3. Electrical Structure of Thunderstorm Clouds

An isolated thundercloud in the central New Mexico, with rudimentary indication of how electric charge is thought to be distributed and around the thundercloud, as inferred from the remote and *in situ* observations. Adapted from Krehbiel (1986).

$Q_P = 40$ C

$Q_N = -40$ C

$Q_{LP} = 3$ C

$H_P = 12$ km

$H_N = 7$ km

$H_{LP} = 2$ km
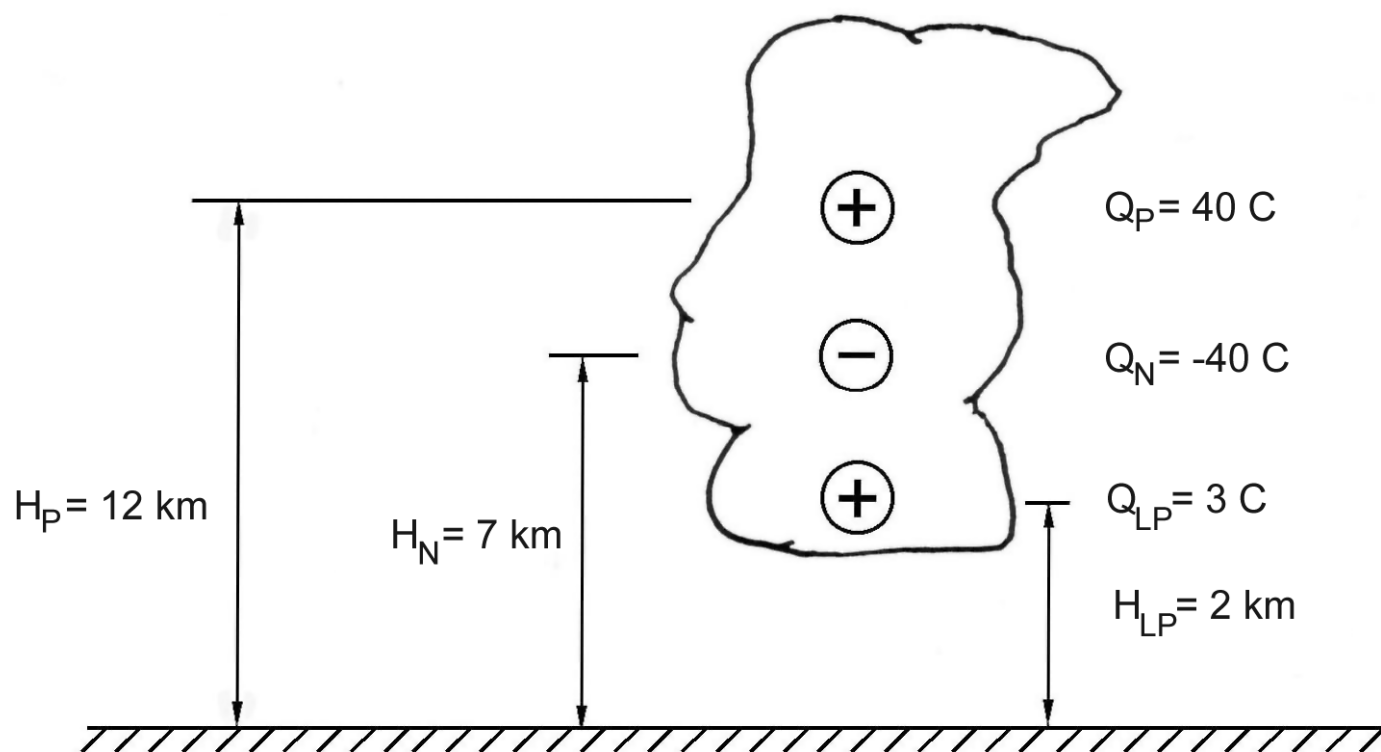
A vertical tripole representing the idealized gross charge structure of a thundercloud. The negative screening layer charges at the cloud top and the positive corona space charge produced at ground are ignored here.
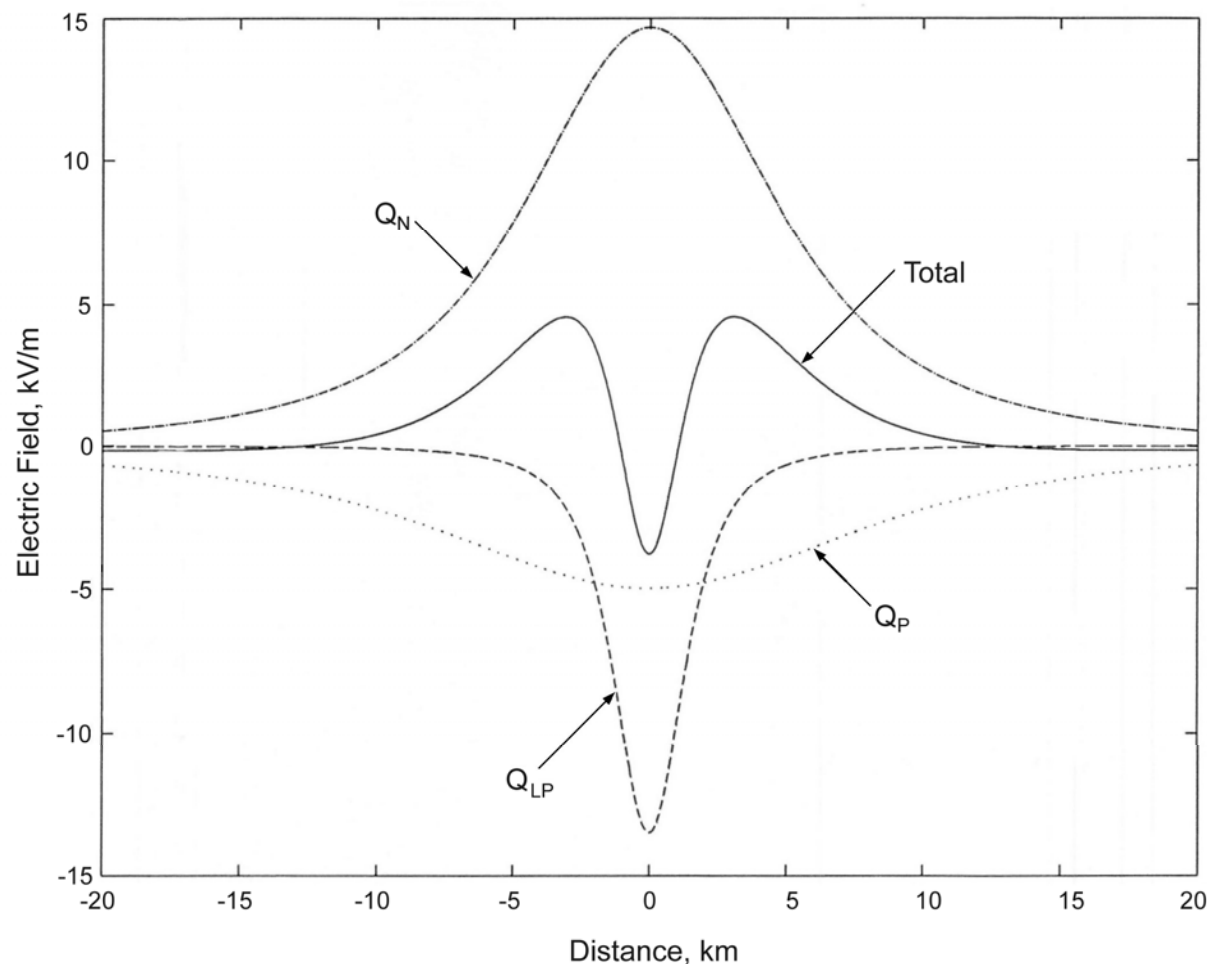
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$$|E| = 2|E^{(-)}|\cos(90° - \alpha)|$$

