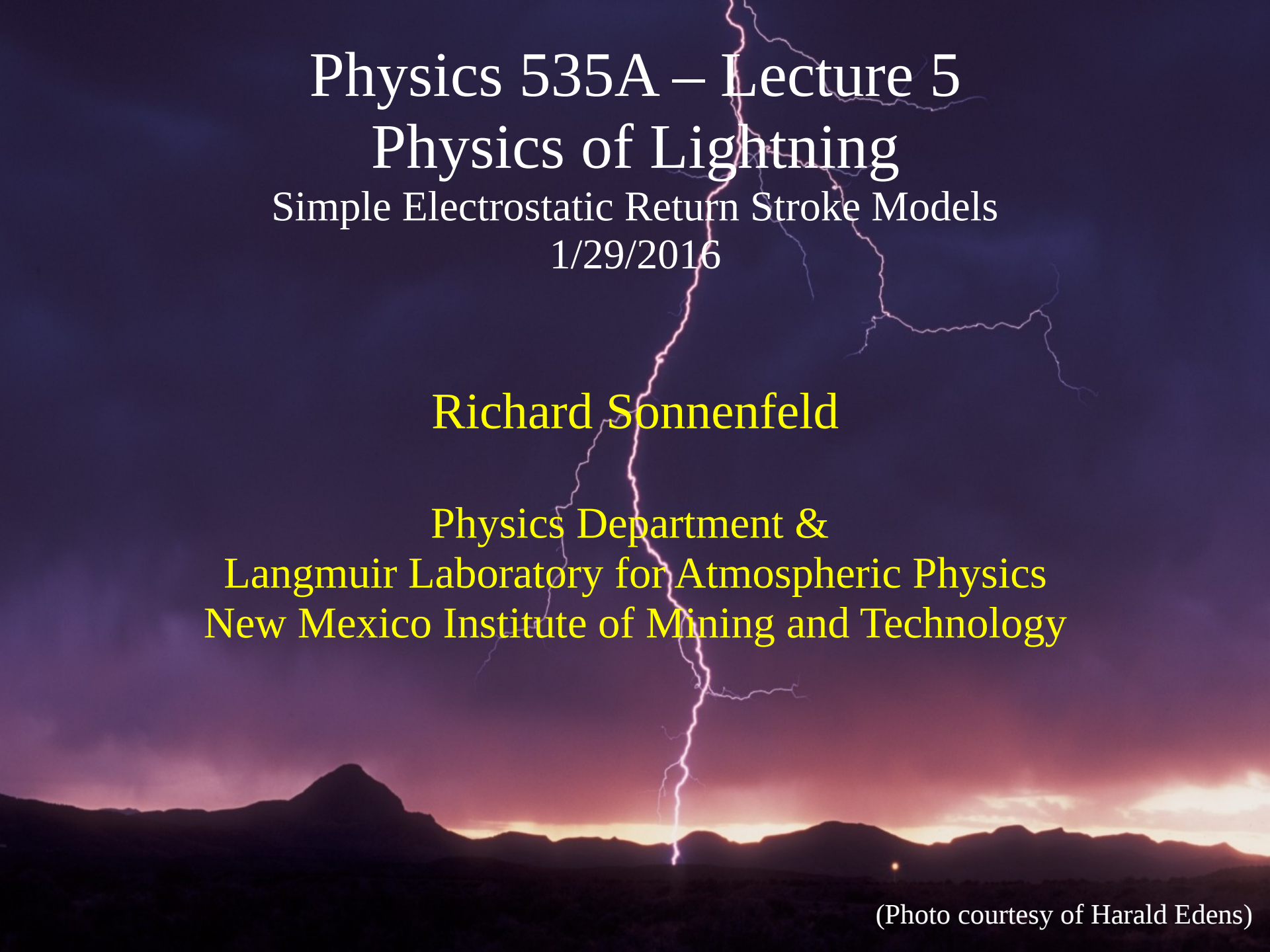
Physics 535A – Lecture 5
Physics of Lightning
Simple Electrostatic Return Stroke Models
1/29/2016

Richard Sonnenfeld

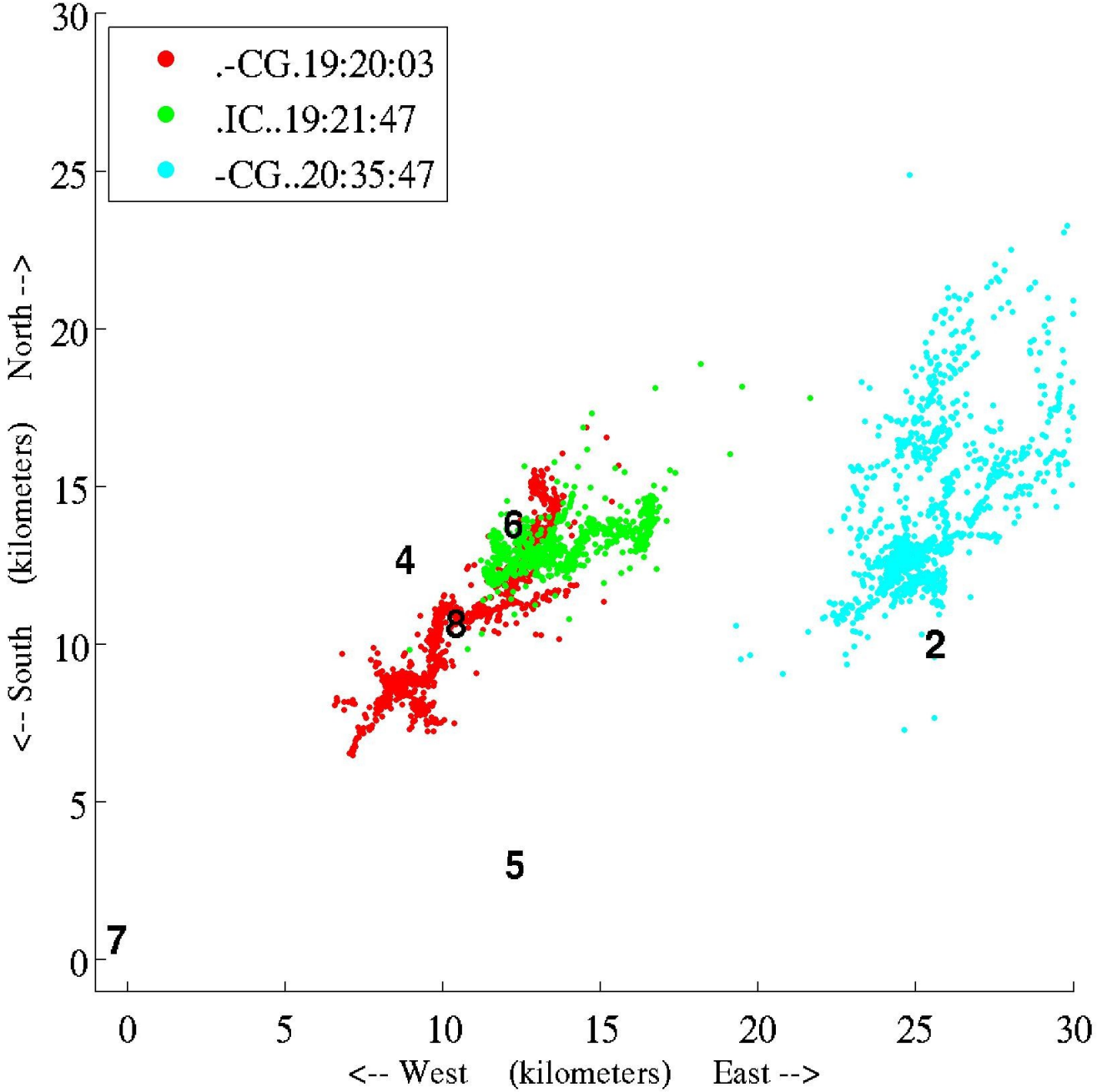
Physics Department &
Langmuir Laboratory for Atmospheric Physics
New Mexico Institute of Mining and Technology

