REMOTE SENSING OF RADIO EMISSION FROM CONVECTIVE CLOUDS INCLUDING TRANSMISSION VIA SPORADIC *E*

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ABSTRACT

Narrow band slices have been taken of the radio emission spectrum from convective clouds in the frequency range from 30 mc./sec. to 550 mc./sec. and at 7.5 kc./sec. to monitor long and short range lightning discharges. Despite the careful choice of the bands to avoid interference from manmade sources, a major problem is the identification of spurious noise. In spite of these interferences, radiation apparently associated with growing convective clouds has been observed from an aircraft. The number of discharges per km.^{2} per sec. observed at the different frequencies is a function of receiver sensitivity, suggesting that "atmospherics" vary greatly in spectral intensity. The number of discharges observed generally exceeds previous estimates. A relation between the occurrence of sporadic *E* and *major* thunderstorm precipitation areas is reported and evaluated in light of previous observations of the similar relationships. Together, the concepts suggest a linkage between strong solar flare activity and anomolous thunderstorm rainfall.

1. INTRODUCTION

Sometime prior to 1957, Dr. Ross Gunn stimulated a research project at the Naval Research Laboratory in Washington, D.C., for the purpose of looking for and studying the microwave emission from thunderstorms. The study was conducted by Gibson [5] who reported that at least in one important instance the radiometer radiation appeared to exceed the upper limit possible for pure thermal radiation and he supposed that it must be due to some sort of electromagnetic energy radiating from the electrified cloud. A number of studies since that time have recorded either radiometer observations or pulse information at UHF, VHF, and microwave frequencies that appear to originate within convective clouds.

A vast amount of research has been done on the characteristics and sources of radio noise of atmospheric and terrestrial origin. The purpose of Gunn's proposal and that of the research reported in this paper is to use the electromagnetic emission from convective clouds to study the behavior of the cloud itself. It is necessary, then, to consider the cloud as a source of radio noise prior to a full lightning discharge as well as during the active discharge stage. It has been known for a long time that many clouds are electromagnetically noisy prior to the onset of lightning and during the periods between flashes. Examples of reports of non-lightning and lightning related radiation at higher frequencies appear in the works of Gibson [5], Fleischer et al. [4], Kimpara [9], Hogg and Semplak [6], and Sartor [16].

Key West, Fla., was chosen as the site of our study because of the regular presence of numerous isolated convective clouds that precipitate and extend through considerable depths of the atmosphere. The studies were carried out during the summer of 1964 using a radio receiving system of five narrow-band receivers and one 7.35 kc./sec. sferics receiver in the maiden research project with the first Queen Air aircraft of the National Center for Atmospheric Research. The system concept used on this research project is geometrically and to some extent, physically, very similar to the reception of atmospherics from a satellite.

This paper reports also the results of an investigation of the relationship between the occurrence of heavy thunderstorm precipitation and sporadic *E*. During the field study occasional interference from radio transmissions via ionospheric sporadic *E* was observed. Many other sources of spurious noise were found and identified or avoided. Most were associated with manmade sources and were eliminated by flying farther away from land to make the measurements. But it was necessary to monitor the 50-mc./sec. band to identify the occurrences of sporadic *E* during the observational periods. After a number of occasions when sporadic *E* was identified as originating from States to the north, a relationship between these occurrences and the occurrence of unusually heavy precipitation in the region between the signal source and the point of our reception was suspected. During the data analysis phase of the Key West field studies, an attempt was made to investigate this suspected relationship.