$$= \frac{|Q|H}{2\pi\varepsilon_o(H^2 + r^2)^{3/2}}$$
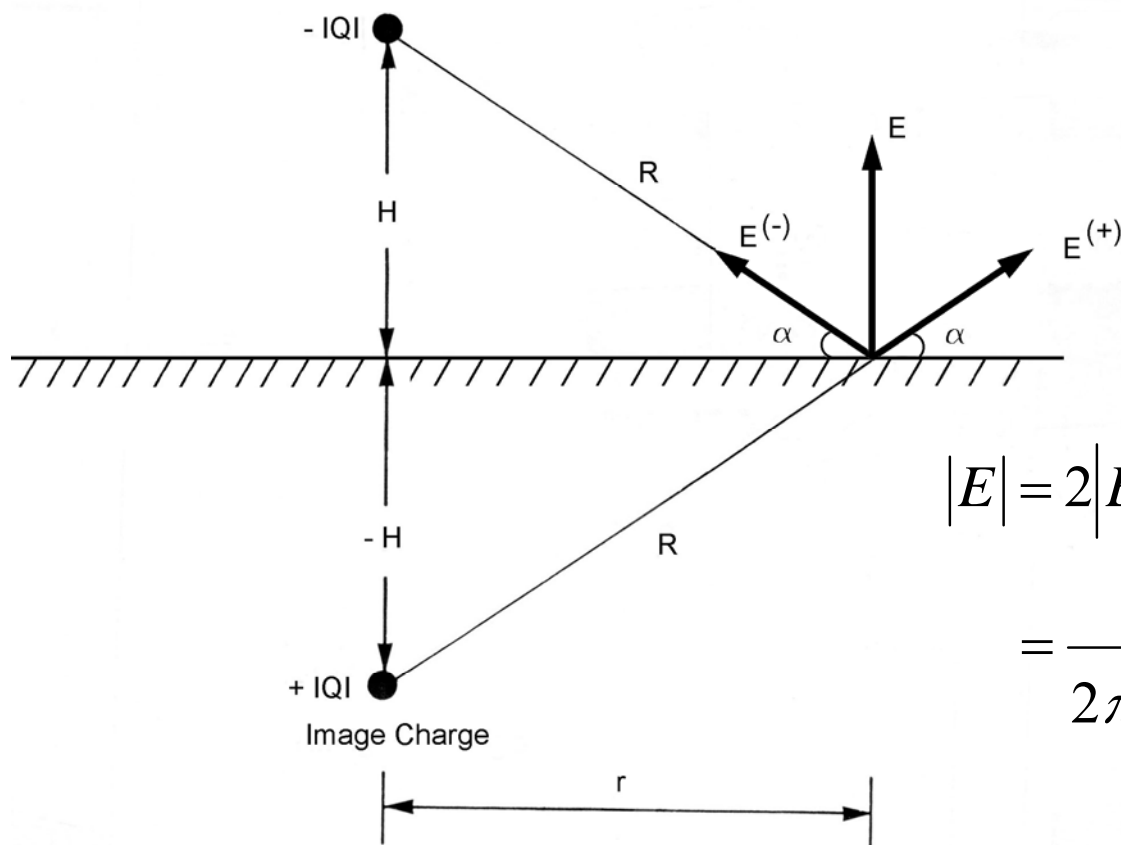
$$= k\frac{\sin\alpha}{R^2} \qquad (|Q| = const)$$

Method of images for finding the electric field due to a negative point charge above a perfectly conducting ground at a field point located at the ground surface.

