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Lightning attachment to lightning rods : a comparison between numerical models and observations in natural conditions

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Introduction

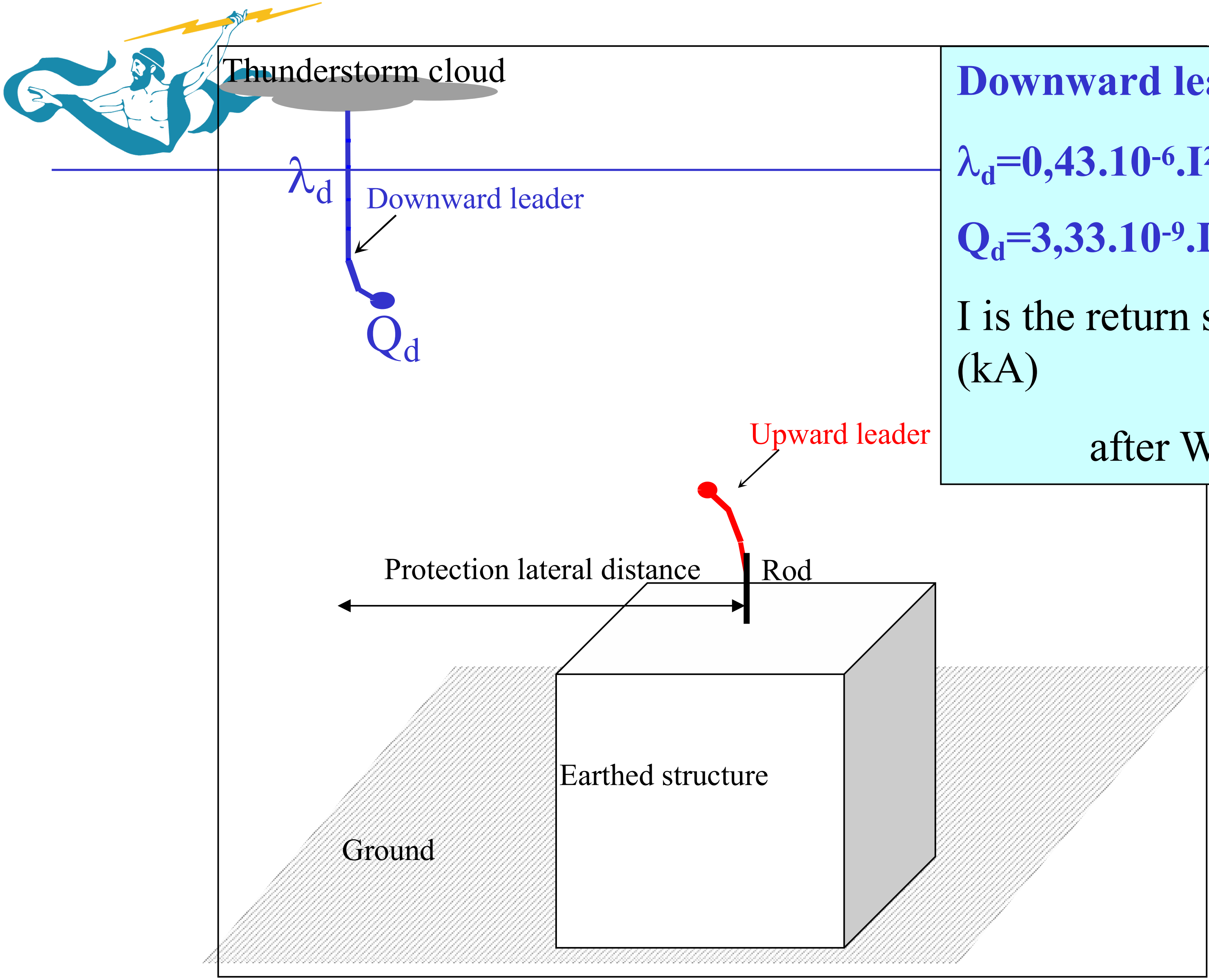
Besides Electrogeometric Model EGM, varieties of numerical models have been built in modern times, especially some more physical based on physics of leaders propagation . Several authors such like Dellera and Garbagnati, Berger and Aït Amar, Becerra and Cooray, have built variants based on electrical discharges physics, the so-called Leader Progression Model LPM.

