Termination of thunderstorm-related bursts of energetic radiation and particles by inverted intracloud and hybrid lightning flashes

A.Chilingarian[1], Y.Khanikyants[1], V.A. Rakov[2], and S.Soghomonyan[1]

[1] *A.I.Alikhanian National Science Laboratory*

[2]*Department of Electrical and Computer Engineering, University of Florida, Gainesville, Florida, USA*

TEPA 2019 Nor Amberd, October 14-17, 2019

Thunderstorm Ground Enhancements (TGEs)

- TGEs (also known as “gamma glows”) are minute-scale bursts of energetic radiation and particles observed during thunderstorms.

- Some of TGEs are suddenly terminated by lightning discharges, clearly indicating their association with electric fields of thunderclouds.

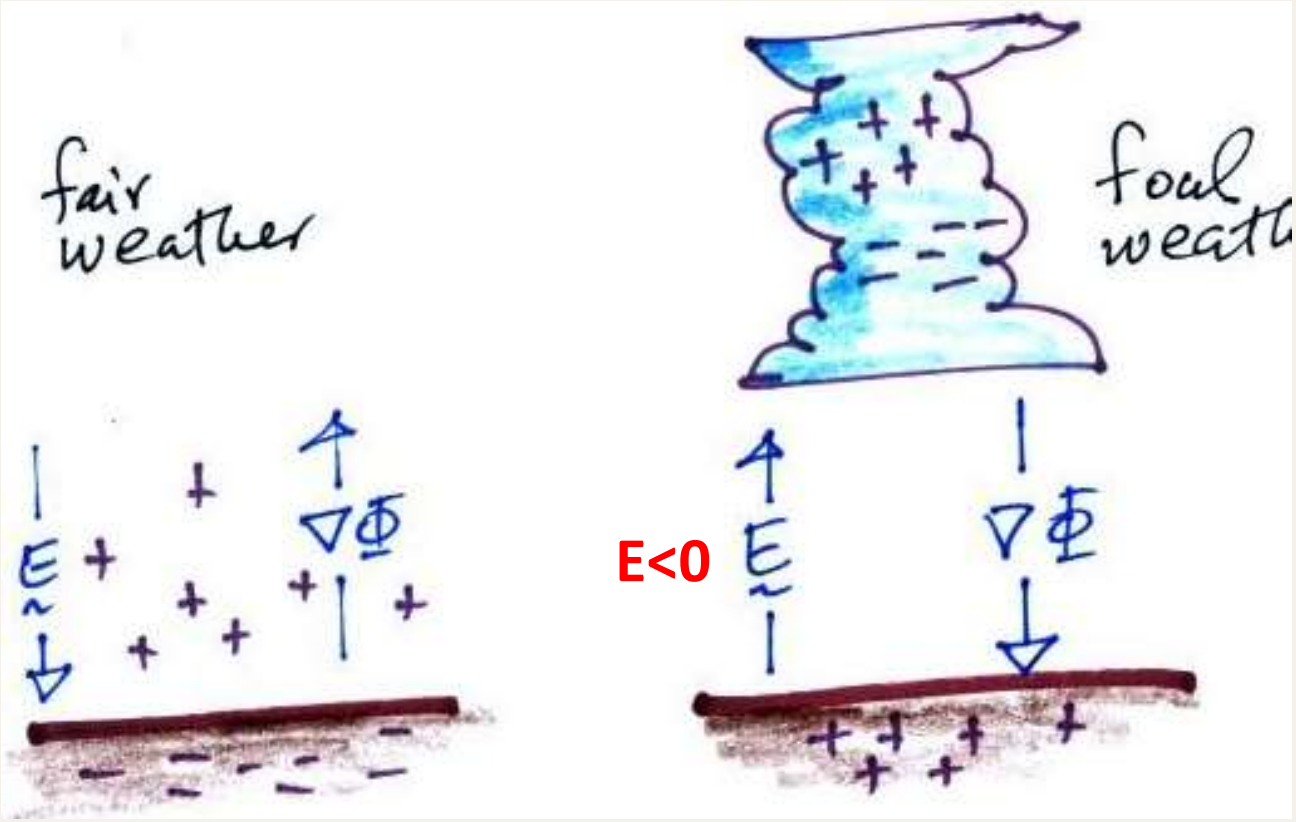
- TGEs are terminated, rather than caused, by lightning

Focus of this talk

- During 2012-2019 a total of ≈ 87 events of TGE termination by lightning discharge has been detected
- For 25 out of 87 events the polarity of electrostatic field change produced by lightning discharge was negative
- Analysis and interpretation of these 25 events are presented here

Sign convention

Atmospheric electricity sign convention : downward directed electric field or field change vector is considered positive



Electrons are accelerated downward to the ground by the upward directed electric field E. This field is considered to be negative.

