Fast electric field waveforms of lightning discharges detected at Aragats mountain in Armenia

A. Chilingarian, G. Khanikyanc, L. Kozliner, S. Soghomonyan
Yerevan Physics Institute, Armenia
Outline

Fast and slow electric field changes of lightning discharges that terminate the Thunderstorm Ground Enhancement (TGE)

• Instrumentation
  • Fast electric field measurement
  • Electric field mill
  • Storm Tracker Lightning detector
  • World Wide Lightning Location Network (WWLLN)
  • Particle detector

• Observation data
HF emission and wideband fast electric field detection system

Active whip antenna

Flat plate antenna with integrator

Digital oscilloscope

PC

MFJ-1022 active whip antenna is used for oscilloscope triggering. Frequency range: from 300 KHz to 200MHz.
Wideband fast electric field measurement system

Diameter $D=0.52\,\text{m}$, Area $A=0.21\,\text{m}^2$

Passive integrator: decay time constant $RC=10\,\text{ms}$

$C=10\,\text{nF}$, $R=1\,\text{M}\Omega$ - input impedance of the oscilloscope

The integrator is a high pass filter with cut-off frequency $f=1/(2\pi RC)=16\,\text{Hz}$

$U\sim E$, $U=1\,\text{V} \quad \longleftrightarrow \quad E\approx 500\,\text{V/m}$

Useful frequency bandwidth of the measurement system: from 16 Hz to $\approx 50\,\text{MHz}$
Digital oscilloscope

Picoscope 3206, Memory depth 1MB
Capture length = 5ms, including 1ms pre-trigger time
Sampling rate $f_s=100\text{MS/s}$, sampling interval=$1/f_s=10\text{ns}$

Recently installed, waiting for data
Picoscope 5244B, Memory depth 512 MB
Capture length = 500ms, including 100ms pre-trigger time
Sampling rate $f_s=62.5\text{MS/s}$, sampling interval=$1/f_s=16\text{ns}$.
Boltek EFM-100 Atmospheric Electric Field Monitor

Log date, time and distance of nearby lightning. Monitor lightning up to 38 km away. Measurements are taken 20 times per second.

Boltek Storm Tracker Lightning detector

Long range detection up to 480 km away.

Differentiates between cloud-cloud and cloud-ground lightning strikes (doubtful)
Particle detector

TGEs analyzed in the present study were observed by an outdoor 3 cm thick scintillator with a sensitive area of 1m$^2$ operated in the particle counter mode.

The registration efficiency is $\sim$99% for electrons and $\sim$5% for gamma rays, the energy threshold is $\sim$1MeV.
World Wide Lightning Location Network (WWLLN)

- The WWLLN ("woolen") is a global lightning network that detects the very low frequency (VLF; 3-30 kHz) emissions from lightning, known as sferics, that propagate long distances through the Earth-ionosphere waveguide.

Adapted from K.L.Corbosiero et al, University of California Los Angeles
The WWLLN is managed by the Department of Earth and Space Sciences at the University of Washington in Seattle, lead by Prof. Robert Holzworth. Yerevan node of WWLLN was established in 2013.
WWLLN data format

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (UT)</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Residual fit error µs</th>
<th>Number of stations</th>
<th>Distance to Aragats station, km</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014/11/01</td>
<td>15:22:46.868845</td>
<td>40.3721°N</td>
<td>44.2815°E</td>
<td>10.4</td>
<td>7</td>
<td>13.9</td>
</tr>
</tbody>
</table>

Calculated as the great-circle distance between the two points with known geographical coordinates according to the “haversine” formula.

- The WWLLN detects all types of lightning strokes that have peak currents with magnitudes above ~35-40 kA.
- Lightnings detected at least by 5 stations of the network are included to the database
- Detection efficiency ≈10%
- Timing accuracy ±16µs
- Location accuracy 5-10 km
Thunderstorm Ground Enhancement terminated by lightning flash, April 20, 2015
### April 20, 2015 18:00:14 WWLLN data

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Lat</th>
<th>Long</th>
<th>ResErr</th>
<th>Nsta</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>'2015/04/20'</td>
<td>'18:00:14.757270'</td>
<td>[40.4719]</td>
<td>[44.1030]</td>
<td>[14.4000]</td>
<td>[12]</td>
<td>6.7km</td>
</tr>
</tbody>
</table>

![Map showing Aragats Station and the timestamp](image-url)
Fast electric field waveform of April 20, 2015, 18:00:14.757 lightning, 6.7 km
Fast electric field waveform of April 20, 2015, 18:02:01 lightning

Time relative to trigger

240mV

500μs

500ns

Trigger
### Type and polarity of two lightnings of April 20, 2015 according to Storm tracker data