2. RECEIVING AND RECORDING SYSTEM

The radio receiving system consisted of receivers tuned in approximately octave steps to 30.0, 50.5, 144.05, 220.5, and 550.1 mc./sec. and transistorized to allow low power consumption, high reliability, and low weight. The 7.35-kc./sec. tuned RF sferics receiver was intended for the identification of all lightning discharges in or beyond the area covered by the higher frequency receivers. All six were narrow-band (10 kc./sec.) to avoid interference. Details of the radio receivers, the recording system, and other instrumentation are described in detail by Sartor

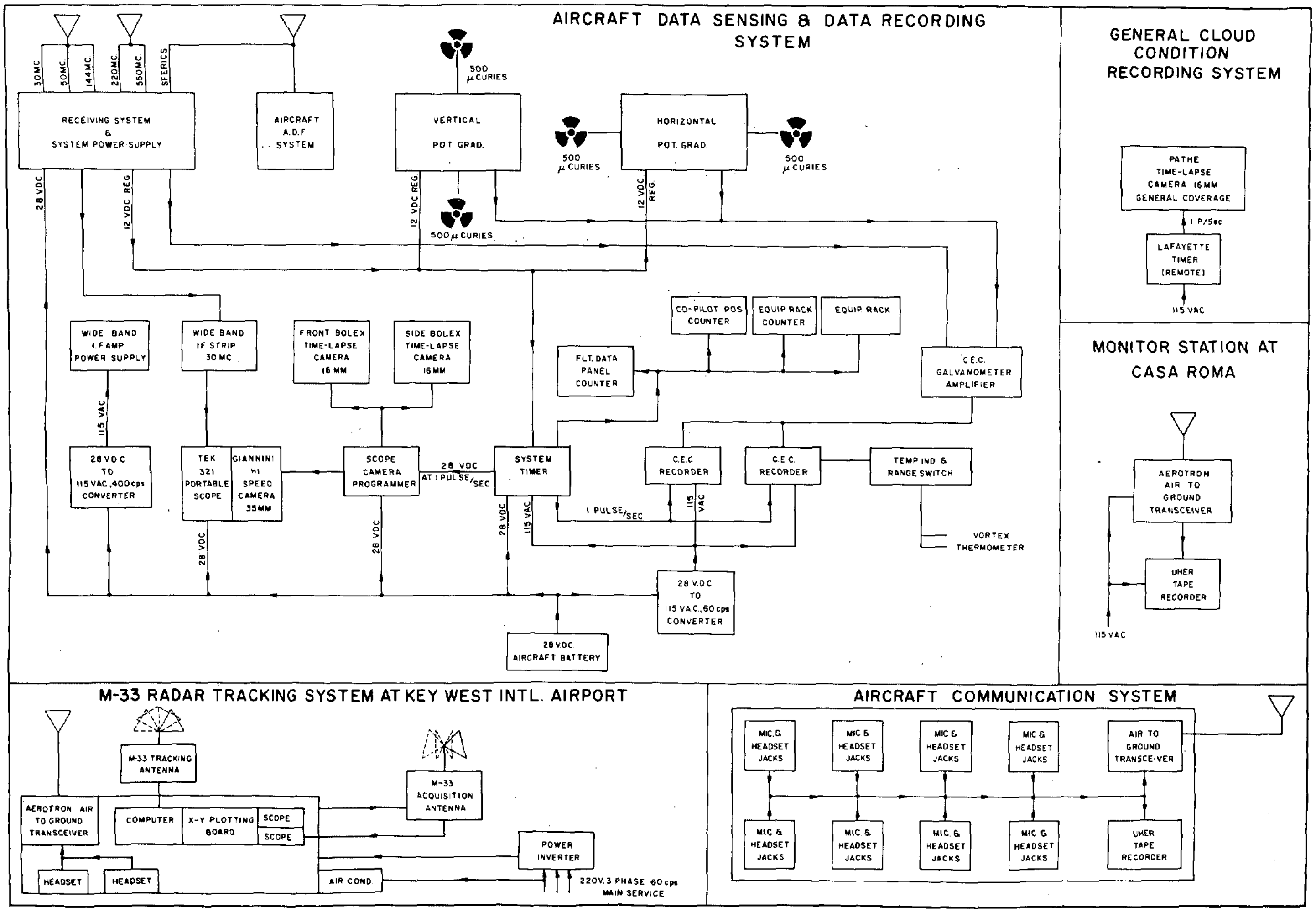

FIGURE 1.—Aircraft data-sensing and data-recording system.

and Eden [18]. A 50-mc./sec. converter was used with a Drake TR-3 transceiver to monitor the amateur band at 50 mc./sec.

