Instrumentation for cloud charge measurements using aerial platforms

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The electrical conductivity of air results from molecular cluster ions, which are produced by cosmic rays and natural background radioactivity. Attachment of cluster ions to droplets and particles causes charging, and depletes ion concentrations. Near the upper and lower boundaries of layer clouds, unipolar charge regions occur, generating highly charged droplets and aerosol particles. The effects of charge on cloud microphysical processes are largely unexplored, and only a few direct in situ atmospheric measurements have been made. Because of the radiative importance of clouds and the possibility of widespread small effects of charge on cloud processes, more in-situ measurements to evaluate charge effects in the fair weather cloud boundary region are desirable. To undertake such measurements, a sensor, capable of operating at high vertical resolution, is described. It measures bipolar air conductivity via a voltage decay method. The sensor has been tested on free and tethered balloons, but could also be used on other aerial platforms.

1. Charge and fair weather

The concept of the global electric circuit is based on observations showing that Earth's surface and the ionosphere form two plates of a spherical capacitor, with a weakly conducting material (the atmosphere) in between.

Charge generators in disturbed weather regions transfer positive charge upwards, causing the ionosphere to acquire a potential of ~ +300kV (V_i). The large ionosphere-surface potential difference causes a small conduction current (J_c) to flow in fair weather regions (see Fig 1).

The finite conductivity of the atmosphere results from the presence of ions, generated by cosmic rays and, near the surface, decay processes from Earth's natural radioactivity.

Ion removal results from self recombination and ion attachment to aerosol particles, and, in clouds, to droplets.

Attachment of small atmospheric ions to aerosol or droplets causes:
- a decrease in air conductivity due to the drop in mobility associated with the larger ion-aerosol particle.
- charging of the aerosol due to interactions with the electrically charged ions.

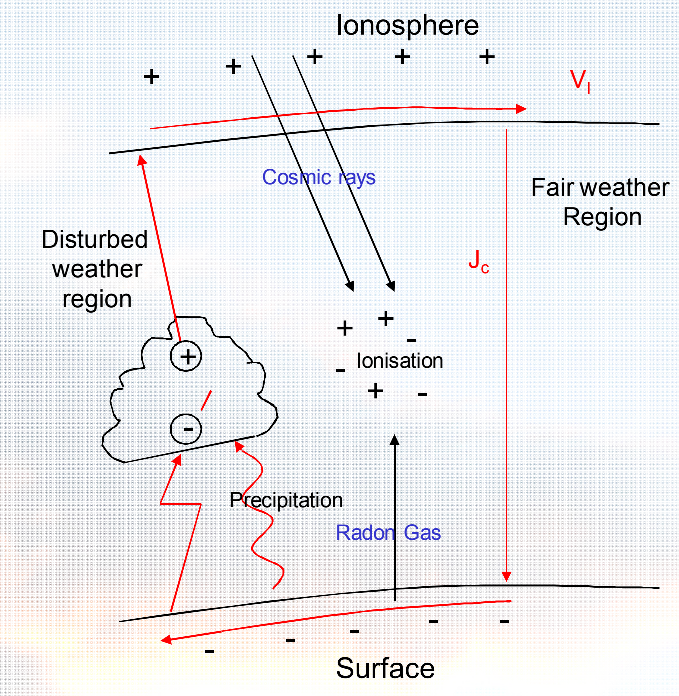


Fig 1. The Earth's global electric circuit

2. Why measure charge in clouds?

The conduction current density, J_c, links the global circuit with charged processes on cloud boundaries and Earth's cloud cover.

One mechanism by which this may occur is through charging of cloud and aerosol particles near horizontal cloud boundaries, as a result of the vertical ion flow via J_c, [1], [2] (see Fig 2).

This will occur primarily near layer clouds of large horizontal extent.

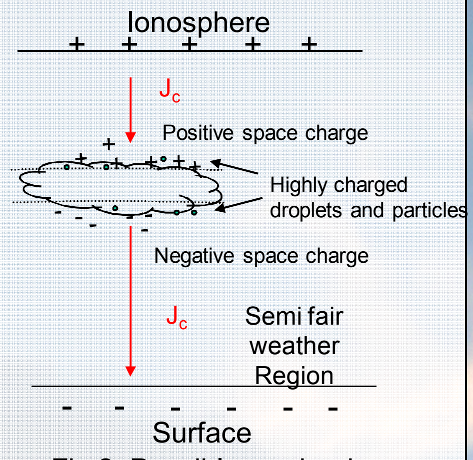


Fig 2. Possible mechanism linking J_c with cloud charge.

At the cloud/clear air boundary:

- Ion-aerosol attachment creates a conductivity gradient.
- This generates space charge, ρ, of one sign, on cloud edges.
- Charge transfer occurs during interactions between ions and cloud droplets/aerosol particles.
- Droplet charge depends on the ratio of polar conductivities, which may be large in these areas.

