Reports

Radio Observation of the Electromagnetic Emission from Warm Clouds

Abstract. *Microdischarges observable at 30 and 50 Mcy/sec appear from within cumulus clouds in an early stage of their development whether the temperatures within the clouds are above or below 0°C. Laboratory observations of radio emission from colliding drops may provide information on the physics of clouds in the atmospheres of this and other planets.*

The radio emission observed at 30 and 50 Mcy/sec during the early stages in the growth of cumulus clouds demonstrates the existence of an electrification process which operates at temperatures entirely above 0°C. The intermittent nature of this emission suggests that microdischarges within the cloud may play an important role in the electrification process itself. Dickey (*1*) observed the power spectrum of the radio emission from charged mercury drops discharging against a grounded probe. He found that the power emitted showed a peak at a frequency that was a function of the diameter of the drops. The experiment was in accord with the theory that the drops act as quarter-wave antennae of wavelength equal to the distance along their surfaces, resulting in the equation, $\lambda = 2\pi D$, where λ is the wavelength of the peak power emitted from the discharge of a drop of diameter D. These experiments have been repeated qualitatively in the laboratory (*2*), and an electromagnetic emission in the range predicted by Dickey was found. For charged mercury drops several millimeters in diameter, the emission appeared strongly in the centimeter region of wavelength as well as at longer wavelengths. These radio signals could be produced equally well by contact of uncharged mercury drops with quartz or plexiglass, a matter which might be of some consequence, in planetary atmospheres, along the lines suggested by Tolbert and Straiton (*3*).

When the mercury drops were replaced with drops of distilled water, no emission in the centimeter region could be observed whether or not the drops were charged, and regardless of the substance with which they made contact. However, radiation at lower frequencies appeared as a consequence of collision between charged distilled-water drops and any other conducting or partially conducting surface including other distilled-water drops of lesser or opposite charge. No spectrum analysis of the emission from water drops has yet been made, but the radiation appeared at frequencies on the order of tens of megacycles. The electromagnetic radiation from water drops of the same size as the mercury drops might be expected to appear at a considerably lower frequency because of the difference in the time of relaxation of charge in the two media, resulting from the difference in their specific inductive capacity and conductivity.

The emission resulting from the collision between charged water drops in free fall is much weaker that that caused by the usual laboratory noise. For this reason, the experiment had to be conducted entirely within a shielded room with isolation line filters in series with the power and ground lines.

If radio emission of the type observed in the laboratory could be observed and recorded from natural clouds, some useful information might be obtained on the electrical activity and possibly on the physical state of clouds. To this end, a preliminary field experiment was designed and carried out during the summer of 1963. Electromagnetic emission not associated with lightning has been observed in the past (*2–4*). These observations offered further assurance that the type of radiation sought could be found.

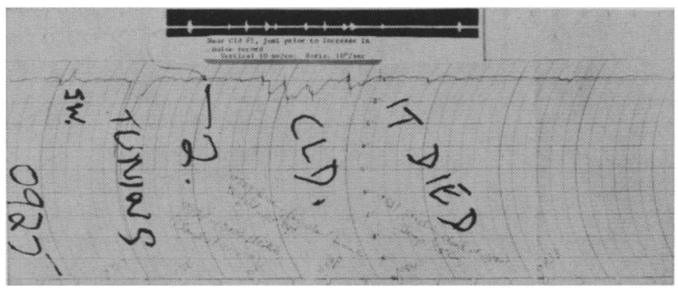
One important possibility requiring investigation in this way is the existence and nature of a warm-cloud electrification process. The field project was designed to provide evidence for the nature of warm-cloud electrification, as well as for the character and frequency of the electromagnetic radiation from later stages of convective-cloud development.

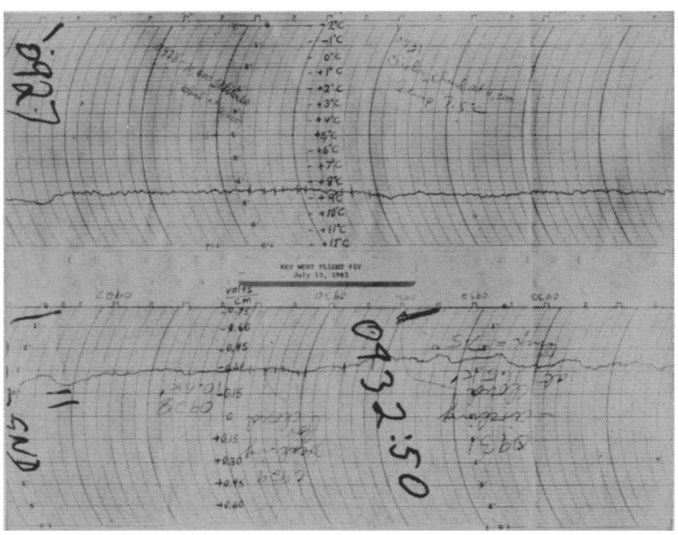
A twin-engine Bonanza aircraft was equipped with radio receivers, a temperature probe, and electrometers for obtaining the vertical potential gradient. With the airborne radio equipment it was possible to observe the cloud noise from 0.5 to 30 Mcy/sec and at 50 Mcy/sec, from approximately 145 Mcy/sec, 16 Gcy/sec, and 30 Gcy/sec. A time-integrated signal at 30 Mcy/sec was obtained with the antenna, aircraft, and receiver system so calibrated that a quantitative measure of the electromagnetic power could be obtained. The integrated emission at 30 Mcy/sec was recorded simultaneously with the vertical electric field of the atmosphere and the temperature at the altitude of flight.