Electric field components of the ambient atmosphere were measured by probes mounted on the top and the bottom of the airplane (vertical field) and nose and tail (horizontal field). Outside air temperature was measured by a vortex thermometer (Meteorological Research, Inc., Model 803) mounted under the wing of the aircraft.

The collected data were recorded on two Consolidated Electrodynamics Corporation Model 5-124 recording oscillographs. A digital timer was designed for accurately timing the entire data-recording program. The timer provided 1 pulse/sec., 1 pulse/5 sec., 1 pulse/15 sec., 1 pulse/50 sec., and 1 pulse/min. These pulses were applied to one channel of each of the CEC recorders. The 1-sec. pulses also activated two time-lapse cameras. One was located in the front of the aircraft, aimed forward to photograph the cloud under study on an approach flight path. The other was located on the left side of the aircraft to photograph the cloud while circling it. A voice-operated Uher tape recorder in the aircraft recorded all conversations on the aircraft during the flights. A M-33 radar tracked the aircraft during flight to help reconstruct the flight path in relation to the cloud position. The acquisition portion of the set was also used to determine when clouds were precipitating. The general schematic diagram for the aircraft and ground research sensing and recording system is shown in figure 1.

3. INSTRUMENT CALIBRATION

The aircraft antennas were calibrated on the ground by moving the transmitter about the aircraft in a fixed radius circle. The resulting antenna patterns are superimposed in figure 2, which is shown not to provide specific information, but to illustrate the complexity, irregularity, and contrasts of the patterns. The effect of this situation on the study will be discussed later.

In-flight aircraft antenna calibrations were attempted at 50 mc./sec. and 144 mc./sec. using a transmitter operated from a small sandbar about 6 mi. off the southern coast of the Keys. Although these efforts provide valuable qualitative information on the antenna patterns in the vertical, quantitative calibrations were impossible because of the lack of accurate tracking information. The radar could not pick up the aircraft at the low flight altitudes

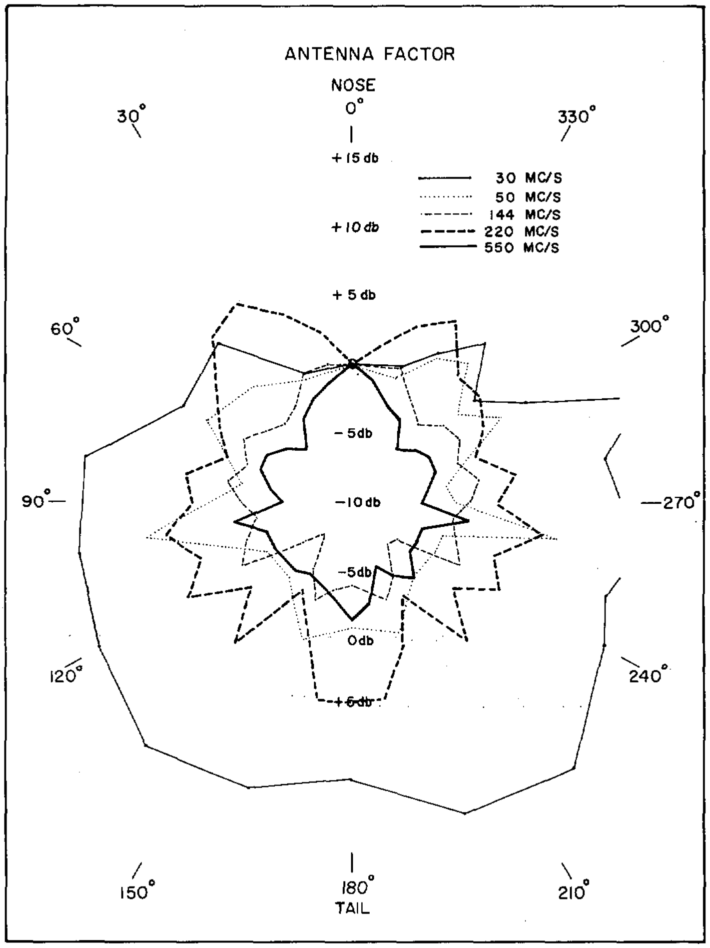

FIGURE 2.—Polar diagram of antenna factors expressed in decibels deviation from aircraft nose-on configuration.

needed for calibration, and on-board flight data information was not available.

