Electric field changes produced by lightnings that abruptly terminate the Thunderstorm Ground Enhancements (TGEs)

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Outline

- Motivation

  Which types of lightning can terminate the TGE?

  Where is located the accelerating electric field responsible for the TGE?

  At which stage of the lightning is the TGE terminated?

- Introduction

  Lightning types, cloud charge structure, electrostatic field polarity reversal

- Instrumentation
- Principles of lightning type identification
- Observation data

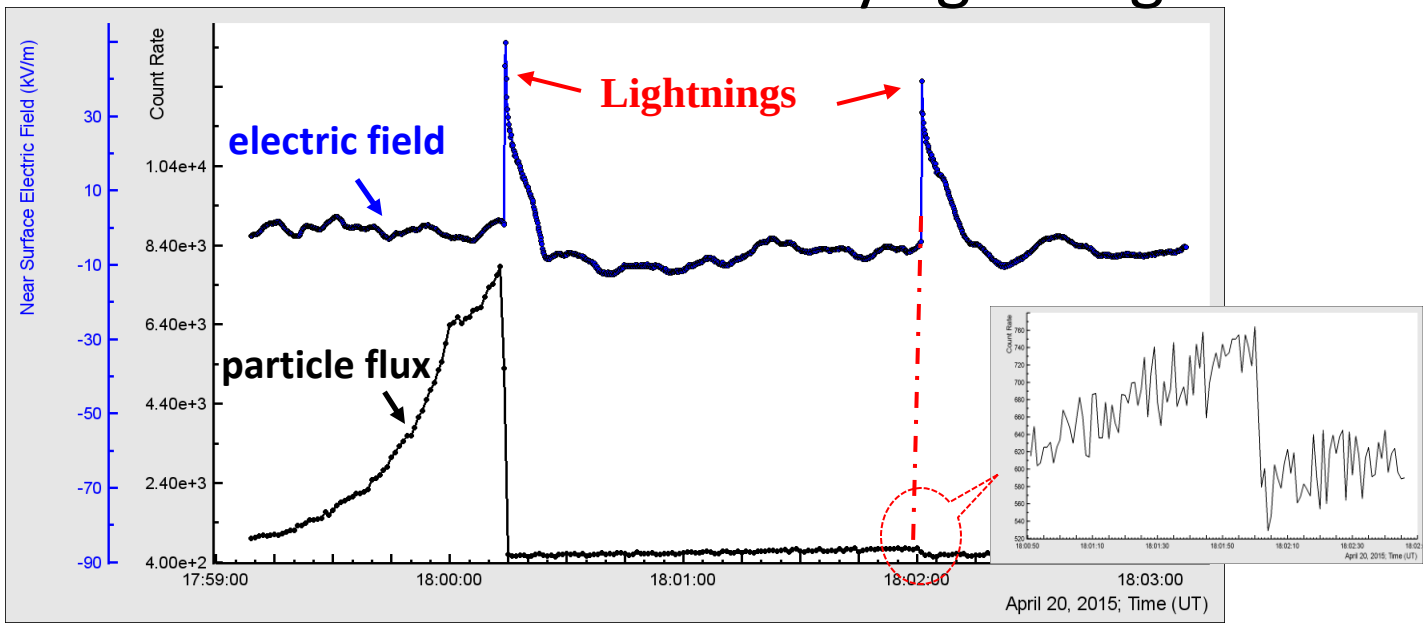
  1) Lightnings not associated with TGE,

  examples of identified lightning types

  2) Lightnings that terminate the TGE, analysis of 23 events

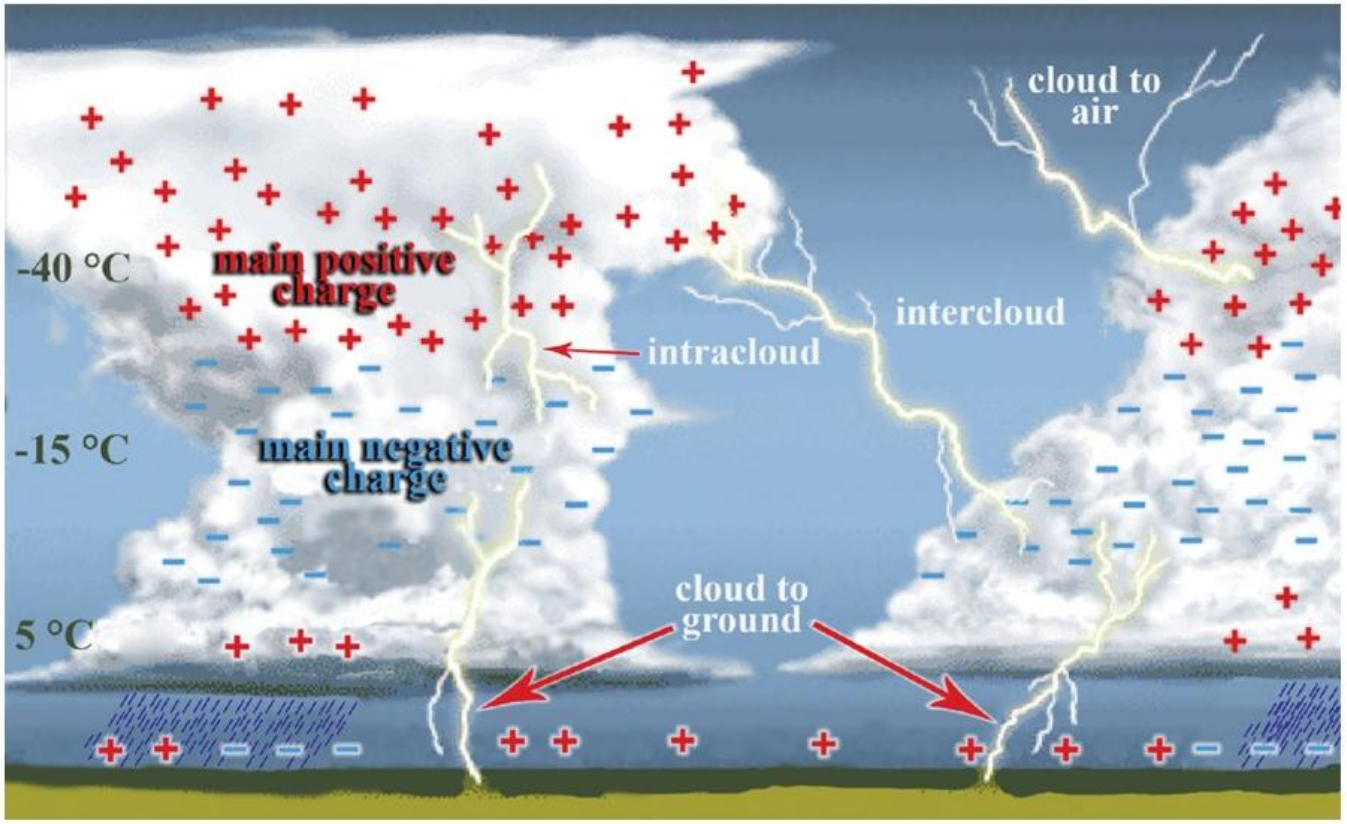
- Conclusion

Thunderstorm Ground Enhancement (TGE) can be terminated by lightning flash



- Which types of lightning can terminate the TGE?
- Where is located the accelerating field responsible for TGE and which is "switched off" by the lightning discharge?
  a) between main negative and lower positive charge region
  b) between main negative and the ground
  c) both inside and beneath the thundercloud
- At which stage of lightning does the TGE termination occur?
  a) at the moment of lightning stroke;
  b) at the moment of the rearrangement of electric field in the cloud;
  c) after rearrangement

Lightning flashes can be grouped into two categories: those that strike the ground and those that do not



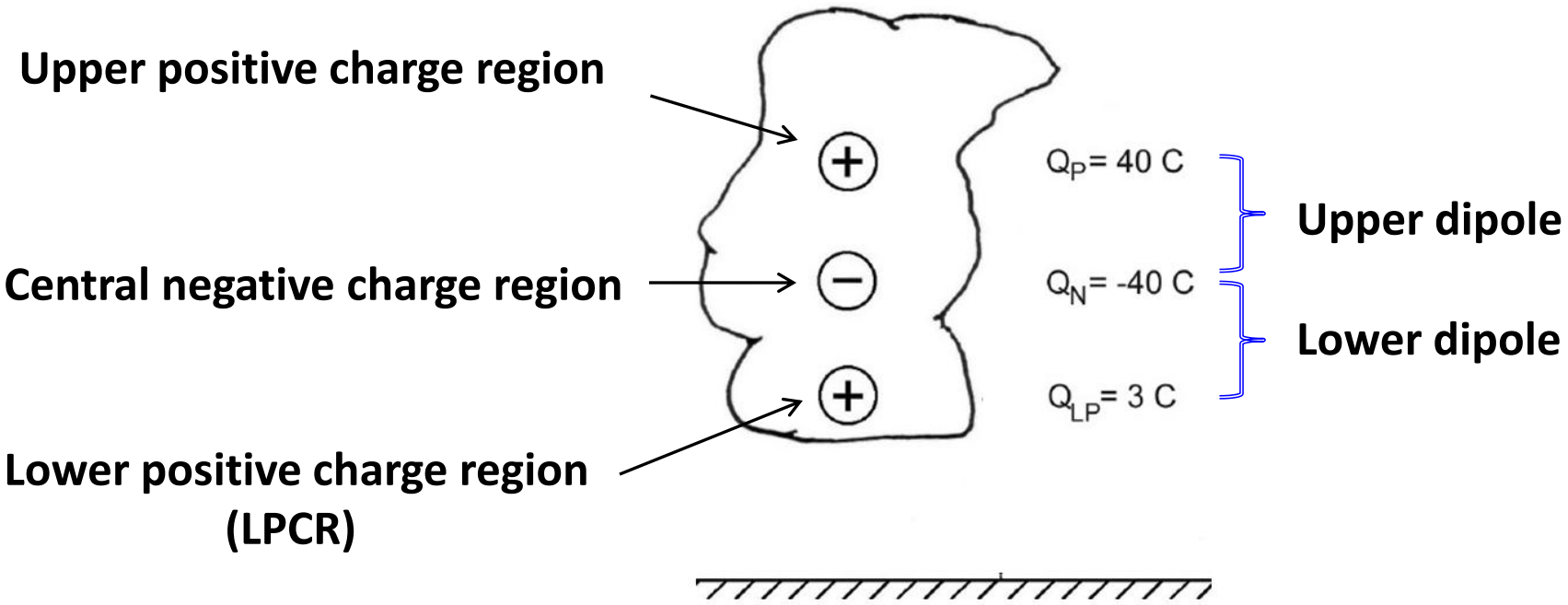
Intracloud, intercloud, and cloud-to-air discharges (ICs) comprise around 75% of lightning discharges.

25% of all lightning discharges is made up of cloud-to-ground discharges (CGs).

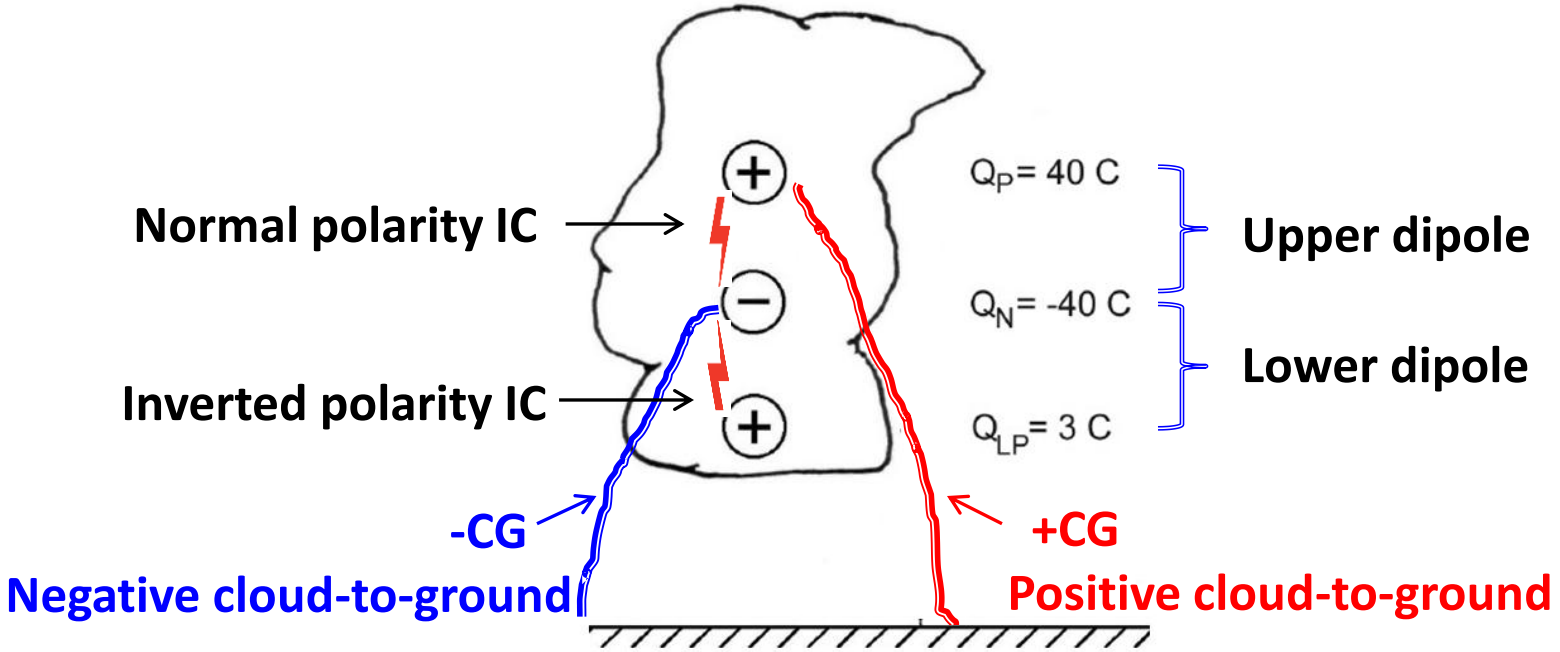
Among CGs : -CG ≈95%, +CG ≈ 5%

Adapted from Dr. Amitabh Nag's presentation in Vaisala webinar

Vertical tripole charge structure of the thundercloud (normal electrification)