Highly-charged droplets/particles exist at cloud edges.

2.1 Evidence of current flow through clouds

J_c has been measured from 1966 to 1979 at Kew Observatory, London [3].

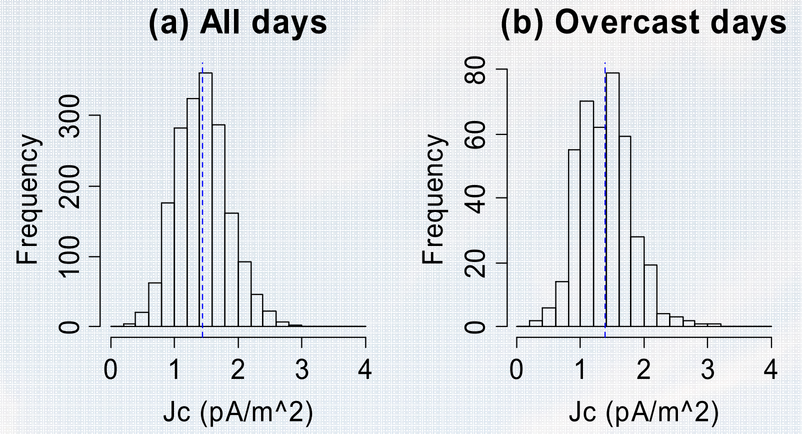


Fig 3. Histograms of J_c data from Kew, London, from 1966 to 1979 on fair weather days. Cloud was identified from a diffuse radiation method [4].

Fig 3. shows two histograms of J_c data (a) on all dry days and (b) only on dry days with full cloud cover (i.e. overcast). The distributions are similar, with medians of 1.44pA m^{-2} and 1.38pAm^{-2} respectively (shown by the dotted blue lines). In order for this to occur, J_c must flow through the cloud.

2.2. Effects of charge on cloud droplets

Charge on droplets/particles on cloud boundaries may be large enough to influence electrically sensitive cloud microphysical processes e.g. condensation [5].

If the droplet is sufficiently charged, the critical supersaturation required for a cloud droplet to grow may be reduced, for example altering the height at which cloud formation begins [6].

At present, knowledge of the magnitude of charge on droplets/particles inside and around stratiform clouds is poor.

This poster presents a new instrument designed to detect charge inside clouds. The instrument measures bipolar air conductivity, by responding to positively and negatively charged atmospheric cluster ions.

3. Bipolar air conductivity sensor

3.1 Principles of operation

The sensor uses a technique to measure the electrical conductivity of air which was first developed by H. Gerdien [7]. It consists of two cylindrical electrodes, between which a bias voltage is applied. Ions of the same polarity as the outer electrode are repelled towards the inner electrode, where they generate a voltage change. The voltage change is measured via a sensitive electrometer circuit, and the conductivity inferred from an exponential fit to the voltage trace. More details on the sensor are given in [8].

3.2 Sensor properties

- Two sets of electrodes are used to measure bipolar conductivity simultaneously. Allows ratio of polar conductivity to be determined.
- Inner electrode supported by two PTFE struts, air wired to electrometer to minimise leakage.
- Each set of electrodes is ventilated by a fan to ensure airflow into the tube. Electronics is located inside a shielded box.

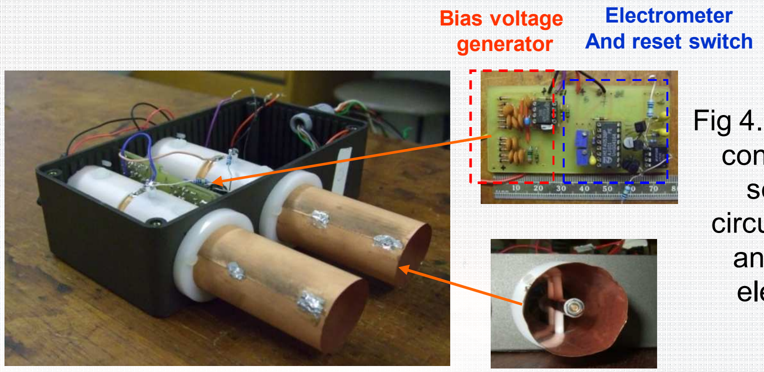


Fig 4. Bipolar air conductivity sensor, circuit board, and inner electrode

- Lightweight: 350g (including 2 x 9V PP3 and 4 x 1.5V AAA to power circuit and fans respectively).
- Small: Outer box 15 x 8 x 5cm; tubes 3 x 15cm
- Inexpensive: Total parts cost ~£50 (GBP)

3.3 Electronic Circuitry

Consists of two main stages :

Electrometer and reset switch: measures voltage changes and periodically sets the inner electrode voltage to a known value. This employs a double j-FET configuration to provide an ultra-low leakage switch for the reset.