The electric field probes were calibrated by flying close to a thunderstorm until the aircraft went into corona and then setting the electric field recording to show full-scale deflection in the thunderstorm electric field. Thus, whenever a significant deflection of the recorder occurred during subsequent observations, it could be associated with the magnitude of thunderstorm fields. The importance of the electric field information is to enable us to determine when the aircraft was in corona and to identify this as a source of spurious radio information as well as to positive information on the existence of strong electrification in the cloud studies.

4. DATA ANALYSIS

Previous laboratory and field results by Sartor [15, 16] suggested that for the study of clouds, pulse information on their electromagnetic radiation characteristics might be used to study the stage of particle growth and electrification. The amplitude of the pulses versus distance from a possible cloud source was to have been used to study the electromagnetic radiation characteristics as a function of the development of the cloud. The data were analyzed frequency-by-frequency in two ways. First, a simple pulse count was made of those pulses that extended significantly above the general noise level. Second, the amplitude of the pulses was taken into account by integrating over 1-sec. intervals in some cases, and over 10-sec. intervals in other cases. The simple pulse count data are the most significant for comparing with previous studies.

Sporadic E interference was identified by the arrival of amateur transmissions from distances far beyond the radio horizon. The geographical location of these transmissions was determined by the identification of amateur call letters and from location statements made by the amateurs during their transmissions. Transmissions via sporadic E were identified as coming from as far north as the New England States, as far west as Colorado, and as far south as the east coast of South America. There were 4 days with positive identification of sporadic E during the observation period and each of these days was paired with the nearest day on which sporadic E was observed not to occur. The study was limited to those cases where the transmissions originated from the continental United States because of the readily available meteorological data. *Daily Weather Maps* (U.S. Department of Commerce) were used as the source of meteorological information. The areas from which the transmissions were originating were shaded in on the weather maps and straight lines drawn from the outer edges of these areas to the vicinity of Key West. In the southeastern part of the United States the heavier precipitation in July and August is usually associated with thunder and lightning. Although not uniquely related, the total amount of precipitation in the included area is taken as a measure of the thunderstorm precipitation. All precipitation amounts reported within this triangular area during a 24-hr. period that included the observational period were recorded. The total precipitation amounts in the area on the days with observations of sporadic E were compared with those when sporadic E was observed not to occur. The specific location of the reflecting layer is not identified, nor is there any attempt to measure intensity. By including all the precipitation in the area between transmission sources and point of reception, a considerable degree of insensitivity is introduced into the data.

5. RESULTS

Figures 3 and 4 are photographs of the raw data from the CEC rolls. Figure 3 is the record from one of the flights that provided significant information as to the source of radio noise from a cloud beneath as the aircraft flew over it. In the near vicinity of the top of the cloud preceding and following its center, the radio noise on the most sensitive channel (50 mc./sec.) shows that the pulse frequency and amplitude increase to, and remain at a level much higher than for other portions of the entire

