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Aircraft Observations of Electrical Conductivity in Warm Clouds

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ABSTRACT

Aircraft observations of electrical conductivity and cloud microphsical, dynamical and other electrical parameters were made in warm stratocumulus and cumulus clouds forming during the summer monsoon seasons (June–September) of 1983 and 1985 in the Deccan Plateau region, India. A Gerdien type cylindrical condenser was used for the measurement of electrical conductivity. The variations in the electrical conductivity are observed to be closely associated with the updrafts and downdrafts in the cloud, liquid water content, cloud droplet charge and corona discharge current. The value of electrical conductivity in warm clouds is found to be in the order of 10^{-12} ohm^{-1} m^{-1} which is two orders higher than that observed in clear–air at cloud–base levels in some regions by other investigators.

Classical static electricity concepts predict reduced conductivity values inside clouds. Cloud electrical conductivity measurements, particularly in warm clouds are few and the results are contradictory. The recently identified mechanism of vertical mixing in clouds lends support to convective charge separation mechanism with inherent larger than clear–air values for cloud electrical conductivity and therefore consistent with the measurements reported herein.

I. INTRODUCTION

Measurements of cloud electrical conductivity are few and the results are inconclusive. In situ measurements inside stagnant cloud–air masses accessible at mountain–top locations indicate less than clear–air values for the cloud electrical conductivity (Chalmers, 1976; Rust and Moore, 1977). A few balloon borne measurements inside dynamically active growing clouds indicate larger, up to two orders of magnitude more than clear–air values for cloud electrical conductivity (Israel, 1971; Evans, 1969). Indirect estimates of the electrical conductivity inside thunderclouds also indicate larger values up to 20 times more than clear–air values for the conductivity (Freier, 1962).

Measurements of electrical conductivity in clear–air have been made using balloon borne conductivity sensors in the Indian region (Venkiteshwaran et al., 1953; Mani and Huddar, 1965; Srivastava et al., 1972; Huddar and Rao, 1972). Observations of electrical conductivity inside monsoon clouds are important for the understanding of cloud electrification processes. A Gerdien type electrostatic coaxial cylindrical collector (Gerdien, 1905; Chalmers, 1967) for airborne measurements has been designed and used for making measurements of electrical conductivity in warm clouds forming during the summer monsoon season (June–September) in the Deccan Plateau region, India. Also, simultaneous measurements of cloud liquid water content (LWC), vertical velocity, cloud droplet charge and corona discharge current were made. The details of aircraft instruments used for measurement of cloud droplet charge, corona discharge current and LWC were described elsewhere (Mary Selvam et al., 1976; Murty et al., 1976). A variometer (Ball Engineering Co., USA) with a pitot tube has been used for

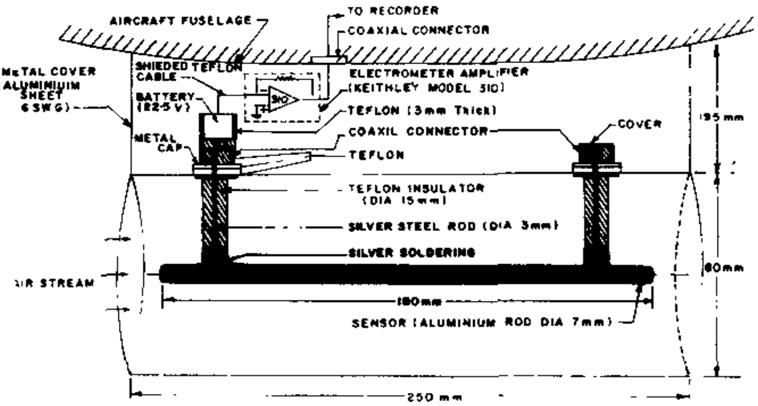

Fig.1. Schematic diagram of the Gerdien type cylindrical condenser for the measurement of electrical conductivity.

the measurement of the vertical velocity (Sethuraman et al., 1978). The details of the Gerdien type sensor, method of computation of the electrical conductivity and the preliminary results of observations made in warm stratocumulus and cumulus clouds during the summer monsoon seasons of 1983 and 1985 are presented in this paper.