Also used: Potential Gradient (PG) defined by grad□ = -E

Instruments and Methodology

Data sources

- Network of electric field mills (Boltek EFM-100)
  1 sec time series of near-surface electrostatic field

- Wideband electric field measurement system:
  electromagnetic emission from lightning (50 Hz-12 MHz),
  1 sec capture length, 40 ns sample interval

- Data of World Wide Lightning Location Network (WWLLN):
  VLF (3-30 kHz) emissions from lightning

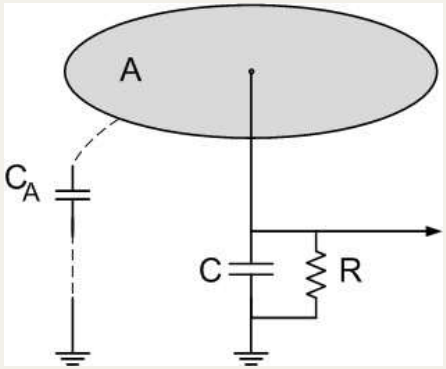
- Energetic radiation and particle detector:

60 cm thick plastic scintillator with sensitive area 1 m^2 sensitive to gamma radiation in the energy range from 4 MeV to 100 Mev

Network of electric field mills installed at Aragats, Nor Amberd, and Yerevan stations

Boltek EFM-100

Wideband electric field measurement system



Flat plate antenna,
50 Hz-12 MHz

Picoscope 5244B,
40 ns sample interval
1 sec record length

A **B** **Ext** **Out**

NI MyRiO board
with GPS timing

MFJ-1022 active whip
Antenna, 0.3-200 MHz

Particle detector

Methodology of lightning type identification

- Polarity of electrostatic field change
- Reversal of electrostatic field change with distance
- Characteristic features in fast electric field waveform
- Optical images of lightning discharges
- WWLLN data

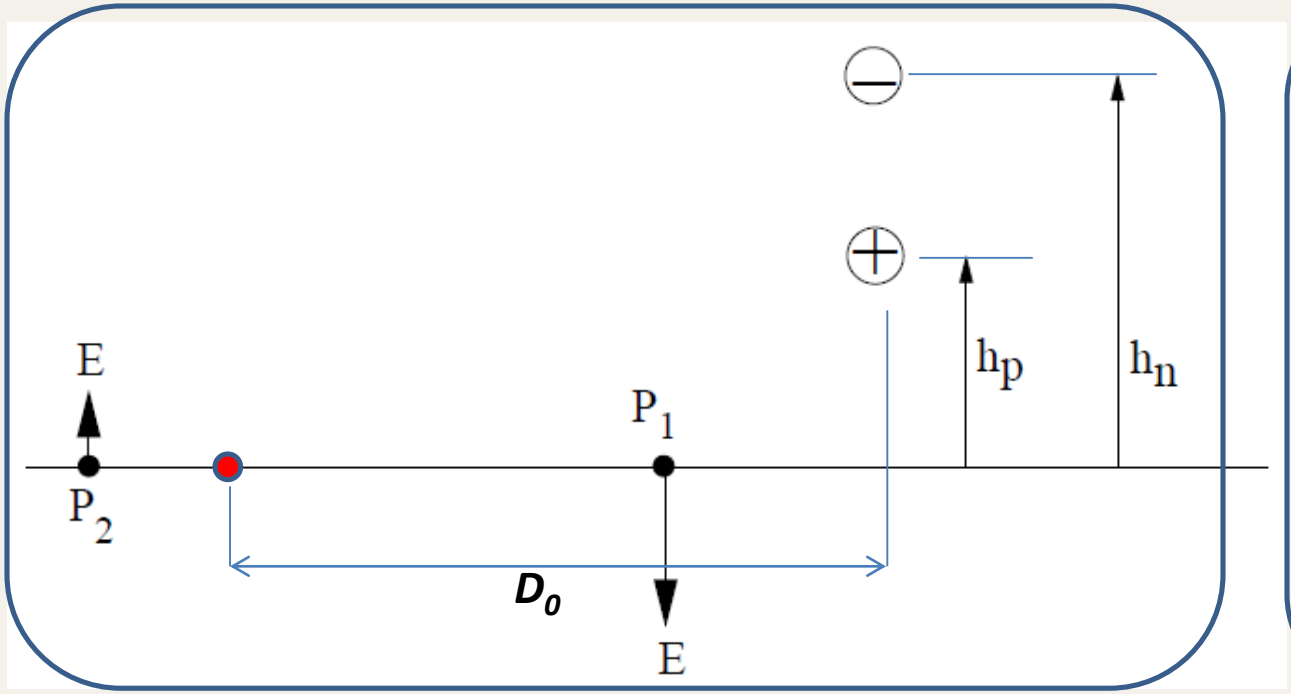
Polarity reversal of electrostatic field change □E with distance