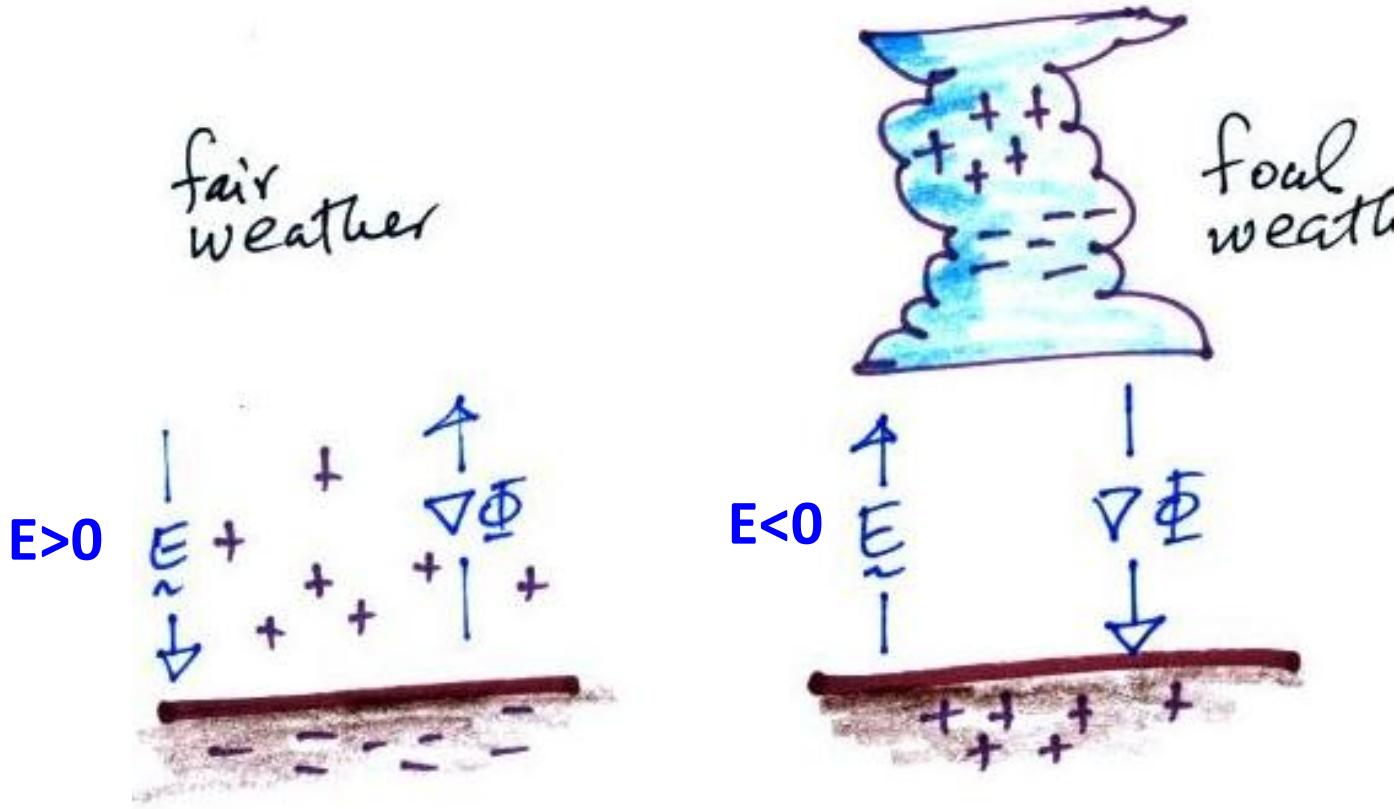
Vertical tripole charge structure of the thundercloud (normal electrification), Intracloud (IC) and cloud-to-ground (CG) flashes



"Beneath and nearby normally electrified storms, negative CG flashes and normal-polarity IC flashes have the dominant effect of reducing the negative charge overhead. Therefore both produce positive (atmospheric electricity sign convention) electrostatic field changes " (Krehbiel et al., 2014 , Newsletter on Atmosph. Electricity V 25 No 2)

Sign convention

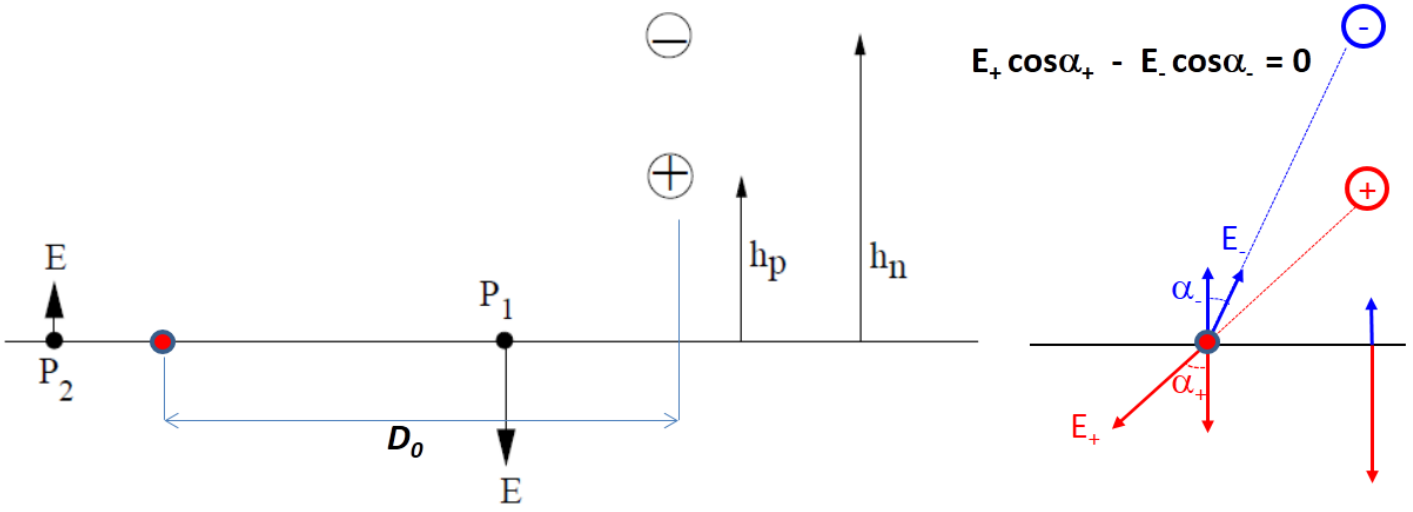
Atmospheric electricity sign convention : downward directed electric field or field change vector is considered to be positive



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 $\Delta\Phi=-E$

Polarity reversal of electrostatic field associated with vertical dipole



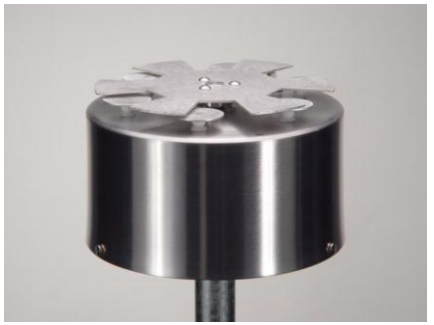
Observer at P_1 on the conducting ground experiences a downward-directed electric field while the distant observer at P_2 measures a upward-directed field. The intermediate point between P_1 and P_2 where the electric field vanishes yields the field-reversal distance D_0 :

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

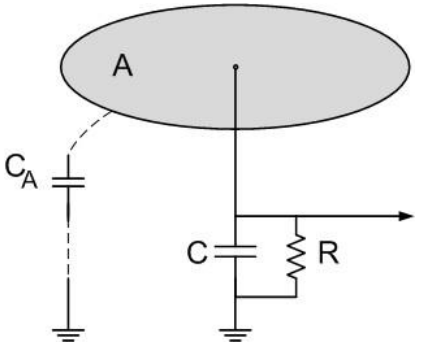
Intracloud lightning – dipole discharge, the electrostatic field change may reverse polarity
Cloud-to-ground lightning – monopole discharge, no polarity reversal

Instrumentation

- Network of electrostatic field meters
  in Aragats, Nor Amberd and Yerevan
  1 sec and 50 ms time series

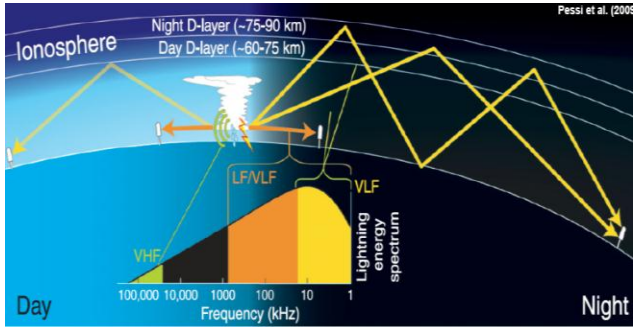


- Fast wideband electric field detection in
  Aragats with GPS timing system.
  1 sec capture length, sample interval 40ns



- Lightning photography in Aragats and Byurakan
  30frame/sec

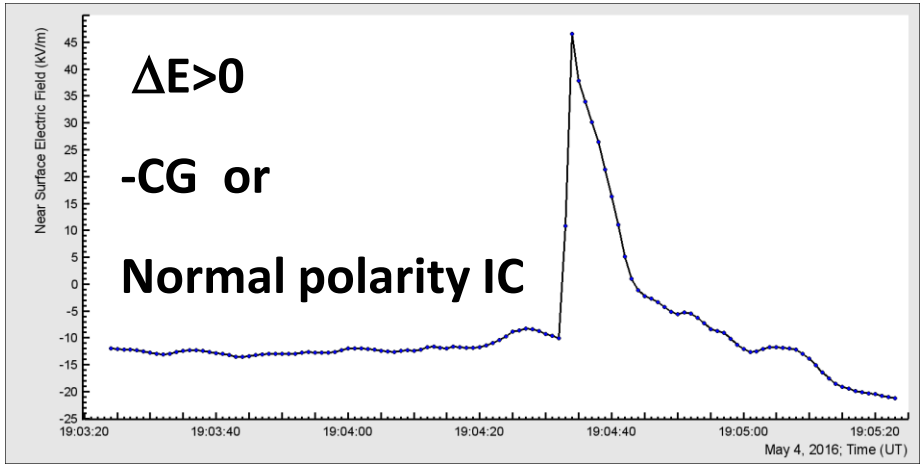
- World Wide Lightning Location Network
  (WWLLN, “woolen”). Detects VLF (3-30KHz)
  emissions from lightning, has about 60 nodes
  over the globe. Yerevan node established in 2013

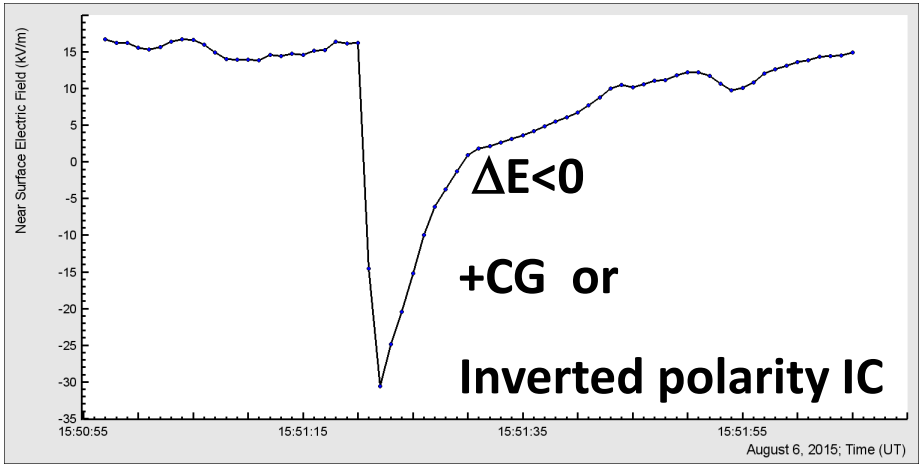


Data used for the lightning study

- Polarity of electrostatic field change
- Polarity reversal of electrostatic field change with distance
- Distance to lightning from EFM-100 field mill
- Lightning photo
- Characteristic features in fast electric field waveform
- WWLLN data

Electrostatic field change produced by different types of lightning flashes (atmospheric electricity sign convention)





Principles of lightning type identification

Initial polarity of electrostatic field change: ΔE>0 / ΔE<0

ΔE>0

-CG or

Normal polarity IC

ΔE<0

+CG or

Inverted polarity IC

Polarity reversal of electrostatic field change with distance detected by network: Yes/No