II. CONDUCTIVITY SENSOR

A schematic diagram of the Gerdien condenser used for the measurements is shown in Fig. 1. The instrument was installed to the belly of the DC−3 aircraft in the nose portion as shown in Fig. 2. The Gerdien conductivity sensor mainly consists of two concentric cylinders,the inner cylinder (collector) consists of an aluminium rod of diameter 7 mm and of length 180 mm. The outer cylinder is an aluminium cylindrical shell of inner diameter 80 mm and of length 240 mm. The collector is electrically isolated from the outer shell with teflon insulators as shown in the figure. A bias voltage of 22.5 V is applied to the collector. The current flow in the collector resulting from the collection of ions from the cloud−air is measured using a suitable electronic measuring system which consists of an electrometer amplifier (Keithley, USA, Model 310) with feedback resistance of 10^{10} ohms and a milliamp strip chart

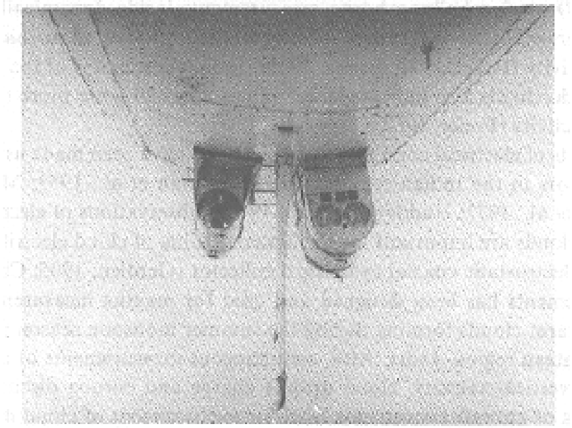

Fig.2. Figure showing conductivity measuring instrument (right side) and cloud droplet charge sensor (left side) mounted below the nose of the DC−3 aircraft.

recorder (Esterline Angus, USA).

III. THEORY AND COMPUTATIONS

The electrical conductivity was computed using the theory described by Chalmers (1967). If V is the potential difference (22.5 Volts in these experiments) between the two cylinders of the Gerdien condenser, the electric intensity at a point distance r from the axis of inner cylinder can be expressed as

$$E = \frac{V}{r \ln a/b}.$$

An ion of mobility w thus moves in time dt through a radial distance $dr = wEdt$. If we consider the ions which start at the outer cylinder and move inwards toward the inner cylinder, the time required to traverse a radial distance dr is given by

$$dt = \frac{r \ln a/b}{wV} dr$$

and the total time to get from the outer to the inner cylinder is

$$t = (\frac{a^2 - b^2}{2}) \frac{\ln a/b}{wV}.$$

During this time, the air will have moved a distance Ut along the cylinder. If this distance is less than the length L of the part of the inner cylinder connected to the measuring instrument, then the whole of the inward-moving ions will be collected. But in practice, since U, the mean velocity with which aircraft moves horizontally is large (50 ms^{-1}), Ut will be large and only a fraction of the ions will reach the inner cylinder. Only those ions which started near the axis than a certain critical distance R will be collected. Therefore,

$$U(R^2 - b^2) \ln a/b = 2wVL$$

and

$$R = \sqrt{\frac{2wVL}{U \ln a/b} + b^2}.$$

By substituting the values of U =50 ms^{-1};w =$1.5 \times 10^{-4} ms^{-1}$; V =22.5 volts; a =0.04 m; b= 0.0035 m; L =0.18 m in the above equation, the value of R comes to be about 4.714×10^{-3}m. This means that those ions which come to within a distance of about 4.714 mm from the axis of inner cylinder will be collected. For a full-scale deflection of the pen of the chart recorder used, 1 mA current is required or in terms of voltage, V_R, it will be 1.5 volts since the resistance of the recorder is 1500 ohms. The maximum current, I, which flows through the collector due to the collection of ions can be expressed as V_R / R_f where R_f is the feedback resistance of the electrometer amplifier (10^{10} ohms)or I = 1.5×10^{-10} amps. According to Riecke's formula, where V is the potential difference between the two electrodes and C is the capacitance, the charge arriving at the central cylinder in unit time is $Q = CV$, so that the current I is given by $I = CV\lambda / \varepsilon_o$, where ε_0 being the permittivity of free space (8.854×10^{-13} F/m) and λ conductivity. The capacitance of a cylindrical condenser is given by