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The electric field at ground due to the vertical tripole, labeled "Total", as a function of the distance from the axis of the tripole. Also shown are the contributions to the total electric field from the three individual charges of the tripole. An upward directed electric field is defined as positive (according to the physics sign convention).
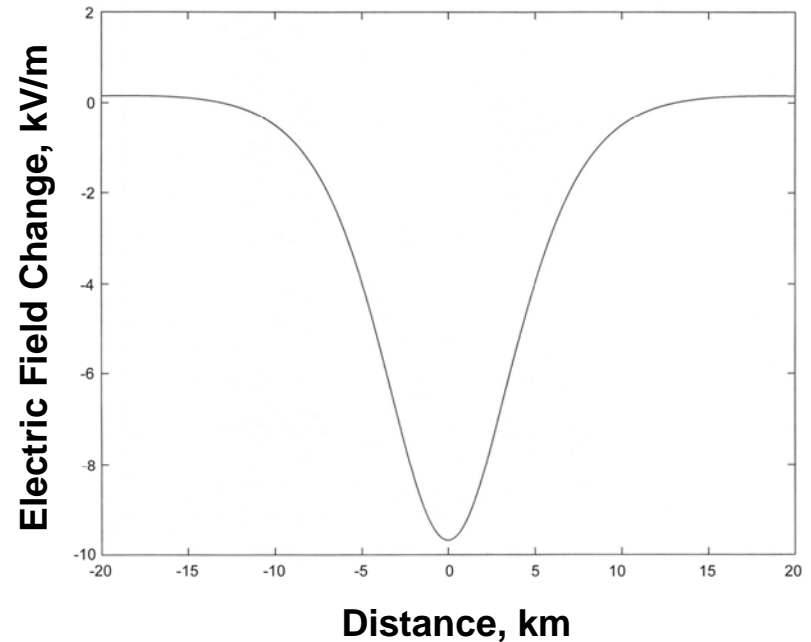
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Cloud Charge Structure and Mechanisms of Cloud Electrification

**Electric Field Change Due to Negative Cloud-to-Ground Discharge**
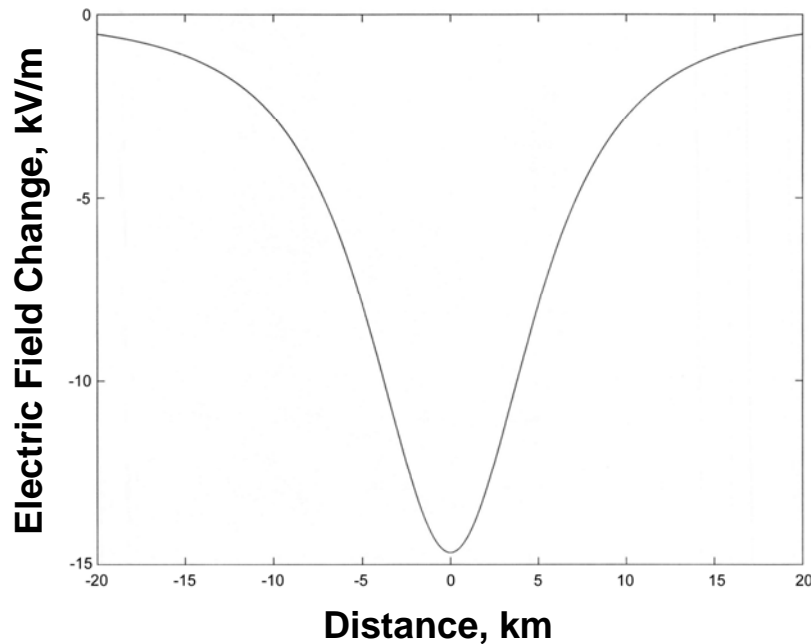
Electric field change at ground, due to the total removal of the negative charge of the vertical tripole via a cloud-to-ground discharge, as a function of distance from the axis of the tripole. Note that the electric field change at all distances is negative.

**Electric Field Change Due to a Cloud Discharge**

Electric field change at ground, due to the total removal of the negative and upper positive charges of the vertical tripole via a cloud discharge, as a function of distance from the axis of the tripole. Note that the electric field change at close distances is negative, but at far distances it is positive.