Yes
Normal polarity IC

No
-CG or
Normal polarity IC

Yes
Inverted polarity IC

No
+CG or
Inverted polarity IC

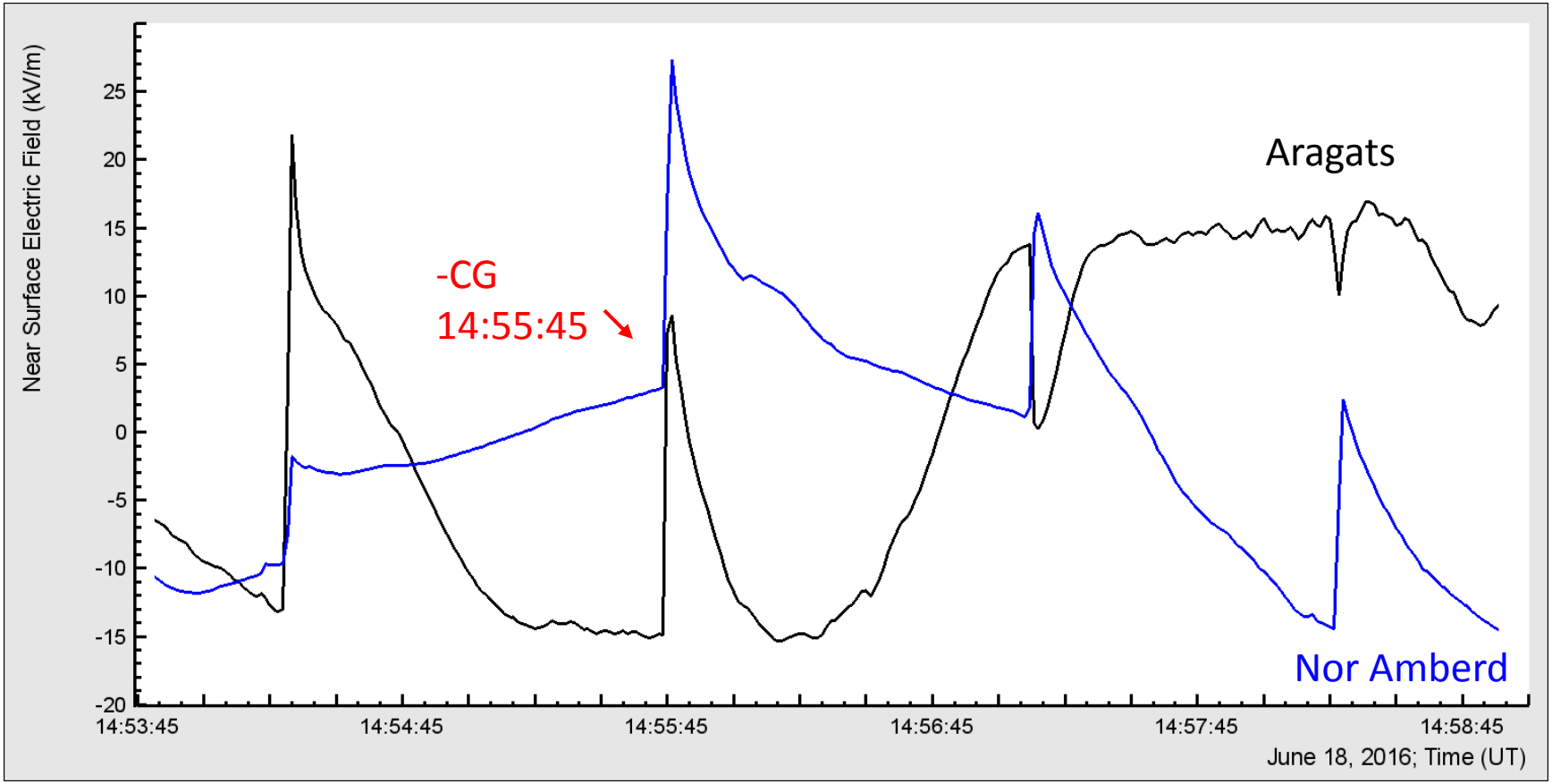
To distinguish between CG and IC

- **Examine lightning photos**
- **Analyse fast electric field waveforms, look for characteristic features. Pulses wider than certain threshold are interpreted as being produced by return strokes in CG flashes.**
- **Look for coincidence with WWLLN data (90% of events detected by WWLLN are CG)**

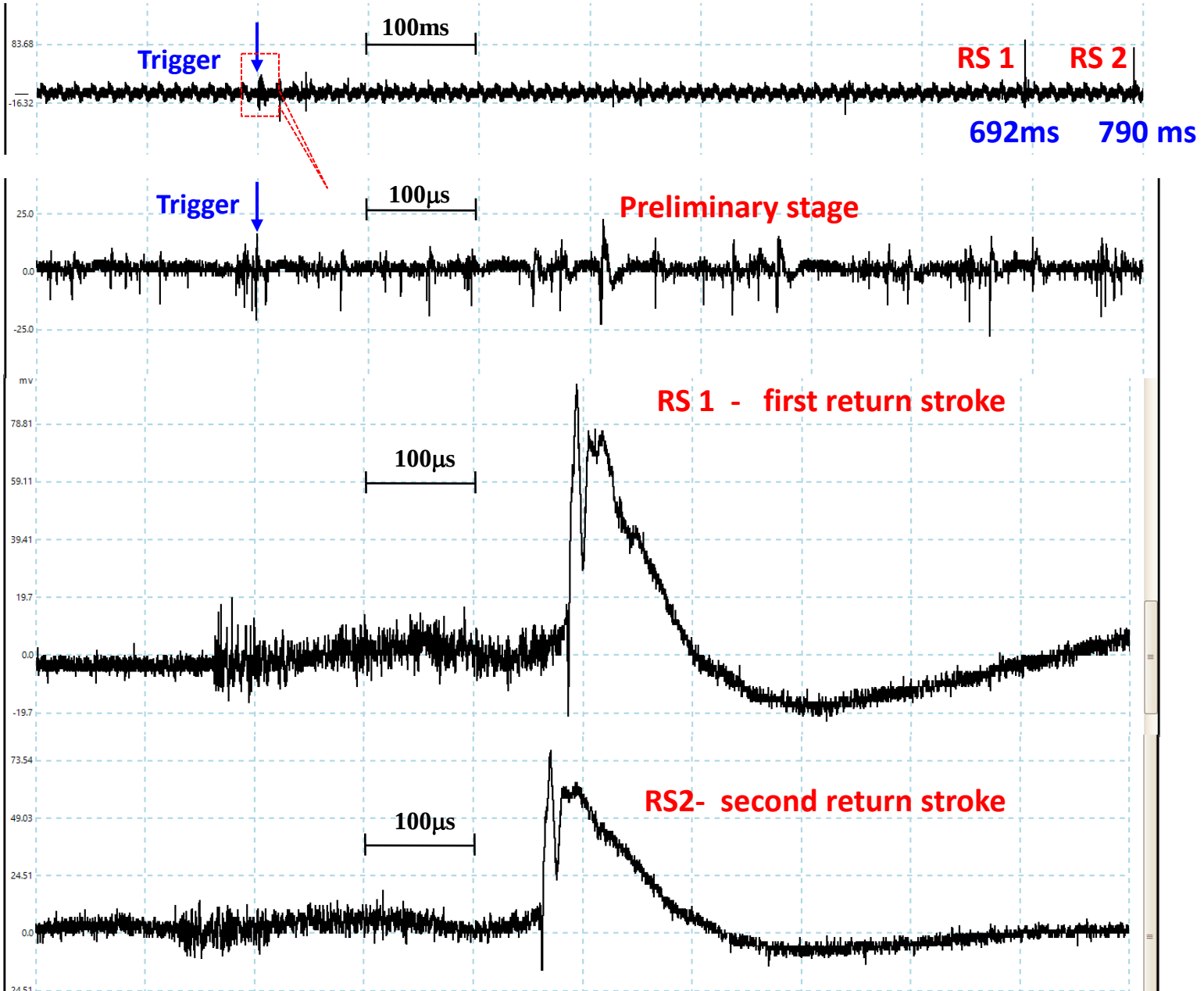
Examples of identified lightning flashes not associated with TGE