Introduction

- Our goal is to compare previsions of the LPM with natural lightning observations, especially those presented by Saba and his team in Brazil looking at lightning attachment to rods at top of high buildings.

- Two aspects are considered in the paper, first the development of upward leaders from the rods or vulnerable points of the buildings, then the subsequent completion of the flash to the rods.

- This will exhibit competition between several upward leaders, either created at the rods tips on a building or at the rods tips on another structure at the building vicinity.



Downward leader charge:

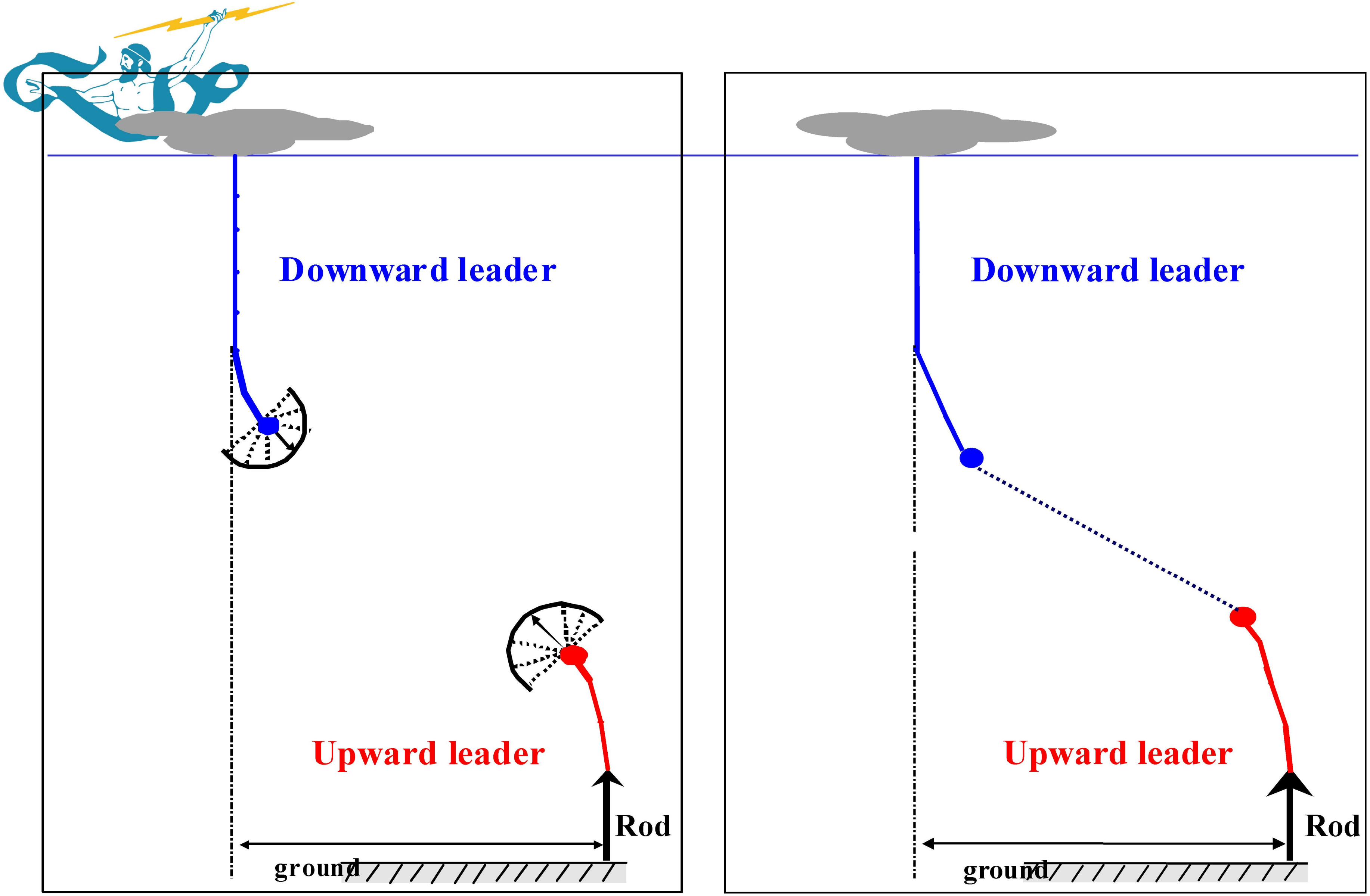
$\lambda_d=0,43.10^{-6}.I^{2/3}$

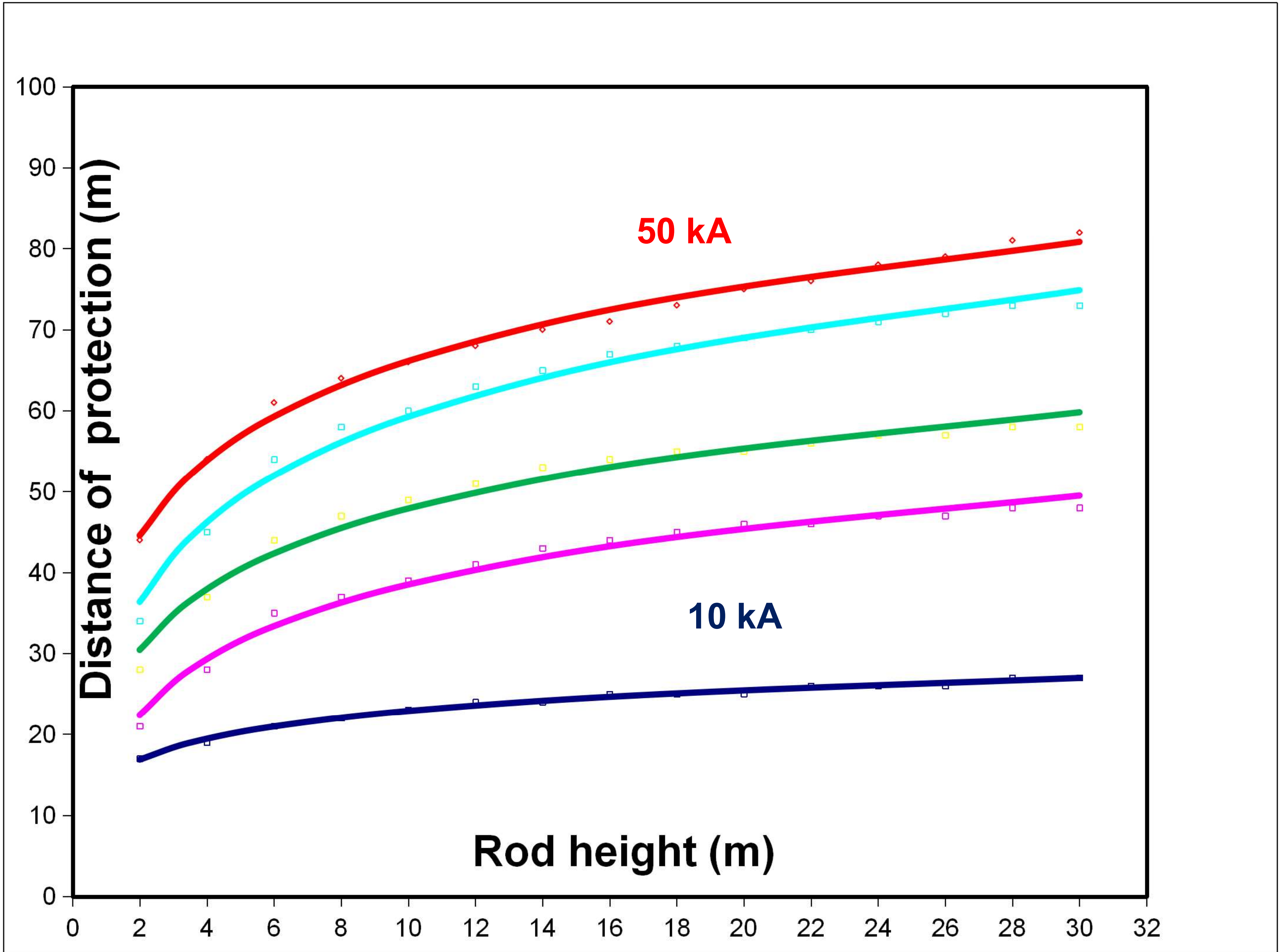
$Q_d=3,33.10^{-9}.I^{4/3}$

I is the return stroke current (kA)

