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Electric charge in clouds at temperatures above 0°C

ANNA MANI, M. V. SIVARAMAKRISHNAN and S. P. VENKITESHWARAN

Meteorological Office, Poona

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1. Introduction

It is well-established that heavy rain can fall under certain conditions, from clouds whose temperatures are nowhere below the freezing point and where the Bergeron mechanism is not applicable, and coalescence of droplets can provide the initial step in the growth of rain drops. It is, however, generally believed that lightning discharges occur in heavy cumulus or cumulonimbus clouds in which glaciation has begun to be apparent, and most of the theories so far advanced on the development of electric charges in the clouds assume the change of state to play a direct role in the electrification of the cloud.

2. Role of freezing processes in thunderstorm electrification

Kuettner (1950) has found that a high precipitation is an indispensible requirement for the electrical activity in a cumulonimbus, the central lightning area usually being coincident with the area of the highest precipitation intensity. The onset of lightning activity coincides with the appearance of heavy solid precipitation within the cloud. Byers and Braham (1950) believe that environment temperatures of about —20°C are required before lightning is initiated, while Workman and Holzer (1942) suggest that initial charge separation probably takes place in the lower levels of the cloud where the temperature is about —10°C. Workman and Reynolds (1949) in a later paper state that thunderstorm electricity is a phenomenon associated with vertical convection and precipitation involving the ice phase of water and probably the ice phase in combination with supercooled water. He finds that separation of electric charge within the cloud is closely associated with the precipitation mechanism and does not take place until precipitation processes are well under way, at temperatures between 0° and —15°C, most probably between —5° and —10°C. The first internal flash occurs about 12 minutes after the initial radar echo, which by this time has approached the —30°C level and started to descend. At the same time precipitation appears at the cloud base.

Wormell (1953, 1955) also found that "the appearance of visible signs of glaciation is a rather reliable indication that the intense electric fields are developing, although not necessarily that lightning will occur. . .The location of the main region of charge separation (near the —10°C level), and the fairly close association in time of the appearance of intense fields and of visible signs of glaciation at the cloud top suggest that the presence of ice and perhaps of ice and supercooled water in juxtaposition, is an essential to the main process of charge separation, or at any rate to its final stages". Findeisen (1940) reports that the distrubances in aircraft radio-equipment are much more noticeable when the plane is in or near the part of the cloud containing ice. Smith (1951) has produced some negative evidence pointing to the same conclusion. Frost (1952), from observations made at Singapore, also concluded that "lightning appears unlikely to be encountered with cloud tops below 35,000 feet", at which level the transition from cumulus to cumulonimbus cloud occurs in the tropics. There is thus a "consensus of opinion that the occurrence of lightning is associated with the stages of the cumulonimbus life cycle after the time when a large number of ice crystals may be expected to have formed within the cloud (*e.g.*, by penetration above the —40°C isotherm)" (Jones 1955).

The generally accepted view thus seems to be that freezing processes or changes of state play a direct role in the electrification of the clouds. This is however, contradicted by observations of lightning in clouds that are everywhere above the freezing temperature. Though this phenomenon is familiar to meteorologists and pilots in the tropical regions, published reports of such occurrences are very scanty. The best report published is that of Hal Foster (1950) who observed lightning from two warm clouds, while flying over them in the mid-Pacific. Based on this observation and unpublished reports of similar occurrences and considering the occurrence of volcanic lightning, Ross Gunn (1956) formulated a mechanism for the occurrence of electrical discharges inside clouds, in which freezing processes or changes of state play no direct role in the electrification. His opinion that "contemporary views of the electrification processes within active thunderclouds require a fundamental reorientation at this time", is considered controversial by Appleman (1957), who doubts the validity of the single published observation of Foster and of the theory based on it. He concludes that until conclusive evidence is presented, it is not possible to state whether or not lightning can be initiated in clouds that are everywhere above 0°C.

3. Electric charge in rain

Thunderclouds, which produce rainfall rates exceeding about 18 mm/hour, are known to produce intense electric fields greater than 1000 volts/metre at the ground (Wormell 1953) which are predominantly negative, though periods of equally intense positive field also occur often associated with very heavy rainfall. These high fields are generally thought to be associated with the presence of ice in the cloud. Simpson (1949) in a study of rain electricity lists a number of occasions of fairly heavy rain without any pronounced electrical effects. Smith (1951) from an analysis of Simpsons' observations taken at Kew over a period of two years finds that on 7 occasions intense rain was associated with only weak electric fields. On 6 of these occasions the temperature at the level of the cloud top estimated from a tephigram was —3°C, whereas on the numerous occasions on which intense rain was associated with strong electric fields the estimated cloud top temperature was always below —10°C. The absence of any considerable charge was presumed to suggest the absence of ice in the cloud.

