Artificially Triggered Lightning in Guangdong, China

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Introduction

Overview of GCOELD

**GCOELD:** Guangdong Comprehensive Observation Experiment on Lightning Discharge.

**Duration:** Every summer from 2006 to now.

**Organizers:**
- Chinese Academy of Meteorological Sciences
- Guangdong Meteorological Bureau

**Contents:**
- Discharge process in triggered lightning and natural lightning
- Effects of lightning discharge on other objects.
- Testing of lightning detection equipment.
- Lightning striking the high structures.
- Investigations into lightning location technology.
Introduction

Triggered lightning in Conghua, Guangzhou

Lightning on high buildings in Guangzhou
TV Tower: 600 m
upward leader: 394 m

Lightning on tower in Shenzhen (360 m):
a lightning current system on the top of the tower

70km

120km
Experiment of triggered lightning

Field experiment site
- Triggering lightning
- Lightning physics
- Lightning protection testing

Layout of the test equipment at the TLF field site. (a): Control room (rocket launches and data acquisition are conducted from here). (b): Wooden house (the lightning rod is installed above it and the current-measuring equipment is covered by it). (c): Region for measurement of electric parameters. (d): Iron tower (a model of a communication tower). (e): Automatic weather station. (f): Region for test of surge protection devices. (g): 10 kV overhead line. (h): Wind turbine. (i): Petrochemical instrument (sensor and power of distribution control system). (j): Buried cables. (k): Shields constructed by brick, concrete and steel mesh.
Experiment of triggered lightning

(a) Sheet iron house
Lightning rod
Wooden box

(b) Rocket
Ignitor
Fiber ~90 m

(d) Transmitters
Coaxial shunts
Rogowski coils

(c) Launch controller
Experiment of triggered lightning

Classical Triggering lightning

Triggering lightning on tower
Experiment of triggered lightning

- Type: CS110 (Campbell Scientific, INC.)
- Sampling rate: 1 Sa s\(^{-1}\)

Radar echo (30dBz) electric field mill (\(\geq 8\text{kV/m}\))
Experiment of triggered lightning

Observation of electric and magnetic field

- Fast antennae with a time constant of 2 ms and a band-width of 1 kHz–2 MHz,
- Slow antennae with a time constant of 6 s and a band-width from 10 Hz to 3 MHz,
- Loop magnetic antennae with a band-width of 100 Hz–5 MHz.
- Collected by the DL750
- Sampling length: 2 s
- Sampling rate: 10 M Sa s\(^{-1}\)
Experiment of triggered lightning

Type: MotionPro Hs-4
Photographic panel: 512 × 512 pixels
Pixel size: 16 × 16 µm
Shooting rate: 5000 fps
Exposure time: 197 µs

Optical observation

High speed camera

Total-sky lightning channel imager
Shooting rate: 50 fps
Experiment of triggered lightning

- Current measurement: Pearson coil, Bandwidth, 150Hz~150MHz
- a resistive–capacitive voltage divider to measure the induction voltage, divider voltage ratios, 204.9:1 and 203:1

- GPR measurement: voltage divider, divider voltage ratio, 1:2500
## Experiment of triggered lightning

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of triggered lightning</th>
<th>No. of launched rockets</th>
<th>Altitude/classical triggering</th>
<th>Successful Rate</th>
</tr>
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<tbody>
<tr>
<td>2006</td>
<td>6</td>
<td>18</td>
<td>0/6</td>
<td>33%</td>
</tr>
<tr>
<td>2007</td>
<td>12</td>
<td>21</td>
<td>2/10</td>
<td>57%</td>
</tr>
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<td>2008</td>
<td>5</td>
<td>22</td>
<td>1/4</td>
<td>23%</td>
</tr>
<tr>
<td>2009</td>
<td>7</td>
<td>28</td>
<td>2/5</td>
<td>25%</td>
</tr>
<tr>
<td>2010</td>
<td>6</td>
<td>28</td>
<td>3/3</td>
<td>21%</td>
</tr>
<tr>
<td>2011</td>
<td>13</td>
<td>23</td>
<td>2/11</td>
<td>56%</td>
</tr>
<tr>
<td>2012</td>
<td>2</td>
<td>14</td>
<td>1/1</td>
<td>15%</td>
</tr>
<tr>
<td>2013</td>
<td>8</td>
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<td>28%</td>
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<td>2015</td>
<td>20</td>
<td>24</td>
<td>1/19</td>
<td>83%</td>
</tr>
<tr>
<td>2016</td>
<td>13</td>
<td>19</td>
<td>1/12</td>
<td>68%</td>
</tr>
<tr>
<td>2017</td>
<td>16</td>
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<td>80%</td>
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<td>2018</td>
<td>27</td>
<td>43</td>
<td>1/26</td>
<td>63%</td>
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<tr>
<td>total</td>
<td>150</td>
<td>312</td>
<td>15/135</td>
<td>48%</td>
</tr>
</tbody>
</table>

### 2006-2018
- 150 triggered lightning discharges
- 148 negative polarity (135 classical triggering; 15 altitude triggering)
- 2 positive polarity without return strokes
Experiment of triggered lightning

Current measurement system

Grounding grids
10 m in side length
5 m in side length of each grid
grounding resistance of 6.7 Ω

Advantages:
- Excellent anti-interference capability
- High accuracy (error range: 0.3%)
- Coverage of different magnitudes of current
Results of triggered lightning current

An example of the current waveform of a classical TLF (T150612161626). (a): Whole current waveform. (b): The IS current. (c) and (d): Partial enlarged details of the first and second RS current waveforms and the following continuing currents, respectively. The current waveforms shown in a, c, and d were recorded using the channel with a $\pm 50$ kA measuring range, whereas that shown in b was recorded using the channel with a $\pm 2$ kA range. ICCP: Initial continuous current pulse.
Results of triggered lightning current

Distributions of the main parameters of return strokes (n=106).