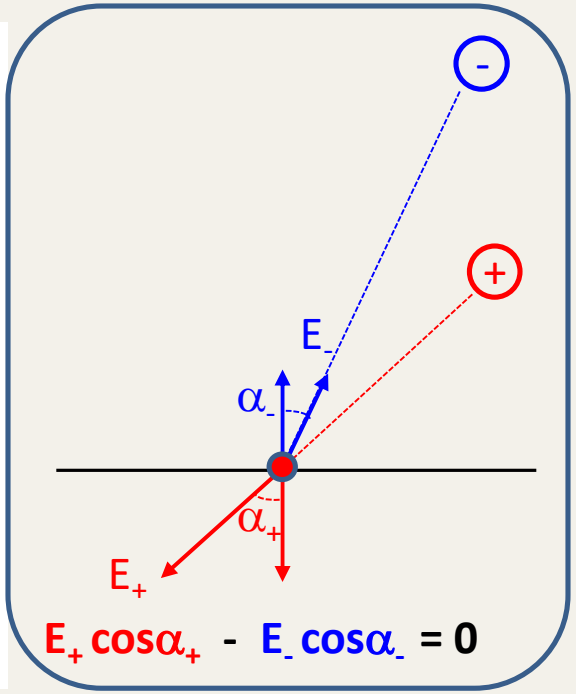
Polarity reversal of □ E with distance can occur only for cloud discharges, while the polarity of □ E produced by cloud-to-ground discharges is always independent of distance

Type equation here.

Rakov, V. A., and M. A. Uman (2003), Lightning: Physics and Effects, Chapter 3;
MacGorman, D. R., and W. D. Rust (1998), The Electrical Nature of Thunderstorms, Chapter 3;

Electrostatic field reversal associated with a vertical dipole





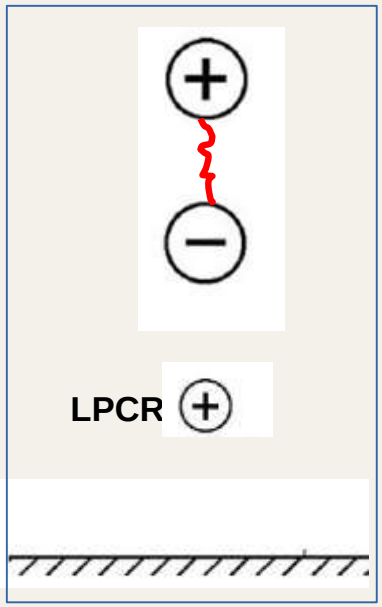
Observer P_1 on the conducting ground experiences a downward-directed electric field while the distant observer at P_2 measures a upward-directed field. The intermediate point between P_1 and P_2 where the electric field vanishes yields the field-reversal distance D_0

$$D_0 = \sqrt{(h_p h_n)^{\alpha}(h_p^{\alpha} + h_n^{\alpha})}, \quad \alpha = 2/3.$$

Intracloud lightning is a dipole discharge, the electrostatic field change may reverse polarity Cloud-to-ground lightning is a monopole discharge, the polarity is independent of distance.

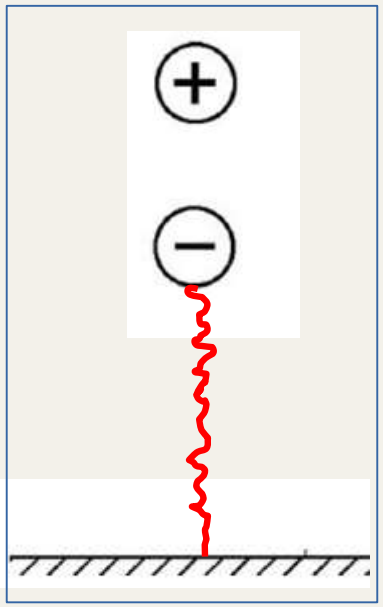
Criteria for lightning type identification

Normal IC



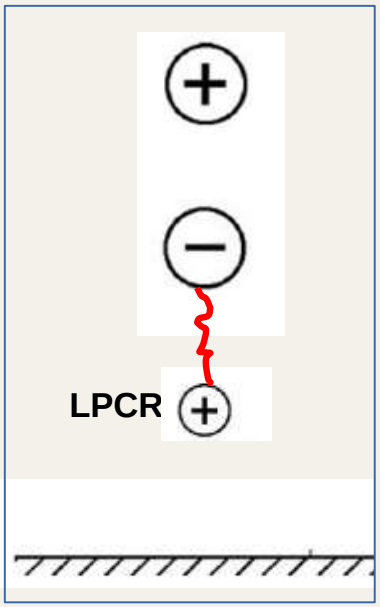
Close □ E is positive, distant □ E is negative.

