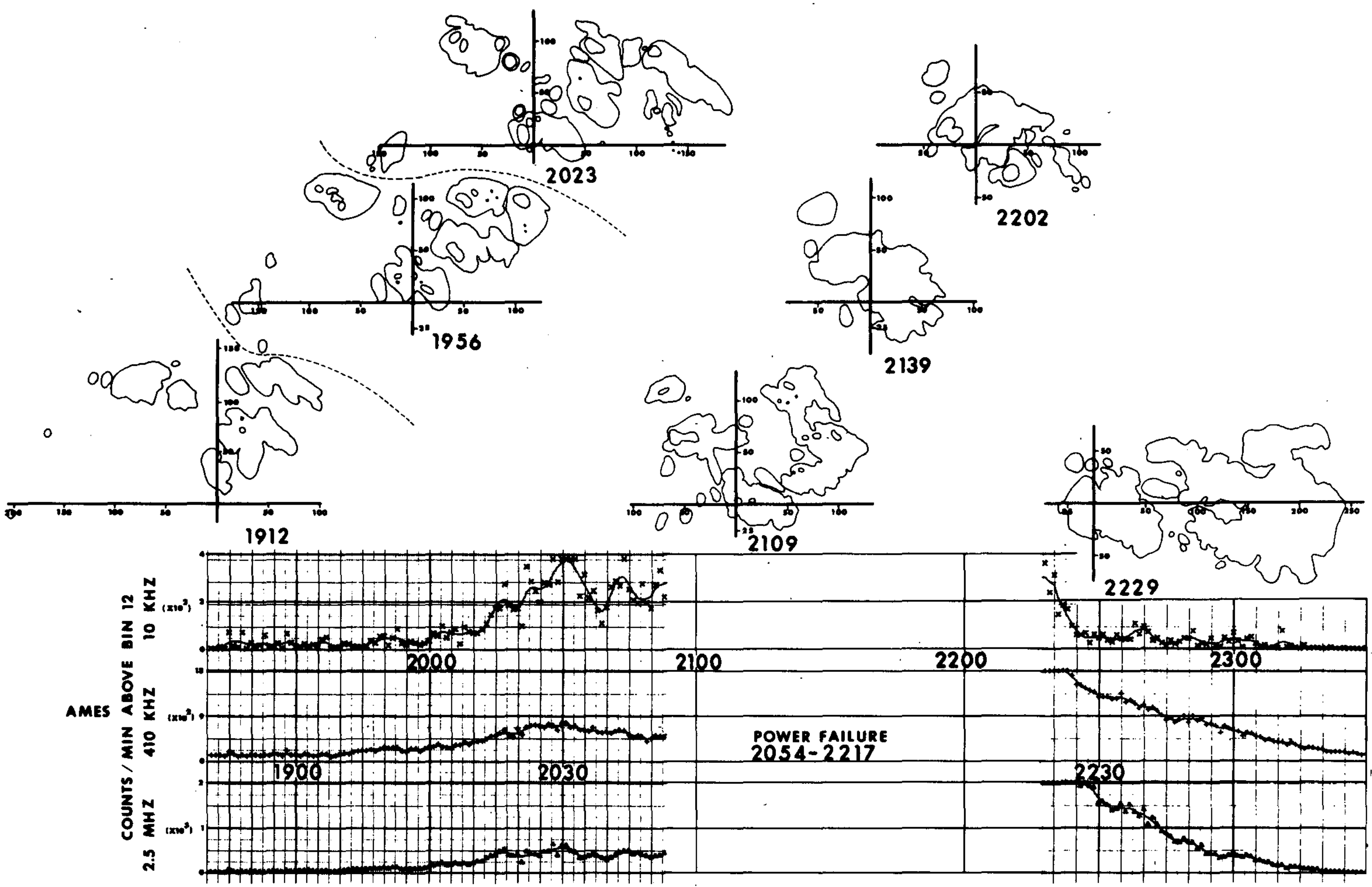

FIG. 10. Radar echo outlines and radio noise data from the Ames station on 18 June 1974. Ames is located at the intersection of the radar plot axes; distances are in km. The fatality-producing Ankeny tornado was near an indention in the radar echo at 2229 about 30 km south of Ames. A dozen tornado touchdowns and very large hail were reported in central Iowa.

