4a. Properties of negative downward lightning discharge to ground - I
A drawing illustrating various processes comprising a negative cloud-to-ground lightning flash. Adapted from Uman (1987, 2001).
Interstroke Intervals

Histogram of 516 interstroke intervals in 132 flashes in Florida and New Mexico (GM is about 60 ms). Intervals preceding strokes that initiated long continuing currents are shown shaded (GM is about 30 ms).
Continuing Currents and M-Components

Examples of continuing-current waveshapes in triggered lightning. In each figure, the arrow indicates the assumed beginning of the continuing current. The number in the upper left corner indicates the order of the return stroke in the flash. (a) Type I, more or less exponential decay with superimposed M-current pulses; (b) type II, a hump with superimposed M-current pulses followed by relatively smooth decay; (c) type III, a slow increase and decrease in current, with superimposed M-current pulses throughout; (d) type IV, a hump with superimposed M-current pulses followed by a steady plateau without pronounced pulse activity. Adapted from Fisher et al. (1993).
Return Strokes vs. M-components

Portion of current record showing return stroke and two M-component pulses with a 1 kA saturation level. Adapted from Fisher et al. (1993).

Examples of typical current pulses. (a) A typical return stroke pulse with a fast wave front and slower tail. (b) A typical M-component pulse with a more or less symmetrical wave shape. Note the more than 3 orders of magnitude difference in rise time. Adapted from Fisher et al. (1993).
Schematic representation of current versus height profiles for three modes of charge transfer to ground in negative lightning subsequent strokes: (a) dart leader/return stroke sequence, (b) continuing current, and (c) M-component. The corresponding current versus time waveform represents current at the ground. Adapted from Rakov et al. (2001).
Photographic Record

M Components

Electric Field Record

Continuing Current

C Field Change

1 V/cm

R Change  J Change

M Change

K Change

Electric Field Change Record

Flash With Continuing Current Interval (Flash no. 106. 20 km Distant)

Time, ms
Photographic Record

Electric Field Record

Electric Field Change Record
Flash Without Continuing Current (Flash no. 109, 19 km Distant)

\[ E_0 \text{ V/cm} \]

Time, ms
Various lightning processes emit electromagnetic signals with a peak in the radio-frequency spectrum at 5 to 10 kHz, when observed at distances beyond 50 km or so. At frequencies higher than that of the spectrum peak, the spectral amplitude varies approximately inversely proportional to the frequency up to 10 MHz or so and inversely proportional to the square root of frequency from about 10 MHz to 10 GHz (Cianos et al. 1973).
Fig. 4.8. Examples of electric field waveforms of the type used by Clarence and Malan (1957) to introduce the so-called BIL structure of the electric field prior to the first return stroke and to interpret the B stage as a vertical discharge between the main negative charge center and the lower positive charge center in the cloud: (a) field at 2 km, (b) field at 5 km. Adapted from Clarence and Malan (1957).
Initial (preliminary) breakdown in ground discharges (CGs)

A vertical tripole representing the idealized gross charge structure of a thundercloud. Initial (preliminary) breakdown is shown to occur between the main negative and lower positive charge centers.

Initial (preliminary) breakdown in a cloud-to-ground discharge: (a) time waveforms from the beginning of the flash to the first return stroke with the initial (preliminary) breakdown indicated by PB and leader indicated by L1, (b) the radiation (274 MHz) sources of PB. Adapted from Shao (1993).
Fig. 4.9
A vertical tripole representing the idealized gross charge structure of a thundercloud. Initial (preliminary) breakdown is shown to occur between the main negative and main positive charge centers.

All the VHF radiation sources in azimuth-elevation format for a Florida cloud flash (IC). The sources exhibited a two-level structure, the upper-level channels, b1, and b2, and the lower-level channel, c, being connected by a vertical channel, a.

S denotes the region where the flash started and the arrows indicate the direction of motion of negative charge.

Channel a is fully formed during the first 20 ms, channels b1 and b2 during the following 100 ms or so, and channel c during the last 200 ms or so. Adapted from Shao and Krehbiel (1996).
Initial (preliminary) breakdown in ground (CGs) and cloud (ICs) discharges

Examples of electric field pulse waveforms characteristic of (a) the initial breakdown in negative ground flashes, (b) the initial breakdown in cloud flashes, and (c) the compact intracloud discharges.

Typical total duration: 20-40 μs
Typical Interpulse intervals: 70-130 μs

Typical total duration: 50-80 μs
Typical Interpulse intervals: 600-800 μs

Typical total duration: 10-30 μs
(left) A schematic illustration (not to scale) of electric field enhancement and reduction effects of the lower positive charge region (+Q_{LP}) below the main negative charge region (-Q_{N}). The main positive charge region is not shown. Arrows indicate the direction of vertical components of electric field vectors. The total electric field is enhanced, \((E_N + E_{LP})\), between the negative and positive Charge regions and reduced, \((E_N - E_{LP})\), below the positive charge region.

(right, top) Schematic representation of preliminary breakdown stepping process in negative ground flashes. Negatively-sloped arrow indicates the overall downward extension of negatively charged channel through the LPCR. Three steps giving rise to current (and light) pulses are shown. Each current pulse originates at the tip of downward-extending channel and propagates upward (positively-sloped arrows). (right, bottom) A sketch of expected electric field record of resultant wideband PB pulse train.
Streak-camera photograph of a downward negative stepped leader within 360 m of ground. Time advances from left to right. The left part of the photograph was overexposed in the reproduction process in order to enhance the intensity of the early portion of the leader image. Adapted from Berger and Vogelsanger (1966).
Streak photograph of stroke 3 in a flash that occurred in Gainesville, Florida on 10 August 1982. The image on the left is due to the dart leader, and the brighter image on the right is due to the return stroke. Adapted from Jordan et al. (1997).