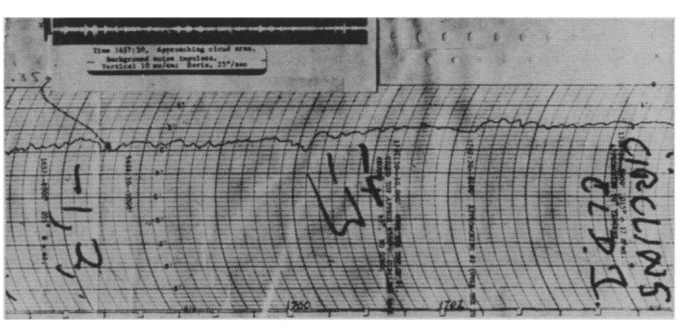
The flight plan called for the aircraft to cruise at 3000 meters in search of suitable clouds. Once a building cloud was sighted and the decision was made to study it, the pilot headed the airplane directly toward the cloud. The radio measurements were in operation during the approach. When the aircraft was about 100 meters from the cloud, a rapid climbing turn was started in an attempt to reach the level where the temperature was 0°C before reaching the top of the cloud. During the climb and turn, the aircraft was headed away from the cloud for a number of minutes depending on a subjective estimate of the rate of growth of the cloud; the plane then headed once again directly toward the cloud. The purpose of this maneuver was to localize the source of the electromagnetic radiation being received. Upon return to the vicinity of the cloud, if the previous maneuver had promised successful localization of the radio emission, the race with the cloud top to the 0°C isotherm was continued by circling the cloud at a convenient distance. Dissipation of the cloud or its growth into a mature thunderstorm usually terminated the observation, since the radio emission at 30 Mcy/sec and higher frequency not associated with lightning was obliterated on the appearance of both of these events.

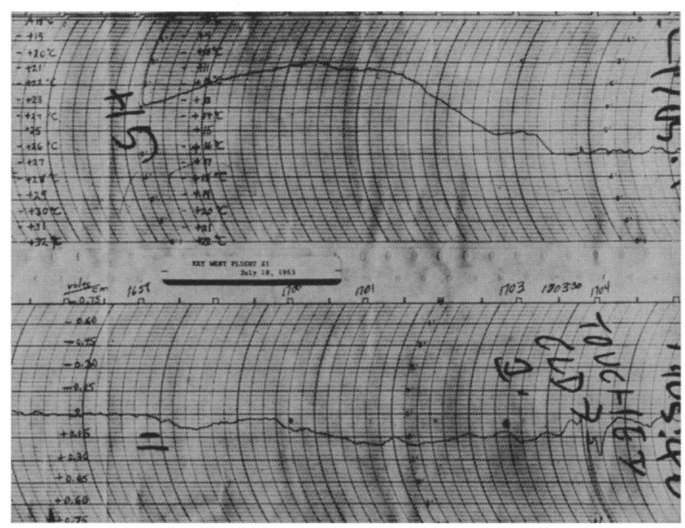
Although it was theoretically possible to make measurements in one form or another at the frequencies already mentioned, the system operating most satisfactorily responded to emission at 30 and 50 Mcy/sec. As a result, these frequencies were studied almost exclusively. The radio emission obtained was taken from the receivers by means of a signal-integrating thermocouple just prior to the audio stage. The integrated signal at 30 and 50 Mcy/sec rose above the level of the noise background on only a few occasions, although the audio response to noise bursts was much more frequent. Figure 1 is a scope photograph of the individual pulses received from a cloud before the integrated signal was strong enough to show an excursion above the system noise. The background noise taken when no clouds were in the vicinity of the aircraft, at this setting on the oscilloscope, is typical of the portion of the trace between the pulses shown in Fig. 1. Figure 2 shows both the Esterline-Angus recordings of the temperature at the altitude of flight and the vertical potential gradient, made simultaneously with the records shown in Fig. 1. The remarks on the charts in the figures relate, among other things, the position of the cloud to that of the aircraft.