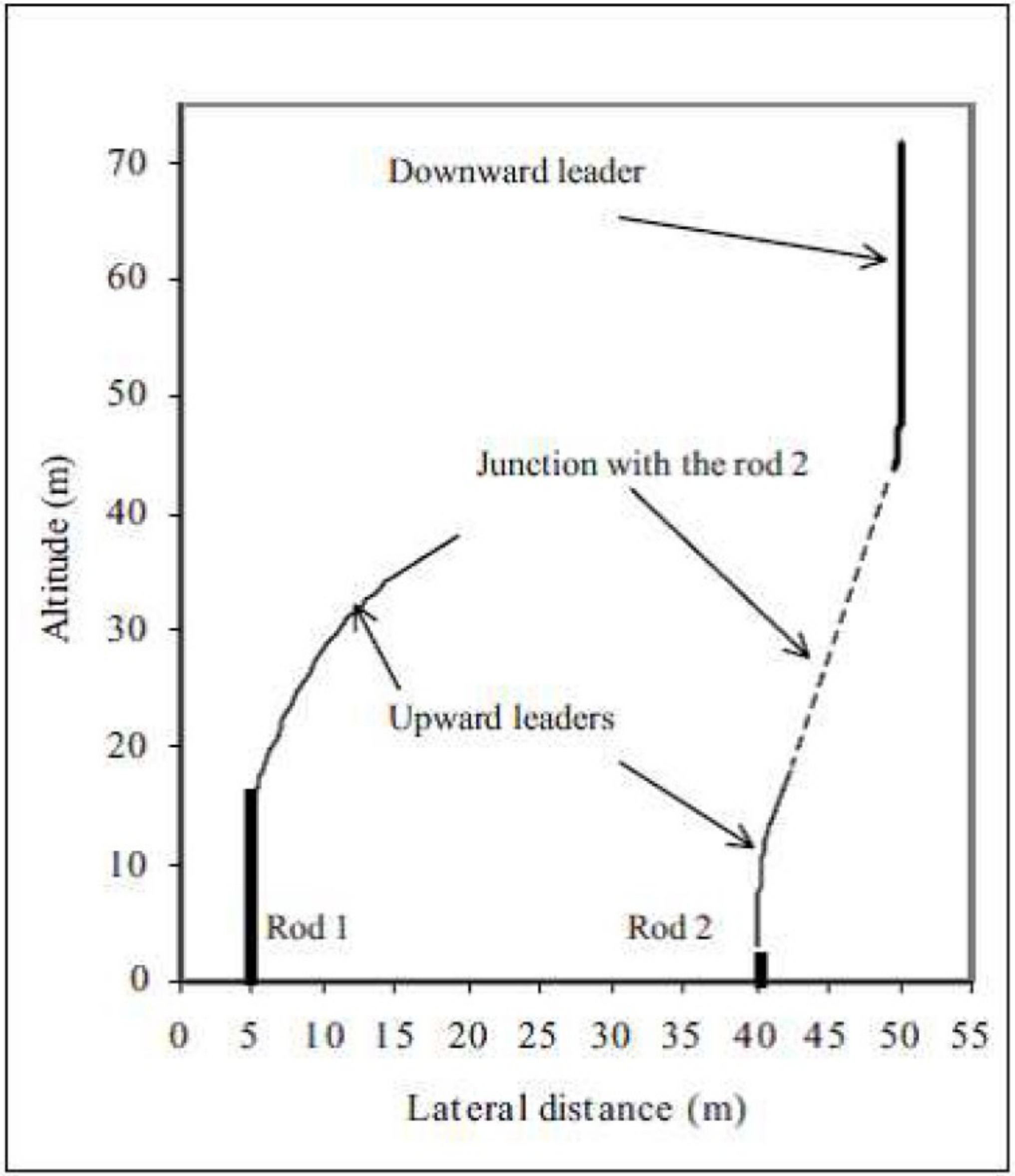
after Waters & Petrov