But observations at Poona of the electric field at the earth's surface and the charge brought down by raindrops during rain contradict the above conclusion. They show that all rain drops that fall during a thunderstorm are not charged, spells of rain even from freezing clouds occurring with no charge. In the monsoon months at Poona during long periods of steady rain from above the freezing level, as indicated by the existence of "melting bands" in radar echoes, the rain that falls carries no charge. An example of this is illustrated in Fig. 1 in which are reproduced portions of the following records for 2 August 1956 during continuous rain.

(A) Electrograph record from 0800 to 1300 IST,

(B) Rain electrograph record from 0800 to 1240 IST,

(C) Record of intensity raingauge from 0900 IST on 2-8-56 to 0800 IST on 3-8-56,

(D) Record of rainfall for the same period as (C), and

(E) Photographs of the melting band taken on an SCR 717 C, radar 9·1 cm at 1117 and 1205 IST.

Nearly 3·6 inches of rain fell from 0900 to 2400 IST. There was a fairly large negative potential near ground from

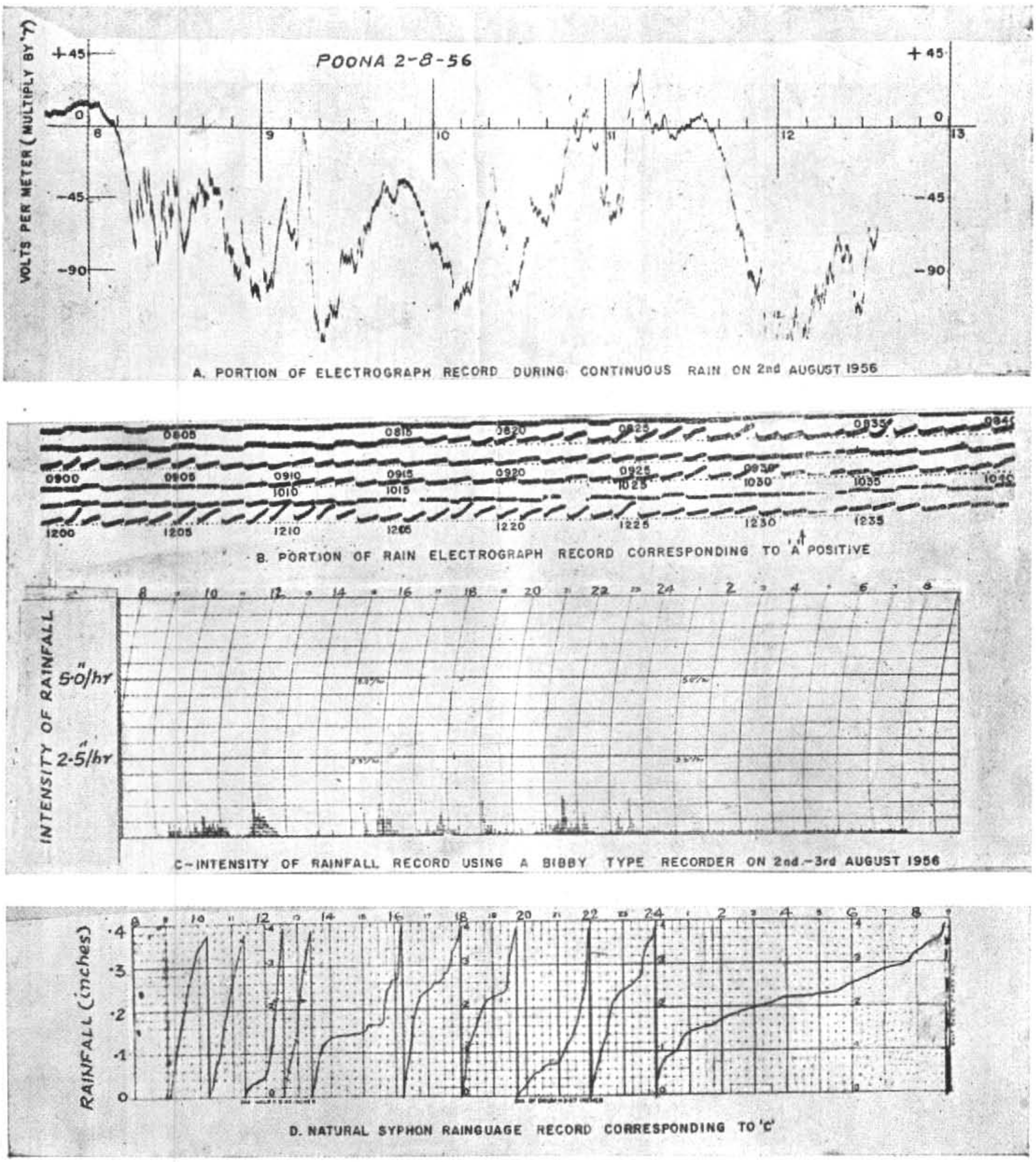
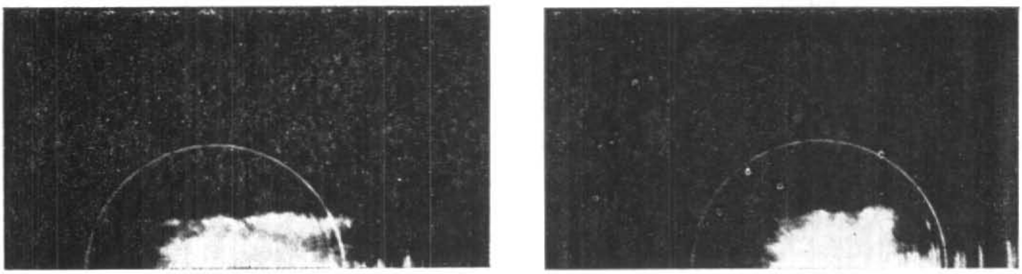