$$C = \frac{2\varepsilon_o L}{\ln a/b}.$$

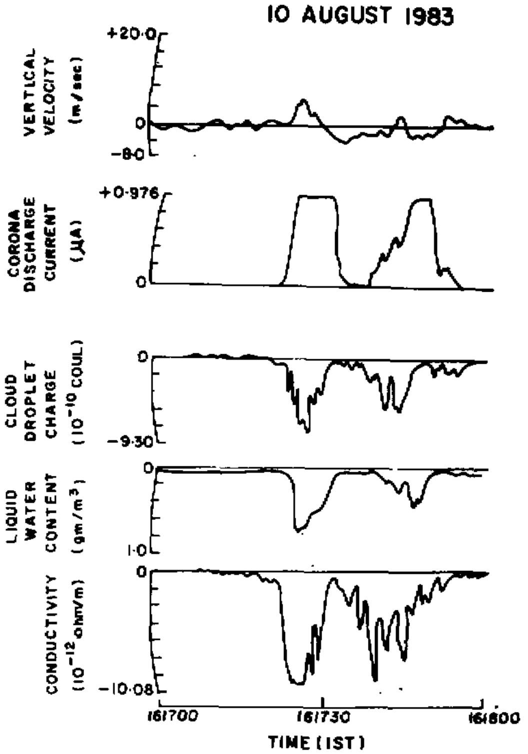

Fig.3. Typical example of simultaneous measurements of vertical velocity, point discharge current, cloud droplet charge, liquid water content and negative electrical conductivity made in a warm cumulus cloud on 10 August 1983.

Hence, the conductivity λ corresponding to full-scale response of the strip chart recorder is 14.359×10^{-12} ohm^{-1} m^{-1}.

The present Gerdien sensor was designed particularly to record variations in the electrical conductivity in monsoon clouds and accordingly the electronic measuring system was developed. Also, while designing the instrument proper care was taken to protect the sensor / electronic measuring system from wetting. The sensitivity of the sensor was adjusted to measure the values of conductivity in the range 10^{-11} to 10^{-12} ohm $^{-1}$ m^{-1}. It has been done based on the range of values recorded in cloud-air during the field testing of the instrument. The types of clouds sampled were warm stratocumulus and cumulus with a maximum vertical thickness of 1.5 km. The clear-air conductivity values at the cloud-base levels in the Indian region were reported to be in the order of 10^{-14} ohm^{-1} m^{-1} (Venkiteshwaran et al., 1953; Mani and Huddar, 1962; Srivastava et al., 1972; Huddar and Rao, 1972) and these are below the detection limit of the present sensor.

Some investigators have observed that the current collected by the Gerdien condenser may be influenced by convection and diffusion (e. g., Kodera et al., 1983). The errors due to the above effects would be significant only in case of the measurements made by supersonic aircraft and rockets. In the present measurements the errors due to the above effects would be minimum as the cruising speed of the aircraft (DC-3) used for the measurements is very low (about 180 km / h). Other possible errors in the measurement of conductivity could be (i) due

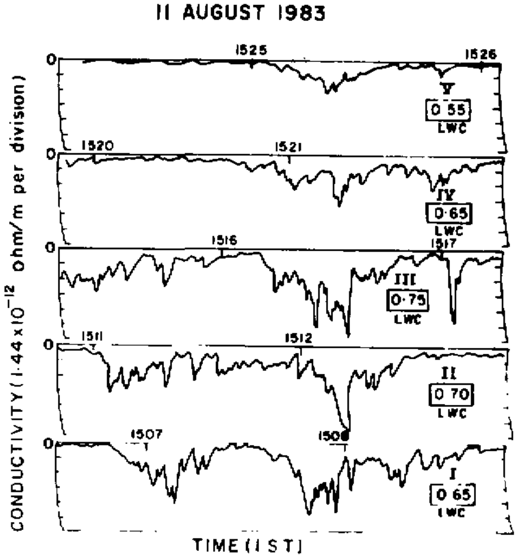

Fig.4. Typical example of negative electrical conductivity variation inside a stratocumulus cloud during five consecutive aircraft traverses (I to V) made on 11 August 1983.