Negative CG
June 18,2016 14:55:45

Electrostatic field June 18,2016

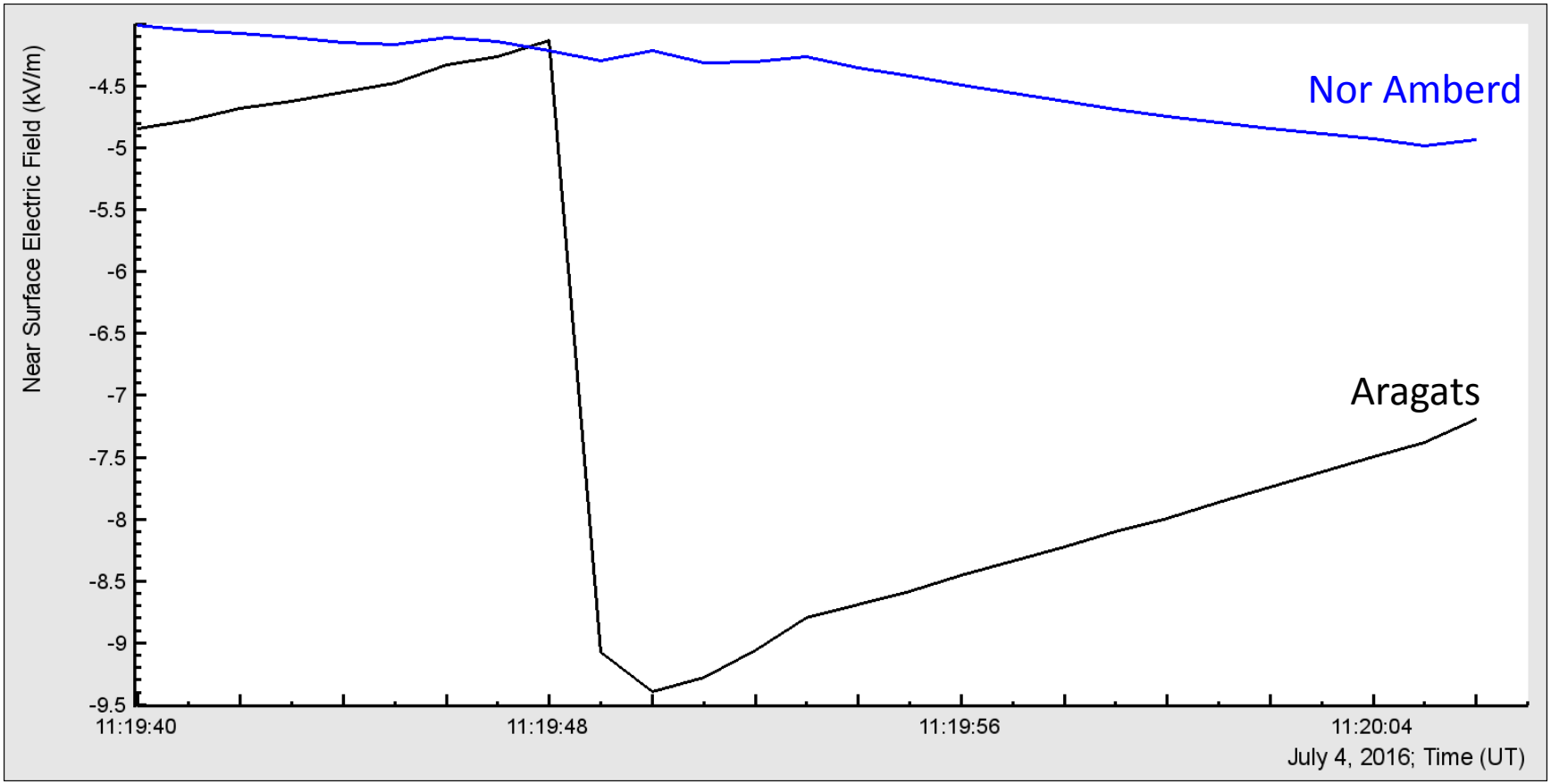


Fast electric field, June 18, 2016 14:55:45



Positive CG
July 4, 2016, 11:19:49

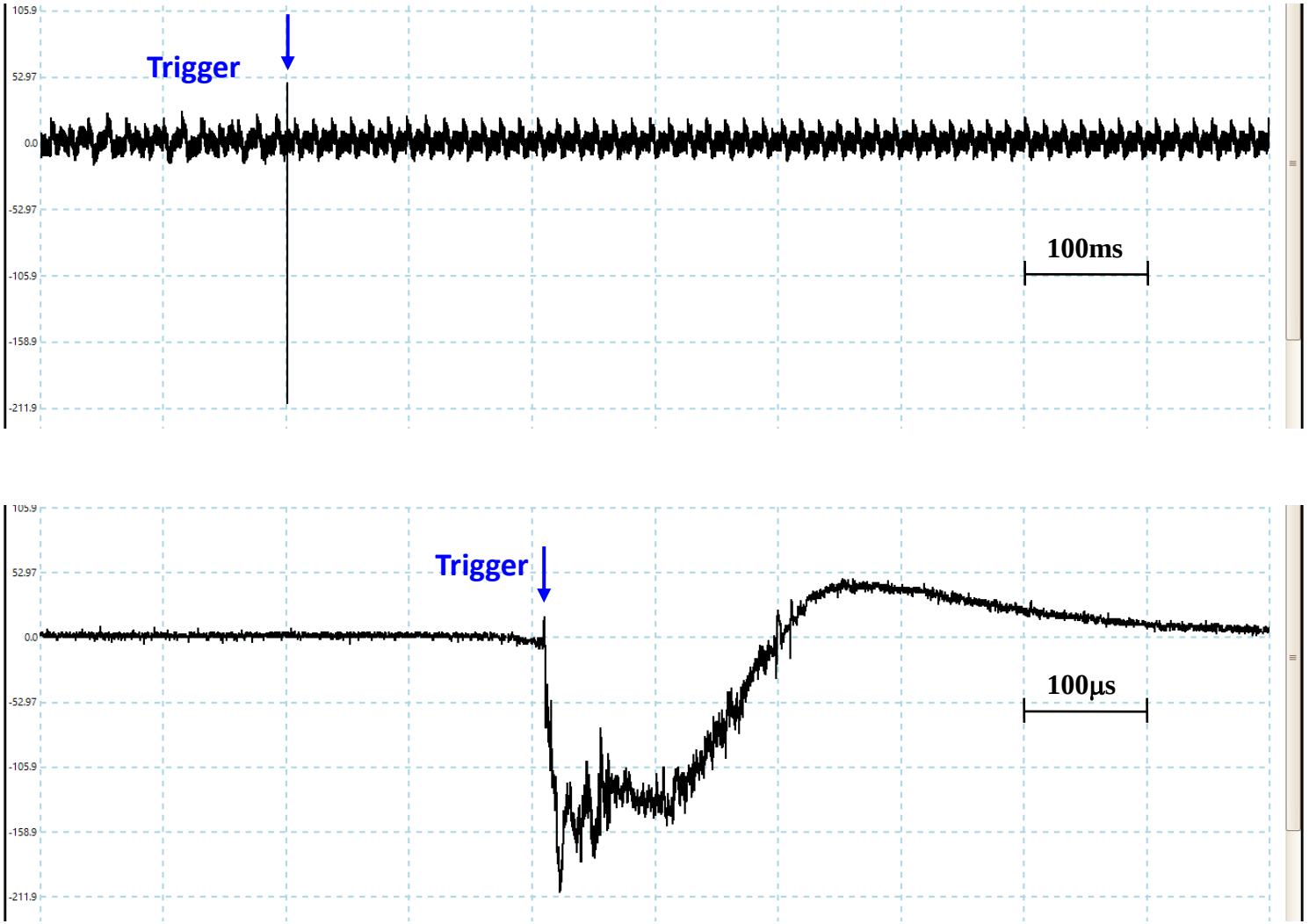
Electrostatic field July 4,2016, 11:19:49



WWLLN data:

Date	Time	Latitude	Longitude	Error, µs	Nst	Distance
7/4/2016	11:19:48.897	40.4313	44.2235	16	8	5.7km

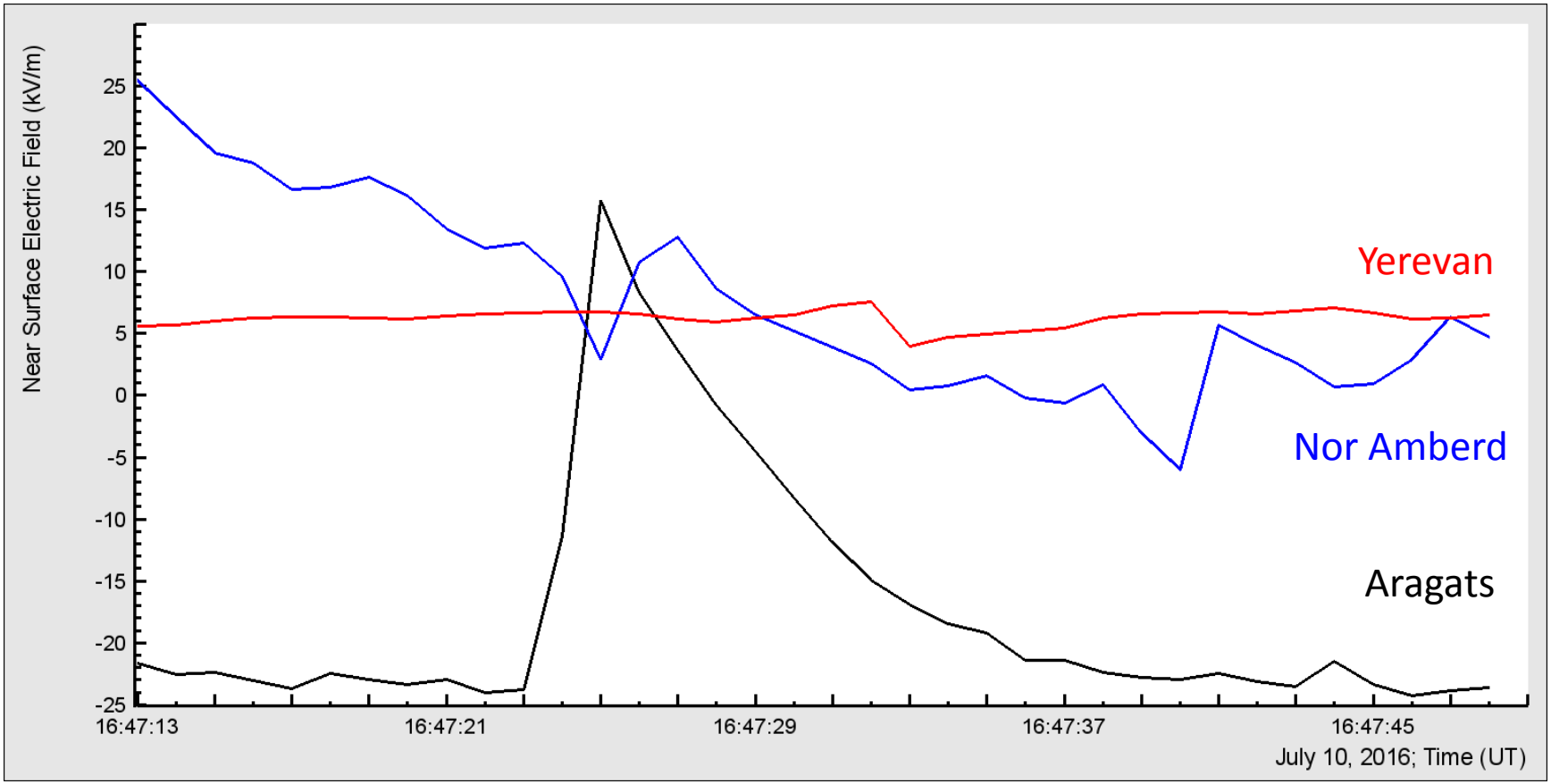
Fast electric field, July 4, 2016 11:19:49



Only one return stroke : typical for positive CG

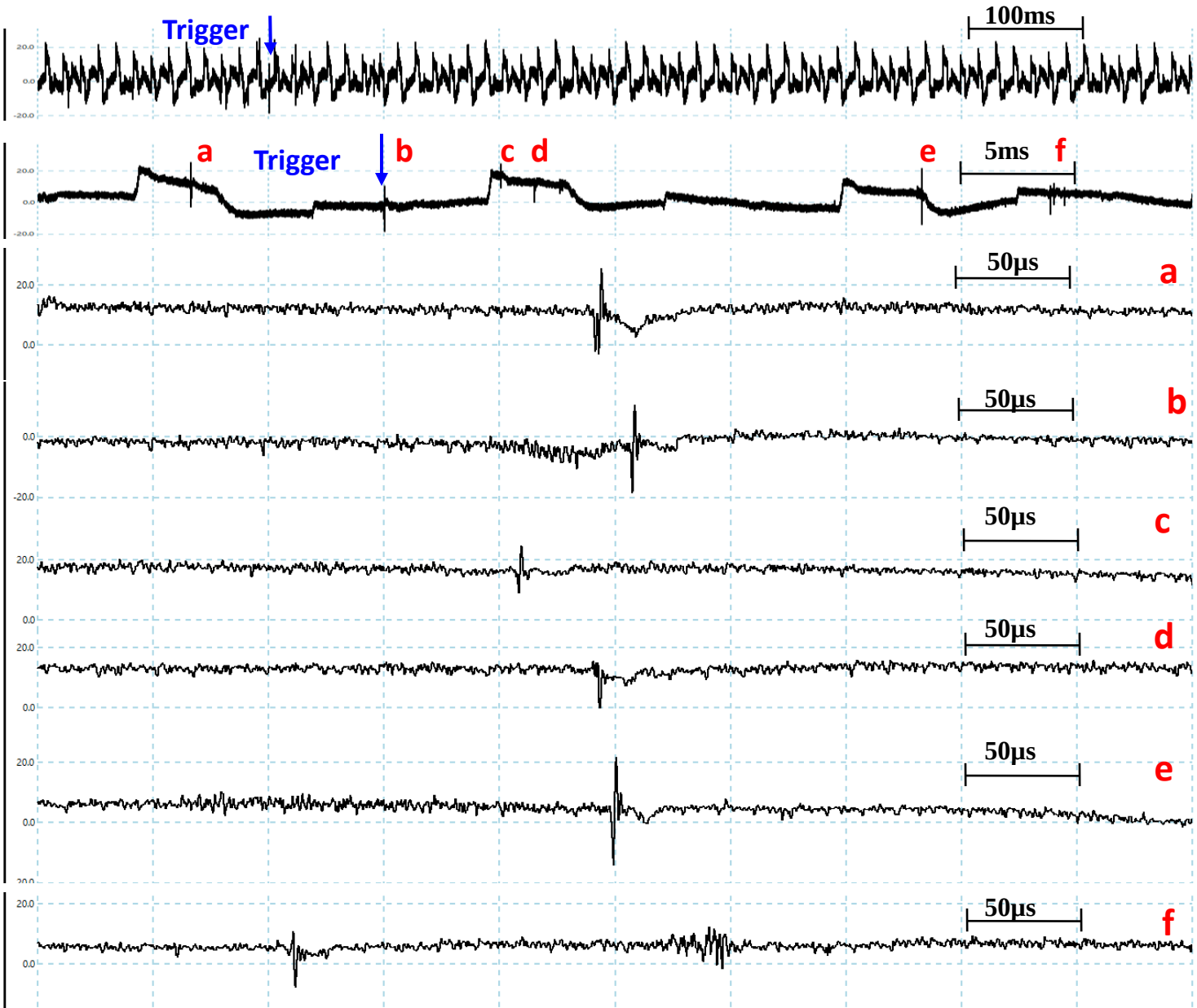
Normal polarity IC
July 10,2016, 16:47:25

Electrostatic field July 10 2016, 16:47:25



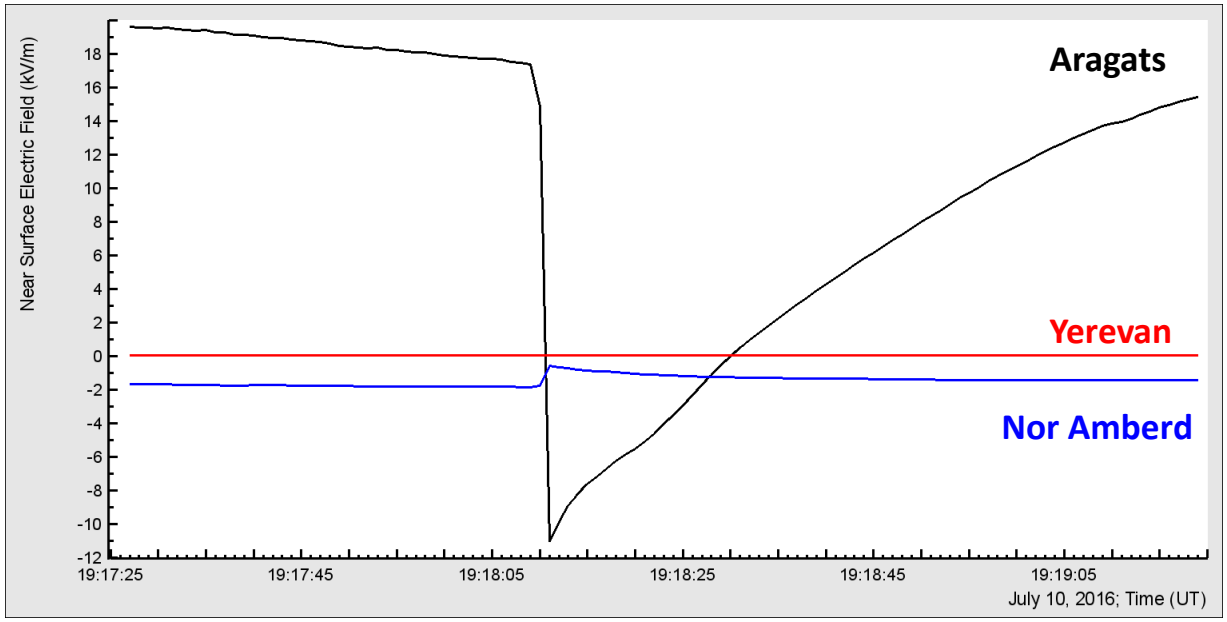
Polarity reversal of electrostatic field change is observed