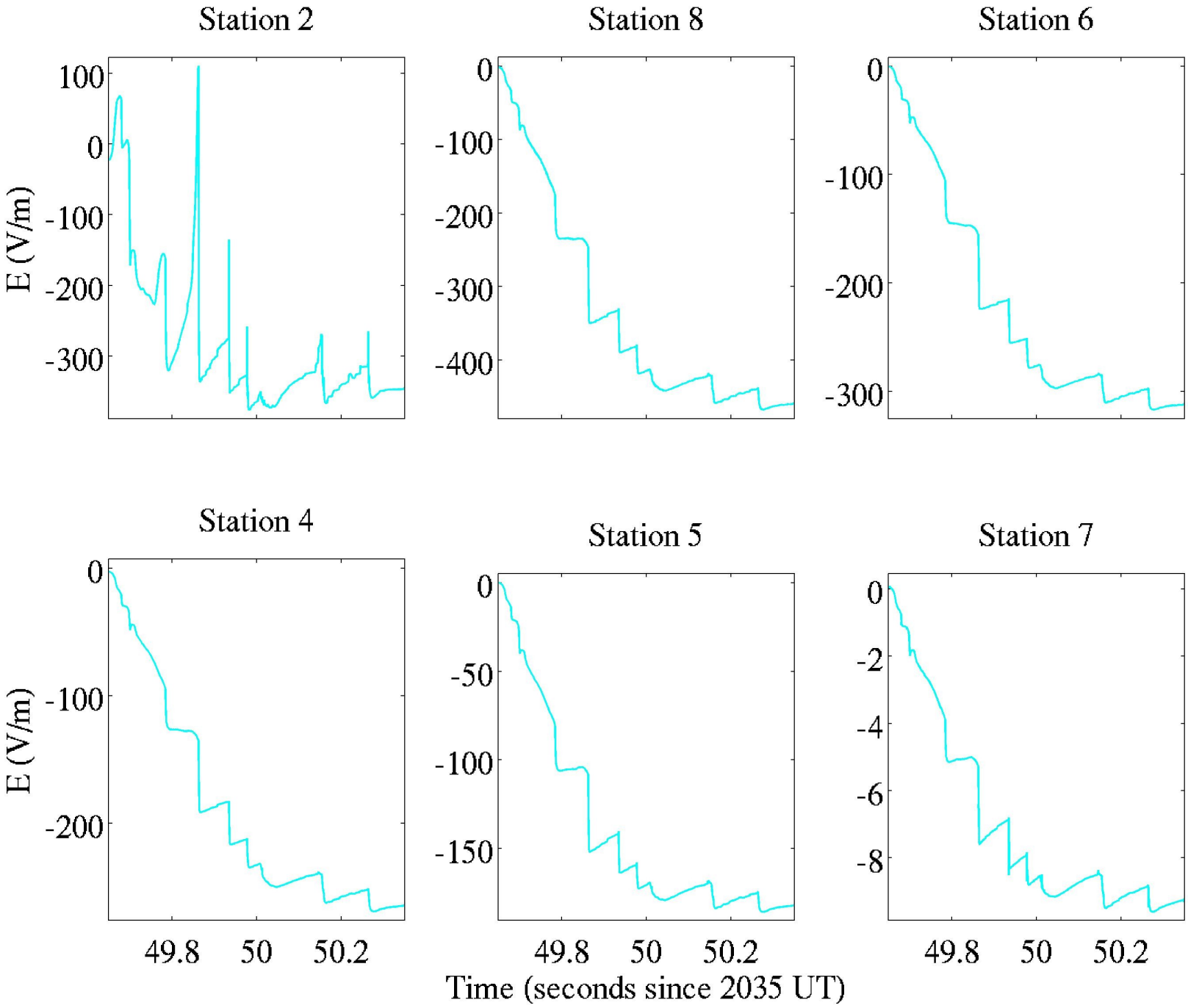


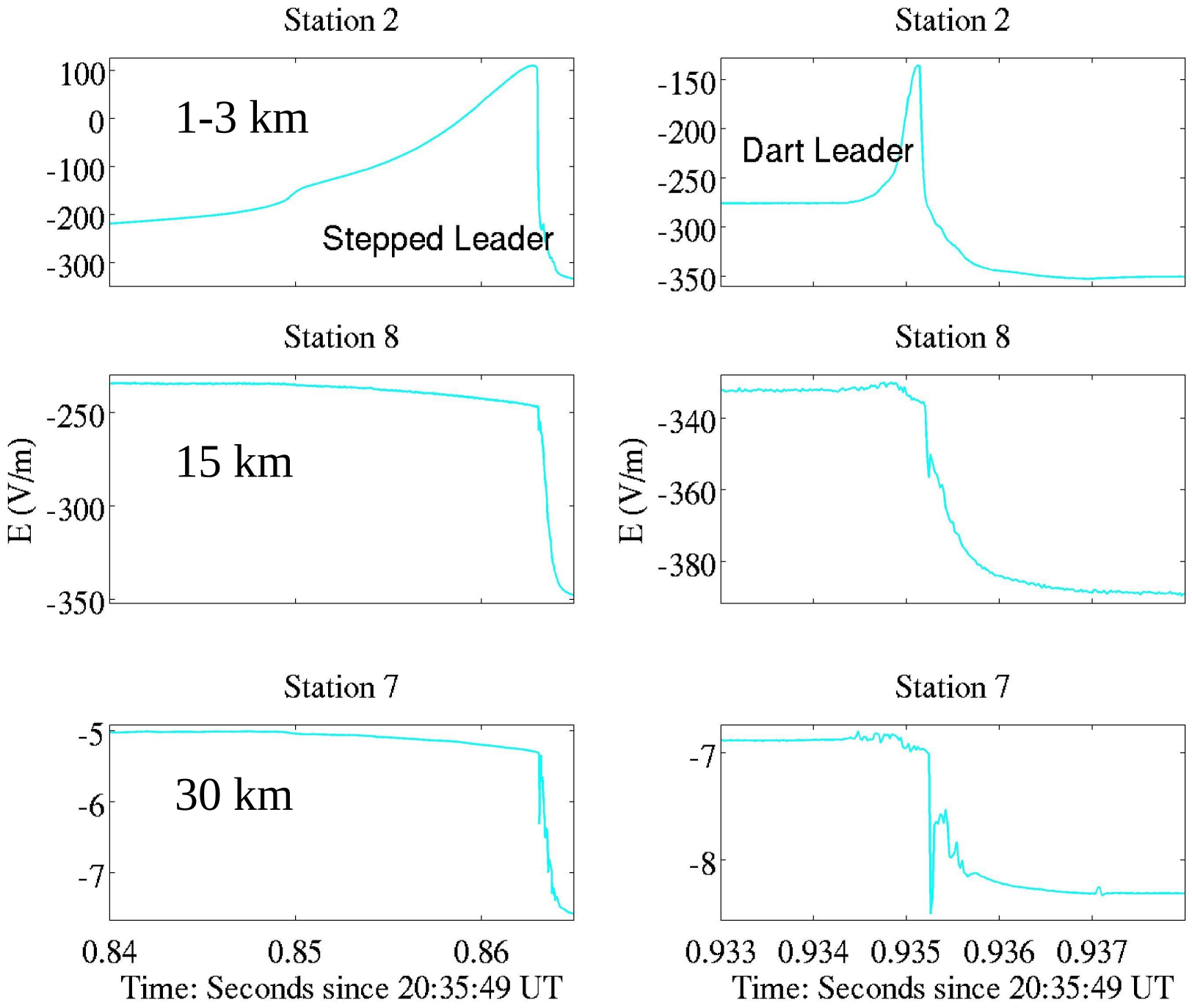
(Photo courtesy of Harald Edens)