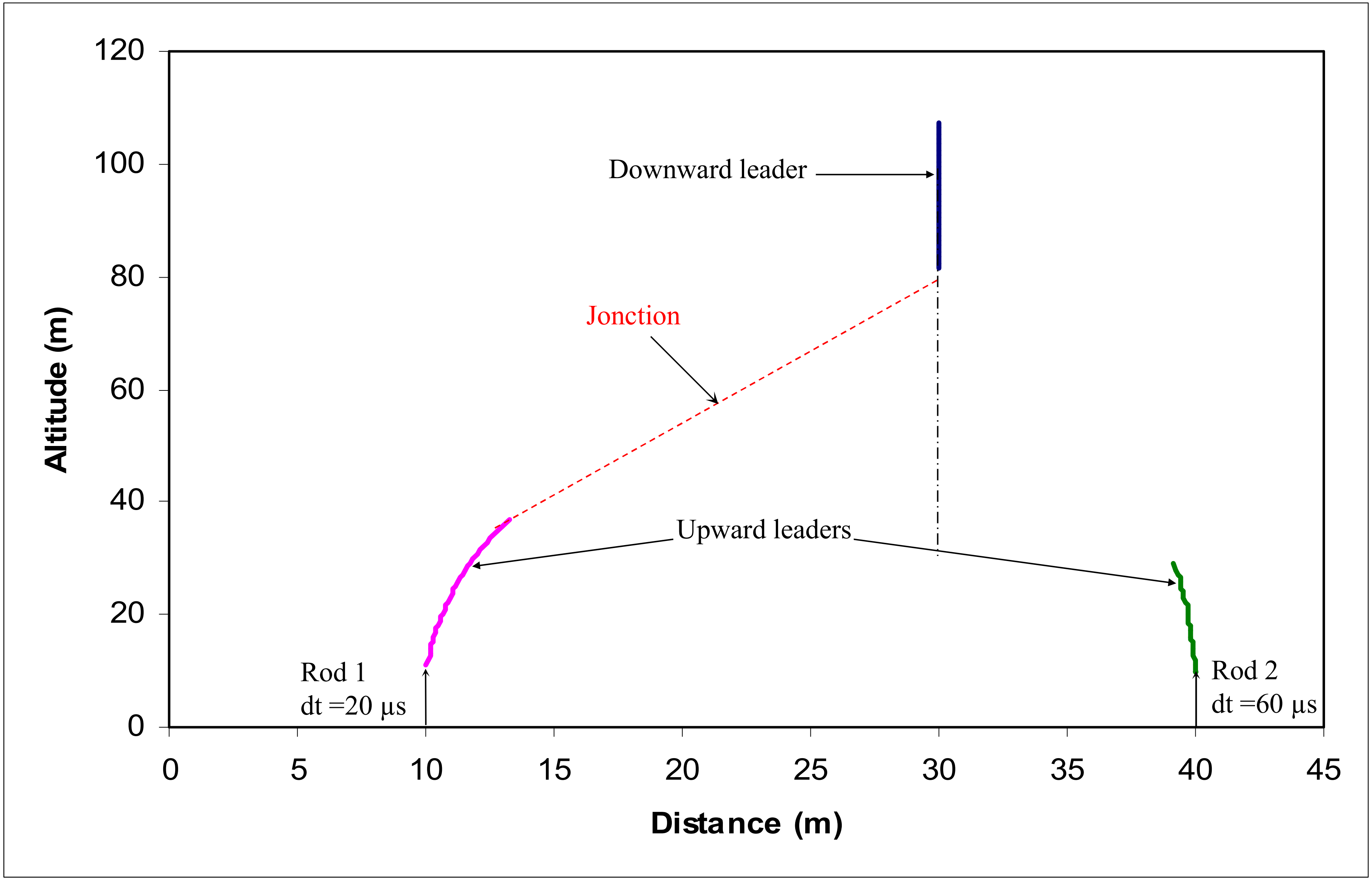
An illustration of downward and upward leaders