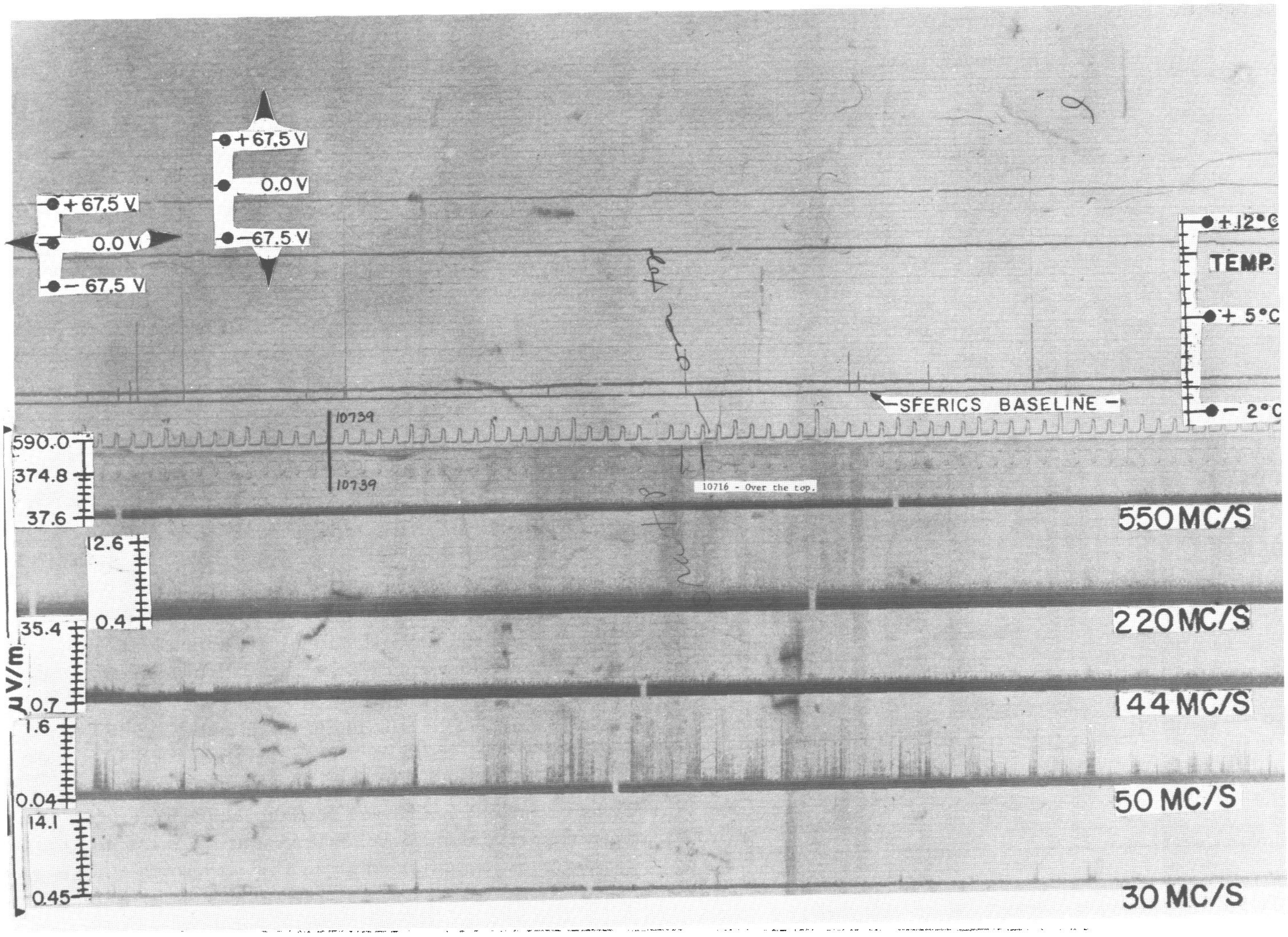

FIGURE 3.—CEC oscillograph records of radio noise data from aircraft passing over rapidly building cumulus cloud.

flight. The cloud on this pass was growing vigorously while on the subsequent pass the cloud was dissipating and no discernible increase above background was noted in the radio noise (fig. 4) at 50 mc./sec. We had learned earlier to anticipate this relationship of radio noise with developing cumulus by monitoring the radio noise with a pair of earphones. Only on this flight and one other was the aircraft close enough to an electromagnetically active cloud, at the proper combination of circumstances, to provide positive identification of the developing cloud as a source of radiation distinguishable from other atmospherics. This small sample is not definitive for establishing the cloud in this early stage as the source, but other sources or interference were not readily apparent.