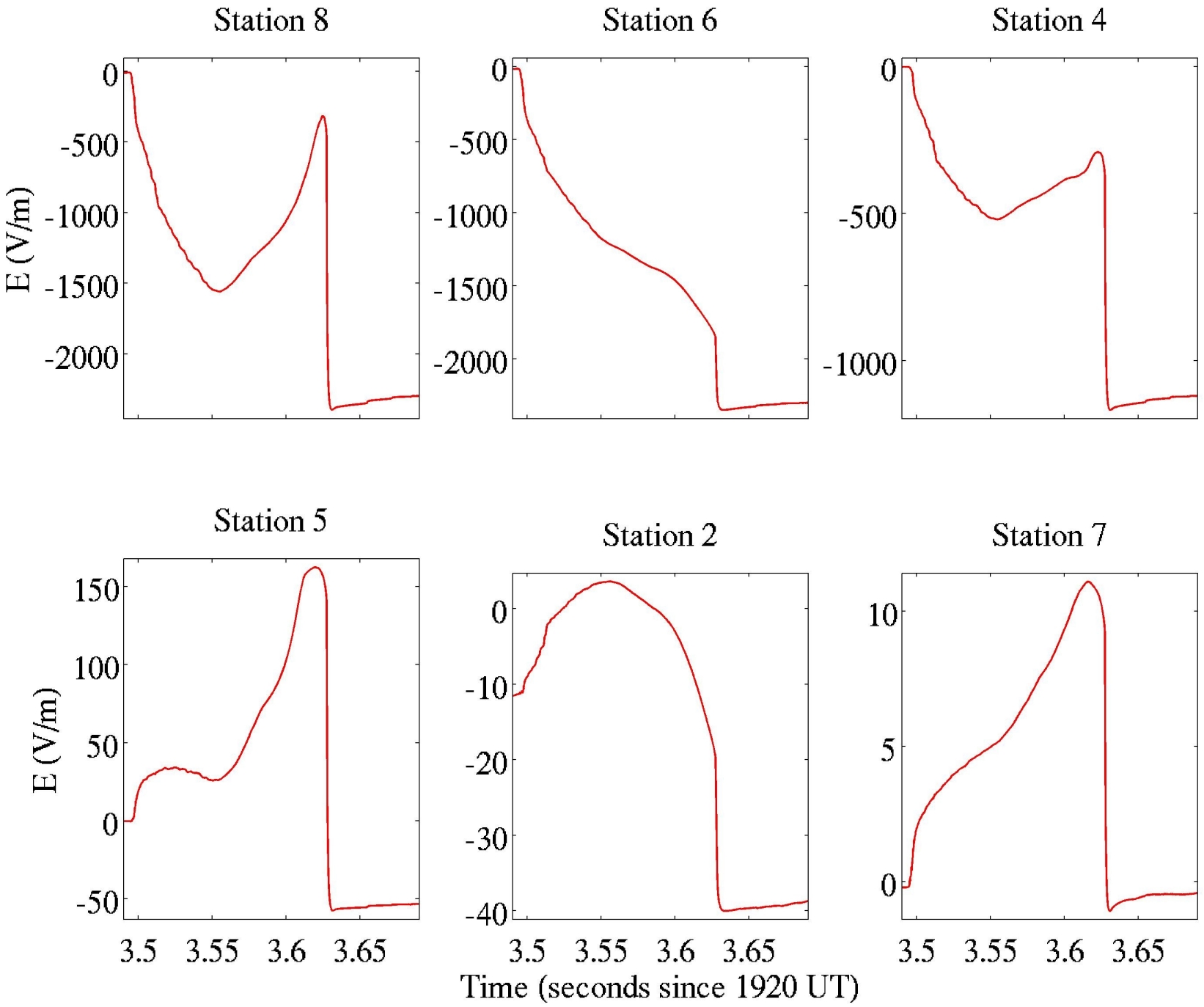
Lecture 4

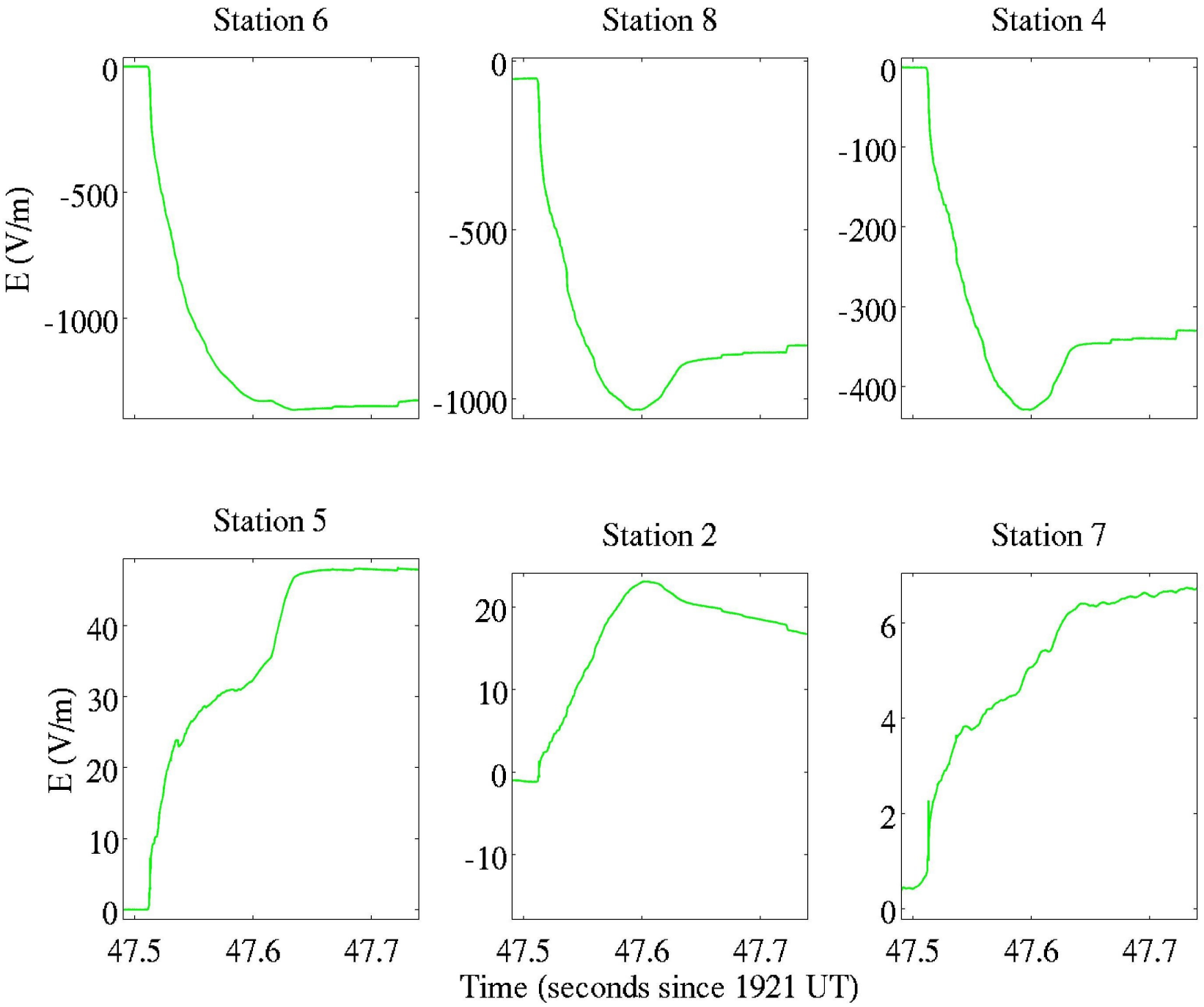
Showed first few slides … actual data … introduced image charges


Flashes and Station Locations
.-CG.19:20:03
.IC..19:21:47
-CG..20:35:47
<-- South (kilometers) North -->
<-- West (kilometers) East -->
0
5
10
15
20
25
30
4
6
8
2
5
7


Station 2
Station 8
Station 6
Station 4
Station 5
Station 7
E (V/m)
E (V/m)
100
0
-100
-200
-300
0
-100
-200
-300
-400
0
-100
-200
-300
0
-100
-200
0
-50
-100
-150
0
-2
-4
-6
-8
49.8
50
50.2
49.8
50
50.2
49.8
50
50.2
Time (seconds since 2035 UT)


Station 2
100
0
-100
-200
-300
1-3 km
Stepped Leader
Station 2
-150
-200
-250
-300
-350
Dart Leader
Station 8
E (V/m)
-250
-300
-350
15 km
Station 8
E (V/m)
-340
-360
-380
Station 7
-5
-6
-7
30 km
0.84
0.85
0.86
Time: Seconds since 20:35:49 UT
Station 7
-7
-8
0.933
0.934
0.935
0.936
0.937
Time: Seconds since 20:35:49 UT


Station 8
Station 6
Station 4
Station 5
Station 2
Station 7
E (V/m)
E (V/m)
0
-500
-1000
-1500
-2000
-500
-1000
150
100
50
0
-50
-10
-20
-30
-40
10
5
0
3.5
3.55
3.6
3.65
Time (seconds since 1920 UT)


Station 6
Station 8
Station 4
Station 5
Station 2
Station 7
E (V/m)
E (V/m)
0
-500
-1000
0
-500
-1000
0
-100
-200
-300
-400
40
30
20
10
0
20
10
0
-10
6
4
2
0
47.5
47.6
47.7
47.5
47.6
47.7
47.5
47.6
47.7
Time (seconds since 1921 UT)

Lecture 5

Showed how distributed fit better than lumped (showed rest of the slides). Asked how you could tell IC's from Cgs (no return strokes … K-changes perhaps going different directions at different distances)

Multi-station field-change measurements

With Multi-station field change data, you can:

Distinguish IC from CG flashes

Measure polarity of a flash

Possibly locate the charge center.

Quantify the charge transferred.

Electrostatic return-stroke model Distributed

Let CG flash begin one kilometer above main negative charge center (6 km).

Let leader extend at 0.001c. For each “step” put a charge dQ-=steplength*lambda.

Let lambda be a constant= -1 mC/m

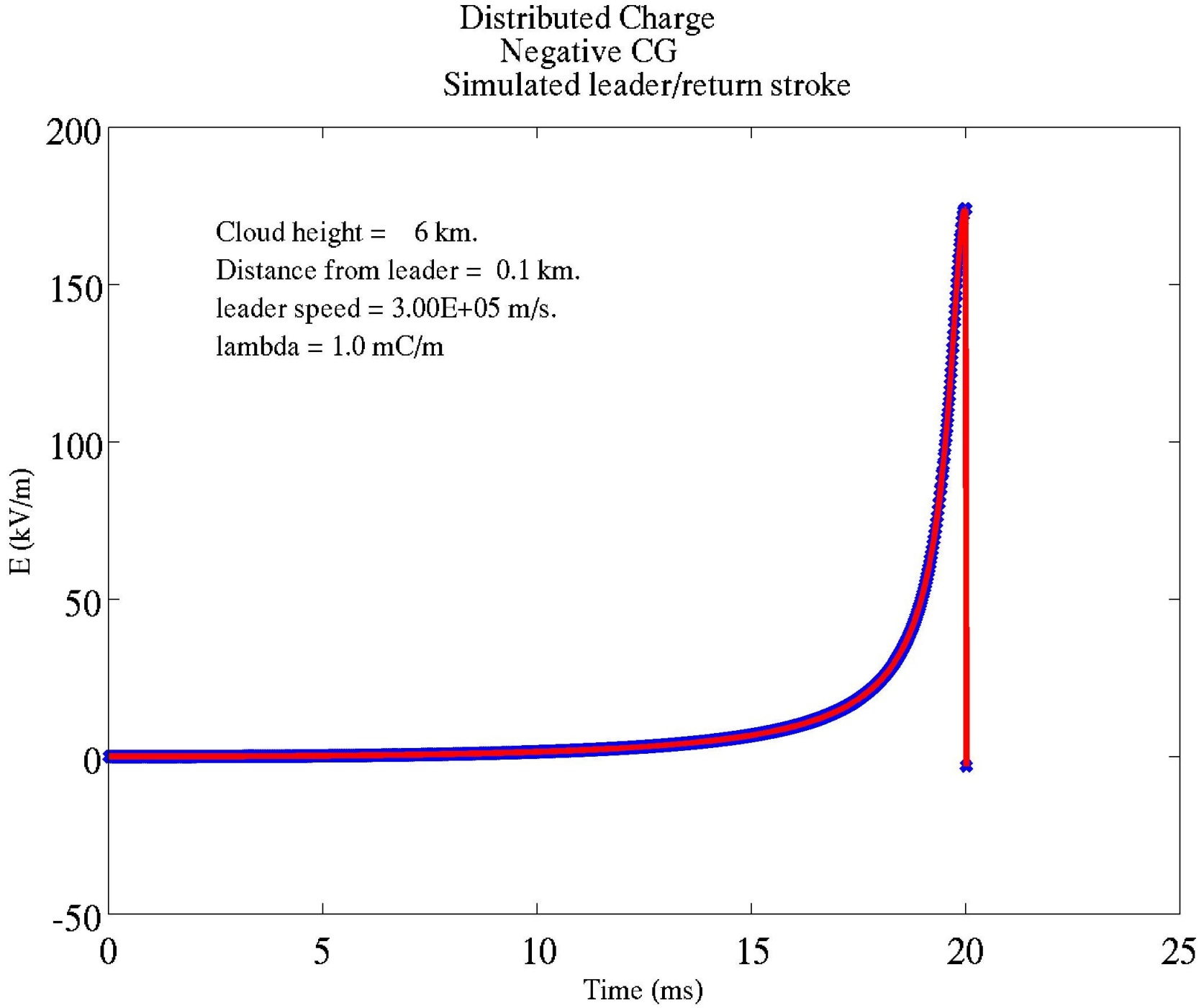
As leader extends, leave behind an opposite charge Q+ at the origin site of flash. So Q+ grows by dQ every time the leader extends.