POONA 2-8-56
VOLTS PER METER (MULTIPLY BY '7')
A. PORTION OF ELECTROGRAPH RECORD DURING CONTINUOUS RAIN ON 2nd AUGUST 1956
B. PORTION OF RAIN ELECTROGRAPH RECORD CORRESPONDING TO 'A' POSITIVE
INTENSITY OF RAINFALL
5·0"/hr
2·5"/hr
C–INTENSITY OF RAINFALL RECORD USING A BIBBY TYPE RECORDER ON 2nd.–3rd AUGUST 1956
RAINFALL (inches)
D. NATURAL SYPHON RAINGUAGE RECORD CORRESPONDING TO 'C'

Fig. 1 (A to D)



1117 5 M 1205 5 M

Fig. 1(E). Melting band on 10-cm radar on 2 August 1956

Figures in the left and right hand bottom corners indicate time in IST and range marks in miles respectively

Fig. 2

A—Area of lightning—later extending to right as shown

0810 to 1050 IST, the charge on the rain being positive. At 1117 IST when the "bright band" was observed, no charge was however, recorded on the rain electrograph. The electrical potential gradient near the ground was also small. From 1200 to 1300 IST, though the melting band persisted the rain carried a positive charge, the potential gradient near the ground having again a fairly large negative value. It is therefore clear that rain from freezing clouds is not always necessarily associated with large electric fields and *vice versa*.

4. Observations of lightning in warm clouds

Published observations of lightning in warm clouds are, as stated earlier, very few. Foster (1950) in his observations of the two warm-type thunderstorms in mid-Pacific reported that the cloud was approximately 5500 ft from base to top and for approximately 30 minutes the flashes occurred at the rate of one flash per ten seconds. The plane flew directly over one of the clouds at a true radar altimeter reading of 8100 ft m.s.l. The top of the cloud was about 100 ft below and the corrected air temperature as determined by the dry bulb thermometer as they passed over the cloud was 6°C. The freezing level had been observed above 1500 ft during descent, and the temperature increased steadily below the freezing level, with no inversions observed.

Recently S. S. Karanjia (*Indian J. Met. Geophys.* 1958) sailing between Mombasa and Karachi reported on 24 January 1958, lightning from a cumulus cloud (C_L 2), at 23°42′N and 65°45′E. The flashes occurred at the rate of about one flash every two seconds. Forks of lightning were frequent and were seen to run horizontally. When the C_L 2 dissolved, lightning also ceased. Though other observers have reported similar occurrences, they have not received the attention they deserve, nor have satisfactory theories been advanced to explain their occurrence.