Downward leader
Upward leader
Rod
ground
Downward leader
Upward leader
Rod
ground

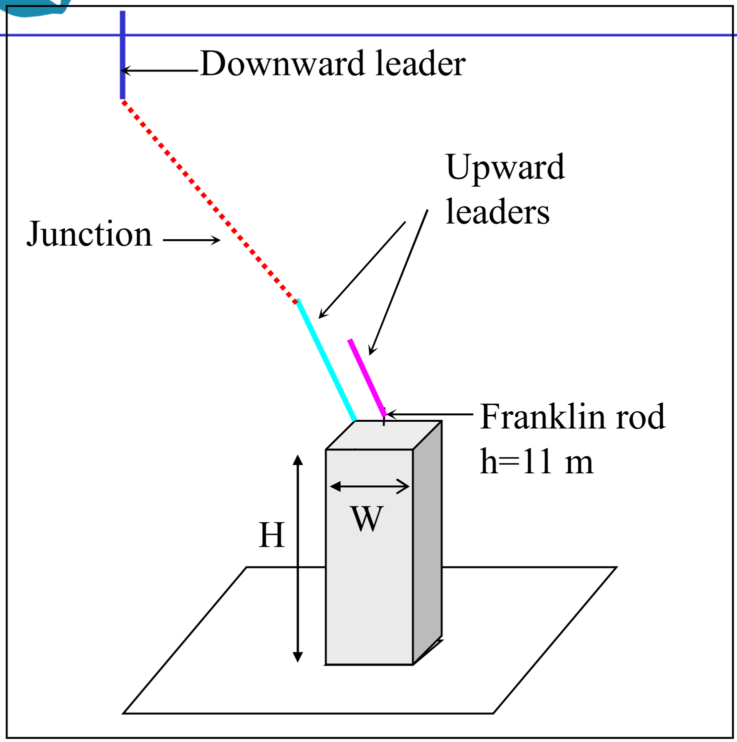


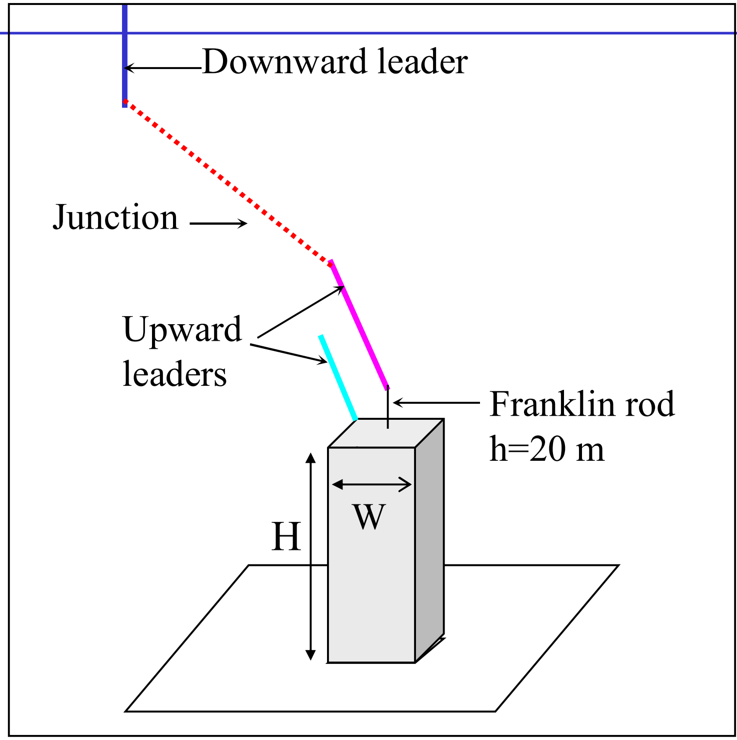
50 kA
10 kA
Distance of protection (m)
Rod height (m)
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32


Downward leader
Junction with the rod 2
Upward leaders
Rod 1
Rod 2
Altitude (m)
Lateral distance (m)
0
10
20
30
40
50
60
70
0 5 10 15 20 25 30 35 40 45 50 55