Fast electric field, July 10, 2016 16:47:25



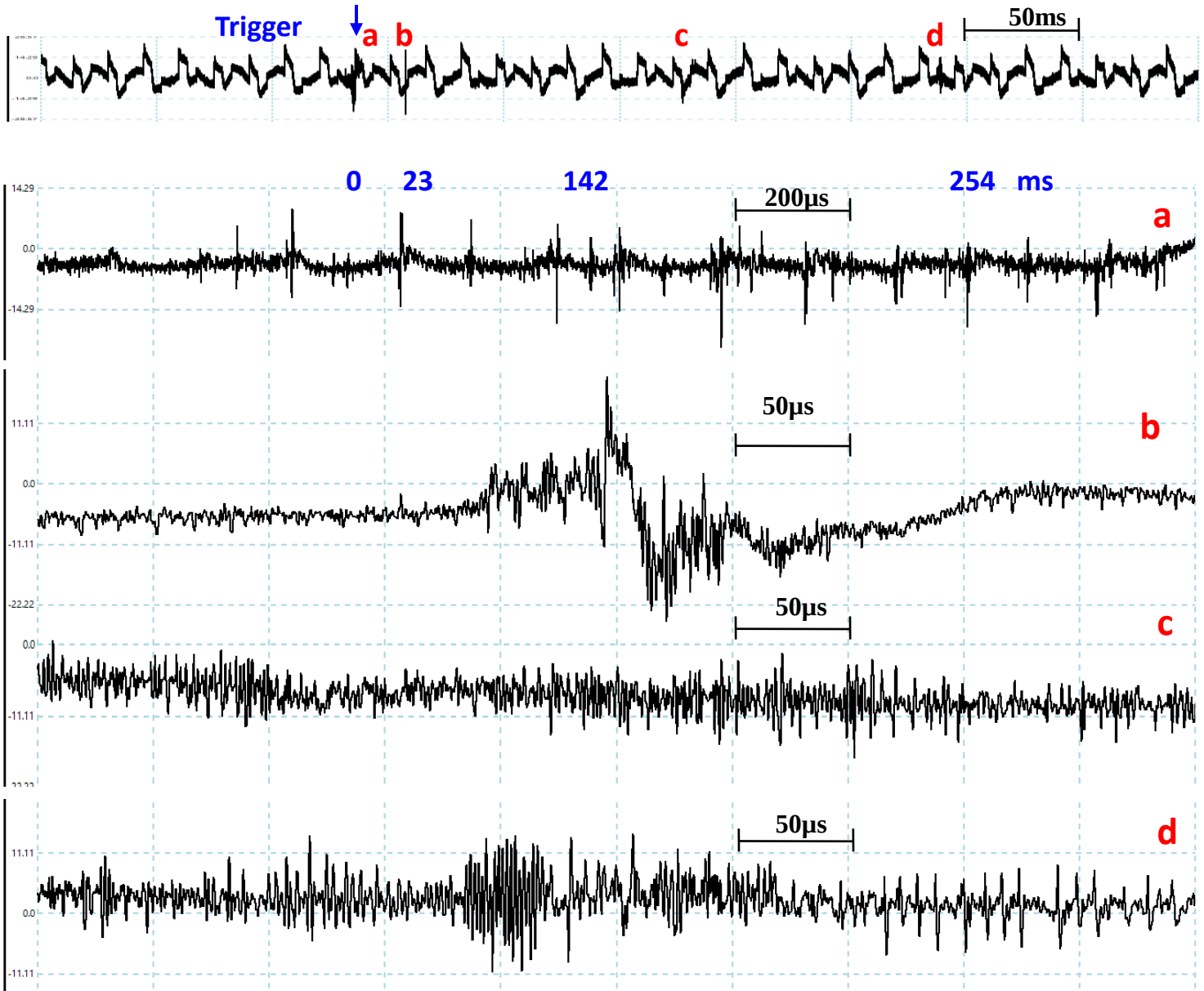
Inverted polarity IC flash
July 10, 2016, 19:18:10

Electrostatic field July 10, 2016, 19:18:10



Polarity reversal of electrostatic field change observed

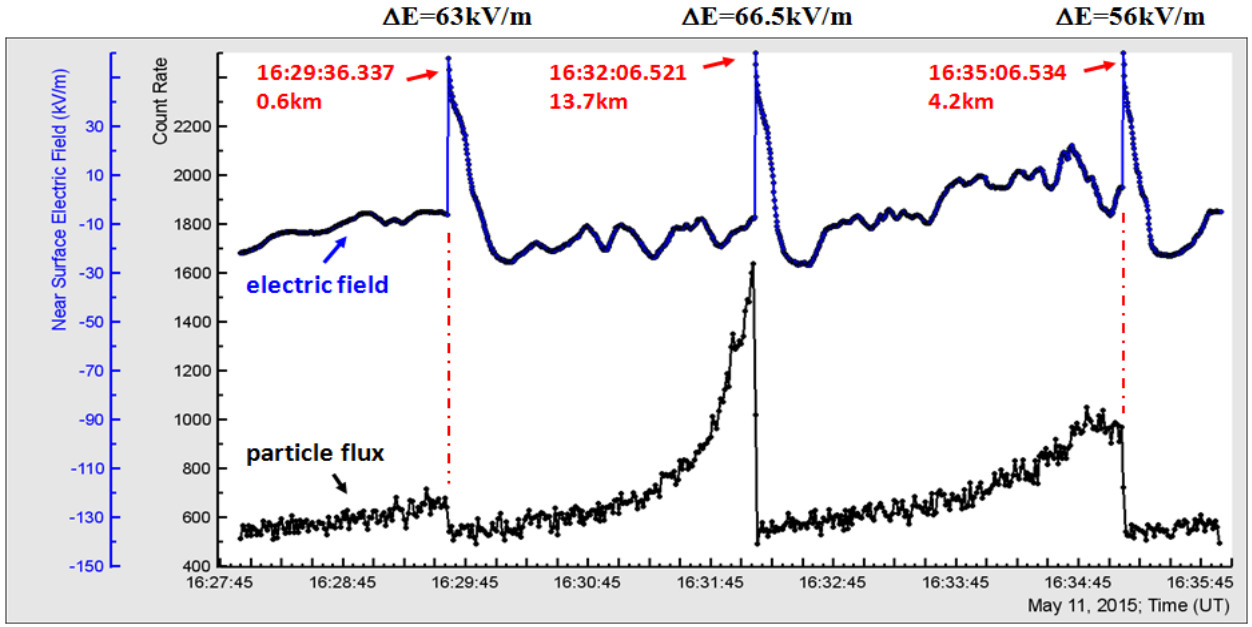
Fast electric field, July 10, 2016 19:18:11

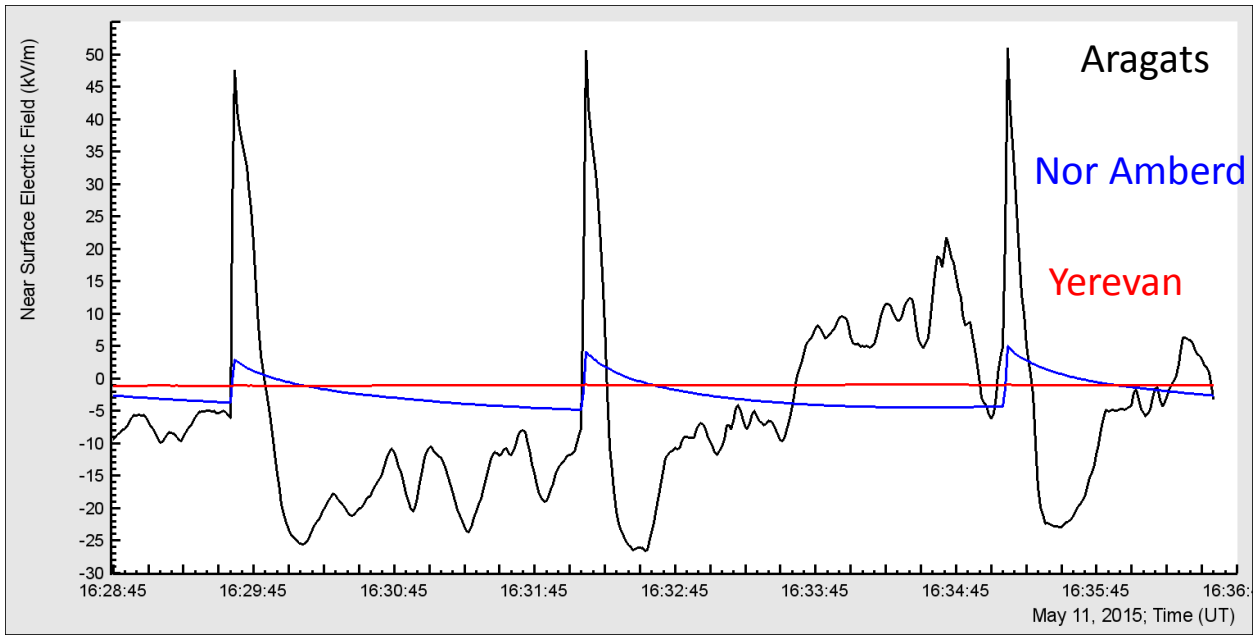


Examples of TGEs terminated by lightning flashes (23 events analysed)

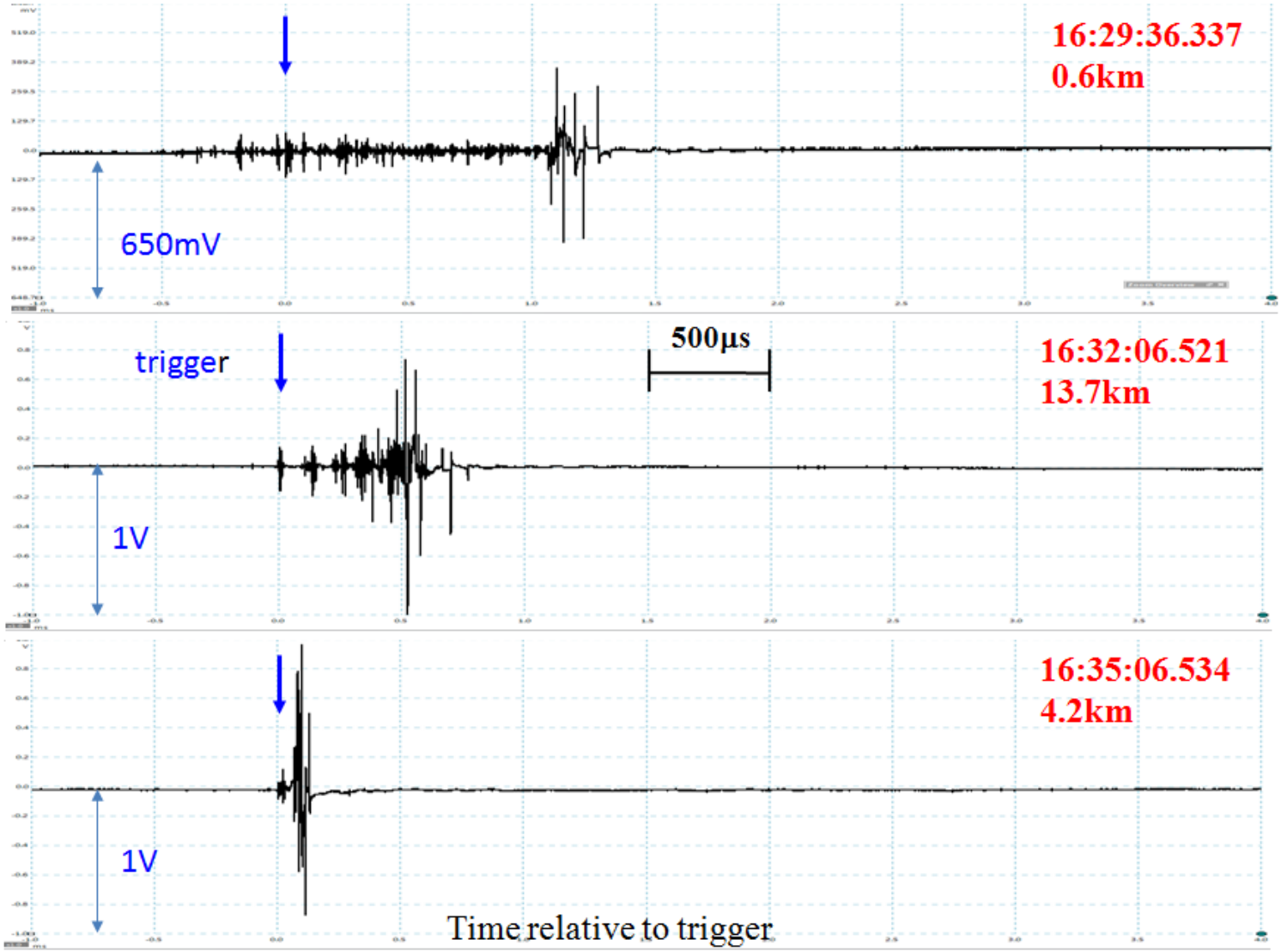
Three TGEs terminated by negative CG flashes May 11 ,2015

Electrostatic field and count rate (upper picture) and electric field measured by 3 field mills