Table 1 gives the field strength in microvolts per meter of the minimum discernible signal and for 0.1 in. deflection in the CEC charts. All receiver-recorder combinations have a bandwidth of 10 kc./sec. The average number of pulses per second rising one CEC chart division

TABLE 1.—*Receiver sensitivities and chart deflection*

Frequency (mc./sec.)	Field strength for minimum discernible signal (μv./m.)	Field strength for 0.1-in. chart deflection (μv./m.)
30	0.141	0.446
50	0.013	0.05
144	0.223	1.12
220	0.126	0.399
550	11.899	18.671

(0.1 in.), or more, above the background noise at each frequency is shown in table 2 for each of four flights on separate days. Horner [7] gives estimates of the number of discharges occurring per km.^{2} per sec. from a number of sources. His table is reproduced as table 3. There is considerable variation in the NCAR data from day to day, however most of the counts fall within the limits listed by Horner [7] or exceed them by not more than one order of magnitude. Only the "Sferics" (7.35 kc./sec.) receiver counts fall generally below Horner's estimates

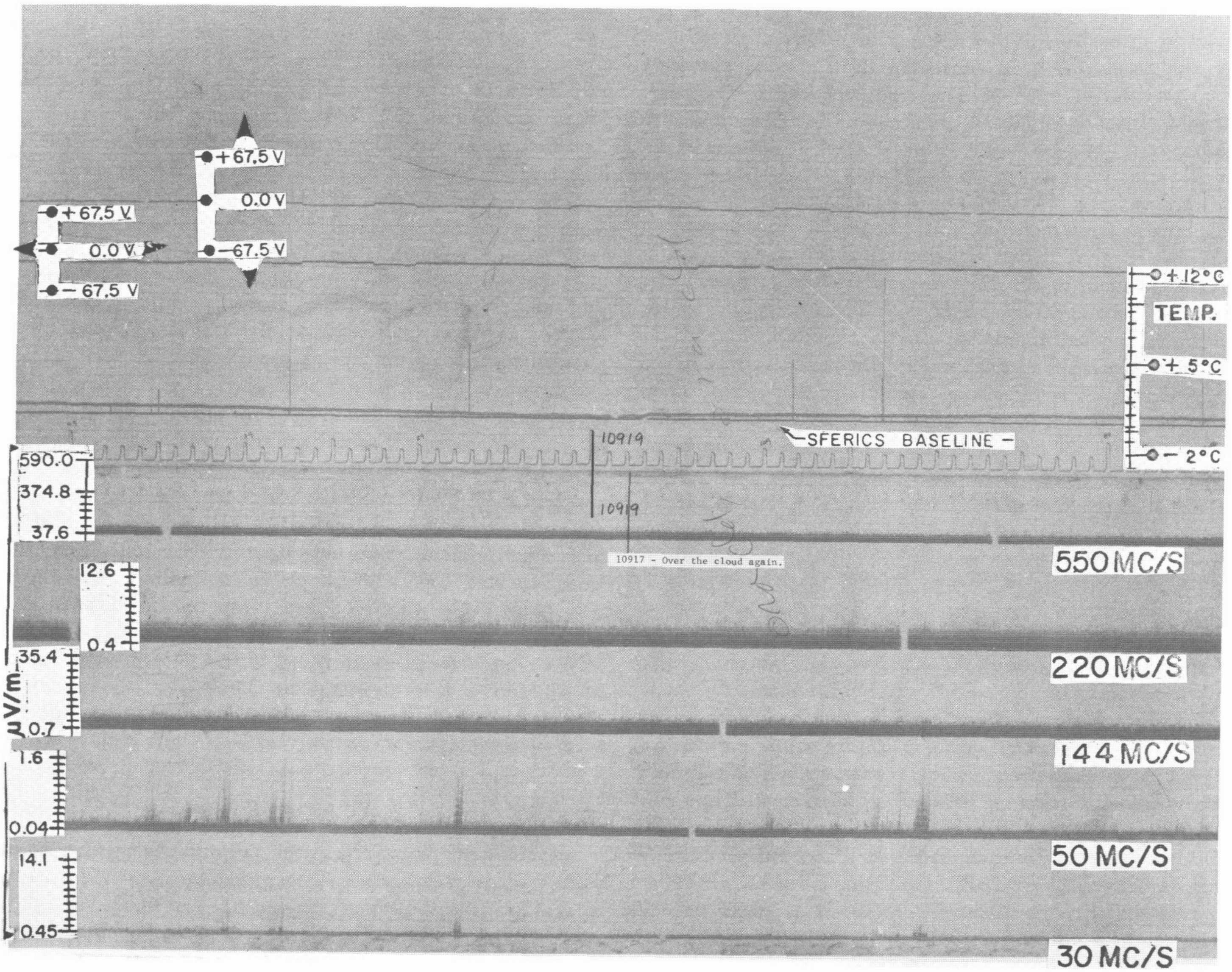

FIGURE 4.—CEC oscillograph records of radio noise data from aircraft passing over cloud of figure 3, but in dissipating stage.

TABLE 2.—*Average of total discharge count per sec. per km.² from radio noise data*

Frequency	July 30	Aug. 4	Aug. 6	Aug. 7
7.35 kc./sec.	2.53×10^{-6}	1.73×10^{-6}	5.14×10^{-6}	1.48×10^{-6}
30 mc./sec.	7.69×10^{-6}	9.67×10^{-6}	23.09×10^{-6}	14.05×10^{-6}
50 mc./sec.	107.79×10^{-6}	53.98×10^{-6}	78.04×10^{-6}	74.88×10^{-6}
144 mc./sec.	19.44×10^{-6}	10.33×10^{-6}	26.35×10^{-6}	15.52×10^{-6}
220 mc./sec.	61.98×10^{-6}	29.50×10^{-6}	35.97×10^{-6}	46.78×10^{-6}
550 mc./sec.	14.54×10^{-6}	5.92×10^{-6}	29.62×10^{-6}	11.73×10^{-6}

TABLE 3.—*Discharges per sec. per km.² **

	N(km.$^{-2}$sec.$^{-1}$)
From lightning flash counters	15×10^{-6}
From strikes to powerlines	16×10^{-6}