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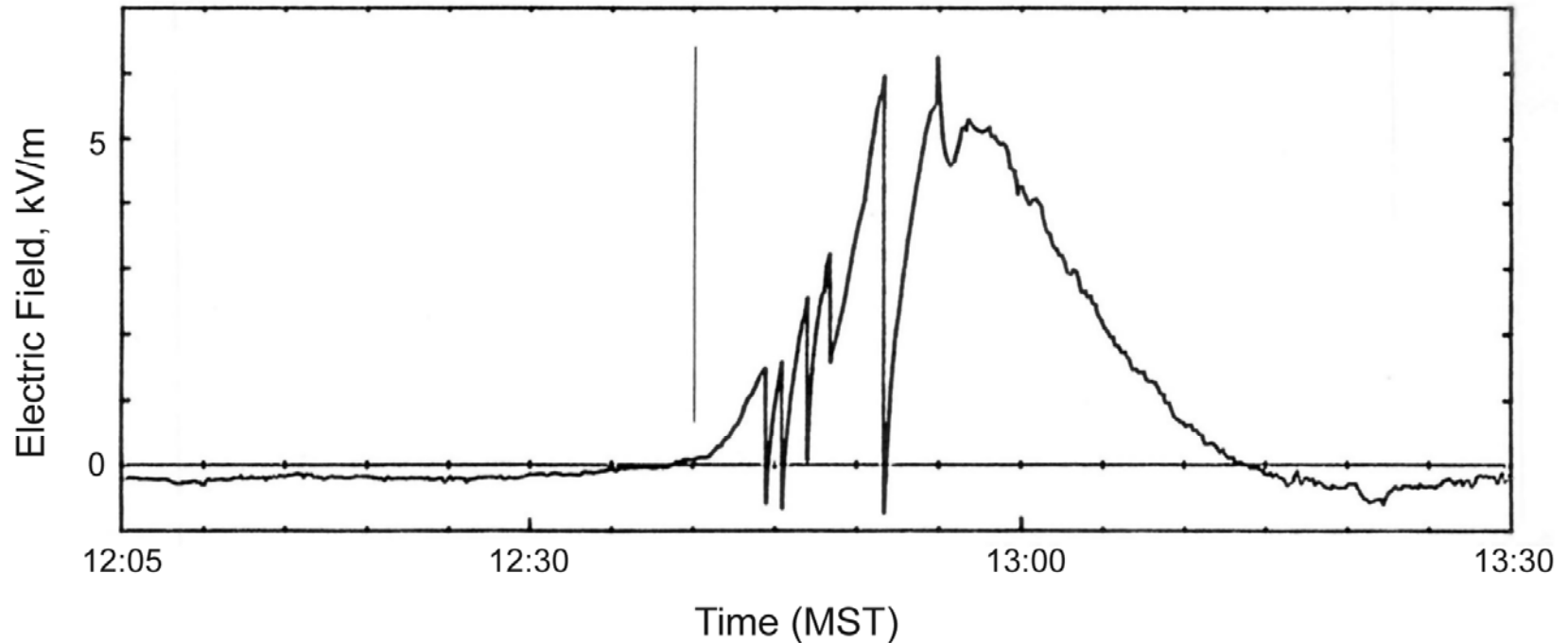
Electric field at the ground about 5 km from a small storm near Langmuir Laboratory, New Mexico, on 3 August 1984. An upward-directed electric field is defined as positive (according to the physics sign convention). The large pulses superimposed on the rising postion of the overall electric field waveform are due to lightning. Adapted from Krehbiel (1986).