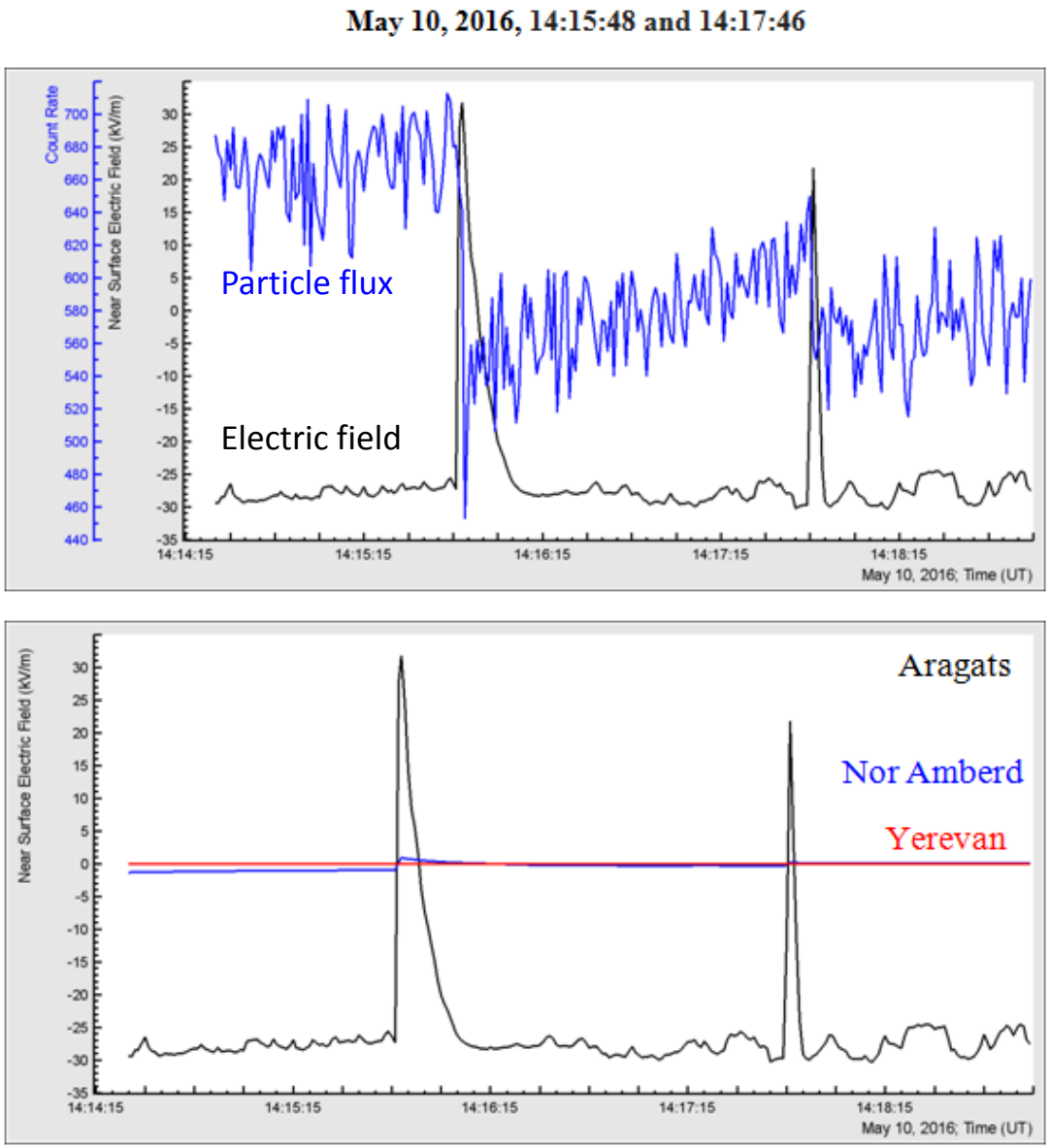
Fast electric field, May 11, 2015, 16:29-16:35



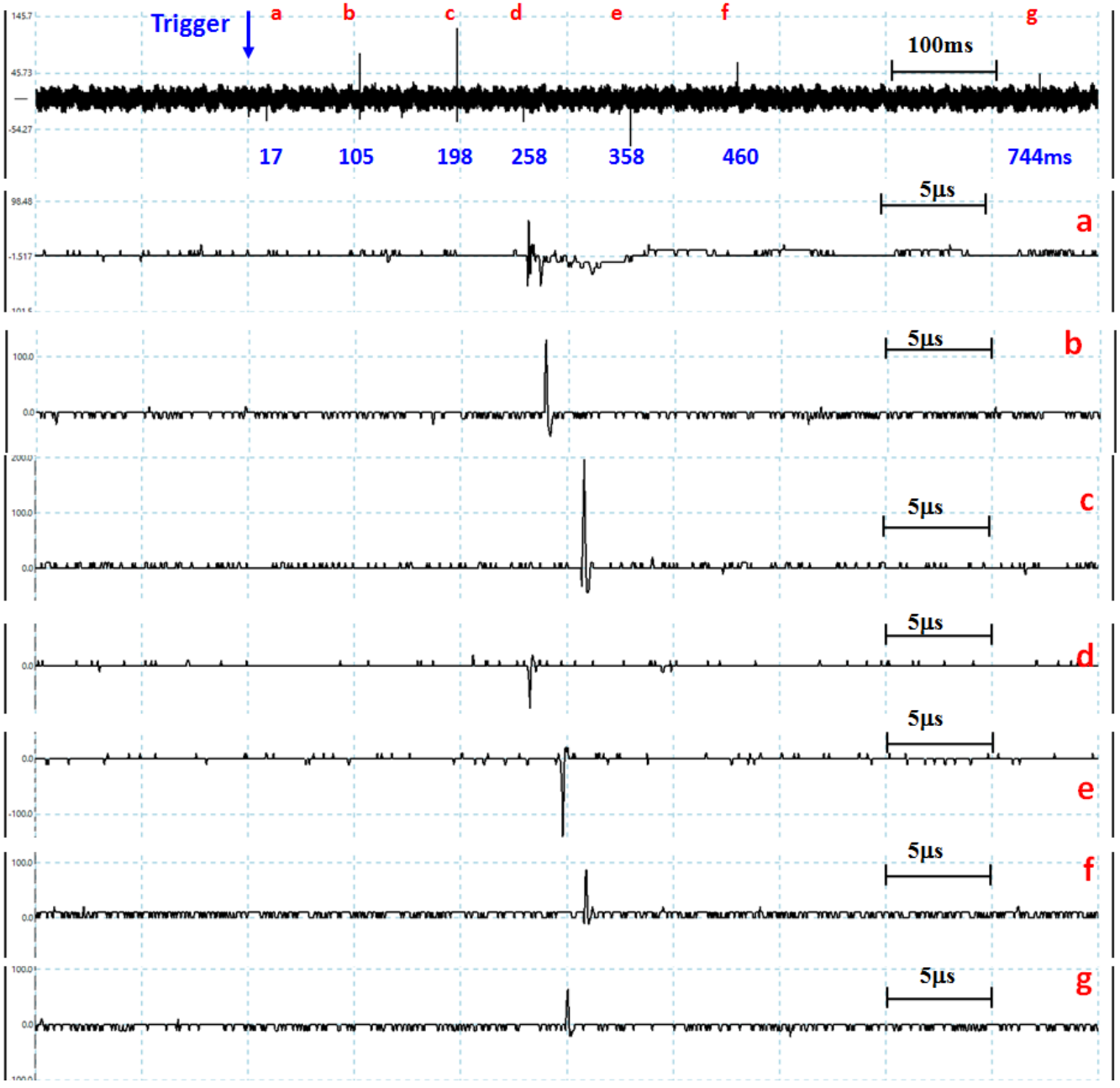
All three flashes have been detected by WWLLN

Two normal polarity IC flashes
May 10, 2016 14:15:48 and 14:17:46

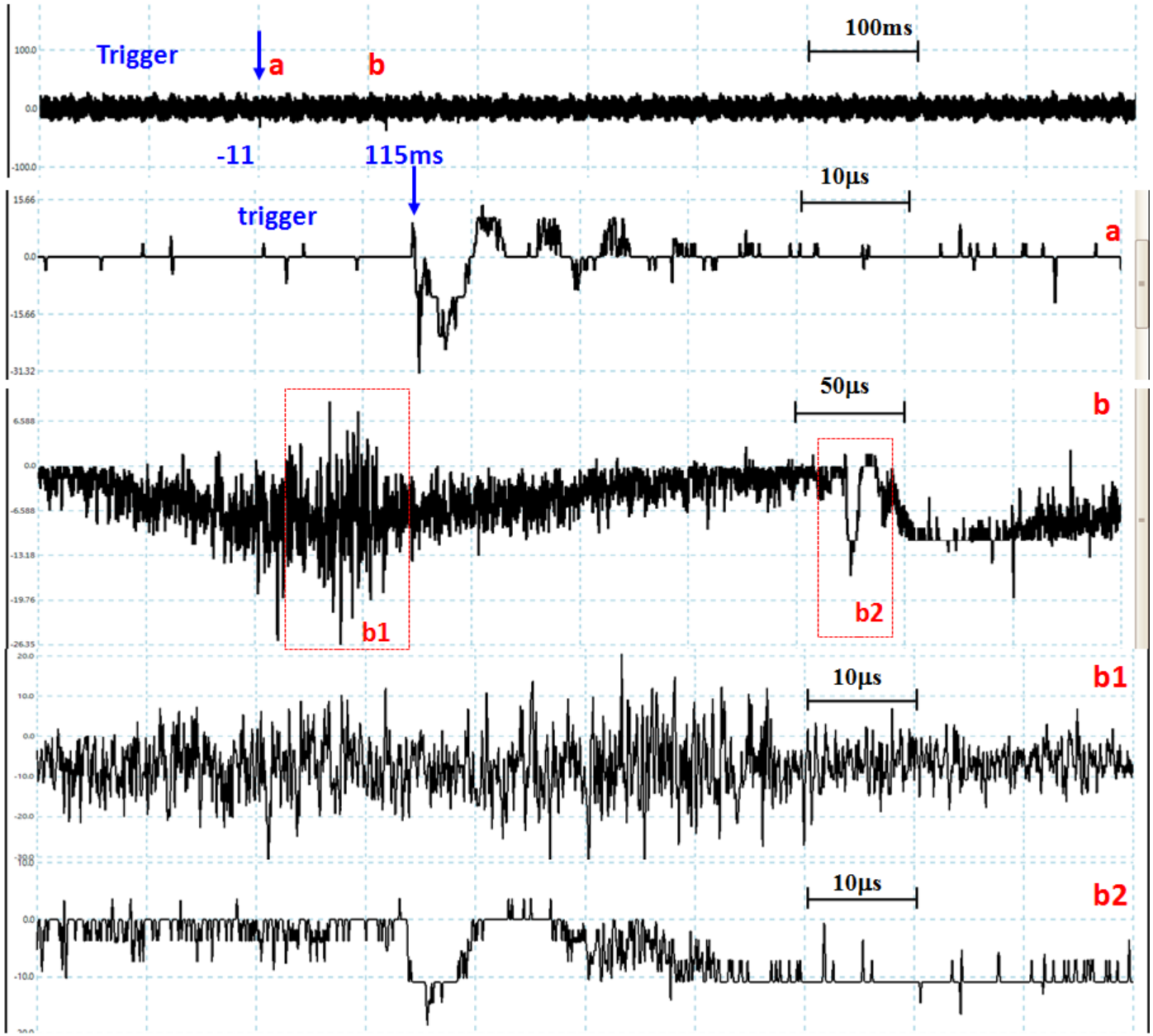
Electrostatic field and count rate (upper picture) and electric field measured by 3 field mills