Bias voltage generator: provides ±30V to the outer electrodes to measure positive and negative conductivity respectively.

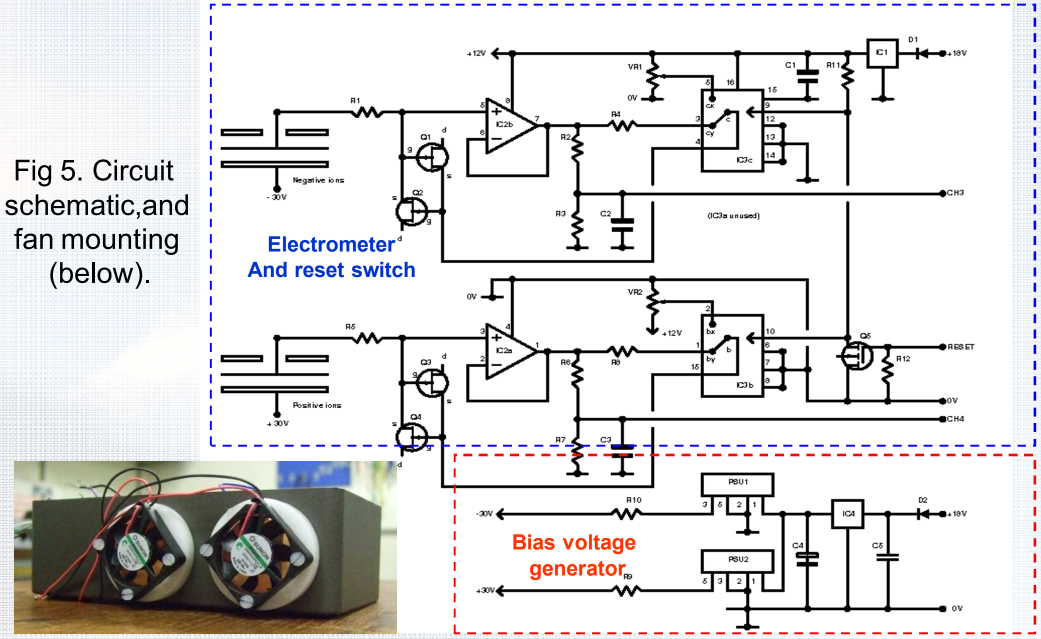
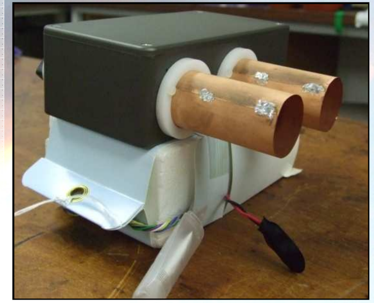


Fig 5. Circuit schematic,and fan mounting (below).

3.4 Deployment

Sensor tested using Vaisala RS80 radiosonde, which provides synchronous pressure, temperature and humidity data, Additional Data Acquisition System (DAS) [9] provides the extra logging channels as well as an automated reset pulse. Resolution is ~5m (1Hz at 5m/s)



3.4 Tethered balloon field campaign

The sensor was tested using a tethered surveillance 20 m^3 helium filled balloon flown at Chilbolton Observatory, Hampshire, UK, in April 2008.

The apparatus was hung beneath the balloon using a 20m nylon rope (see fig 6),and the balloon tethered to the ground by a 1km nylon rope, the length of which was controlled by a winch.

Fig 6. Tethered balloon set up and conductivity sensor (bottom left picture) at Chilbolton, UK. (The grey box in the bottom left picture is an aerosol spectrometer operated by the University of Leeds.)