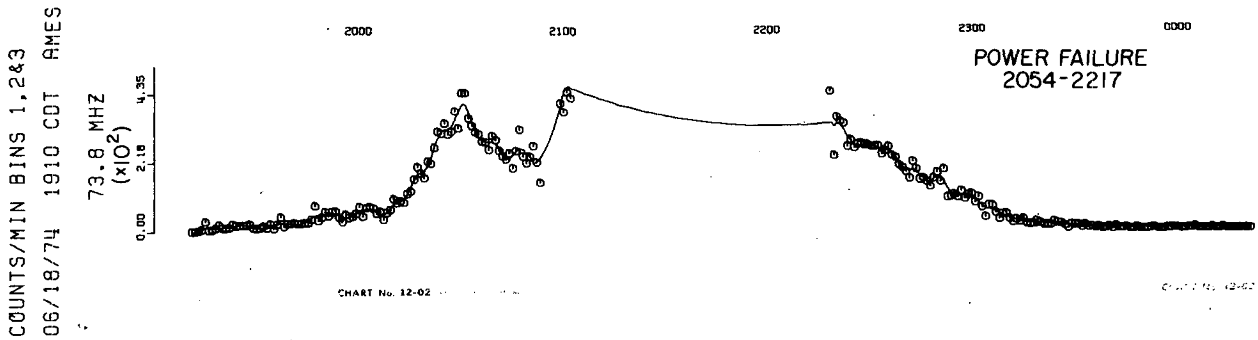

FIG. 11. Plot of high-amplitude radio noise recorded at 74 MHz in Ames on 18 June 1974.

after 2217 may be related to radio noise from the funnel which was just passing out of the immediate area (5 km northwest at 2203 to 5.6 km east at 2220) at that time. In addition, the extremely active thunderstorm complex was moving away from the Ames station.

During the time of the tornado in Ankeny, starting at approximately 2230, a "shelf" or even a slight peak in the noise data is seen on the higher frequency channels, particularly 2.5 MHz in Fig. 12 and 74 MHz in Fig. 11. As the storm receded further in the distance, the count rates fall off as discussed for earlier storms.

5. Discussion and conclusions

a. Radio noise vs storm severity

A main purpose of this investigation was to attempt to answer the question of whether or not radio noise from severe thunderstorms differs from that from nonsevere thunderstorms. To aid in data interpretation, a somewhat arbitrary classification of storms was used: Class A (severe and less than 40 km from the station), Class B (severe and at long range from the station, 40–80 km), Class C (severe storms more than 80 km distant and all nonsevere storms). A "severe" storm was one for which large hail, funnel cloud or tornado reports were verified, or for which the storms showed WSR-57 radar reflections of significant (subjective) areal extent and duration at attenuations of 33 dBm or greater.

The radio noise data were placed into four classifications, according to whether the impulse amplitudes exceeded four threshold levels. Referring to the amplitude bins discussed earlier, threshold levels 1, 2, 3, 4 correspond to all bins, above bin 4, above bin 8, and above bin 12, respectively.

Utilizing these definitions, Fig. 13 shows the peak count rates at Ames for 22 storm systems as a function of receiver threshold. Comparison of the figures shows that the higher frequencies are better discriminators between severe and nonsevere storms: the higher count rates at high thresholds are generally good indicators of severe storms at close range (<40 km). The 10 kHz data are generally much poorer at distinguishing between severe and nonsevere thunderstorms.