Fast electric field, May 10,2016 14:15:48

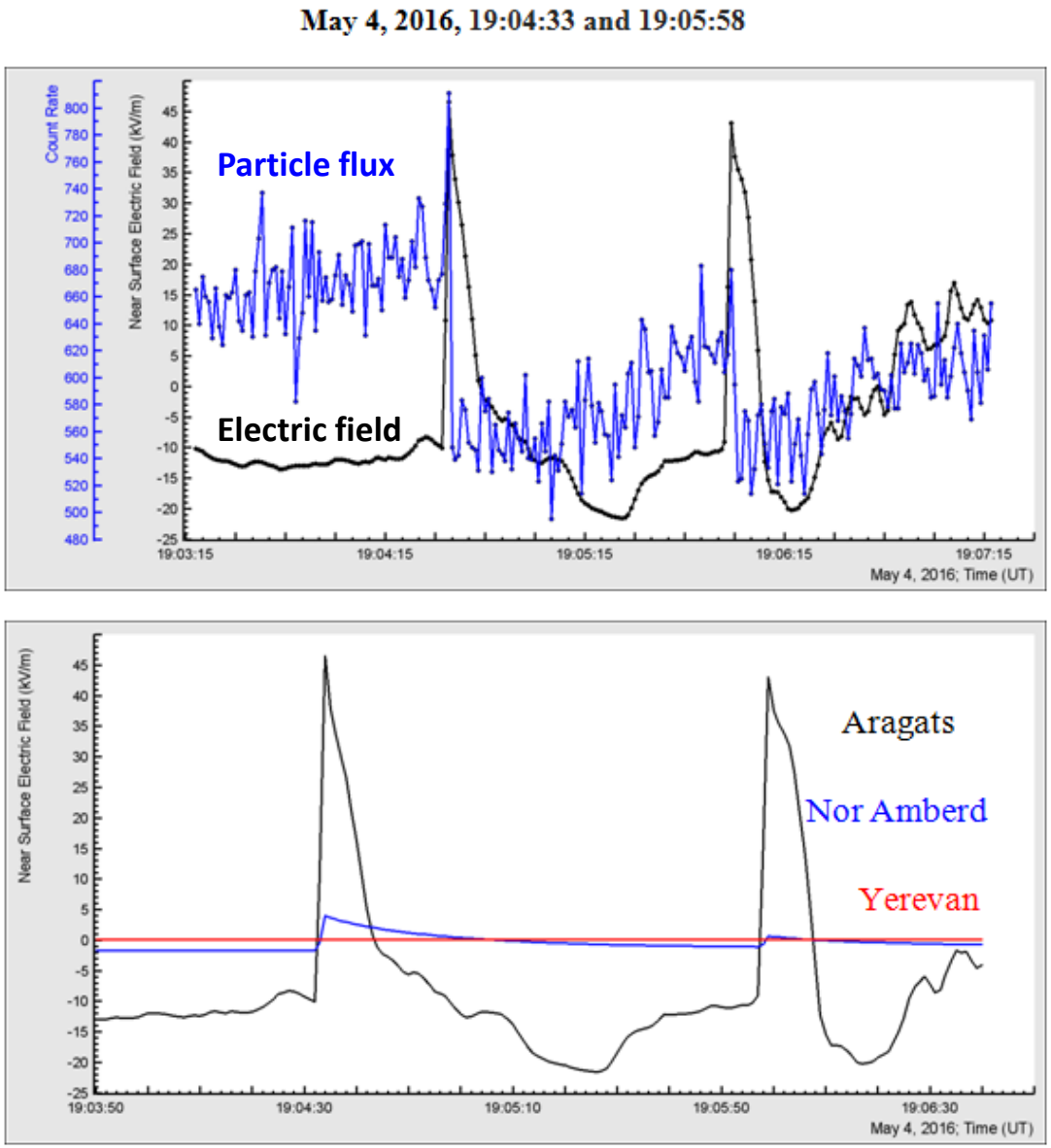


Fast electric field, May 10,2016 14:17:46

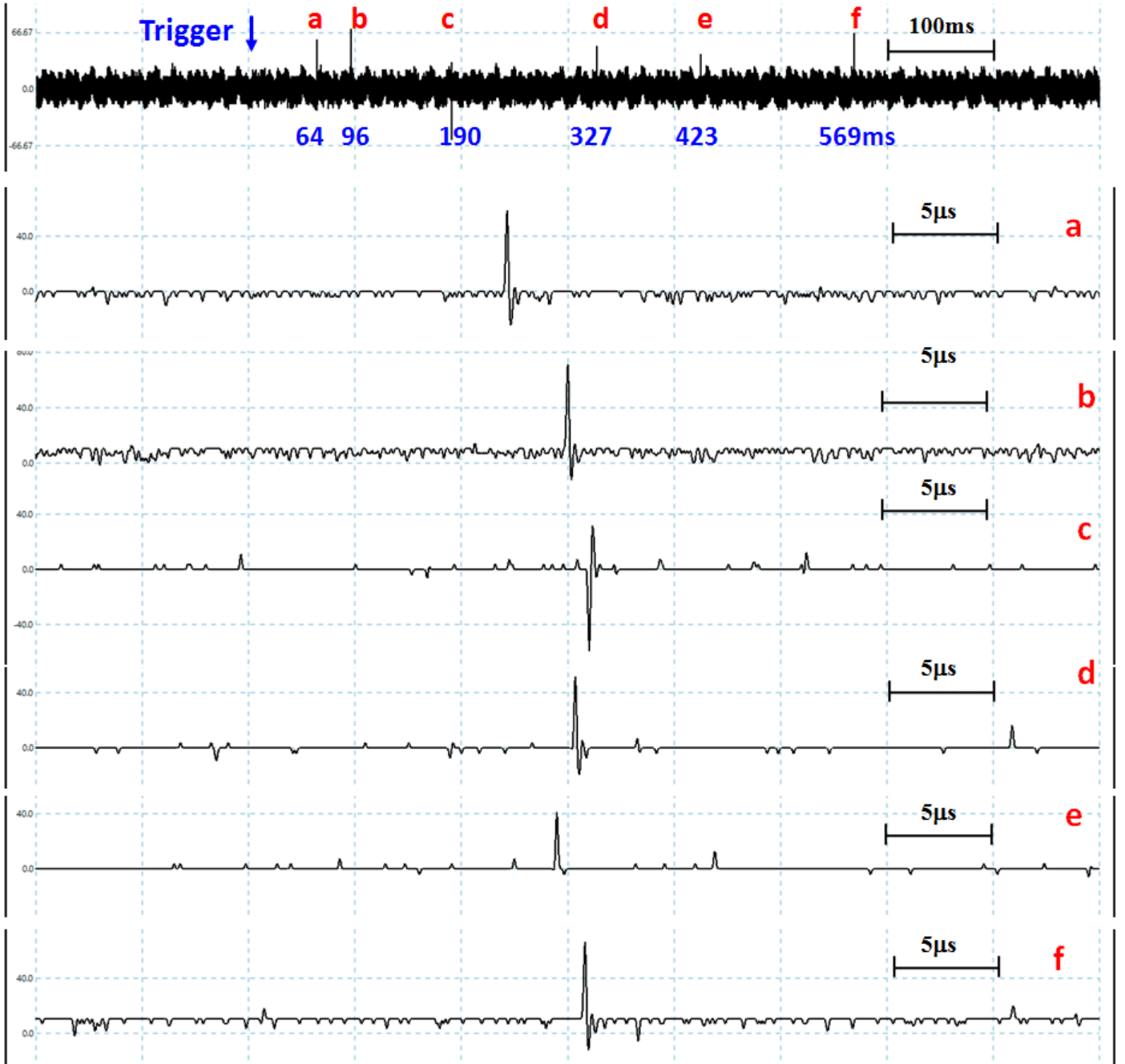


Two normal polarity IC flashes
May 4, 2016, 19:04:33 and 19:05:59

Electrostatic field and count rate (upper picture) and electric field measured by 3 field mills



Fast electric field, May 4,2016 19:05:59

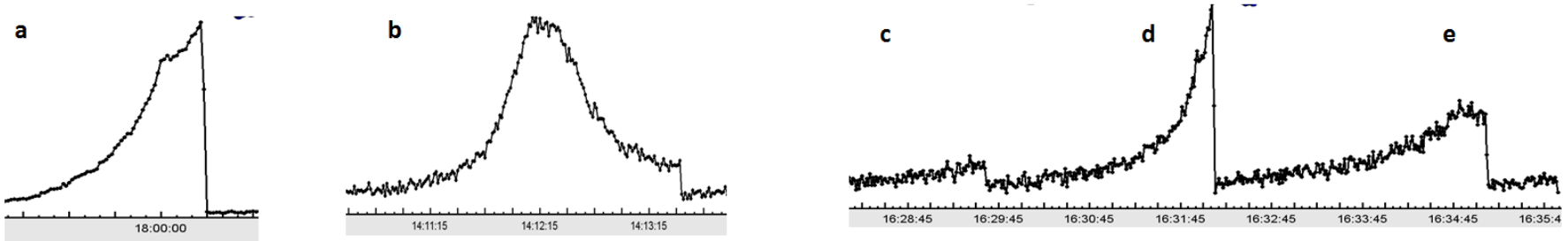


Analysis of 23 events of TGE termination by lightning

Lightning type for 23 events

12 events (52%) Normal polarity IC	6 events (26%) Negative CG	5 events (22%) Type not identified
3 of 12 detected by WWLLN	4 of 6 detected by WWLLN	Not detected by WWLLN

Lightnings terminate TGE equally at the rising edge of the particle flux, at its maximum, and at the decay stage



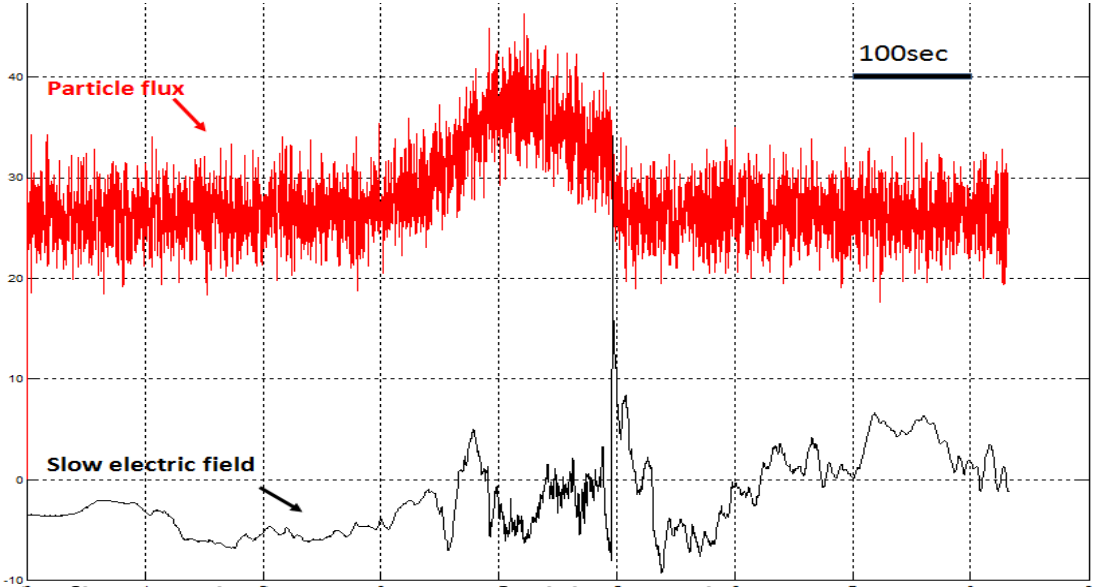
April 20,2015 , 18:00:14, 2 km October 4 ,2014 , 14:13:32, 6.8km May 11,2015 , 16:29:36, 0.6km 16:32:06, 13.7km 16:35:06 , 4.2 km

Positive lightnings (which reduce positive charge overhead) do not terminate TGE

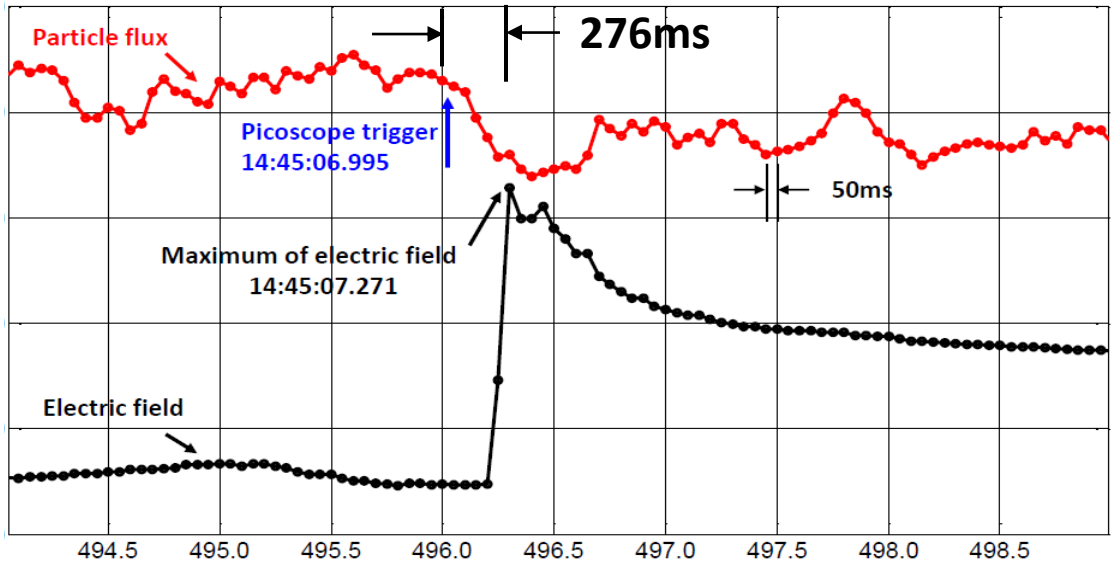
Parameters of electrostatic field change and particle flux drop averaged over 23 TGEs terminated by lightning

Rise time of electrostatic field	235±92 ms
Recovery time of electrostatic field (FWHM)	4.3 ± 2.4 sec
Field surge	61 ± 19 kV/m
Distance to lightning	5.8 ± 3.4 km
Particle flux drop	36 ± 21 %

TGE terminated by lightning, 50 ms time resolution

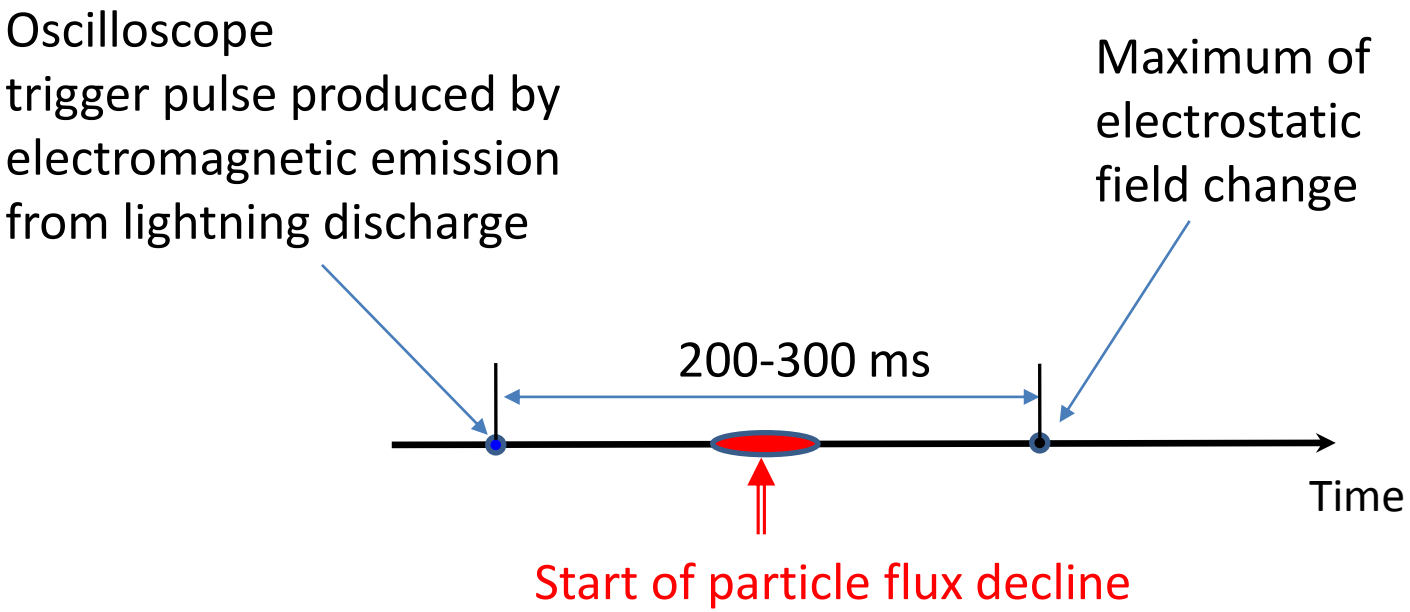


Particle flux and electrostatic field, raw data, 12minute time frame



Particle flux data filtered with a 7-sample moving average filter, 4 sec time frame.