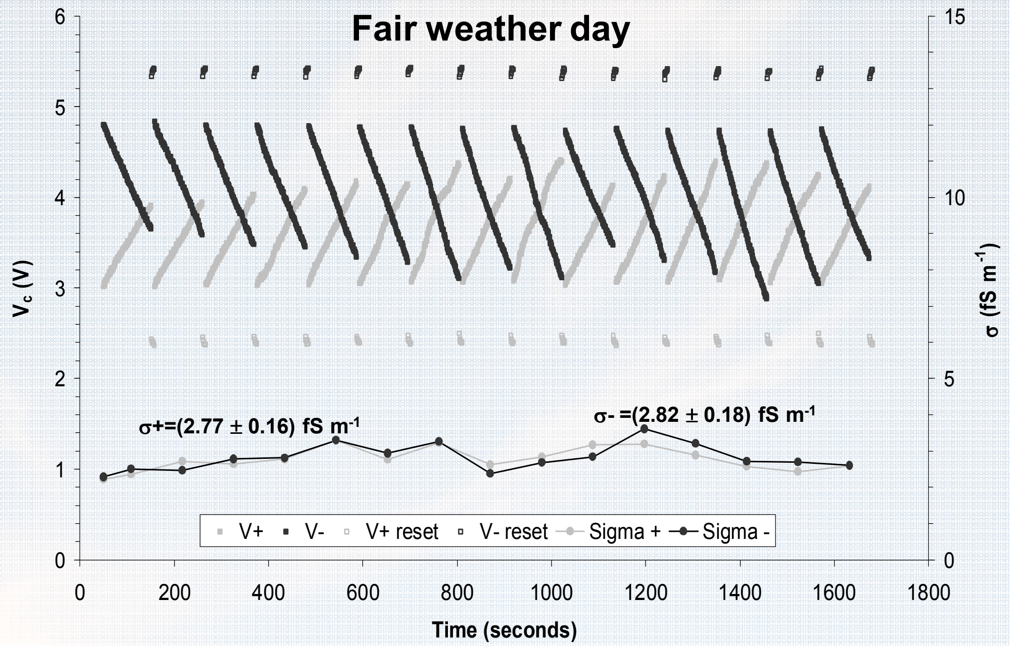


Fig 7. Voltage trace from a fair weather flight on 25/04/08. The balloon remained below cloud base throughout. During measurements, the balloon ascended at ~ 0.1 ms^{-1}, between 300 and 520 m above the surface. The ratio of positive to negative conductivity was σ+/σ- =0.98 ± 0.04.

Measurements from a fair weather day (Fig 7), and non-fair weather day (Fig 8) - during which the sensor reached cloud base, are shown here.

In figs 7 and 8, the two upper traces represent voltage measurements from both central electrodes, where each cycle of 128 measurements is separated by a series of 5 reset voltage measurements. The positive electrode voltage (V+) increases with time as it responds to positive ions, and the negative electrode voltage (V-) decreases.

The two lower traces in Fig 7 show positive and negative conductivity (σ+ and σ-), derived by fitting an exponential to the voltage decay/increase [10].

In Fig 8 at around 8.6 hours the sensor encountered a small cumulus cloud.

There is a clear deviation from normal behaviour, both in the sensor voltage and doppler traces.

The voltage on both central electrodes decreases, indicating the presence of large charged particles/droplets which are not affected by the bias field within the collecting electrodes.

Once the cloud has passed the sensor resumes normal behaviour.

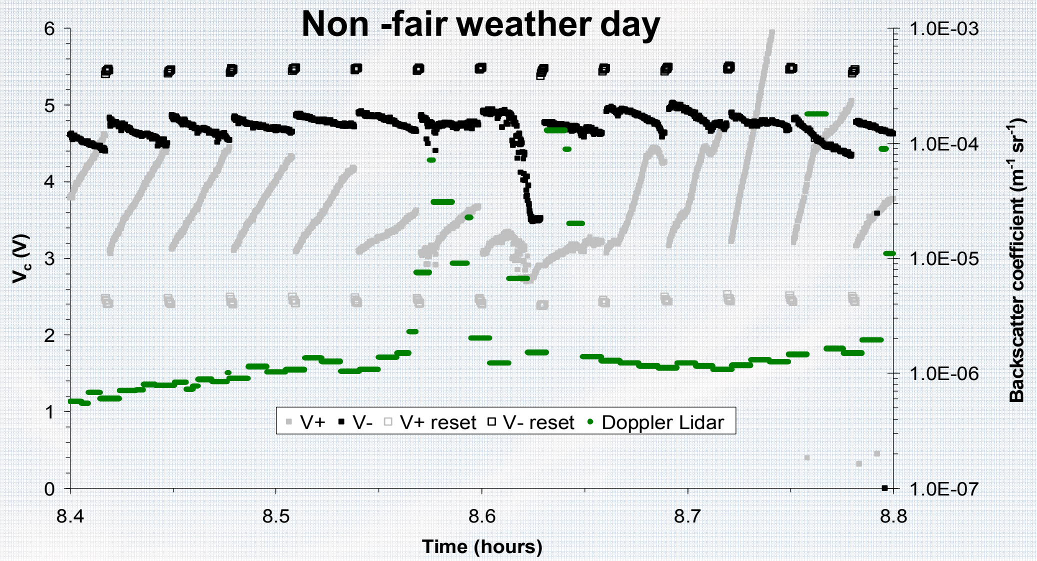


Fig 8. Voltage trace from a non-fair weather flight on 29/04/08. The balloon ascended from 250m-550m and encountered a small cumulus cloud at a height of 450m (~8.6 hours). It is clear that sensor was no longer measuring conductivity in this region (departure from exponential behaviour), but was instead responding to space charge.

5. Conclusions

- **A small inexpensive instrument has been developed for measuring charge inside non-thunderstorm clouds.**

- **Results show evidence of charge in non-thunderstorm cloud bases.**

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