From radio noise	
Short range VLF measurements	3×10^{-6}
Long range VLF measurements	6×10^{-8}
Short range HF measurements	8×10^{-6}
Long range HF measurements	6×10^{-6}

*Reproduced from Horner [7].

from VLF radio noise measurements. This is due to greatly desensitizing the receiver to avoid saturation. Even so, two sets of values do not differ by more than a factor of 2. The per-kilometer² counts from the present UHF data are based on a circular area swept out by the line-of-sight from the aircraft to the upper portions of the distant thunderstorms (an area with a radius of approximately 500 km.). This is probably an overestimate of the count. Thus, we may expect that Horner's accepted figure of 10^{-5} counts per km.² per sec. for the maximum rate of occurrence of discharges of all types is probably somewhat low in comparison with our 50 mc./sec. data.

In obtaining the count per km.², it is assumed that all receivers recorded all atmospheric discharges appearing in the line-of-sight area between the aircraft and clouds extending above the far horizon to a height of approximately 5 km. In the data, the number of discernible pulses appearing at each frequency always is a function of the receiver sensitivity, implying a great range of the spectral intensities of the discharges in the area covered by the receivers, or a variation in the areal coverage from receiver to receiver. It is felt that pulses of greatly variable spectral intensity are required for this difference in any case—not all being strong enough to be picked up by all receivers at any given distance. Thus the irregularity of the antenna patterns in combination with a geographically irregular distribution of atmospheric sources combine to give highly variable pulse counts, difficult to attach physical significance to without further knowledge of source strengths and related physical conditions for discharge spectral intensity.