Time diagram of TGE terminated by lightning



Start of particle flux decline is located between the trigger pulse produced by electromagnetic emission from lightning discharge and the maximum of electrostatic field change.

Conclusion

- All observed lightnings that terminate TGEs, had the dominant effect of reducing negative charge overhead

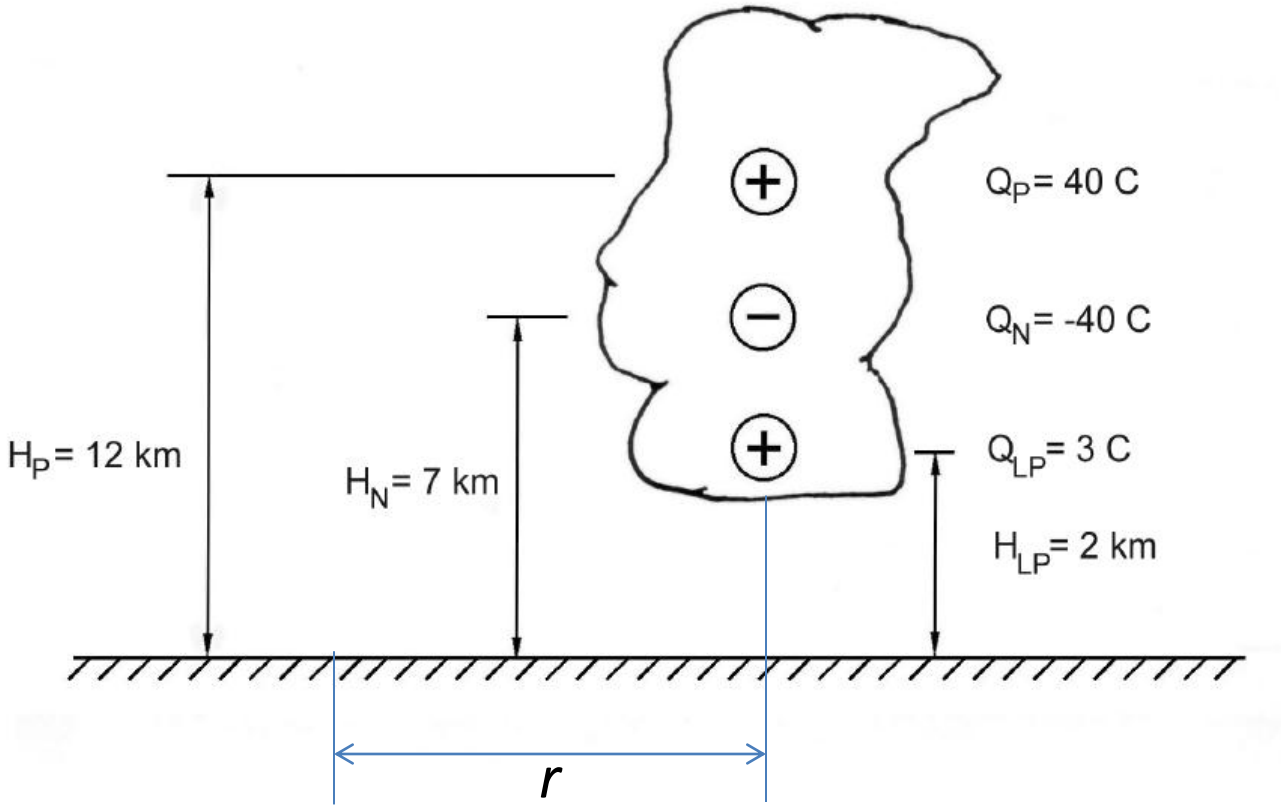
- Central negative charge of the thundercloud plays a key role in the formation of accelerating electric field responsible for the TGE

- The accelerating electric field can be formed by the central negative charge and its mirror image at the ground, or/ and by the central negative charge and the lower positive charge region (LPCR)

- These two fields both inside and beneath the thundercloud can be destroyed by lightning discharges which reduce the central negative charge

Thank you!

Vertical tripole: idealized charge structure of the thundercloud



Electrostatic field at the ground is superposition of three fields:

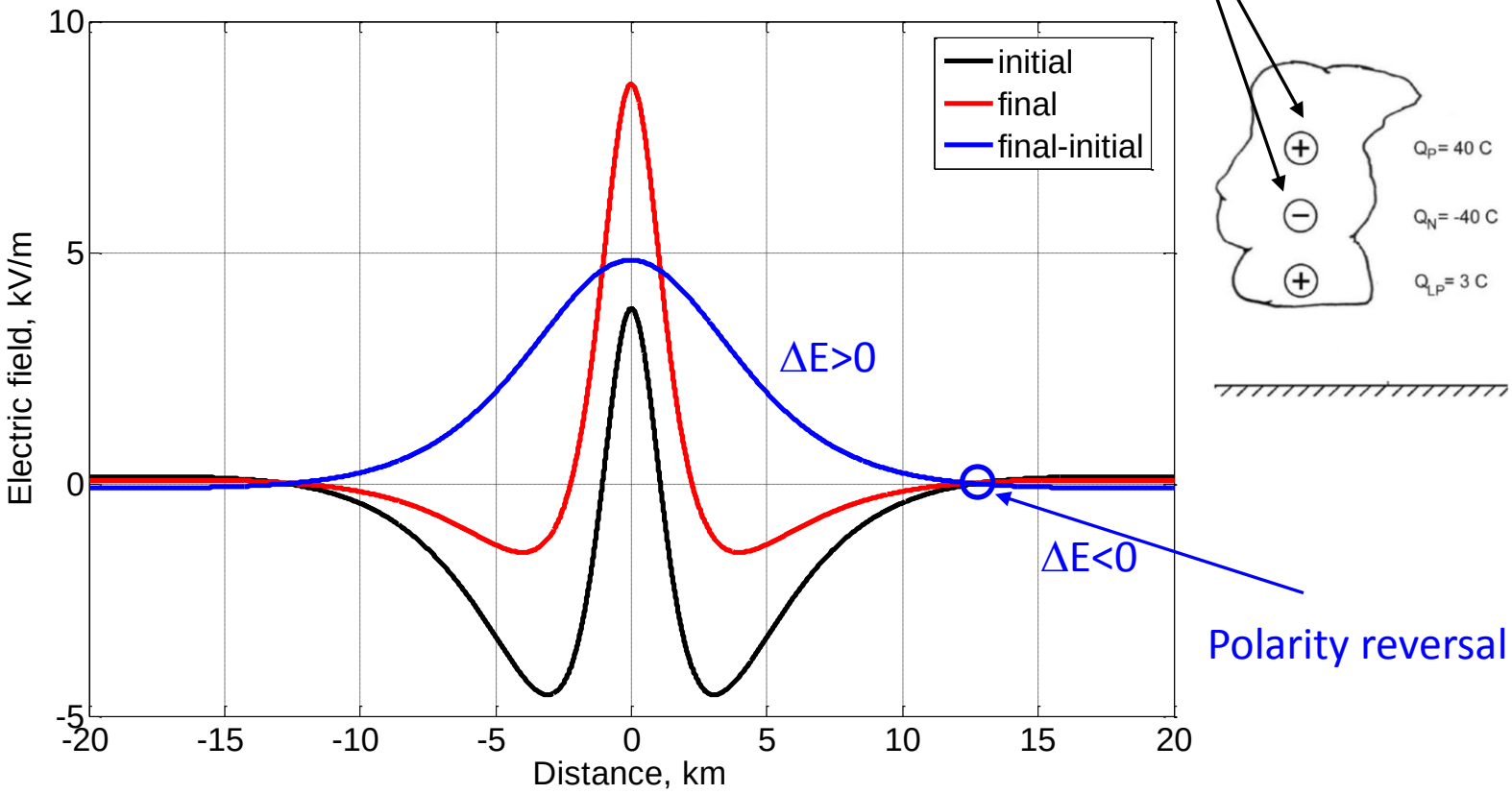
$$E_{total} = E_N + E_P + E_{LP} = \frac{1}{2\pi\varepsilon_0}\left[\frac{Q_N H_N}{\left(H_N^2 + r^2\right)^{\frac{3}{2}}} + \frac{Q_P H_P}{\left(H_P^2 + r^2\right)^{\frac{3}{2}}} + \frac{Q_{LP} H_{LP}}{\left(H_{LP}^2 + r^2\right)^{\frac{3}{2}}}\right]$$

$$\varepsilon_0 = 8.85 \cdot 10^{-12}\, F/m$$

Electrostatic field change caused by partial removal of positive and negative charges in the upper dipole (Normal polarity IC)

Q_P=40, Q_N=-40, Q_{LP}=3, H_P=12, H_N=7, H_{LP}=2
q_P=20 q_N=-20 q_{LP}=3

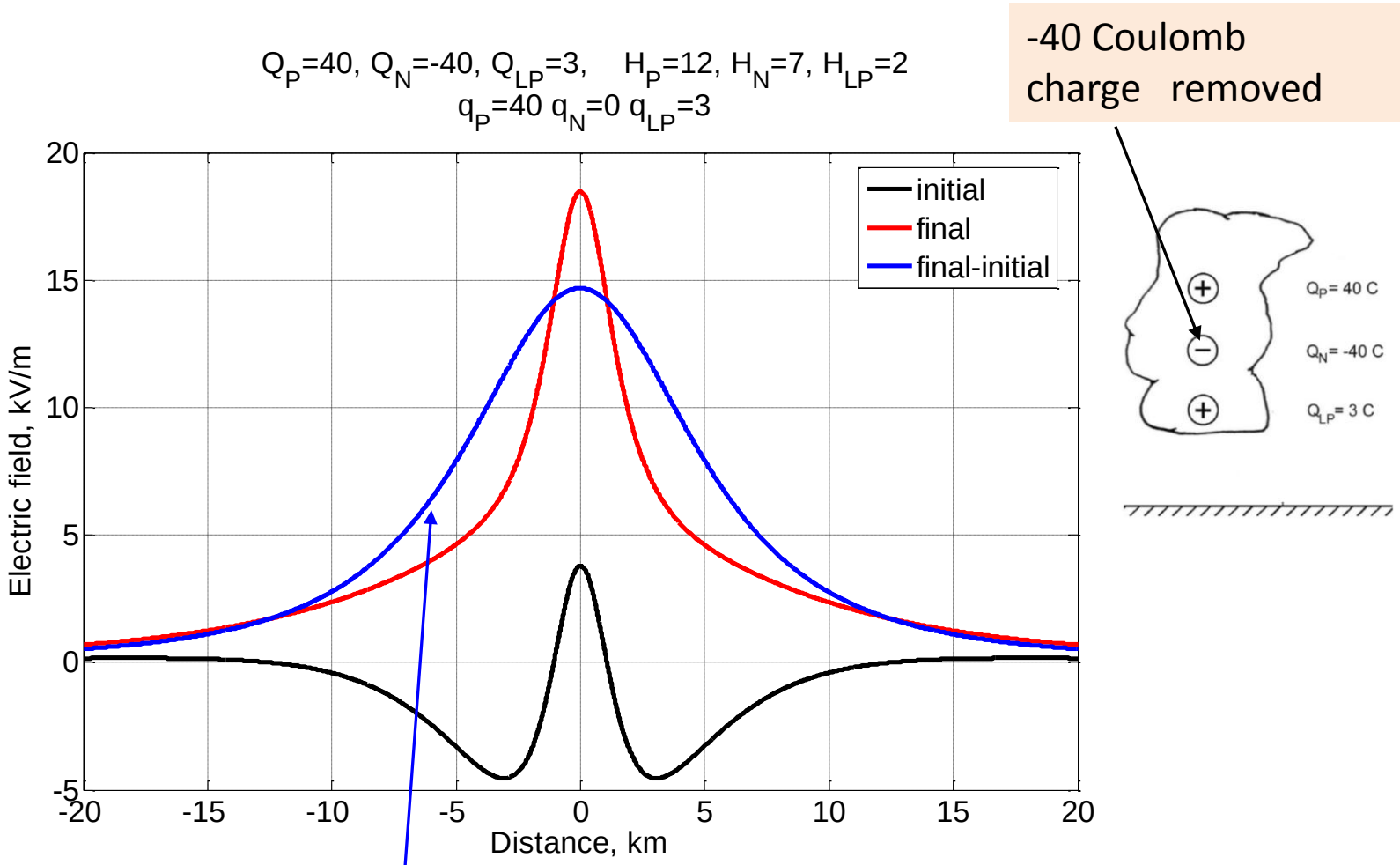
±20 Coulomb charges removed



Field change at close distances is positive but at far distances it is negativ

--Initial field before charge removal, -- final field after charge removal

Electrostatic field change caused by total removal of negative charge (-CG)



Field change at all distances is positive ($\Delta E>0$)

--Initial field before charge removal, -- final field after charge removal

Fast electric field, May 11, 2015 16:29-16:35

Time zoom of previous slide