-CG



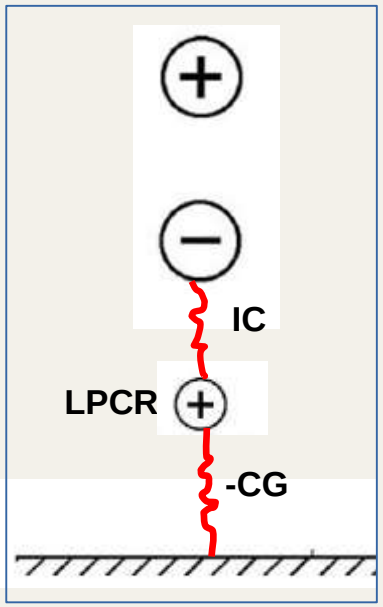
LPCR is small or absent. Both close □ E and distant □ E are positive.

Inverted IC



Close □ E is negative, distant □ E is positive.

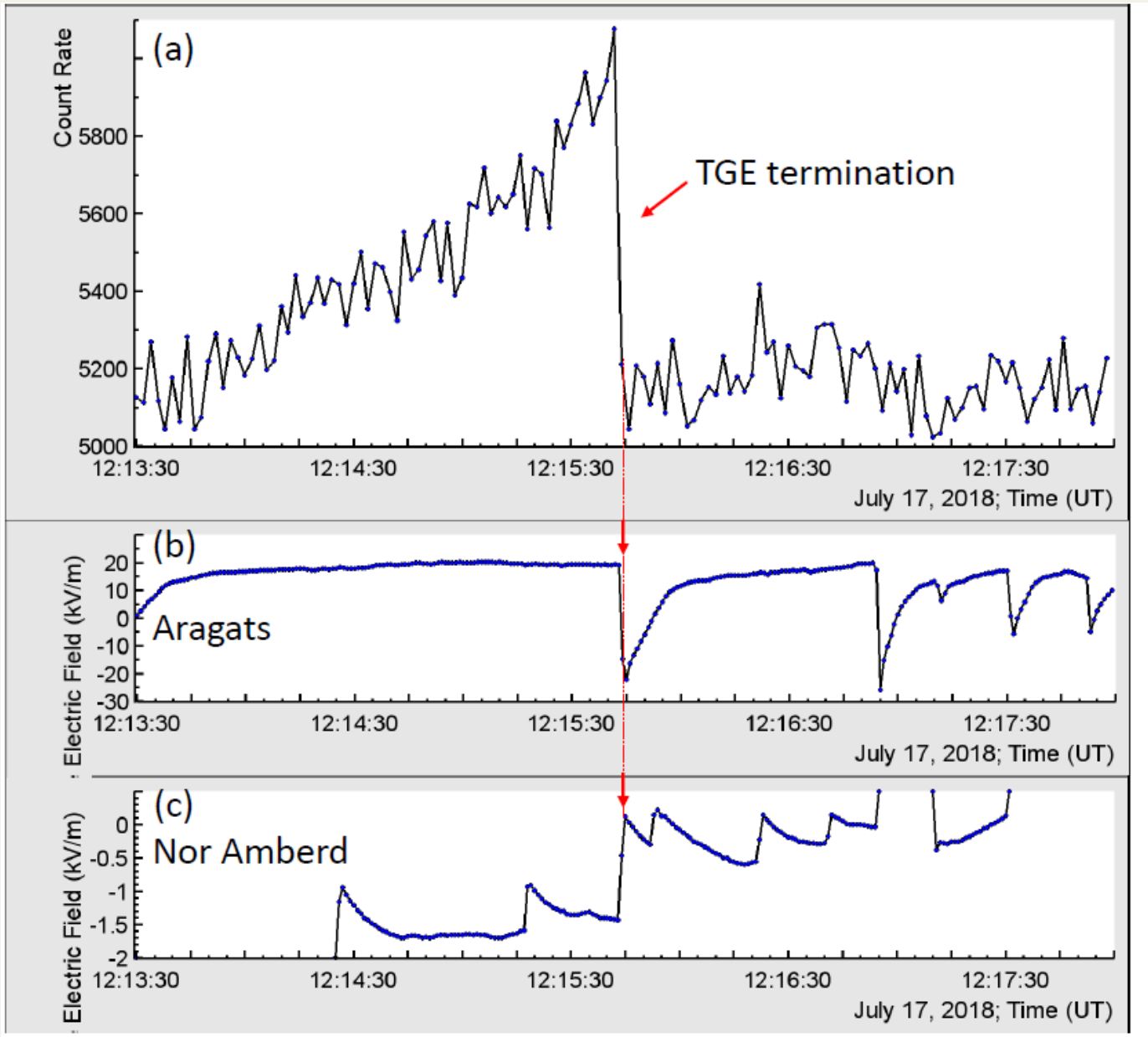
Hybrid flash



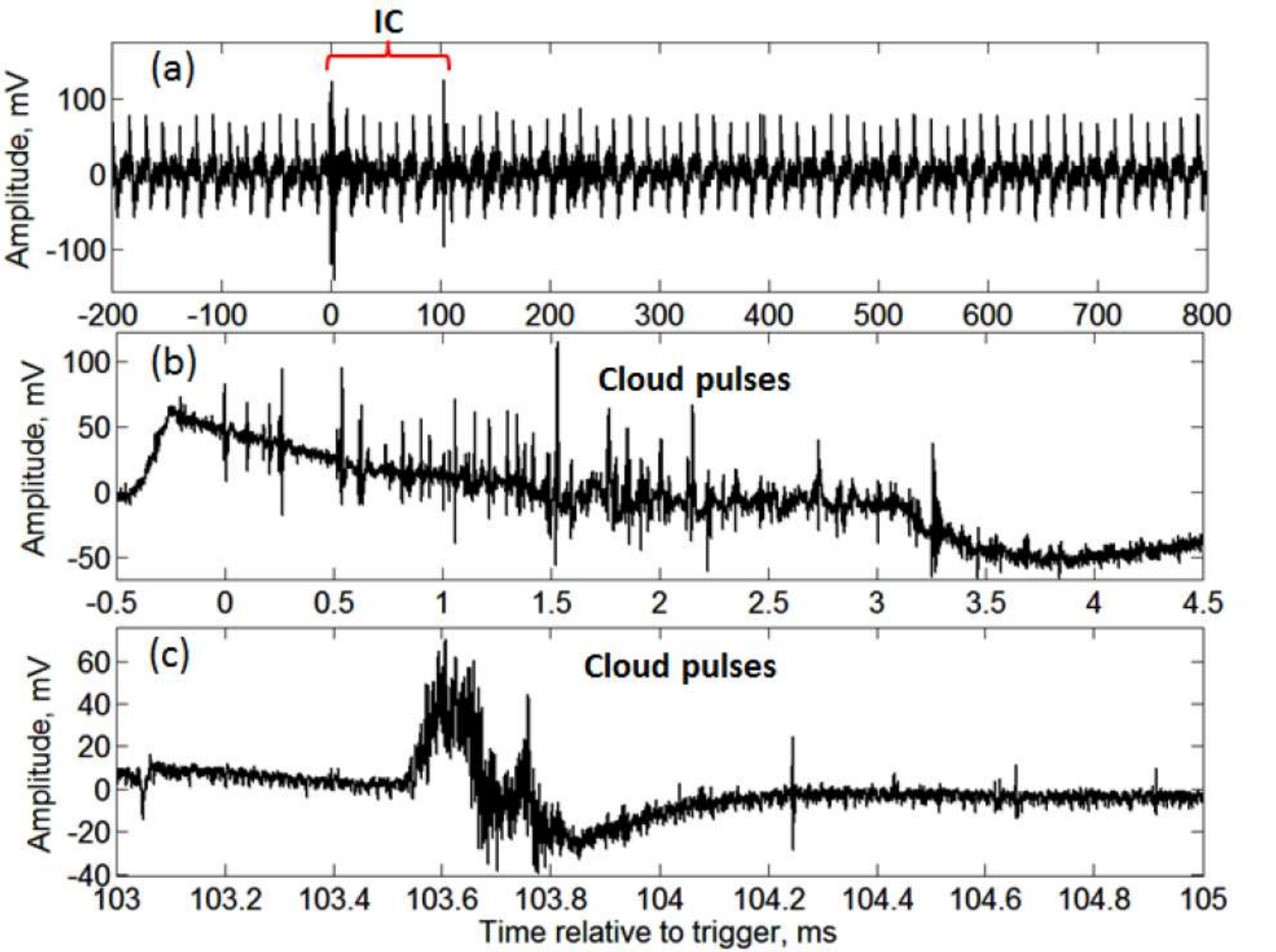
Close □ E is negative, distant □ E is positive. □ E polarity is determined by the inverted IC.