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Electric field changes
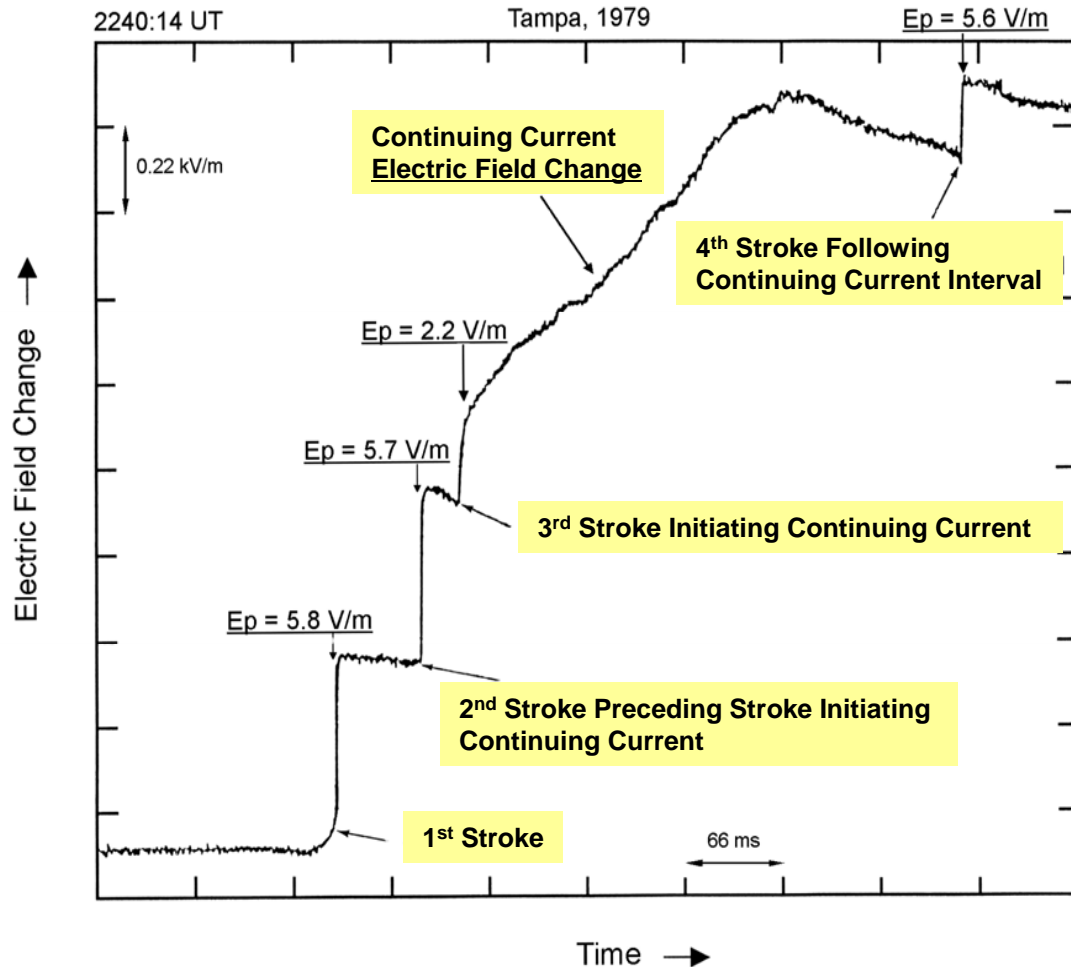
Overall electric field change for a four-stroke flash with a long continuing current following the third stroke. The flash occurred in Florida on July 27, 1979 at a distance of 6.5 km. Microsecond-scale initial electric field peaks are not resolved in this Figure, but their values Ep (normalized to 100 km) are given. Positive electric field change (atmospheric electricity sign convention) deflects upward. Adapted from Rakov and Uman (1990a).
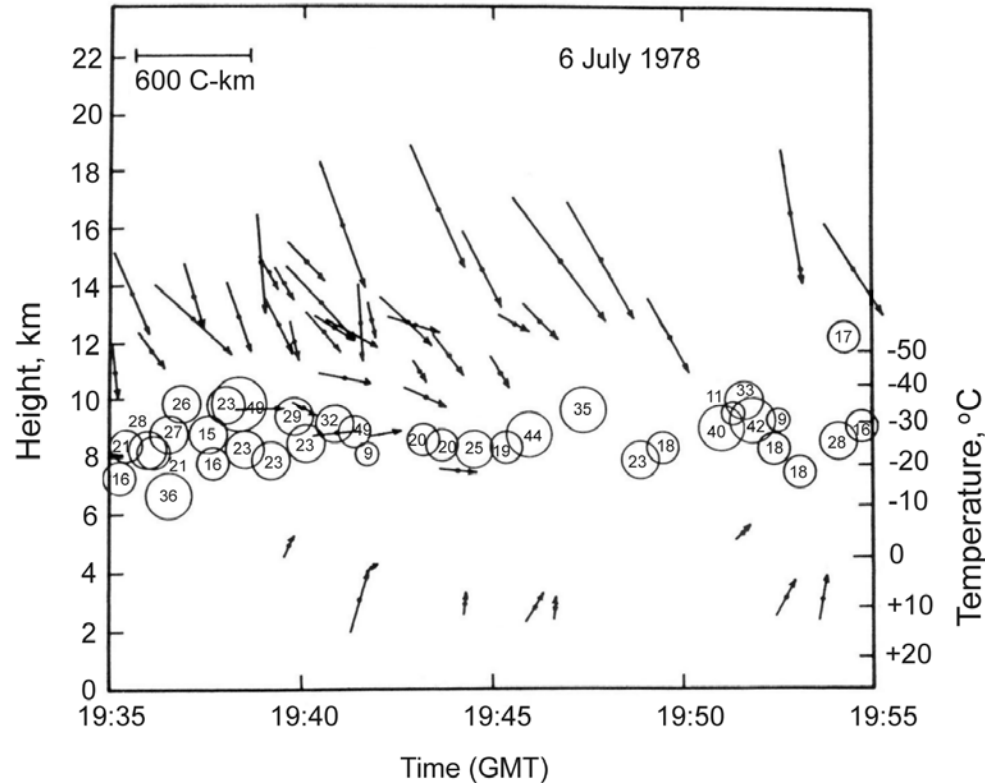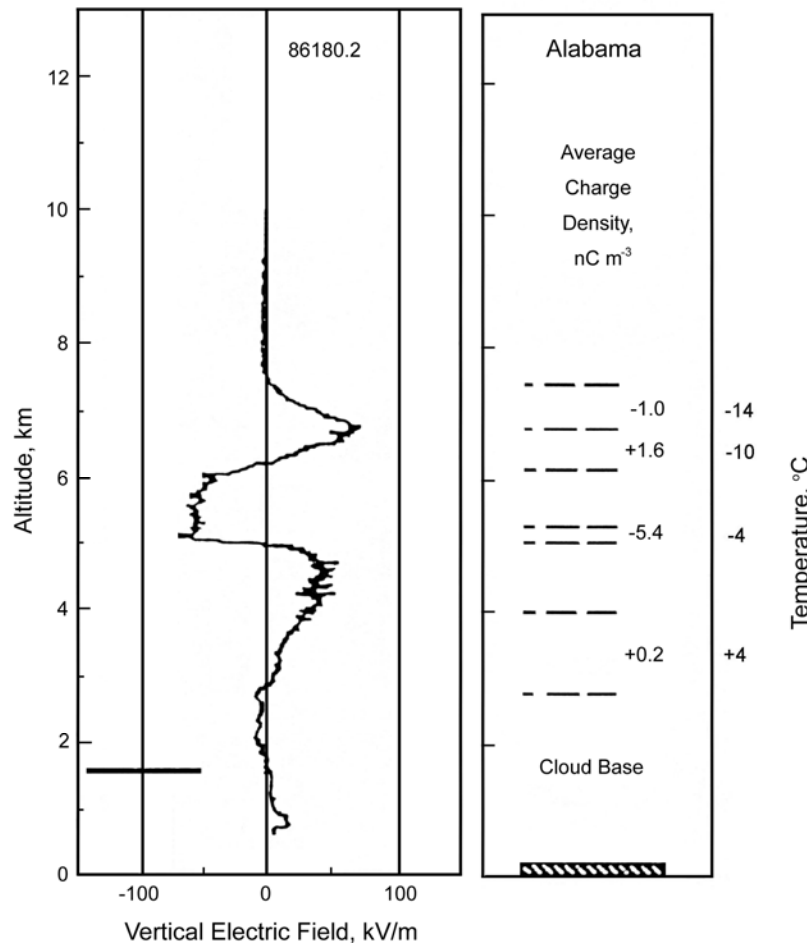
Negative charges (circles) neutralized by ground flashes, and point-dipole charge moments (arrows) describing the effective positive charge transfer by cloud flashes as a function of time for a portion of an active Florida storm on 6 July 1978. The numbers in the circles give the magnitudes of the neutralized charges in coulombs. In cloud flashes, negative charge was effectively transported in the direction opposite to that of the arrow to neutralize a positive charge of equal magnitude. The dot in the middle of each arrow represents the apparent single location of these two charges, the actual locations being indeterminate in the point-dipole solution. Adapted from Koshak and Krider (1989).