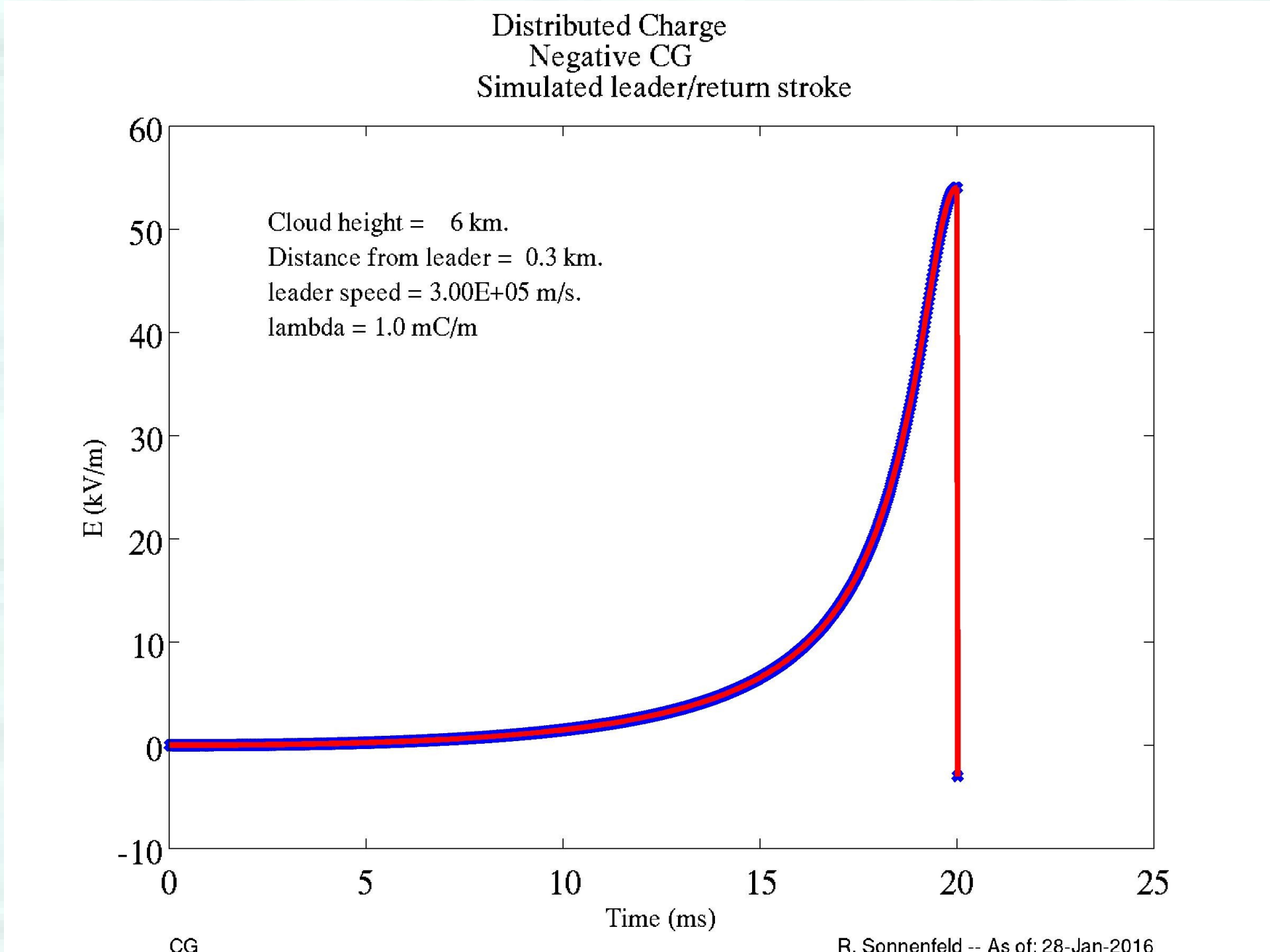
When leader reaches ground, immediately (in <0.1 ms) eliminate all dQ- charges on the leader, leaving only the positive charge Q+ back in the clouds.

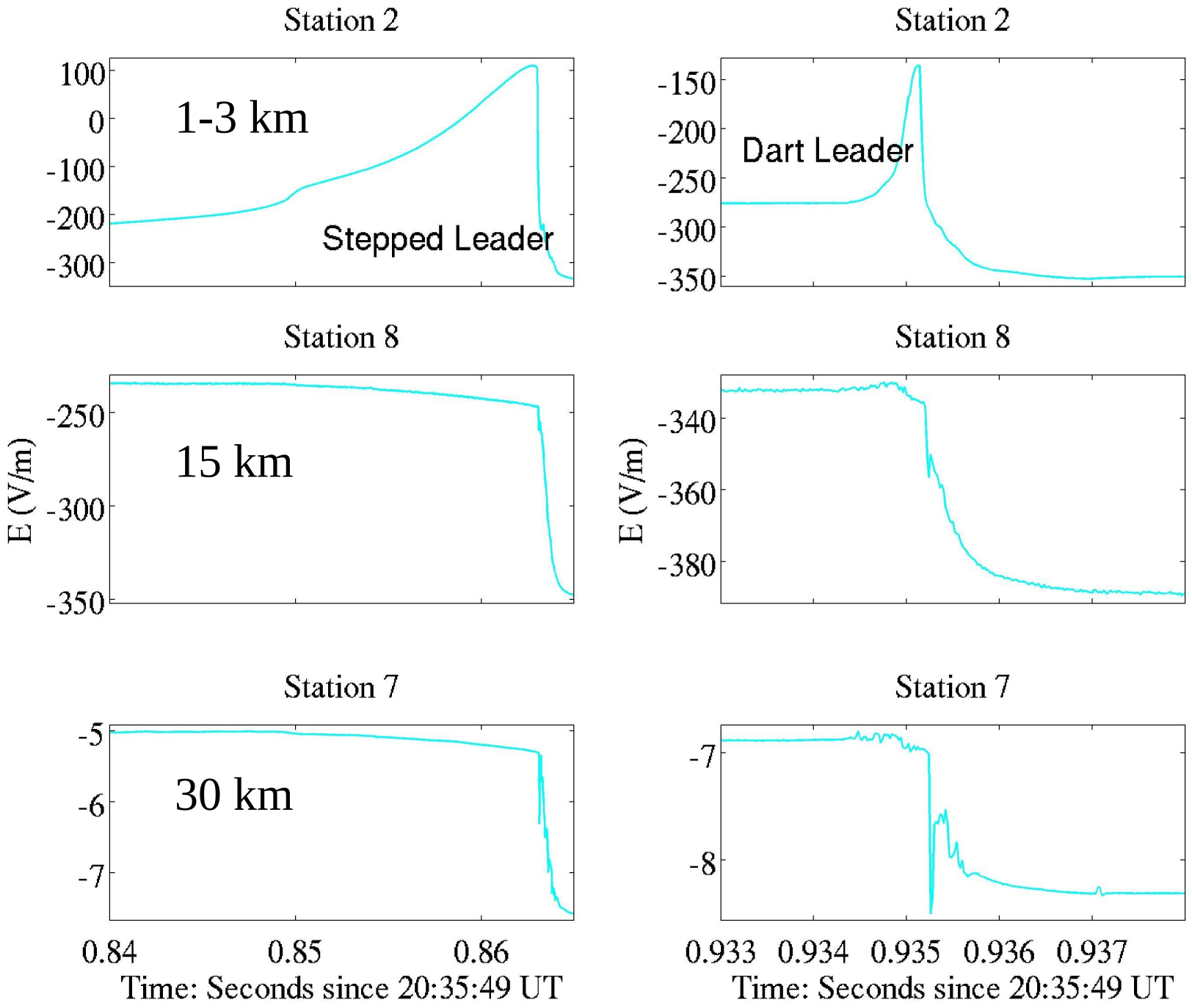
Note: Every charge must have an image charge

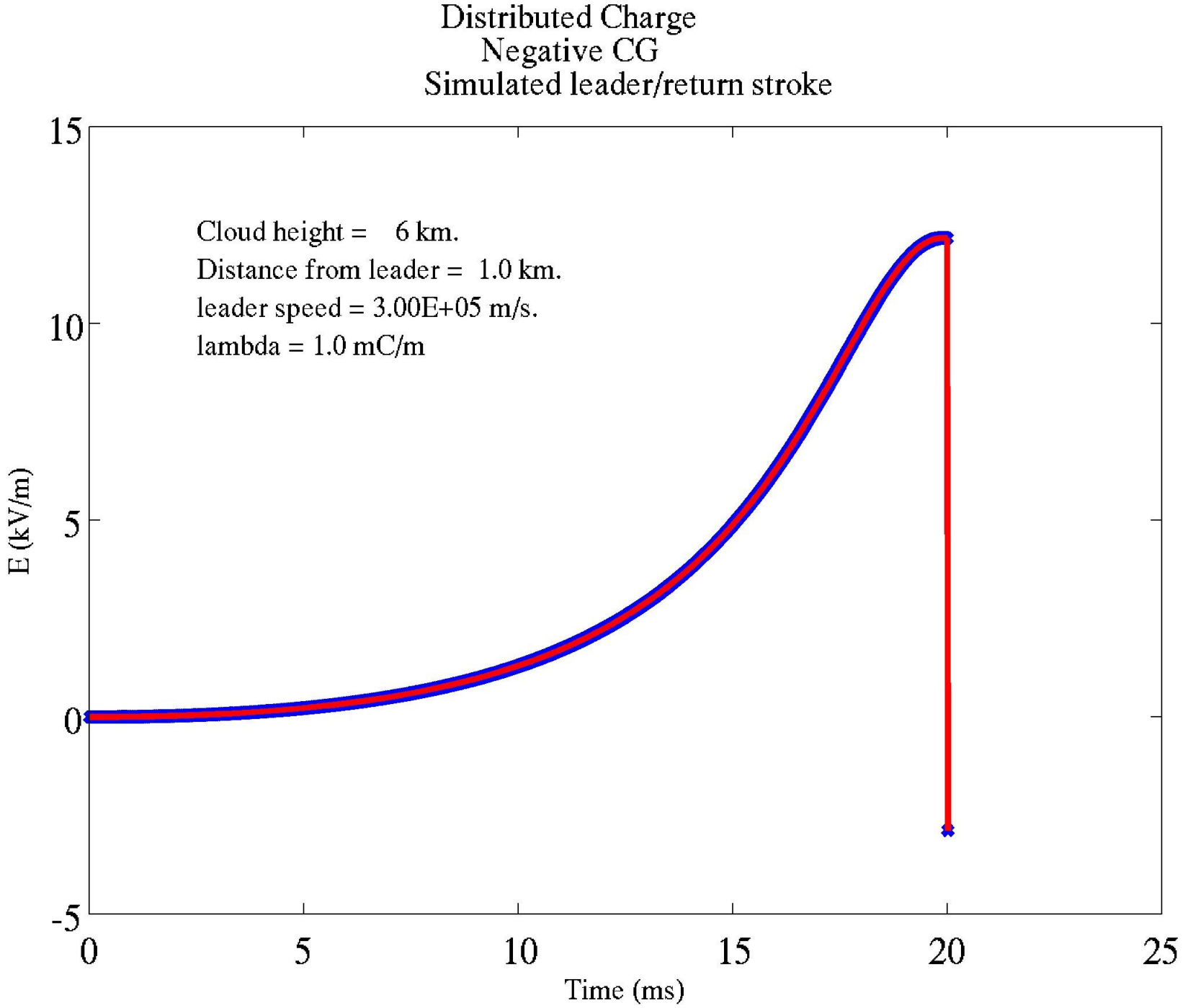
Electrostatic return-stroke model
Distributed