TGE termination events
(3 representative examples)

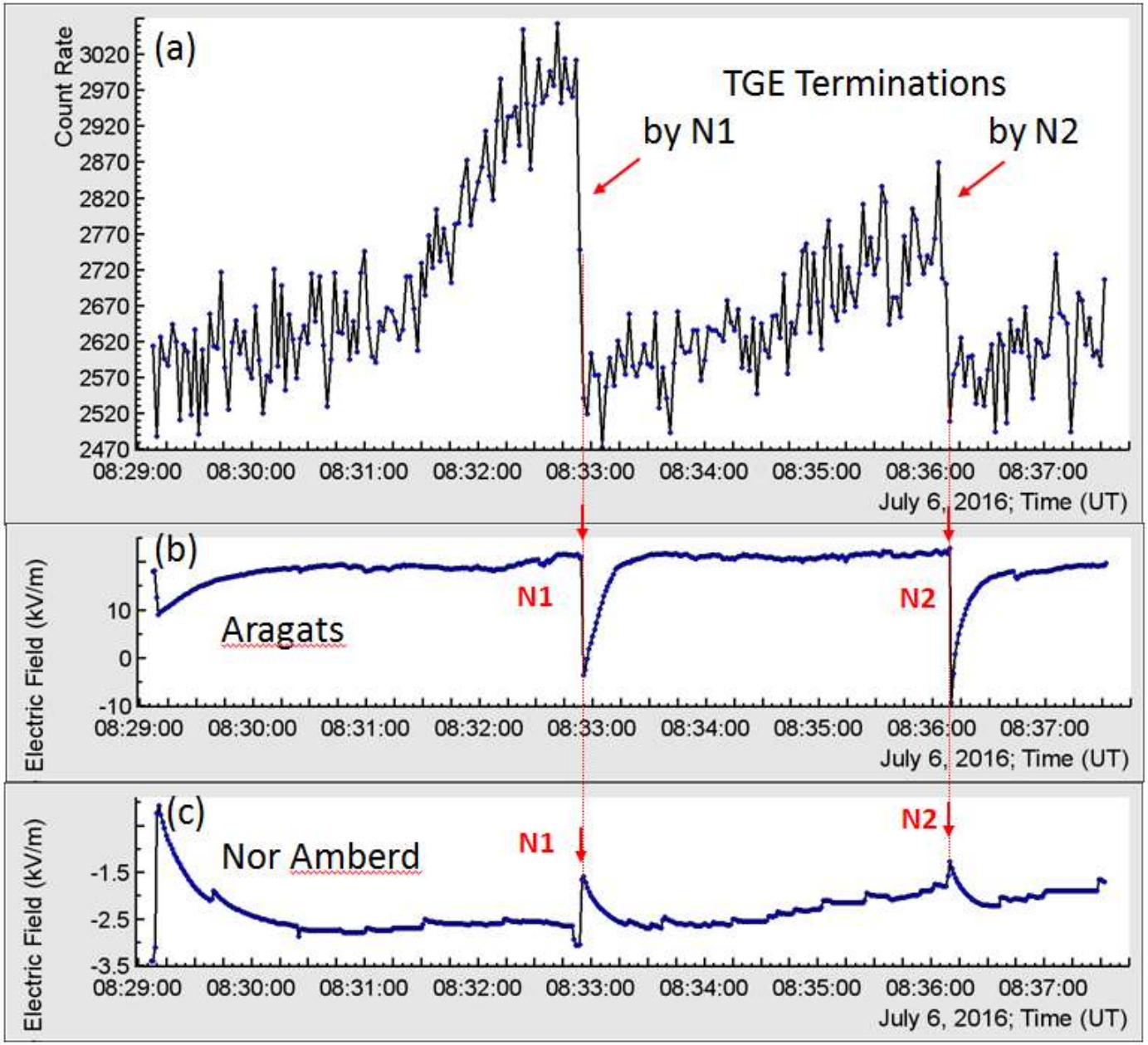
TGE terminated by an inverted IC flash
July 17, 2018, 12:15:44.190