In extra-tropial latitudes, where the freezing level is low, the tops of clouds reach the freezing level before the cloud has attained any depth. The thickness of the cloud carrying the water stage of the rain is small. The condensation level is so low that cloud-to-ground discharges are more common in these latitudes. In tropical latitudes on the other hand, with freezing levels at about 16,000 ft above sea level, as at Poona during September to October, assuming a height of 5000 ft for the cloud base, the thickness of the cloud below freezing level will be about 11,000 ft. Lightning in such clouds can however be noticed from the ground only under certain favourable conditions. The thunderstorm cell must be an isolated one, there should not be so much light that the lightning will not be visible or too little light that the features of the cell cannot be studied and finally it should be possible to estimate the height and extent of the cloud from known landmarks. This means that for successful visual observation and estimation of the height of the cloud, the cloud must develop as a single cell in a known area, just before dawn or after sunset.

5. An observation of lightning in a "warm" cloud at Poona

Two of the authors of this note had an opportunity of observing such a cloud while they were at the National Defence Academy, Khadakvasla near Poona on 5 October 1958 between 1830 to 1900 IST. The sun had just set and an isolated cumulus cell had developed towards WSW. From the shape of the cloud one could definitely say that the cloud was still in the cumulus stage and that freezing had not started. Lightning was first observed to occur in the left half of the cloud and later to extend progressively to higher regions. A rough sketch of the cloud was made and is reproduced in Fig. 2 (p. 412). The flashes of lightning occurred at the rate of about one every 5-10 seconds in the portion marked A and it shifted to the higher regions in the direction indicated by the arrow. The lightning illuminated the whole cloud at intervals, but as the details of the base were not visible, it could not be ascertained whether it was raining from this cloud at the time.

The sky was generally clear except for this cloud and an independent cumulonimbus cloud with its own lightning discharges to the right. The angle of elevation of the top of the cumulus cloud was estimated to be 25°. The distance was estimated to be about 3-4 miles, from the landmarks like the Sinhagarh hills in the vicinity. The height of the top of the cloud was therefore estimated to be about 9000 ft above the place of observation. Khadakvasla being roughly at about 2000 ft, the height of the top of the cloud was about 11,000 ft above m.s.l. Assuming a lapse rate of about 6°C, the temperature at the top of the cloud was estimated to be about 10°C.

More observations of the above type, both from aircraft and from ground should be very valuable. The present note, it is hoped, will help to draw the attention of the meteorologists in India and elsewhere in the tropics to this problem and lead in due course to the elucidation of the nature of the generation and distribution of electric charge in thunderstorms and the initiation of electrical discharges in both freezing and non-freezing thunderclouds.

REFERENCES

Appleman, H. 1957 *J. Met.*, **14**, 1, pp. 89-90.

Byers, H. R. and Braham, R. R. 1950 *The Thunderstorm*, U. S. Dep. of Commerce, Washington D. C., pp. 86-89.

Findeisen, W. 1940 *Met. Z.*, **57**, p. 201.

Frost, R. 1952 *Met. Res. Pap.*, 757, Met. Res. Com. Lond.

Hal Foster 1950 *Bull. Amer. met. Soc.*, **31**, 4, pp. 140-141.

— 1958 *Indian J. Met. Geophys.*, **9**, 4, p. 384.

Jones, R. F. 1955 *Quart. J. R. met. Soc.*, **81**, p. 629.

Kuettner, J. 1950 *J. Met.*, **7**, 5, pp. 322-332.

Ross Gunn 1956 *Ibid.*, **13**, 1, pp. 21-29.

Simpson, G. C. 1949 *Geophys. Mem., London*, **10**, 84.

Smith, L. G. 1951 *Quart. J. R. met. Soc.*, **77**, p. 683.

Workman, E. J. and Holzer, H. E. 1942 A preliminary investigation of the electrical structure of thunderstorms (unclassified), *NACA Tech. Note*, 850.

Workman, E. J. and Reynolds, S. E. 1949 *Bull. Amer. met. Soc.*, **30**, 4, pp. 142-144.

Wormell, T. W. 1953 *Quart. J. R. met. Soc.*, **79**, pp. 3-38.

1955 Theories of thunderstorm Electrification—some general considerations. *Proc. Conf. Atmos. Electr. Geophys. Res. Pap.*, 42, Geophys. Res. Directorate, AFCRC, Bedford, pp. 157-161.