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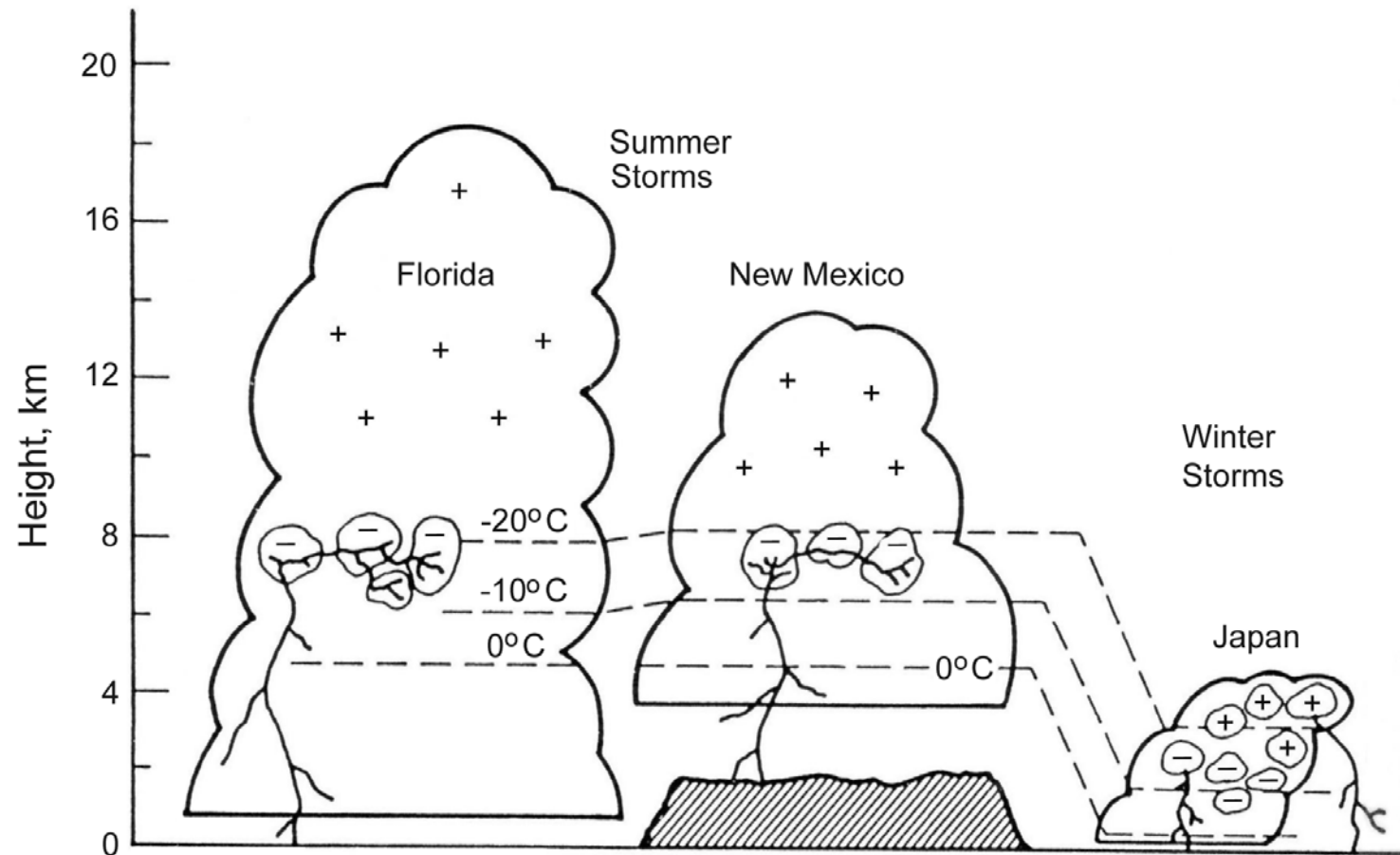
The location, shown by the small irregular contours inside the cloud boundaries, of ground flash charge sources observed in summer thunderstorms in Florida and New Mexico and in winter thunderstorms in Japan, using simultaneous measurements of electric field at a number of ground stations. Adapted from Krehbiel (1986).

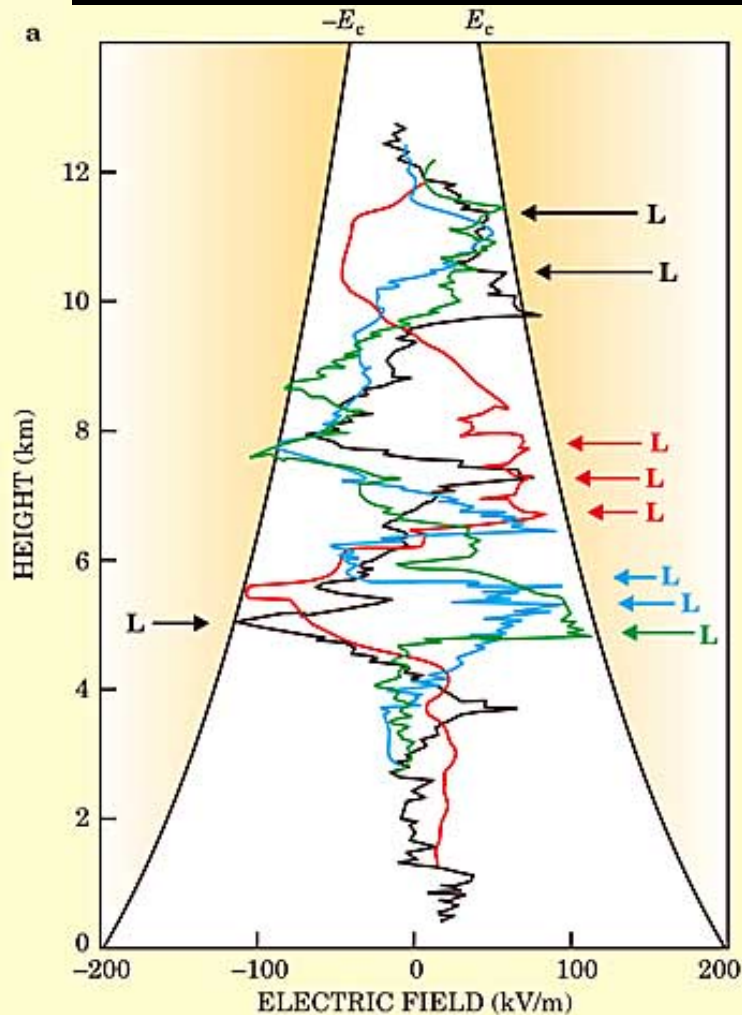# Cloud Charge Structure and Mechanisms of Cloud Electrification