Transmission of atmospherics from far distant sources via sporadic E reflection or refraction may be of some importance in the total counts. In some instances, voice transmissions via sporadic E were observed emanating from sources spread over large areas to the north, west, or south, thus considerably increasing the area of atmospheric reception of the airborne receivers. A relation between the transmission of UHF radiation via sporadic E and the occurrence of heavy thunderstorm precipitation was rather forcibly brought to our attention in trying to eliminate radio transmission considered "spurious" to our main study. The results of this investigation concerning the occurrences of sporadic E will be discussed.

Table 4 gives the total precipitation reported in the area covered and the average precipitation per station reporting precipitation in the same area. The amounts of total precipitation are greater on the days with sporadic E than on the corresponding days without. The probability that the precipitation occurring on all of the sporadic E days will exceed by chance that occurring on all of the corresponding days without sporadic E is $(0.5)^4$ or 6.25 percent; the meteorological variability having been eliminated in so far as possible, by the pairing of days as close together in time as possible, usually consecutive days.

As massive thunderstorms and squall lines extend over two-tenths of the distance from the surface of the earth to the lower layers of the ionosphere, it would not be surprising to find the lower ionosphere markedly affected by these highly electrified storms, especially when they cover extensive areas as they do on some of the days these observations were made. A large number of observers have reported correlations of sporadic E with thunderstorms, e.g., Wilson [21], Ratcliffe and White [13], Bhar and Syam [2], Best et al. [1], Stoffregen [19], Isted [8], Mitra and Kundu [10], Rastogi [11] and [12].

A reliable statistical correlation is not well established in many of these papers. The data referring to larger storms are often diluted with that from the usual thunderstorm activity. As Rastogi [11] points out and our small-sample data indicate, it is only the anomalously large and tall thunderstorms with unusually heavy precipitation that show a correspondence with sporadic E activity. Studies of large highly electrified storm systems on a continuous fast response time are needed.

One intriguing aspect of a relationship between the ionosphere and large thunderstorms is the possibility of a solar-terrestrial weather linkage through the correlation of sporadic E variations and solar-terrestrial changes. The correlation of world-wide thunderstorm activity and solar flare activity observed by Reiter [14] and the correlation between major solar flare activity and high altitude electric field reported by Cobb [3] provides further evidence to this point. One might expect these relationships if the earth's fair-weather electric field is responsible for the initial cloud electrification and is the determining factor for the sign of the thunderstorm dipole as in the inductive charging mechanism promoted by Sartor [17], or the convective mechanism supported by Vonnegut [20].

TABLE 4.—*Total precipitation in the area between the transmission source and Key West on days when sporadic E was monitored, summer, 1964*

Precipitation total for stations reporting precipitation						Precipitation E_s precip. − no E_s precip.
E_s			No E_s			Amount (in.)
Date	No. of stations	Amount (in.)	Date	No. of stations	Amount (in.)	
7/20	8	3.90	7/23	11	3.01	+0.89
7/31	13	3.90	7/30	10	2.42	+1.48
8/3	13	10.04	8/4	5	0.58	+9.46
8/5	11	3.03	8/6	3	1.33	+1.70

6. CONCLUSIONS

Although it appears possible to relate electromagnetic radiation to growing convective clouds prior to full-scale lightning discharges, the information is difficult to isolate from the general background of "atmospherics" noise. The great variability in the spectral intensity of the discharges over a fixed area, however, suggests the possibility of the existence of discharge-producing mechanisms related to the stage of development of convective clouds or the electromagnetic environment within or surrounding them that could provide useful information for the study of the radio emission from the clouds in relation to their physical properties and those of the surrounding atmosphere.

There is statistical evidence that a relationship between heavy thunderstorm precipitation and temperate-latitude sporadic E exists. Further tests are possible by simultaneously measuring sporadic E radio reflection intensity and field changes in the main thunderstorm dipole.

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