to impact of cloud droplets on the collector (Lane-Smith, 1977), and (ii) due to the concentration of electric field lines on the sensor within the cloud which in the case of highly electrified clouds may generate corona. As the clouds sampled were of warm stratocumulus and cumulus type with vertical depth less than 1.5 km the errors due to the above effects will be minimum as these clouds are not highly electrified. Aircraft measurements of atmospheric electric field in monsoon clouds indicated values in the range of 50–200 Vm^{-1} (Murty et al., 1976).

The larger than clear-air values for cloud electrical conductivity observed in warm monsoon clouds are consistent as explained in the following. The recently identified cloud vertical mixing (cloud-top instability) by penetrate downdrafts (Paluch, 1979) indicates enhanced conductivity for cloud-air originating from cloud-top boundary regions. Wagner and Telford (1981) have simulated the enhanced conductivity in such downdrafts originating from ion rich cloud-top boundary regions.

IV. RESULTS AND DISCUSSIONS

Results relating to the simultaneous measurements of electrical conductivity, cloud liquid water content, cloud droplet charge, corona discharge current and vertical velocity made during the summer monsoon seasons of 1983 and 1985 are presented in the following.

During the initial stages of development of the conductivity sensor, observations of negative conductivity alone were made and subsequently observations of positive electrical conductivity were also made. As a result during the summer monsoon of 1983 observations of negative conductivity were alone available and during the summer monsoon of 1985 observations of both positive and negative electrical conductivity were available.

The sample recordings of simultaneous observations of the parameters obtained during aircraft penetrations at a height of 300 m above the cloud-base are shown in Fig. 3. These observations were made on 10 August 1983 in a warm cumulus cloud of vertical thickness of

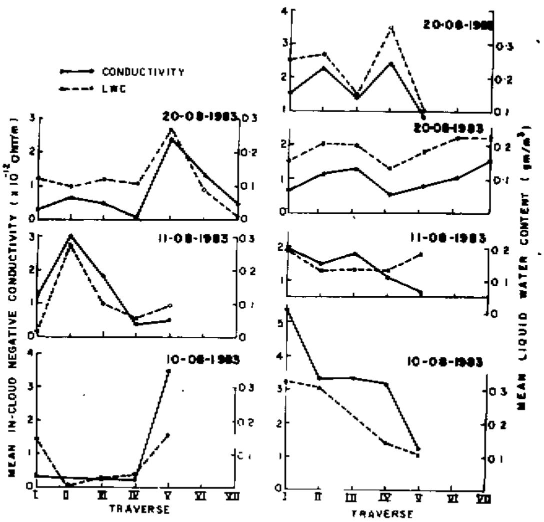

Fig.5. Average in-cloud negative electrical conductivity and liquid water content during different traverses for seven cloud cases.

about 1 km. The cloud-base level was at about 1.3 km above the ground with temperature of 24℃. The cloud droplet charge recorded by the instrument represents the cumulative charge carried by the cloud droplets present in the sampled volume of cloud-air. The full-scale value of 10^{-10} C s^{-1} corresponds to 10^{-17} C for a typical cloud droplet of mean volume diameter 10μm, the total cloud droplet number concentration of 400 cm^{-3} and for the aircraft speed of 50 ms^{-1}. It is seen from the figure that when the cloud droplet charges are negative the corona discharge current is negative. The variations in LWC, Corona discharge current cloud droplet charge and vertical velocity followed those in negative electrical conductivity.