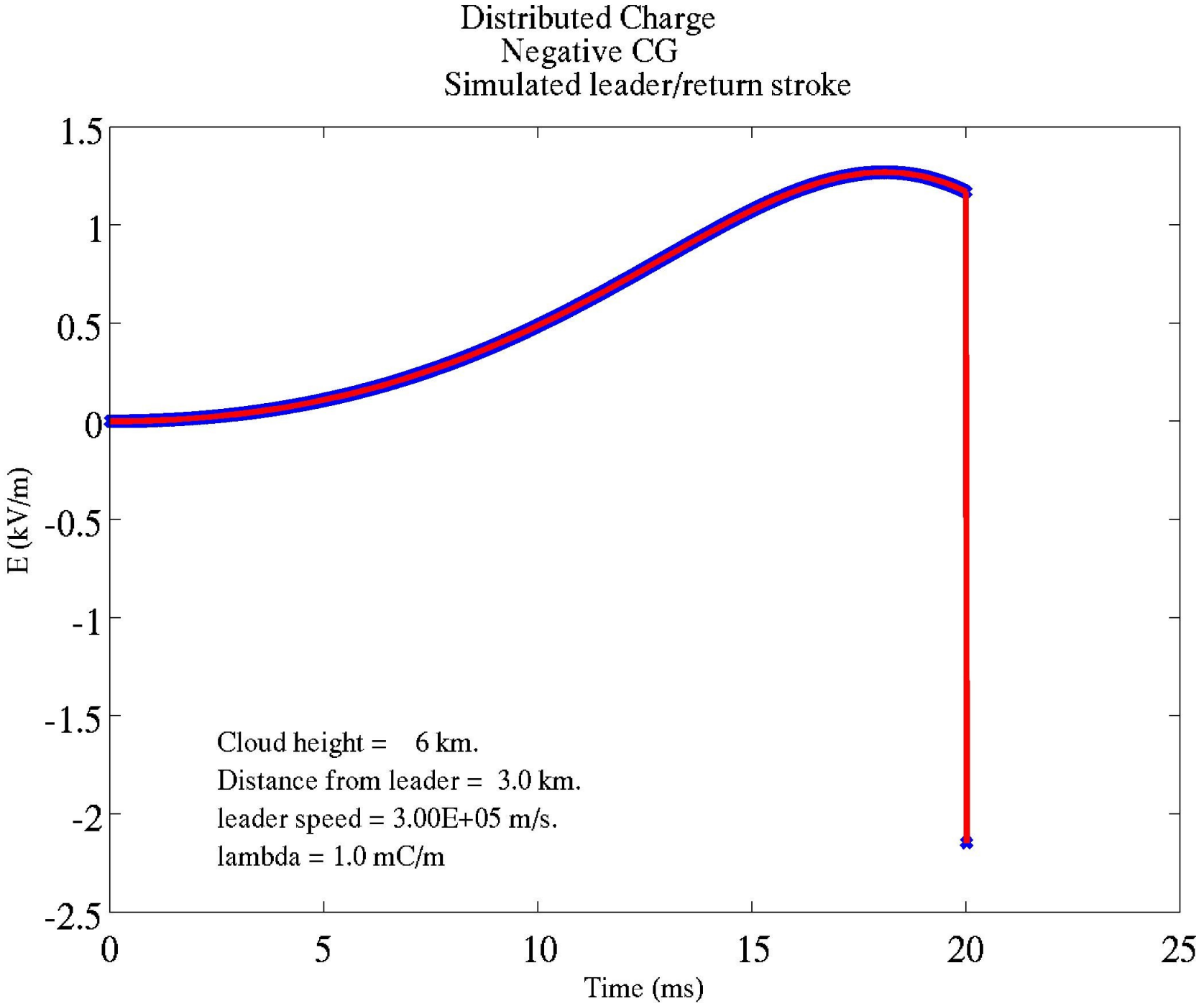
Note: Every charge must have an image charge.

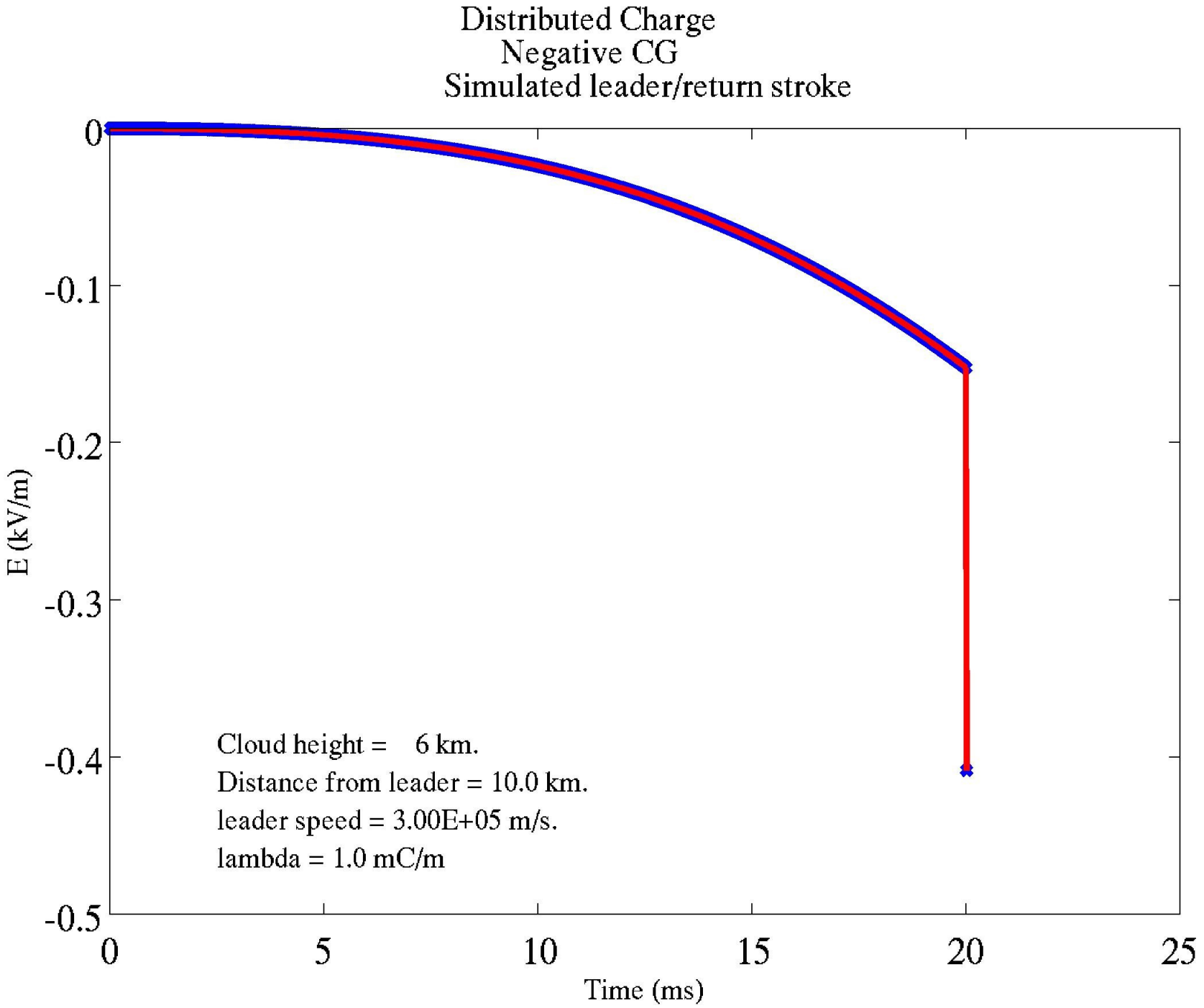

Distributed Charge
Negative CG
Simulated leader/return stroke
Cloud height = 6 km.
Distance from leader = 0.1 km.
leader speed = 3.00E+05 m/s.
lambda = 1.0 mC/m
E (kV/m)
200
150
100
50
0
-50
0
5
10
15
20
25
Time (ms)
CG
R. Sonnenfeld -- As of: 28-Jan-2016