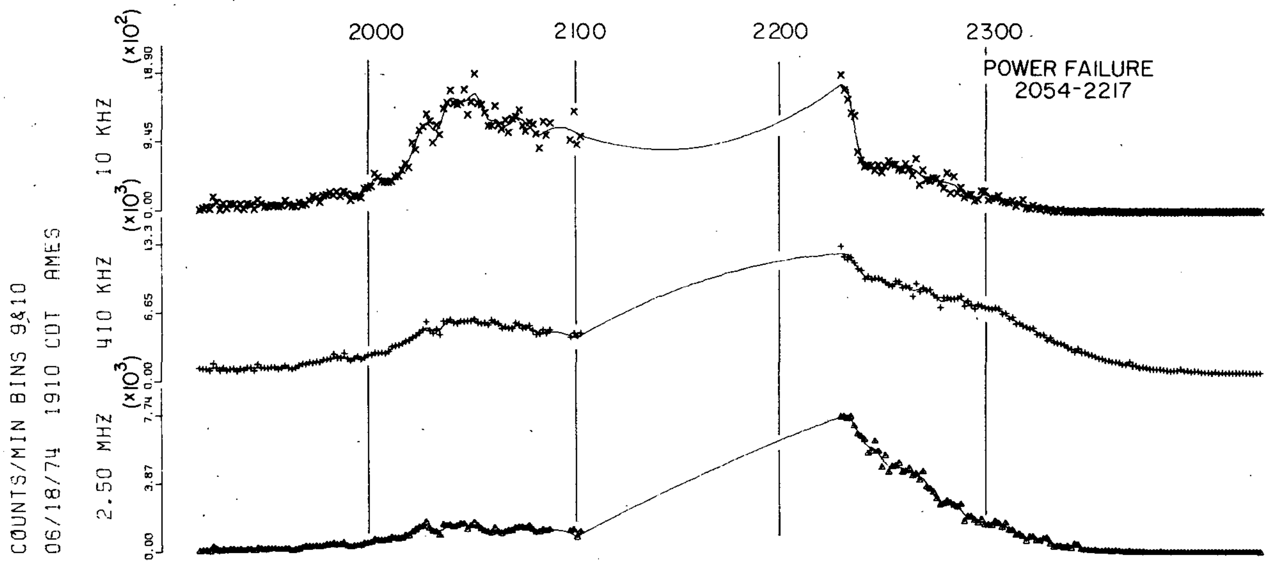

FIG. 12. Plot of intermediate-amplitude impulses (bins 9 and 10) for the Ames station on 18 June 1974.

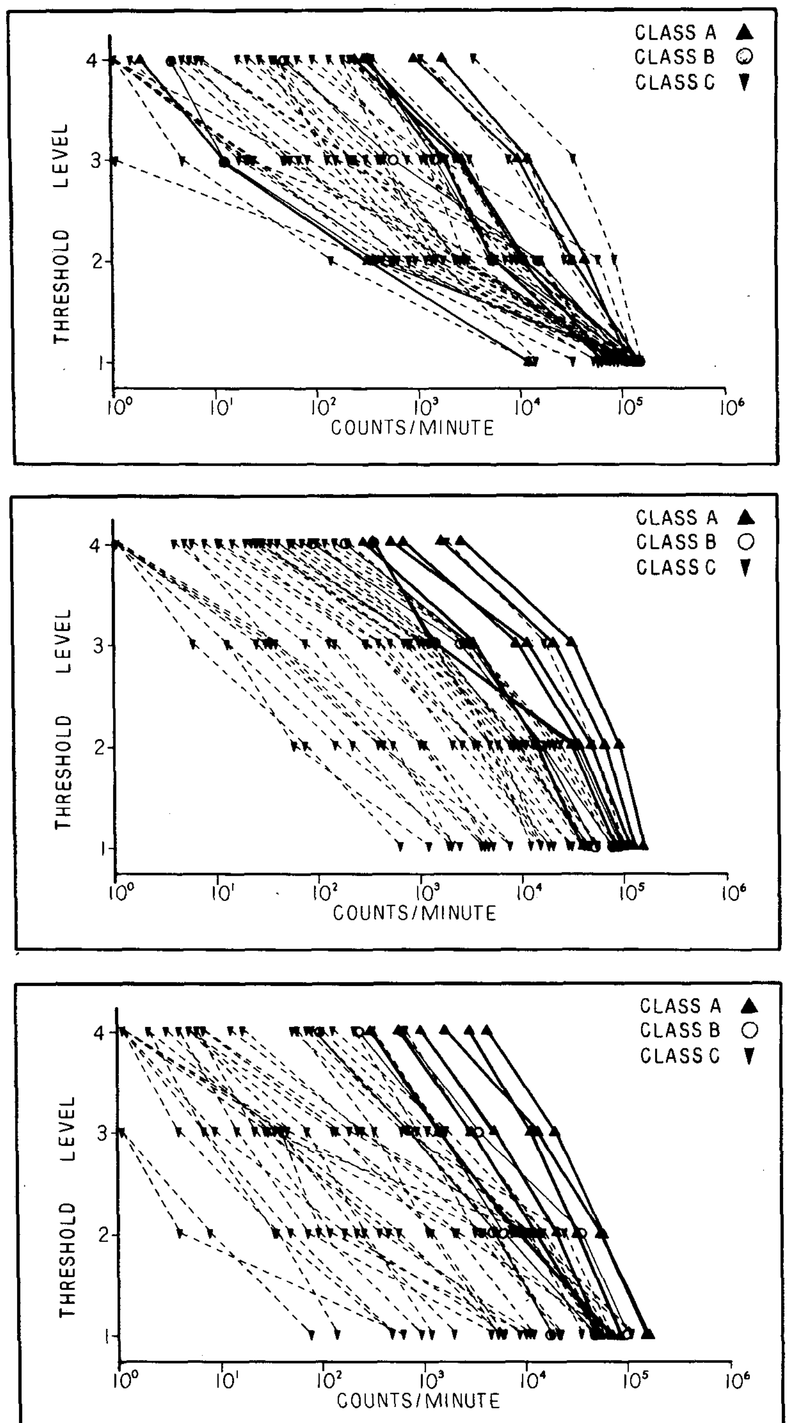

FIG. 13. Peak radio noise count rates for different receiver threshold levels (see text) for the Ames station: (a) 10 kHz, (b) 410 kHz, (c) 2.5 MHz. Class A storms are severe and within 40 km (see text).