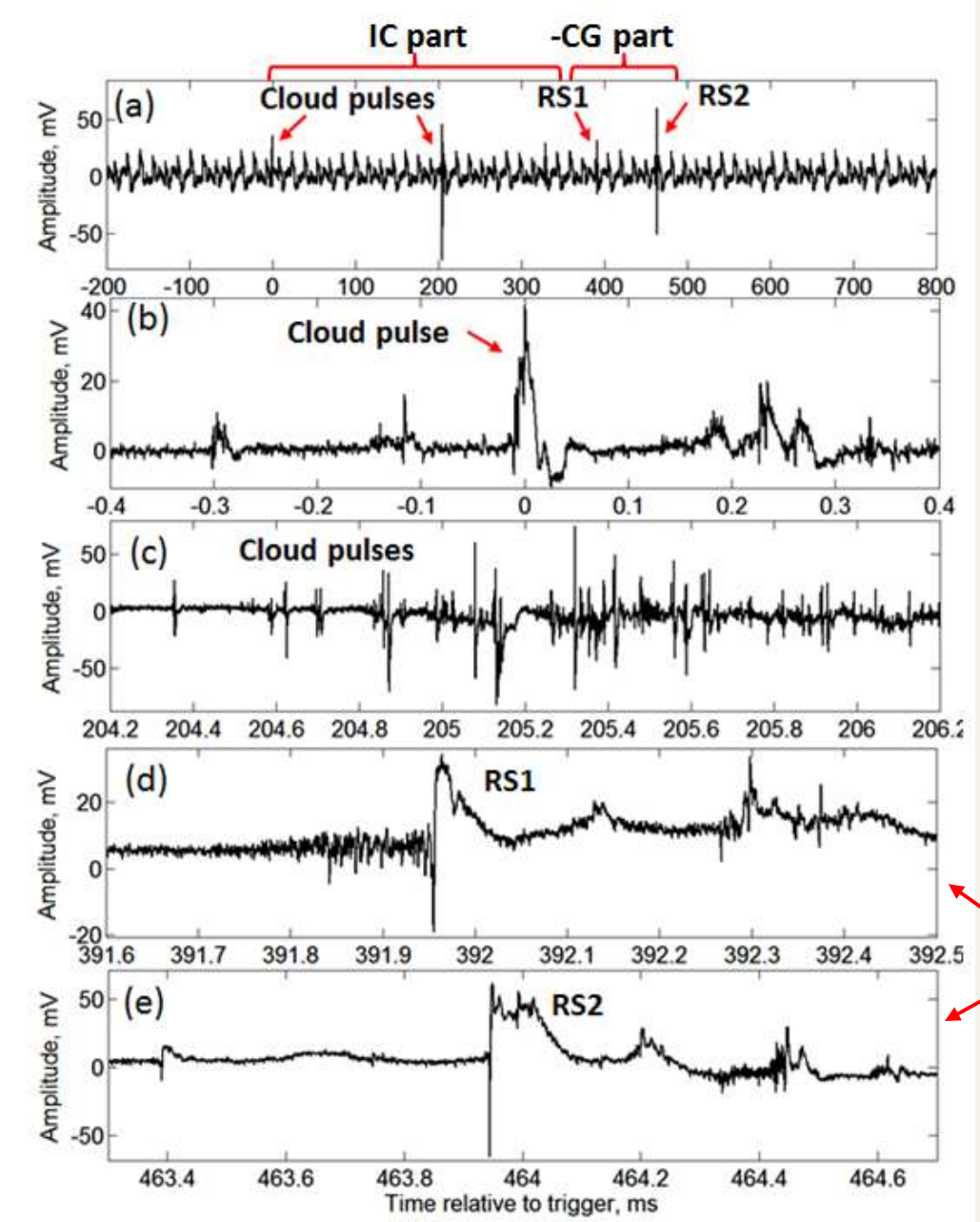
Fast electric field. July 17, 2018, 12:15:44.190



TGE terminated by two lightning flashes
July 6, 2016 08:32:55.253 (N1) and 08:36:10.460 (N2)