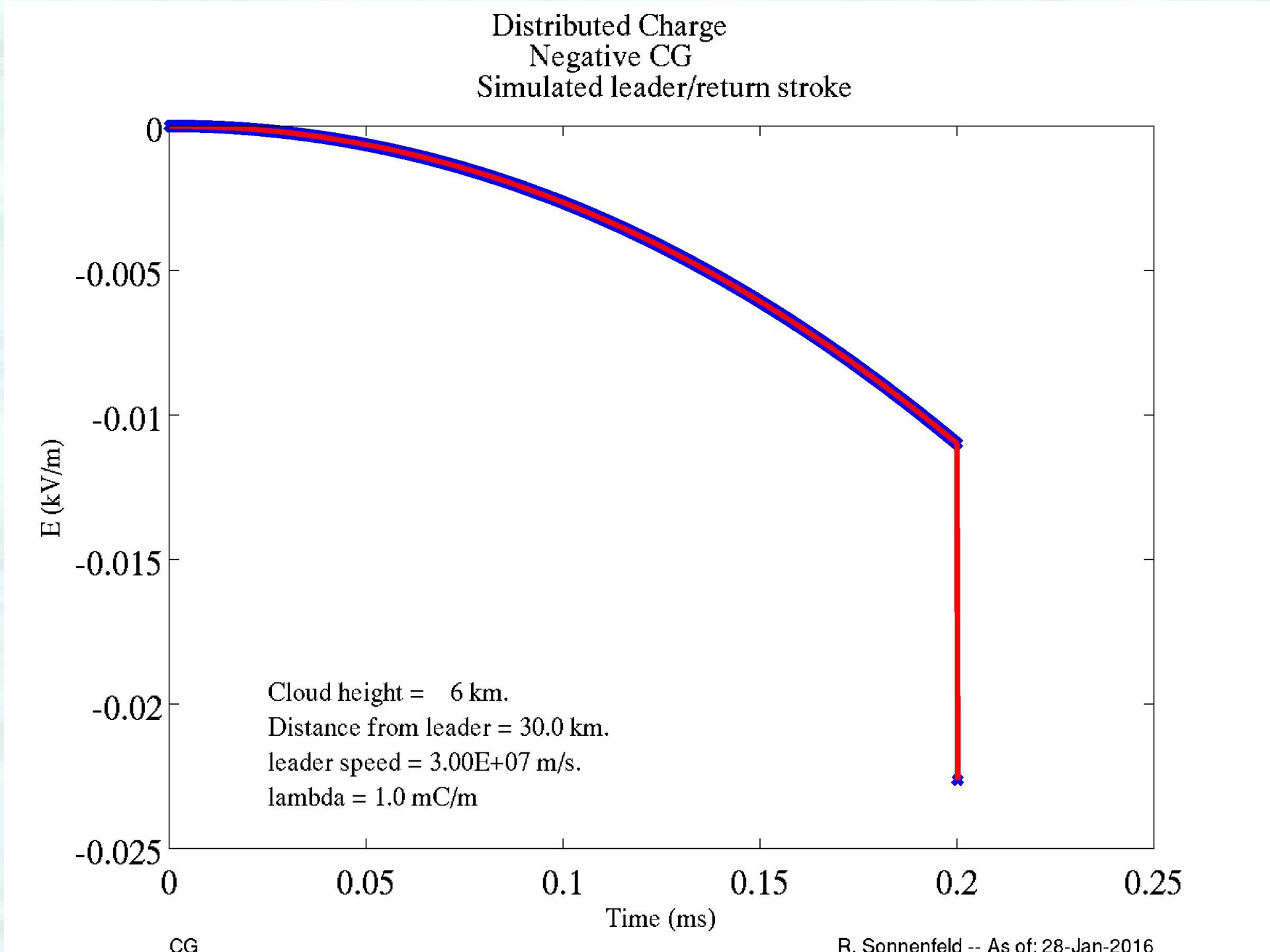

Distributed Charge
Negative CG
Simulated leader/return stroke
Cloud height = 6 km.
Distance from leader = 0.3 km.
leader speed = 3.00E+05 m/s.
lambda = 1.0 mC/m
E (kV/m)
Time (ms)
60
50
40
30
20
10
0
-10
0
5
10
15
20
25
CG
R. Sonnenfeld -- As of: 28-Jan-2016

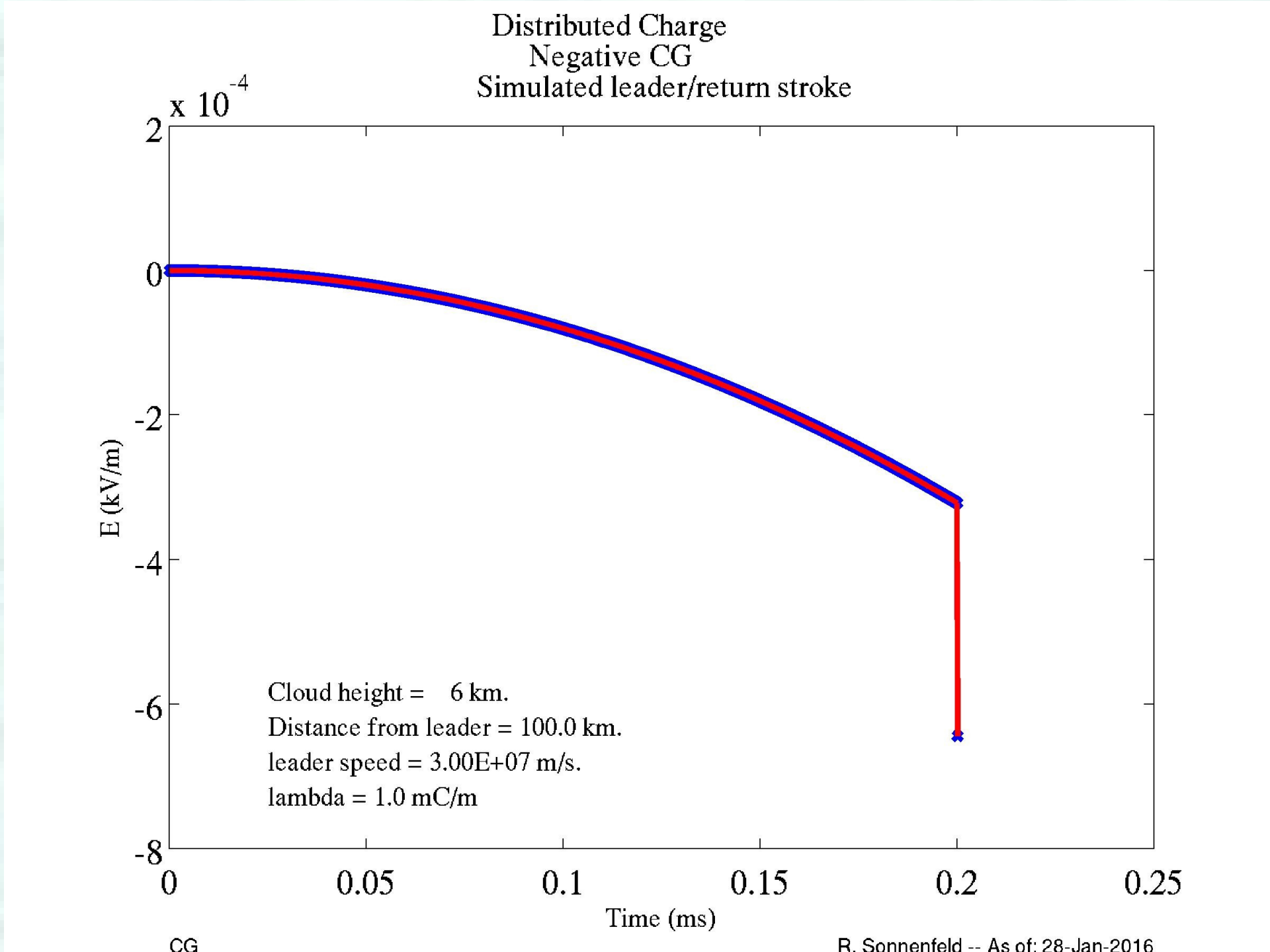

Station 2
100
0
-100
-200
-300
1-3 km
Stepped Leader
Station 2
-150
-200
-250
-300
-350
Dart Leader
Station 8
E (V/m)
-250
-300
-350
15 km
Station 8
E (V/m)
-340
-360
-380
Station 7
-5
-6
-7
30 km
0.84
0.85
0.86
Time: Seconds since 20:35:49 UT
Station 7
-7
-8
0.933
0.934
0.935
0.936
0.937
Time: Seconds since 20:35:49 UT


Distributed Charge
Negative CG
Simulated leader/return stroke
Cloud height = 6 km.
Distance from leader = 1.0 km.
leader speed = 3.00E+05 m/s.
lambda = 1.0 mC/m
E (kV/m)
Time (ms)
15
10
5
0
-5
0
5
10
15
20
25
CG
R. Sonnenfeld -- As of: 28-Jan-2016


Distributed Charge
Negative CG
Simulated leader/return stroke
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
E (kV/m)
0
5
10
15
20
25
Time (ms)
Cloud height = 6 km.
Distance from leader = 3.0 km.
leader speed = 3.00E+05 m/s.
lambda = 1.0 mC/m
CG
R. Sonnenfeld -- As of: 28-Jan-2016


Distributed Charge
Negative CG
Simulated leader/return stroke
0
-0.1
-0.2
-0.3
-0.4
-0.5
E (kV/m)
0
5
10
15
20
25
Time (ms)
Cloud height = 6 km.
Distance from leader = 10.0 km.
leader speed = 3.00E+05 m/s.
lambda = 1.0 mC/m
CG
R. Sonnenfeld -- As of: 28-Jan-2016


Distributed Charge
Negative CG
Simulated leader/return stroke
0
-0.005
-0.01
-0.015
-0.02
-0.025
E (kV/m)
0
0.05
0.1
0.15
0.2
0.25
Time (ms)
Cloud height = 6 km.
Distance from leader = 30.0 km.
leader speed = 3.00E+07 m/s.
lambda = 1.0 mC/m
CG
R. Sonnenfeld -- As of: 28-Jan-2016


Distributed Charge
Negative CG
Simulated leader/return stroke
x 10^-4
2
0
-2
-4
-6
-8
E (kV/m)
0
0.05
0.1
0.15
0.2
0.25
Time (ms)
Cloud height = 6 km.
Distance from leader = 100.0 km.
leader speed = 3.00E+07 m/s.
lambda = 1.0 mC/m
CG
R. Sonnenfeld -- As of: 28-Jan-2016

Electrostatic return-stroke model Lumped

Let CG flash begin one kilometer above main negative charge center (6 km).

Select total charge to transfer (e.g. Q-=-6 Coulombs)

Let leader extend at 0.001c. For each “step” move the ENTIRE Q- to the new location of the step.