The discrete nature of the pulses received from the clouds and their spacing in time explains the infrequent rise of the integrated signal above ambient noise. We knew very little, of course, of the intensity or frequency of the signal that was to be expected on this









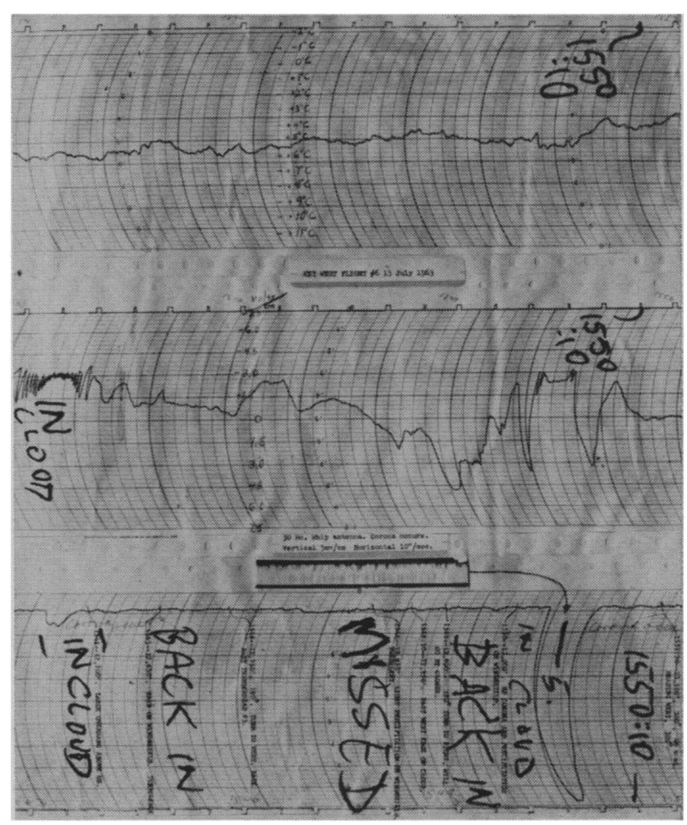


Fig. 1 (top left). Oscilloscope photograph and integrated noise from a 30 Mcy/sec receiver, Key West, 13 July 1963. Fig. 2 (center left). Temperature and potential gradient records simultaneous with oscilloscope photograph and integrated noise from a 30 Mcy/sec receiver, 13 July 1963. Fig. 3 (bottom left). Oscilloscope photograph and integrated noise from a 50 Mcy/sec receiver, Key West, 18 July 1963. Fig. 4 (top right). Temperature and potential gradient records simultaneous with information (50 Mcy/sec) shown in Fig. 3. Fig. 5 (bottom right). Corona oscilloscope and integrated noise (30 Mcy/sec) with simultaneous temperature and potential gradient records, Key West, 15 July 1963.

first excursion into the field. Figure 3 shows the pulses received at 50 Mcy/sec from another cloud, in this case either more active or closer to the aircraft. Figure 4 shows, in addition, the temperature and potential gradient records for the same period. The pulses received at both 30 and 50 Mcy/sec emanated from clouds whose total existence was in an environment where temperatures were several degrees above 0°C. Thus some sort of electrification is established for warm clouds involving the extremely rapid rearrangement of charge required for the production of the observed electromagnetic emission.

In addition to making these measurements, the audio output derived from the higher frequency emission was monitored. From the audio response, the observer could learn that the cloud under study was the source of the radio signals received because of the increase or decrease in the rate and intensity of the pulses as the aircraft approached or receded from a cloud. In regions of strong electric field near a cloud, the cloud noise was replaced by corona noise from points of the aircraft or from the antennae tips. That this noise is distinctly different from the noise of the cloud can be seen by comparison of Figs. 1 or 3 with Fig. 5. This difference, along with the recording of a strong electric field, should provide positive evidence of corona and the interpretation of spurious radio noise.

The signals at 30 and 50 Mcy/sec not associated with lightning or aircraft corona were absent in the vicinity of both mature thunderstorms and the smaller clouds that had reached the peak of their growth and had started to evaporate. The intermittent nature and short duration of these pulses, as seen in Figs. 1 and 3, suggest the existence of many microdischarges in clouds whose temperatures are entirely above 0°C and therefore give evidence of growing electrification without the presence of the ice phase. The growth of the electrification in these clouds may be associated with the mechanism responsible for the observed radio emission in discrete pulses. If this is true, the electrification process, at least of warm clouds, may be related to the smaller scale turbulent and cellular motions in the clouds, either through polarization or charge concentration in the smaller irregularities which subsequently interact at close range to produce a rapid rearrangement of the charge in the manner required to produce the electromagnetic emissions observed. Thus the process of cloud electrification, at least in warm clouds, may include an electrification mechanism quite different from any so far proposed.