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Strike Type (0 is CG and 1 is IC)</th>
<th>Strike Polarity (0 is positive and 1 is negative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18:00:14.054</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>18:00:14.081</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:00:14.114</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18:00:14.155</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>18:00:14.175</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:00:14.189</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:00:14.269</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>18:00:14.316</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>18:00:14.346</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:00:14.366</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>18:00:14.395</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:00:14.456</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Strike Type (0 is CG and 1 is IC)</th>
<th>Strike Polarity (0 is positive and 1 is negative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18:02:01.161</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>18:02:01.169</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>18:02:01.255</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:02:01.278</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:02:01.284</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>18:02:01.298</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:02:01.424</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:02:01.440</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:02:01.472</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>18:02:01.524</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:02:01.544</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>18:02:01.837</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>18:02:01.848</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>18:02:01.894</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>18:02:02.016</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Thunderstorm Ground Enhancement
terminated by lightning flash
October 4, 2014

Lightning
14:13:32
6.8 km
Fast electric field waveform of October 4, 2014, 14:13:32 lightning, \( \approx 6.8 \text{km} \)

- **Time relative to trigger, ms**
- **Amplitude, mV**

**100 ns interval between peaks**

**20 ns period**
Thunderstorm Ground Enhancement
terminated by lightning flash
May 11, 2015

$\Delta E=63 \text{kV/m}$

$\Delta E=66.5 \text{kV/m}$

$\Delta E=56 \text{kV/m}$
Fast electric field waveforms of three lightnings of May 11, 2015

- 16:29:36.337, 0.6km
- 16:32:06.521, 13.7km
- 16:35:06.534, 4.2km

Time relative to trigger

Trigger

650mV

1V
Fast electric field waveforms of three lightnings of May 11, 2015 (10x zoom)

16:29:36.337 0.6km
16:32:06.521 13.7km
16:35:06.534 4.2km
Type and polarity of three lightnings of May 11, 2015 according to Storm tracker

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Strike Type (0 is CG and 1 is IC)</th>
<th>Strike Polarity (0 is positive and 1 is negative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16:29:36.399</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:29:36.464</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:29:36.572</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>16:29:36.588</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:29:36.635</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:29:36.697</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:32:06.519</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:32:06.583</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:32:06.662</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:32:06.722</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:32:06.831</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:35:06.546</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:35:06.561</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>16:35:06.624</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:35:06.670</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>16:35:06.735</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:35:06.750</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:35:06.858</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>16:35:06.873</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16:35:06.984</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

wwlln stamp 16:29:36.337 and distance 0.6km
wwlln stamp 16:32:06.521 and distance 13.7km
wwlln stamp 16:35:06.534 and distance 4.2km
Location of three lightnings of May 11 2015 according to WWLLN data

Aragats Station

N1
16:29:36.337
0.6km

N2
16:32:06.521
13.7km

N3
16:35:06.534
4.2km
Time coincidences of WWLLN and EFM-100 field mill peaks
(137 events during April - June 2015)

Average = -185ms
StDev = 354ms
Median = -217ms
Mode = -266ms
Main parameters of slow electric field changes for lightnings that had terminated TGEs

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Distance to lightning [km]</th>
<th>Start electric field [kV/m]</th>
<th>Maximum electric field [kV/m]</th>
<th>(Maximum-Start) electric field [kV/m]</th>
<th>FWHM of field change [sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 20, 2015</td>
<td>18:00:14</td>
<td>2</td>
<td>1.2</td>
<td>49.2</td>
<td>48</td>
<td>1.1</td>
</tr>
<tr>
<td>April 20, 2015</td>
<td>18:02:01</td>
<td>8</td>
<td>-3.4</td>
<td>39.2</td>
<td>42.6</td>
<td>1.2</td>
</tr>
<tr>
<td>Oct. 4, 2014</td>
<td>14:13:32</td>
<td>6.8</td>
<td>-25.5</td>
<td>58.5</td>
<td>84</td>
<td>5</td>
</tr>
<tr>
<td>May 11, 2015</td>
<td>16:29:36</td>
<td>0.6</td>
<td>-5.7</td>
<td>57.3</td>
<td>63</td>
<td>8</td>
</tr>
<tr>
<td>May 11, 2015</td>
<td>16:32:06</td>
<td>13.7</td>
<td>-6.5</td>
<td>60</td>
<td>66.5</td>
<td>6</td>
</tr>
<tr>
<td>May 11, 2015</td>
<td>16:35:06</td>
<td>4.2</td>
<td>5.5</td>
<td>61.5</td>
<td>56</td>
<td>5</td>
</tr>
</tbody>
</table>

Electric field change is positive  ↓↓ Decrease of negative charge overhead
Termination of observed TGEs:
at the maximum, at the rising edge, at the falling edge

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

- All observed lightnings that abruptly terminate the TGE are negative. The electric field change at the ground is positive and it is attributable to decrease of negative charge overhead. The upward directed electric field which accelerates electrons downward is reduced by these lightnings.

- Which types of lightning can terminate the particle flux, CG, IC, or both?

- Which stage of lightning is responsible for the TGE termination?

- Waiting for fast electric field data with capture length of 500ms to analyze whole lightning flash.
THANK YOU!