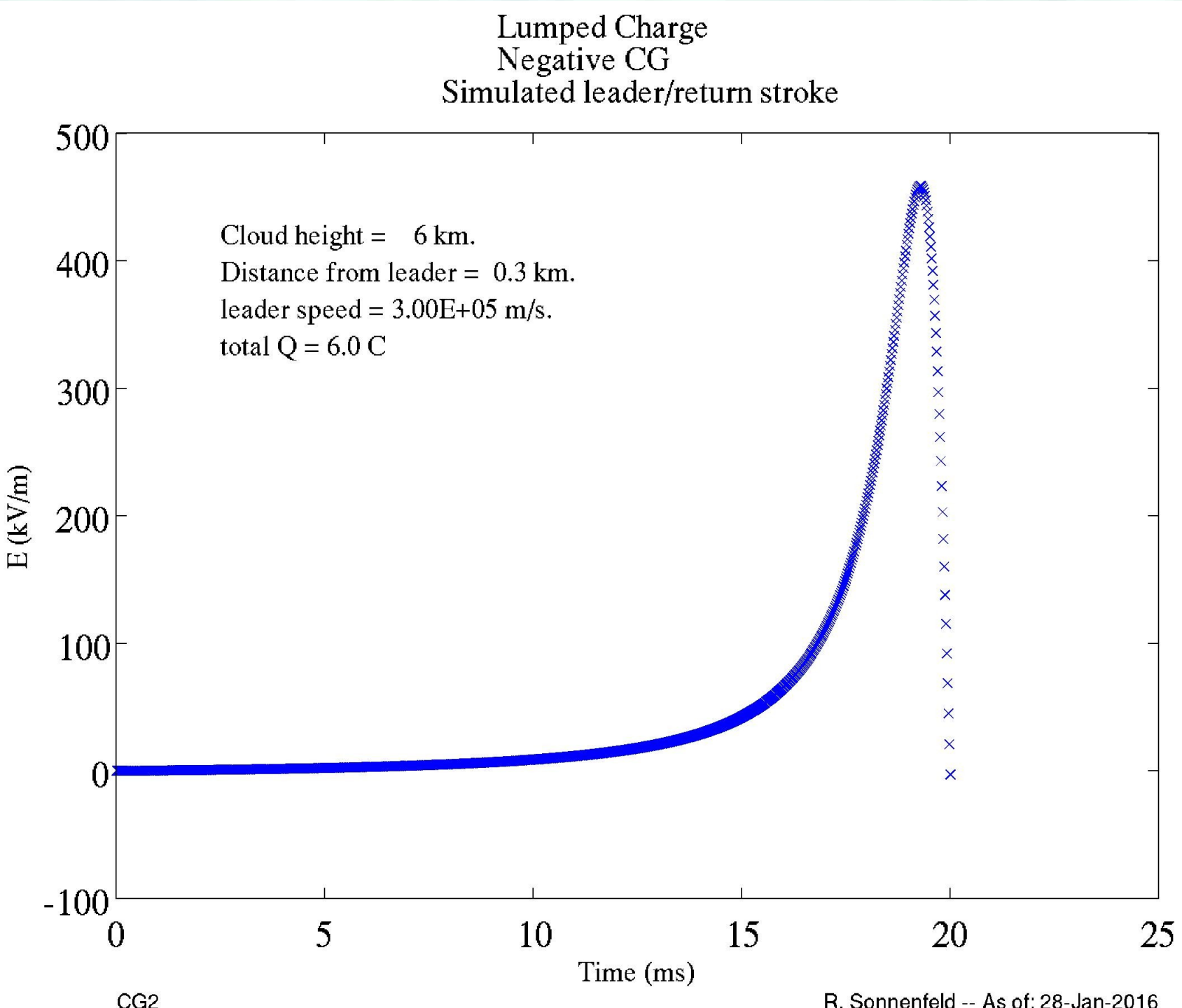
As leader extends, leave behind an opposite charge Q+ at the origin site of flash. Q+ is constant for the entire flash.

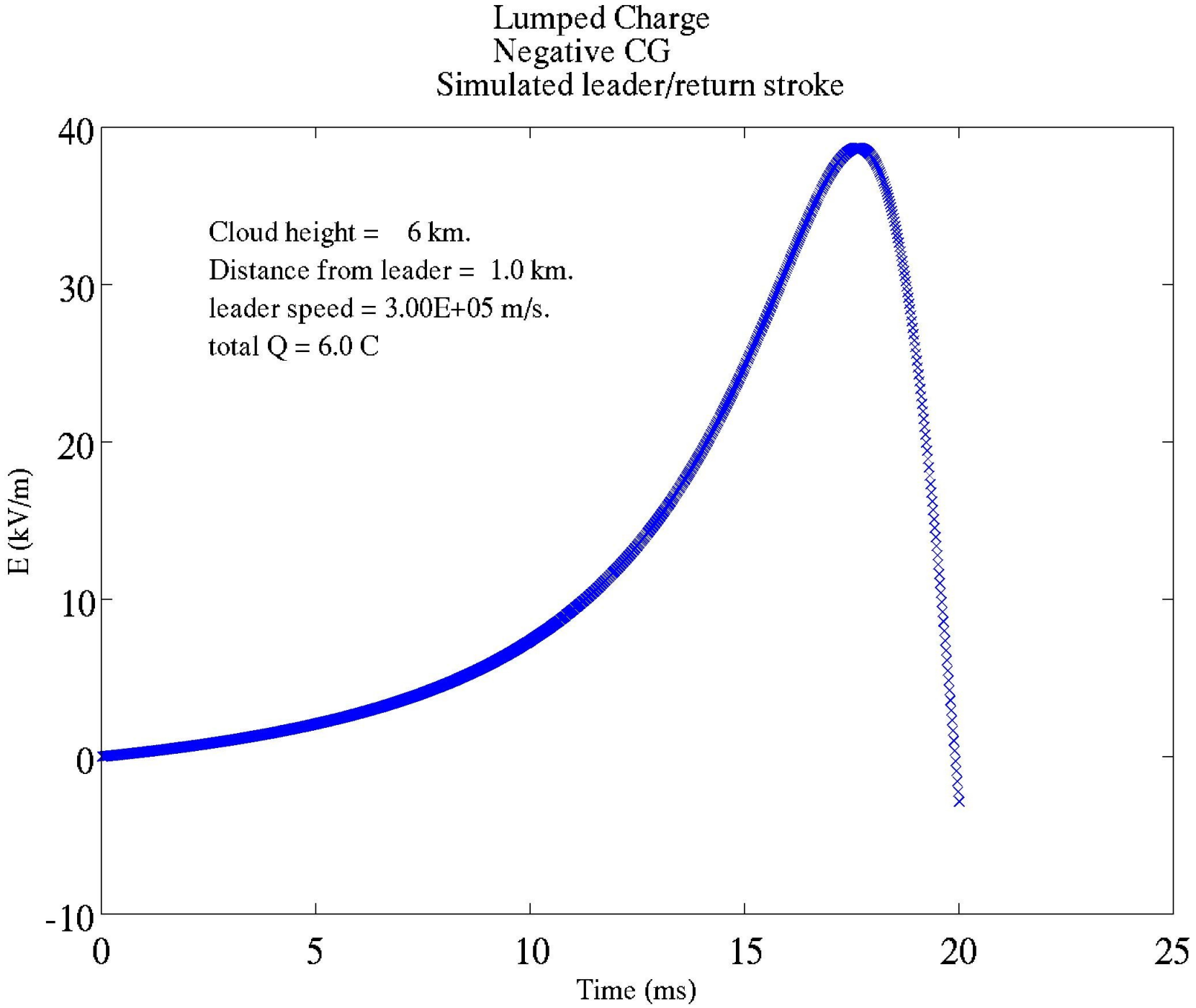
When leader reaches ground, immediately (in <0.1 ms) eliminate Q-, leaving only the positive charge Q+ back in the clouds.

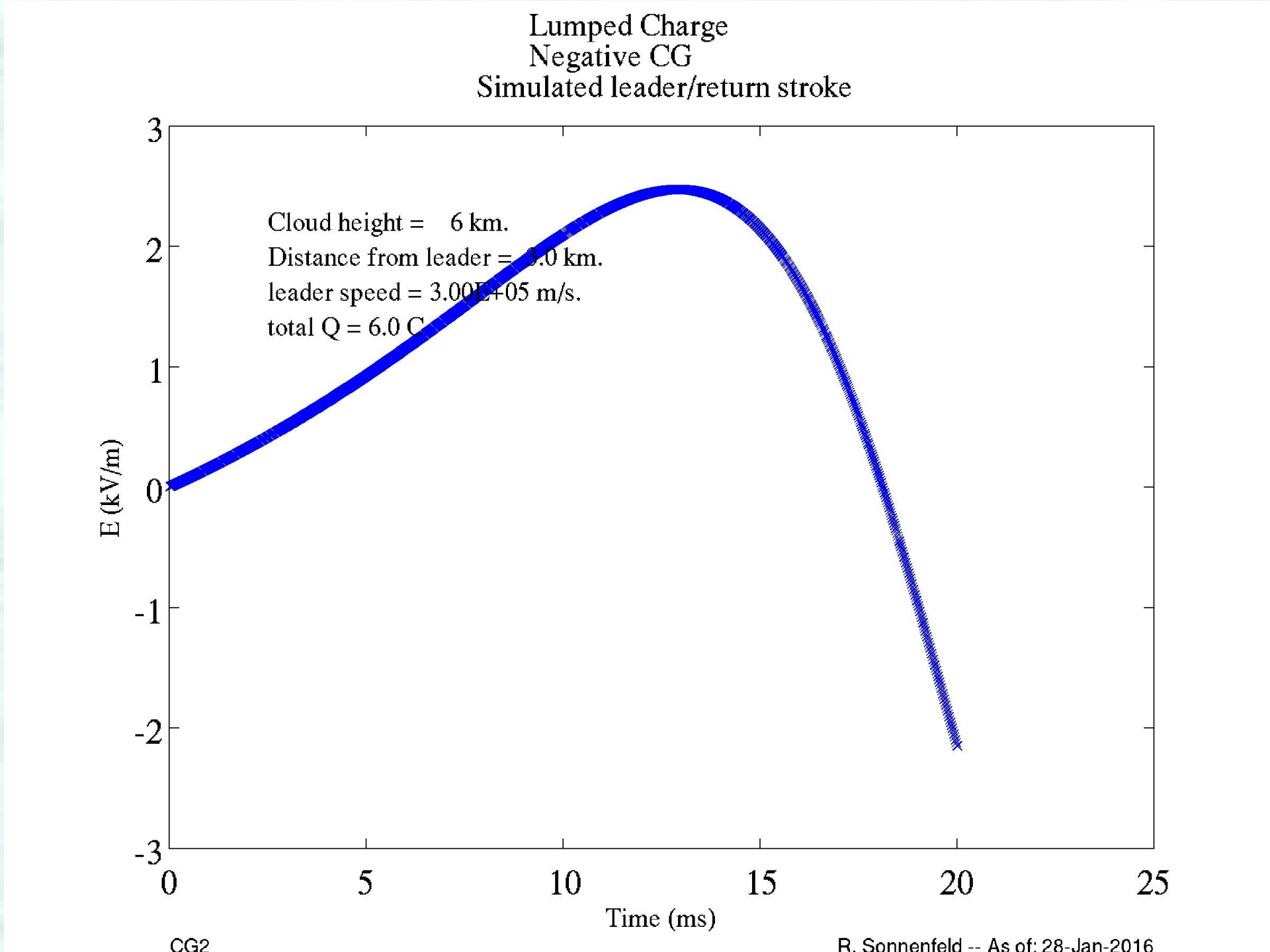
Note: Every charge must have an image charge.