Gauss Law

$$\nabla \cdot E = \rho \Big/ \varepsilon_\circ$$

$$\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z} = \rho \Big/ \varepsilon_\circ$$

$$\rho \approx \varepsilon_\circ \frac{\Delta E_z}{\Delta z}$$

Balloon measurements of the vertical electric field inside a small Alabama thunderstorm. An upward-directed electric field is defined as positive. The values of the inferred average charge density (in nC m^{-3}), assuming that charge regions have large horizontal extent and that the field is steady with time, are shown on the right. The field profile is indicative of a "classical" vertical tripole with an upper negative screening layer. Adapted from Marshall and Rust (1991).

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Cloud electrical environment

Electric field profiles in thunderclouds. Four examples of balloon measurements of the vertical electric field in thunderclouds are presented by color curves, adapted from Marshall *et al.* (1995).

Also shown is the calculated runaway breakdown critical electric field E_c, which decreases with height because of decreasing air density. "L" denotes lightning discharges.

At 6 km
E_c ~ 10^5 V/m (100 kV/m)

E_b ~ 10^6 V/m (1000 kV/m)
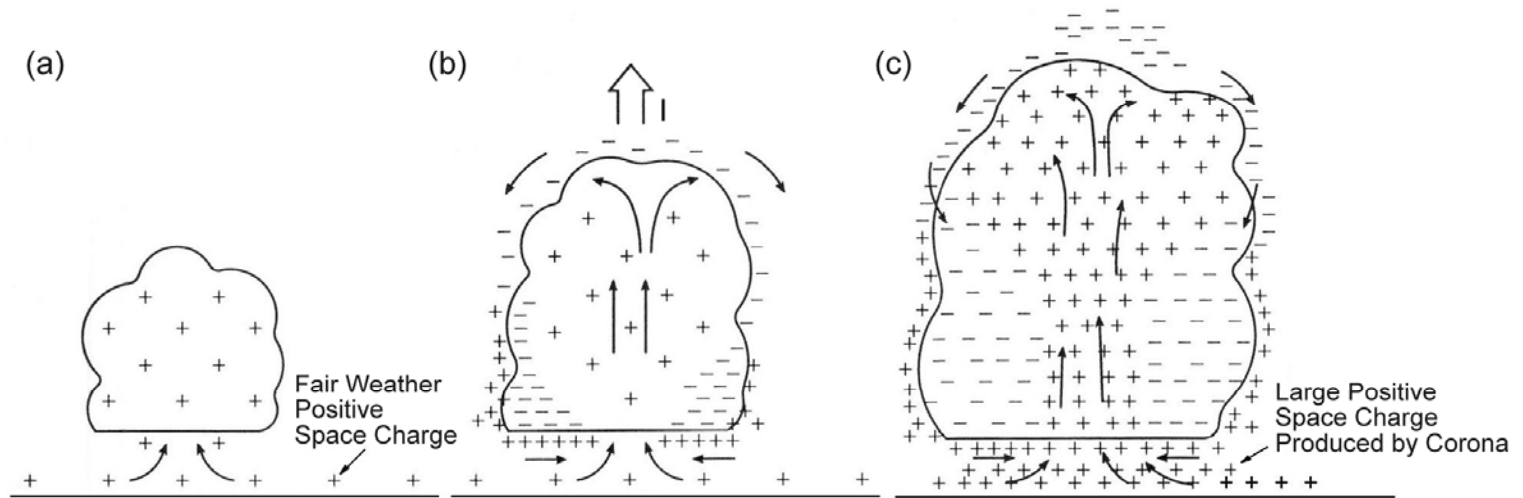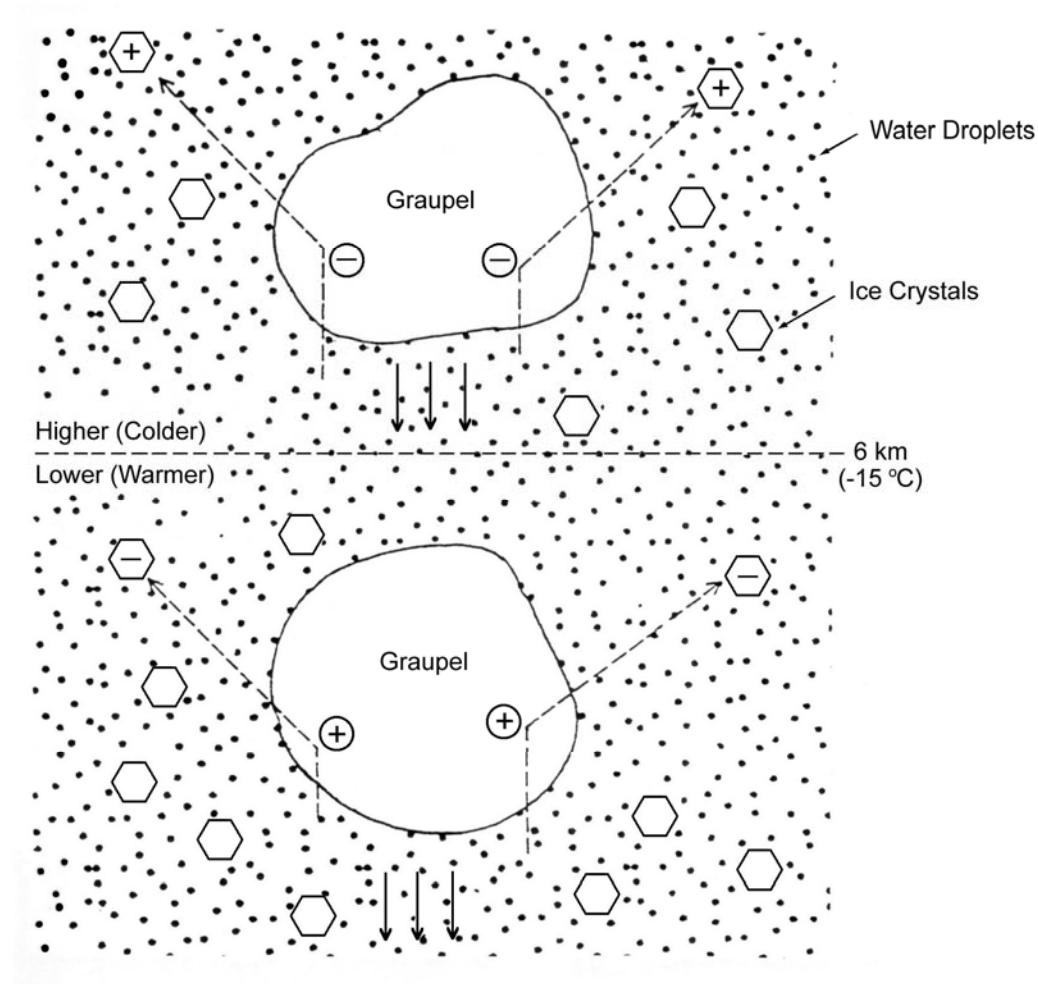(conventional breakdown electric field)