The space-time variations in the negative electrical conductivity recorded during 5 consecutive aircraft traverses (I to V) made in a warm stratocumulus cloud during 1506-1526 hrs LT on 11 August 1983 are shown in Fig. 4. The vertical thickness of the cloud was about 900 m with its base at about 1.0 km above the ground. The temperature at cloud-base level was 24.3℃. The aircraft penetrations were made at about 300 m above the cloud-base. Values of maximum LWC (in g m^{-3}) recorded during each traverse are shown inside a box in the figure. The negative electrical conductivity was maximum (8.64×10^{-12} ohm^{-1} m^{-1}) during the growing stage and the value decreased to 3.24×10^{-12} ohm^{-1} m^{-1} during the dissipating stage of the cloud (Vth traverse). The cloud started dissipating from IVth traverse onwards. The values of LWC were found to be high when the values of electrical conductivity were more.

The observations of negative electrical conductivity and LWC obtained from different aircraft traverses from 7 cumulus clouds made in 1983 were analysed and the mean values for different traverses are shown plotted in Fig. 5. The basic data for obtaining the mean values were extracted from the original recordings at one second intervals which correspond to a resolution of about 54 metres. The vertical thickness of the clouds varied between 1.0 and 1.5 km. These observations indicate that there is a close correspondence between the variations noticed in the electrical conductivity and LWC. Also, it was observed that the electrical

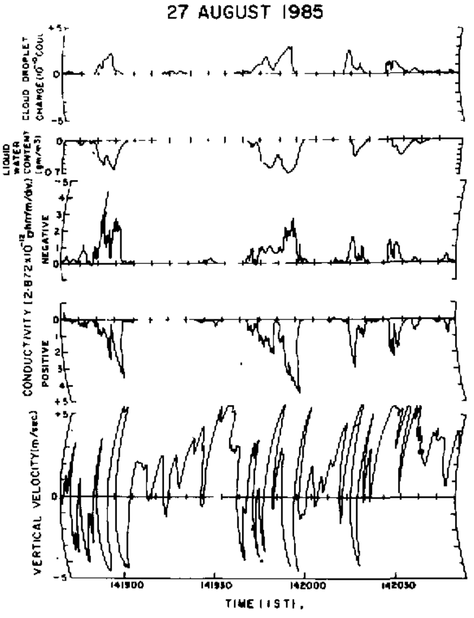

Fig.6. Typical exampls of simultaneous measurements of cloud droplet charge, liquid water content, negative and positive electrical conductivity and vertical velocity made in a warm cumulus cloud on 27 August 1985.

conductivity decreases during the dissipating stages of the cloud.

As mentioned in the beginning, measurements of both positive and negative electrical conductivity were made along with other observations commencing from the summer monsoon of 1985 only. A sample simultaneous recording of cloud drop charge, liquid water content, negative and positive electrical conductivity and vertical velocity are shown in Fig. 6. These observations were made in a warm cumulus cloud during aircraft penetration at an altitude of 300 m above the cloud–base on 27 August 1985. The vertical thickness of the cloud was 1.2 km with the base at about 1.8 km above the ground. The cloud droplet charges were predominantly positive and vertical velocity varied between ± 5 m s^{-1}. The variations in both positive and negative electrical conductivity appear to be associated with those in LWC, cloud droplet charge, updrafts and downdrafts.

Analysis of large number of recordings obtained from warm stratocumulus and cumulus clouds during the summer monsoon seasons of 1983 and 1985 indicated a correspondence among the variations in vertical velocity, corona discharge current, LWC, cloud droplet charge and electrical conductivity. These observations indicate the interdependence of the cloud dynamical / microphysical processes vis–a–vis the cloud electrification.

V. CONCLUSIONS

Aircraft observations of electrical conductivity and cloud microphysical, dynamical and other electrical parameters made in warm stratocumulus and cumulus clouds forming during the summer monsoon season suggested the following.

(i) The value of electrical conductivity was found to be in the order of 10^{-12} ohm^{-1} m^{-1} which is found to be 2 orders higher than that observed in clear-air at cloud-base levels in the region by other investigators.

(ii) There is close association among the electrical conductivity in the cloud, vertical velocity, liquid water content, droplet charge and corona discharge current.

(iii) The electrical conductivity was found to increase during the growing stages of the cloud and decrease during the dissipation stages of the cloud.

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