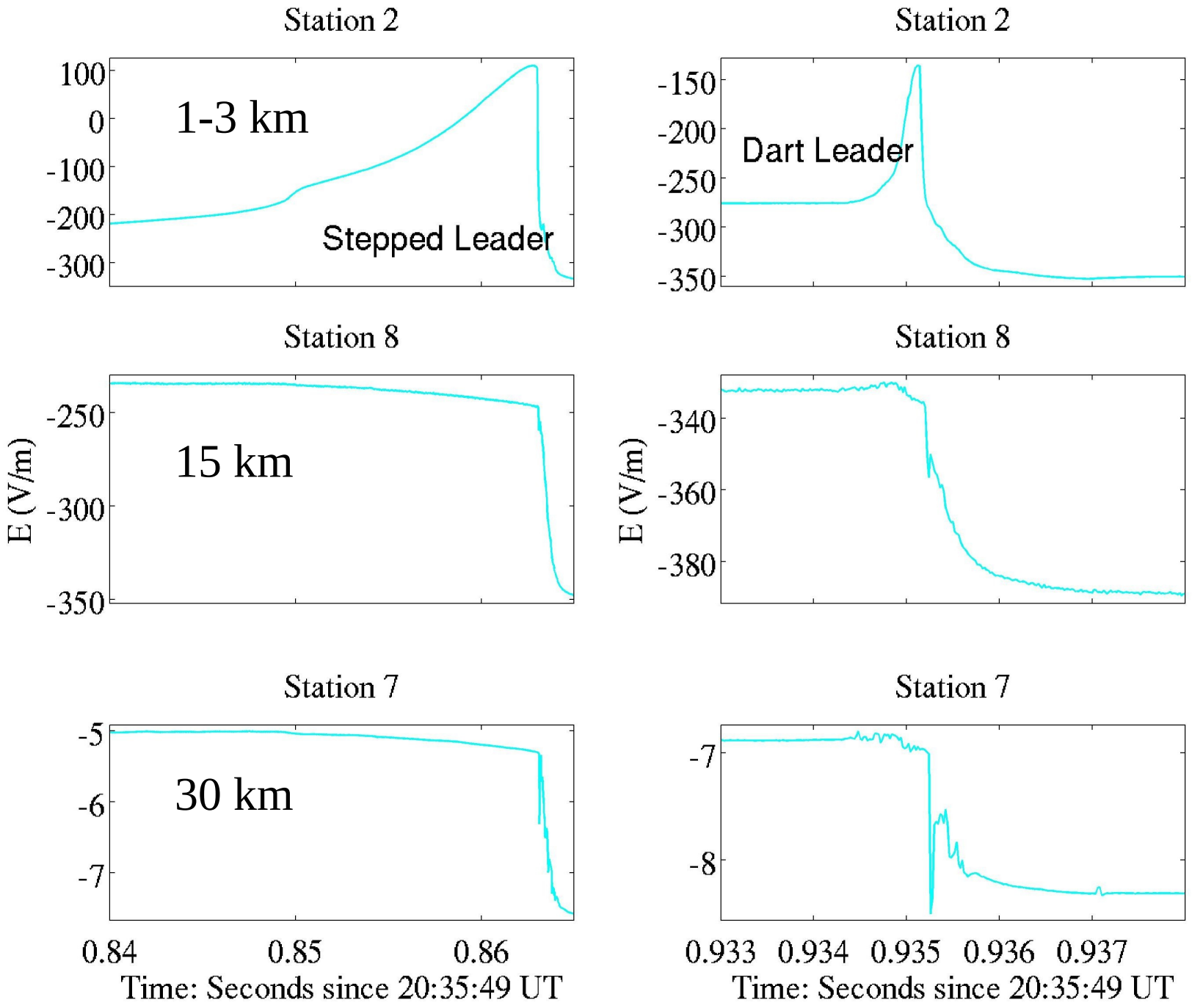
Electrostatic return-stroke model
Lumped

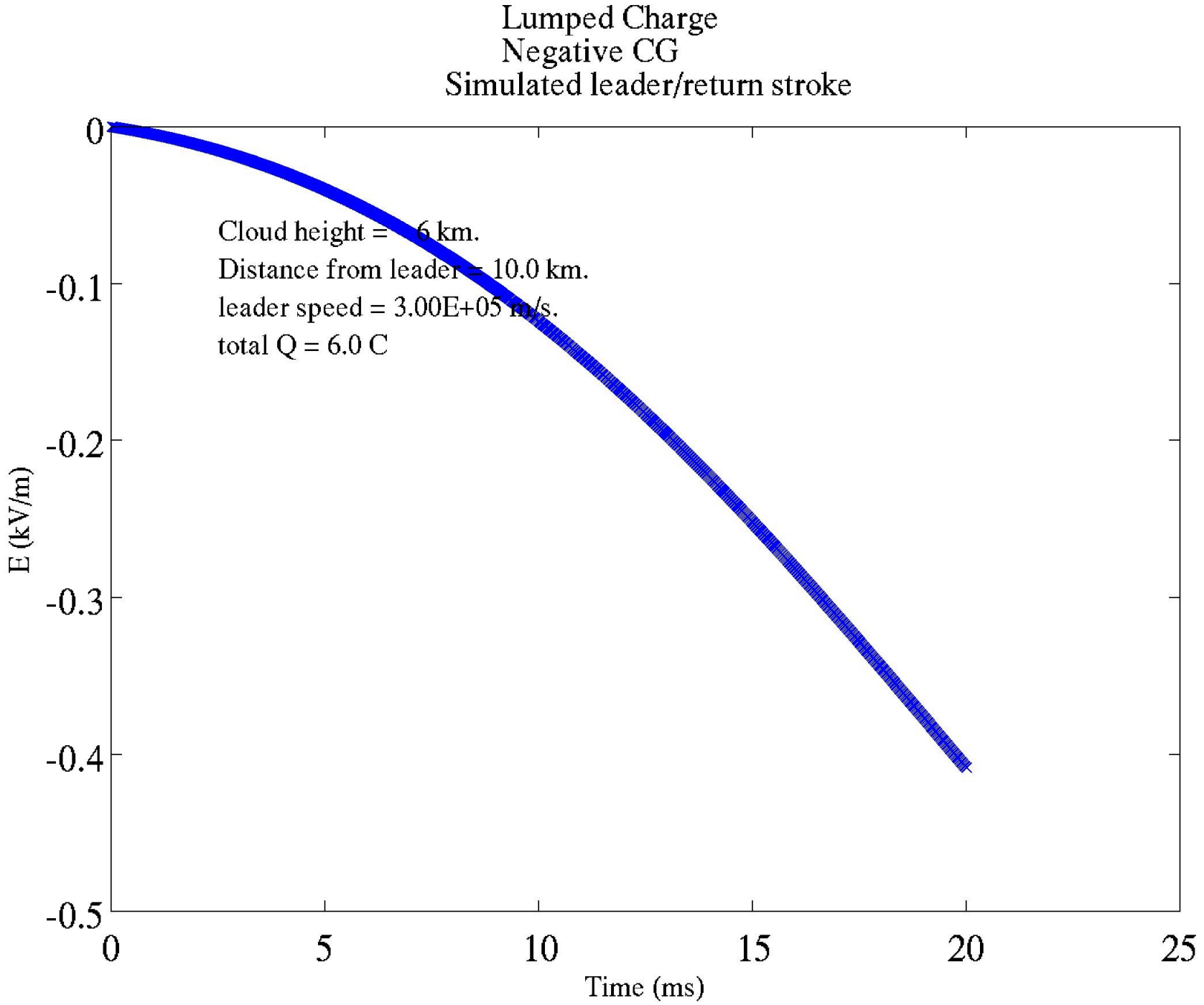
Note: Every charge must have an image charge.


Lumped Charge
Negative CG
Simulated leader/return stroke
Cloud height = 6 km.
Distance from leader = 0.3 km.
leader speed = 3.00E+05 m/s.
total Q = 6.0 C
E (kV/m)
Time (ms)
500
400
300
200
100
0
-100
0
5
10
15
20
25
CG2
R. Sonnenfeld -- As of: 28-Jan-2016


Lumped Charge
Negative CG
Simulated leader/return stroke
Cloud height = 6 km.
Distance from leader = 1.0 km.
leader speed = 3.00E+05 m/s.
total Q = 6.0 C
E (kV/m)
Time (ms)
40
30
20
10
0
-10
0
5
10
15
20
25
CG2
R. Sonnenfeld -- As of: 28-Jan-2016


Lumped Charge
Negative CG
Simulated leader/return stroke
Cloud height = 6 km.
Distance from leader = 3.0 km.
leader speed = 3.00E+05 m/s.
total Q = 6.0 C
E (kV/m)
Time (ms)
3
2
1
0
-1
-2
-3
0
5
10
15
20
25
CG2
R. Sonnenfeld -- As of: 28-Jan-2016


Station 2
100
0
-100
-200
-300
1-3 km
Stepped Leader
Station 2
-150
-200
-250
-300
-350
Dart Leader
Station 8
E (V/m)
-250
-300
-350
15 km
Station 8
E (V/m)
-340
-360
-380
Station 7
-5
-6
-7
30 km
0.84
0.85
0.86
Time: Seconds since 20:35:49 UT
Station 7
-7
-8
0.933
0.934
0.935
0.936
0.937
Time: Seconds since 20:35:49 UT


Lumped Charge
Negative CG
Simulated leader/return stroke
Cloud height = 6 km.
Distance from leader = 10.0 km.
leader speed = 3.00E+05 m/s.
total Q = 6.0 C
E (kV/m)
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
5
10
15
20
25
Time (ms)
CG2
R. Sonnenfeld -- As of: 28-Jan-2016

Multi-station field-change measurements

With Multi-station field change data, you can:

Distinguish IC from CG flashes

Measure polarity of a flash

Possibly locate the charge center.

Quantify the charge transferred.

Conclusion

Distributed charge model fits a flash better than a lumped charge model.