Fig. 3a of Gurevich and Zybin (2005, Physics Today).

Illustration of the convection mechanism of cloud electrification. Adapted from MacGorman and Rust (1998).

Charge transfer by collision in the graupel-ice mechanism of cloud electrification. It is assumed that the reversal temperature T_R is -15 ºC and that it occurs at a height of 6 km.
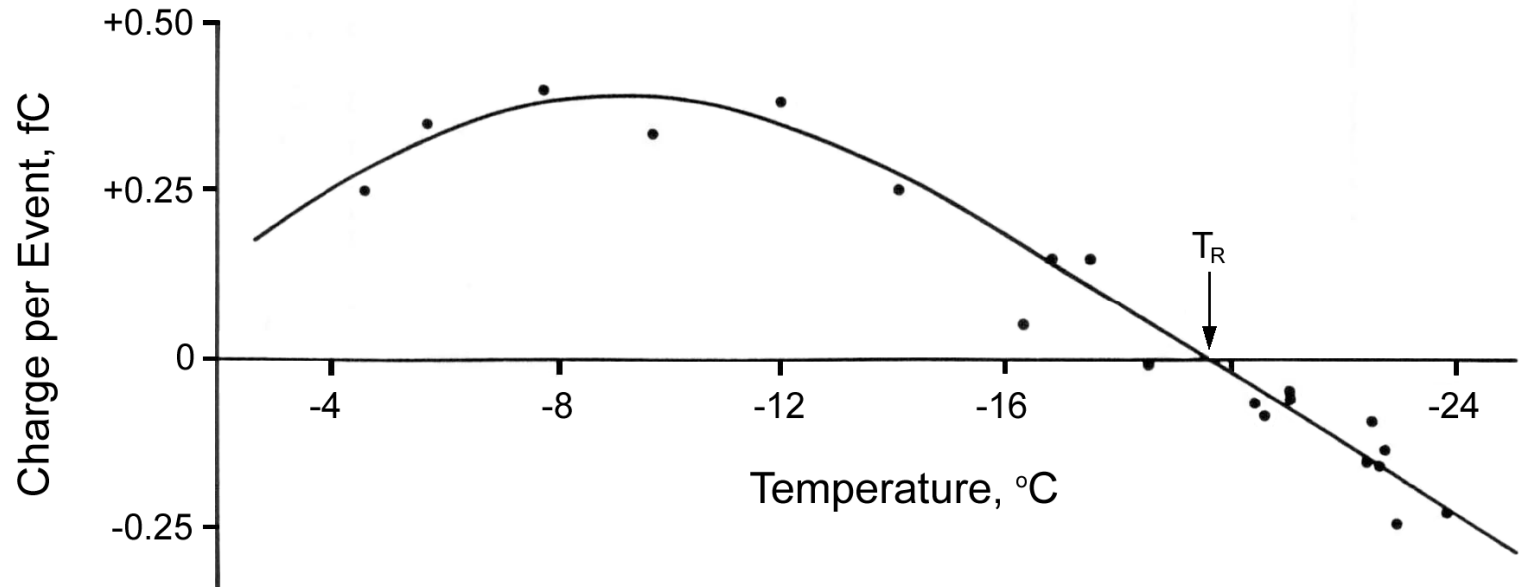
The charge acquired by a riming hail particle (simulated by an ice-covered cylindrical metal rod with diameter 0.5 cm) during collisions with 50 µm ice crystals, as a function of the temperature of the rime in the laboratory. The velocity of impact was 2.9 m s^{-1}. The cloud liquid water content was approximately 1 g m^{-1}, and the mean diameter of the water droplets was 10 µm. Adapted from Jayaratne et al. (1983).