The peak current of most return strokes is between 7.5 and 22.5 kA, and the rise time is between 0.2 and 0.6 μs. The half-peak width is between 10 and 30 μs, and the amount of charge transferred in 1 ms is between 0.5 and 2 C.
Results of SPD testing

Observation arrangement

- Triggering lightning rod
- Rocket launcher
- Coaxial shunt
- SPD1
- SPD2
- Data acquisition unit of AWS
- Power box
- AWS Grounding grid
- Overhead power line
- Wire pole (~2m)
- Residence house
- Observation and launch control room
- North

Dimensions:
- 5.0m
- 9.0m
- 20.5m
- 9.1m
Results of SPD testing

Case one (2014-06-20 15:05:06), 40m away from SPD1

Channel-base current waveform of T201404 (except the return strokes; the others were M-components)
Results of SPD testing

The voltage waveforms between two terminals of the SPD1 during T201404.

- All of the voltage waveform show bipolar pulses first, due to the electric field variation caused by the preceding leaders and return strokes.
- When the negative residual voltage recovers to zero, the voltage of the positive voltage appears.
- The $T_p$ of the four return strokes ranges from 623.4 $\mu$s to 829.4 $\mu$s, with the average being 683.8 $\mu$s.
- The ground potential rise (GPR) maybe play a key role.

Expanded voltage waveforms between two terminals of the SPD in residence house for RS4, RS6, RS7 and RS8 during T201404

$T_p$ : the time interval between the first time the residual voltage reaches zero and the first time the voltage suffers the recoil features.
Results of SPD testing

M-components with minor current

• contrary to the return strokes, the residual voltages of the SPD1 due to the minor M-components are of positive polarity.
• The amplitude of the GPR may be larger than that of the induced voltage at the overhead line.
• in T201404, the SPD1 acted for the 11 return strokes and 13 M-components, and the lightning current via the SPD ranged from 0.2-0.9 kA(AM=0.5 kA)
• The SPD was not damaged. The average duration time of the residual voltage was 157.3us.
Results of SPD testing

Case 2, (2008-08-12 17:09:21), 5m away from SPD2

This lightning contained an initial stage (IS) and eight return strokes
The voltage waveform of the SPD for T200804

Due to the limitation of the recording length, only the waveform of the voltages induced by the IS and the first seven strokes were recorded.
Expanded voltage waveforms for the seven return strokes during T200804

- SPD2 was installed 5 m from the earthing system of rocket launcher.
- The polarity of the residual voltage is positive.
- There is a negative pulse before the residual voltage.
- The voltage tends to decrease to zero when the positive residual voltage of the SPD ends.
- The residual voltages of the SPD2 during T200804 were produced by the GPR.
In T200804, the SPD2 (Imax=20 kA) was damaged.

The SPD2 acted for the 7 return strokes and lightning current via the SPD2 ranged from 0.22-1.64 kA (AM=0.77 kA)

the average duration of the residual voltage was 2.1ms.
Results of SPD testing

1) When the distance between lightning discharge and SPD was about 40m, the residual voltage of the SPD is determined by the voltage induced on the overhead line for processes with large current.

2) When the distance between lightning discharge and SPD was about 5m, the residual voltage of the SPD produced by the GPR.

3) The residual voltage of SPD can be influenced by the GPR when lightning discharge occur near SPD.

4) The more long durations of residual voltage may damage to SPD if the lightning involve more return strokes.
Performance of lightning location systems

- 16 sensors of LLS in Guangdong Province
- Operating for 15 years
- The detection efficiency and locating accuracy of LLS need to be evaluated
- Experiment site of triggered lightning and observation site of natural lightning on high structure were set up
Stroke detection efficiency as a function of peak current measured directly in the triggered lightning experiment.

The arithmetic mean values of the flash detection efficiency and stroke detection efficiency were around 94%, 60% respectively.
33 strokes in classical-triggered lighting were detected with more than 2 reporting sensors. Locating accuracy ranged from 111 to 5,250m, with a mean value of 710m.
From 2008 to 2011, for 22 return stroke processes of artificially triggered lightning, both the directly measurement of peak currents and the corresponding LLS records were obtained. Absolute percentage errors of peak current estimation ranged from 0.4%-42%, with mean value of about 16.3%.
the technology of rocket-wire artificially triggered lightning has been improved, and has successfully triggered 150 lightning flashes, with a mean successful rate of 48%.

Through the direct lightning current waveform measurements, an average RS peak current of 16 kA was obtained.

The mechanism causing damage to lightning protection devices (i.e., ground potential rise within the rated current) was established.

Quantitative assessments of the performance of lightning monitoring systems in Guangdong Province have been conducted.
Thank You for your attention