Data from the Clarion station produced similar plots and are given in Johnson *et al.* (1976). The thunderstorm and small tornado on 30 May 1974 near Clarion yielded count rates among the lowest quartile of those shown in Fig. 13 and thus would not have indicated severity.

b. Comparison of equipment responses

Kachurin *et al.* (1974) found "continuous-noise radio emissions" from thunderstorms and hailstorms in the North Caucasus. The emissions exhibited essentially frequency-independent spectral amplitudes over a wide range of frequencies from 0.5 to 300 MHz. Up to several hundred pulses per second were recorded. Our 410 kHz and 2.5 MHz receiver sensitivity ranges, from 8 μV m^{-1} kHz^{-1} to 16 mV m^{-1} kHz^{-1} for bins 1 to 16, respectively, compare favorably with the amplitudes obtained by Kachurin *et al.* (1974) for ordinary and severe thunderstorms. As previously noted, the limited quantity of 74 MHz data we obtained were similar in behavior to 2.5 MHz data, consistent with the findings of Kachurin *et al.*

Taylor (1972, 1973, 1975) has also reported good resolution between tornadic and nontornadic storms using equipment operating at 3 MHz. Taylor (1975) gives the definition of what he means by a "burst" (500 counts s^{-1} lasting for at least 0.1 s). The average length of a burst may be several times this length. Taylor also finds that 20 bursts min^{-1} usually indicate a severe storm. This level of activity corresponds to a minimum count rate of 1000 min^{-1}, and perhaps several times this value on the average. These count rates refer to impulses which exceed a certain predetermined threshold level, 5 or 2 V m^{-1}, depending on the expected warning range (30 or 70 km). An example is given for the Union City, Okla., tornado, at range of 40 down to 28 km from the detector.

Because calibration of receivers depends sensitively on the exact details of the calibration signals used, it is difficult to quantitatively compare sensitivities of equipment used in different laboratories. The sensitivity of our equipment appears to overlap that used by Taylor. Fig. 13c shows that our 2.5 MHz receiver indicated a severe storm when the count rate for the less sensitive threshold (level 4) exceeded $\sim$1000 min^{-1}, comparing very favorably with Taylor's 20 burst min^{-1} criterion for storm severity with his 3 MHz receiver. It thus appears that the two different systems yield comparable results.

The majority of severe thunderstorms can thus be distinguished by the characteristics of the radio noise they emit. In particular, Taylor's work has involved setting up radio noise equipment for use as an operational aid to tornado forecasting for National Weather Service personnel. There are a number of problems inherent in going from the research stage to that of producing a workable tornado forecasting tool with the radio noise effect. [A discussion of these problems is found in Taylor (1975).]

c. Physical processes

There is little doubt that funnels are sometimes highly electrified (see, e.g., Vonnegut and Weyer, 1966) and that they may on some occasions emit at least low-level RF noise (Lind *et al.* ,1972). However, the little existing information leads one to believe that the majority of the large-amplitude RF noise is not emitted from the funnel itself. This is the conclusion reached by Scouten *et al.* (1972) from a study of the angular distribution of 150 kHz signals from the 1955 Blackwell, Okla., storm. Also, from the directional information obtained by Taylor (1973), it can be inferred that the majority of the larger amplitude RF noise is being emitted from the heaviest precipitation area of the well-organized thunderstorm, rather than from the funnel itself.

The details of the physical processes producing these RF signals are as yet unknown. They almost certainly involve electrification processes associated with the updraft-downdraft couplet in the well-organized thunderstorm. To properly ascertain the details of the processes involved, accurate RF and/or VHF direction measurements on nearby tornadic storms are needed. To correctly interpret the results, it is vital that such measurements be made in conjunction with detailed three-dimensional thunderstorm structure determinations derived from conventional techniques and Doppler radar.

d. Conclusions

These results of extensive computer analyses of thunderstorm radio noise measurements over a broad amplitude range corroborate the work of Taylor (1973, 1975); i.e., large amplitude impulse rates measured with receivers operating in the megahertz range are generally good indicators of thunderstorm severity. In the present study, at least five tornadic events correlated in time with radio noise count rate peaks. On the other hand, no unusual radio noise was recorded during the lifetime of a small, verified tornado at 19 km range. In addition, the count rates for its parent thunderstorm would not have indicated severity.

The present work is thought to represent the most comprehensive integration of severe weather observations and thunderstorm radio noise measurements to date. The correlations between radio noise and tornadic events found here may be smaller than some might have hoped and larger than others had thought; such is the way the real atmosphere behaves. The radio noise effect cannot be expected to provide a perfect tornado warning device; there is an inherent variableness in the radio noise output from tornadic storms. However, the technique remains a useful and complementary indicator of storm severity.

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