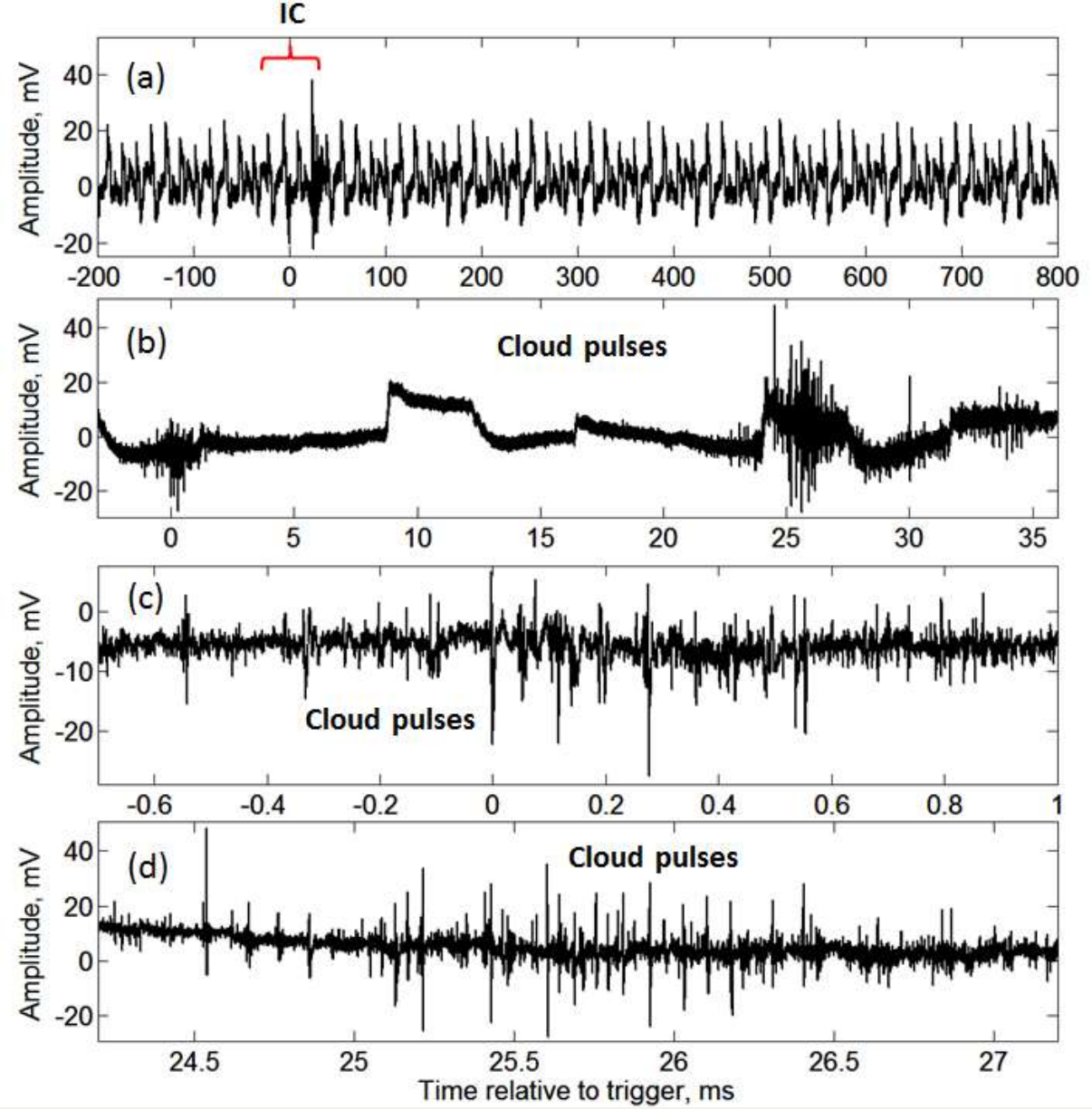


Fast electric field produced by flash N1 hybrid flash: inverted IC followed by -CG



Two return stroke pulses at 392 ms and 464 ms after trigger

Fast electric field produced by flash N2 (inverted-polarity IC flash)



Polarities of electrostatic field E and field change □ E for 25 events of TGE termination

- □ E was negative at the closest station (Aragats),
- Polarity of □ E was reversed with distance (in Nor Amberd)

Indicate that a negative dipole was partially destroyed (negative charge above positive)

- Electrostatic field before the discharge and recovered field after the discharge were positive

Indicates that LPCR was present above the detector

Overview of 74 TGE-terminating lightning events whose type was identified in this study

Lightning types for 74 TGE-terminating events

Lightning type	Number of events	%
Normal IC	34	~46
Negative cloud-to-ground (-CG)	15	~20
Inverted IC	17	~23
Hybrid (Inverted IC followed by -CG)	8	~11
Total	74	100

Parameters for 74 TGE-terminating lightning events whose type was identified in this study

Parameter	Normal IC (34 events)	Negative CG (15events)	Inverted IC (17events)	Hybrid (8 events)
TGE duration, s	183±139	208±90	102±52	144±48
Particle flux drop, %	16±16	22±18	7±5	5±5
WWLLN/Total	4/34	8/15	0/17	2/8

Smaller drop is associated with a smaller change of electron-accelerating electric field. This field change is small because the charge of LPCR is normally much smaller than that of either main negative or upper positive charge region

Conclusions

Main finding of this study :

- We observed termination of TGEs by inverted ICs and hybrid flashes (IC followed by –CG)

- This is the first experimental evidence that the conditions for electron acceleration toward ground needed for production of TGEs can be created between the mid-level negative charge region and the LCPR.

Conclusions

- TGEs can be terminated by 4 types of lightning :
  normal ICs,
  negative CGs,
  inverted ICs,
  hybrid flashes (an inverted IC followed by a -CG)

- All 4 types neutralize some amount of charge in the main negative charge region, and thus reduce the electron accelerating electric field responsible for TGEs

Thank You!