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References and Notes

1. F. R. Dickey, Jr., *Tech. Rept. 123*, Cruft Laboratory, Harvard University, Cambridge, Mass., July 1951.
2. J. D. Sartor, *J. Geophys. Res.* **68**, 5169 (1963).
3. C. W. Tolbert and A. W. Straiton, *ibid.* **67**, 1741 (1962).
4. J. E. Gibson, *Memorandum Rept. 693*, 4 pp., U.S. Naval Research Laboratory, Washington, D.C., 27 March 1957; A. Kimpura, *Proc. Intern. Conf. on Atmospheric and Space Elec., 3rd, Montreaux, Switzerland*, May 1963.
5. I thank B. Vonnegut for encouragement and support of the field research at Key West and the loan of some of the instrumentation used on the aircraft. The assistance of the U.S. Weather Bureau personnel at Key West was invaluable.

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Harappa Culture: New Evidence for a Shorter Chronology

Abstract. *Radiocarbon dates suggest a total time spread of 550 years, from about 2300 to 1750* B.C., *for the Harappa culture.*

The possibility of dating Harappa culture on the basis of written evidence is as yet precluded by our present inability to decipher the Indus script. The date bracket generally accepted as being safe (*1, 2*), about 2500 to 1500 B.C., is based mainly upon Gadd's classical paper (*3*) on seals of the Indus type found in Mesopotamia. With the availability of carbon-14 dates for Damb Sadaat, a site showing Harappan contact, Fairservis (*4*) showed that the earliest date for Harappa culture was about 2100 B.C. Although at that time he retained the total span of about 1000 years, he later suggested a much shorter bracket on anthropological considerations (*5*).

In recent years a large number of carbon-14 dates have become available for some of the important Harappan and allied sites. An analysis of this new evidence strongly suggests a shorter Harappan chronology. I now propose a maximum date bracket of about 2300 to 1750 B.C. for the total time spread of Harappa culture. This shorter bracket is not contradictory to the archeological evidence.

Radiocarbon dates for three main Harappa sites—Mohenjodaro, Kalibangan, and Lothal—and three allied sites —Damb Sadaat, Kot Diji, and Niai Buthi—are given in Table 1. The time brackets discussed in this report are based on 5730 ± 40 years as being the value of the half-life of radiocarbon.

The main Harappan sites from which samples of middle and late levels have been dated are Kalibangan (Rajasthan) and Lothal (Saurashtra). Only one sample representing upper levels of Mohenjodaro has yet been dated; unfortunately, no dates are available for Harappa. All the relevant radiocarbon dates are plotted in Fig. 1. The end of Harappa culture is easily determined from the available dates. A cross-check on the beginning of the culture is available from dates for Damb Sadaat and Kot Diji. Niai Buthi probably provides a check for the date of early Harappa culture.

The mean dates for the upper levels of Kalibangan and Lothal, based on samples TF-25 and TF-150, and TF-23 and TF-19, are 1960 ± 75 and 1840 ± 85 B.C., respectively (*6*). These have to be compared with the single date for the upper level of Mohenjodaro (TF-75) of 1755 ± 115 B.C. The three dates are seen to be consistent with a mean date of 1880 ± 50 B.C. for the end of Harappa culture at these sites. However, since Mohenjodaro was probably one of the most important Harappan seats, the culture may have continued longer there than at Kalibangan and Lothal. In view of this, we consider 1750 B.C. as a probable date for the end of Harappa culture. This estimate is also well supported by the radiocarbon dates available for several post-Harappan Chalcolithic cultures in India (*7*).

The earliest dates for Kalibangan and Lothal have to be based on an extrapolation since the lowermost levels have not been dated. However, Fig. 1 shows that safe limits for the beginning of Harappa culture at these sites can be obtained easily since all the upper levels have been dated. Considering the stratigraphic divisions, we conclude that the Harappa culture at Kalibangan and Lothal started not earlier than 75 and 150 years, respectively, before the lowermost levels for which radiocarbon dates have been obtained.

The mean dates for the lowermost dated levels of Kalibangan and Lothal, based on samples TF-147 and TF-145, and TF-22, TF-27, and TF-26, are 2040 ± 75 and 2000 ± 70 B.C., respectively. Taking one standard deviation on the mean of the earliest and