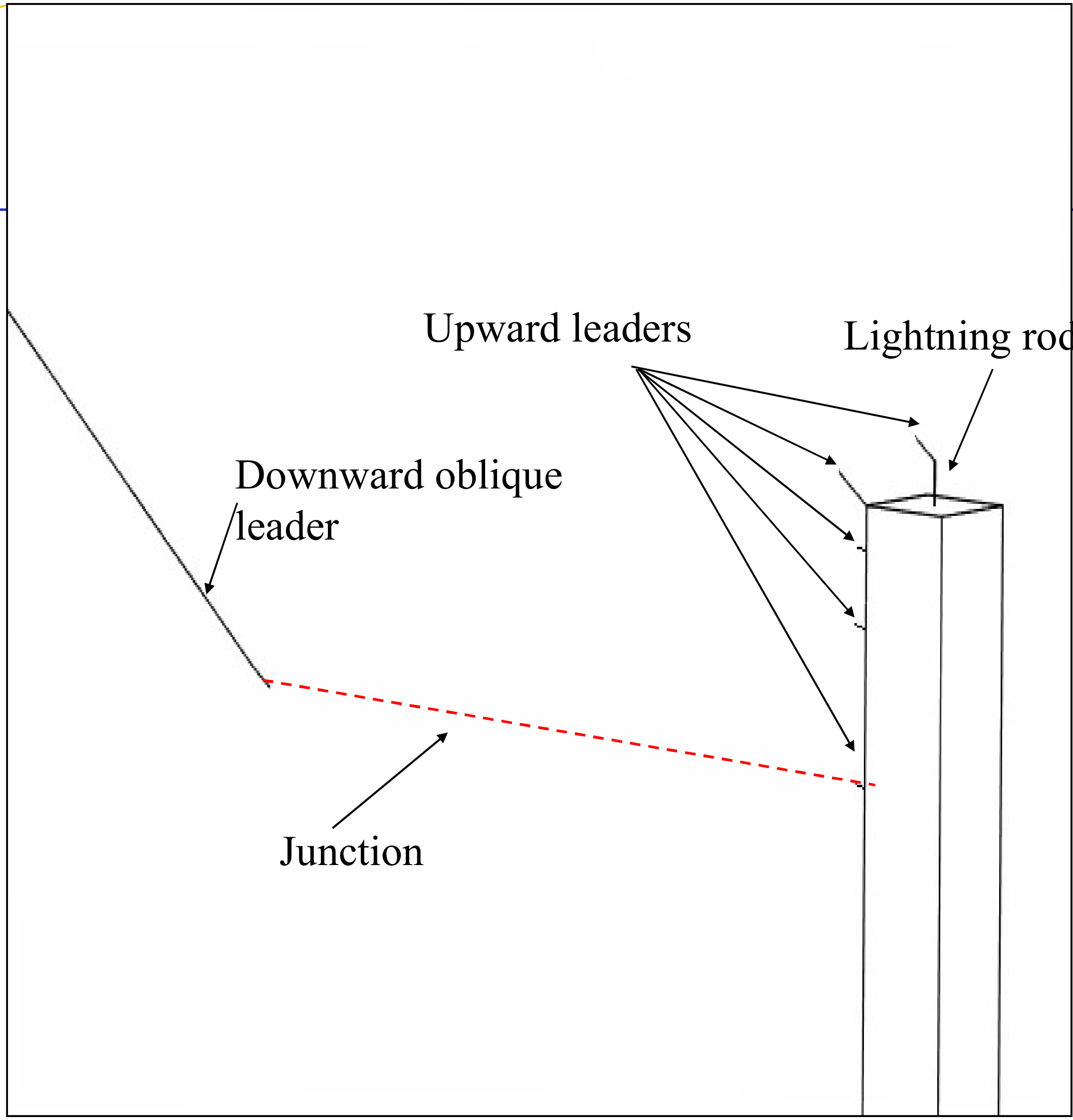
The effect of the delay time dt on the competition of two lightning rods. h=10 m, I=50 kA, Rv=1, Vd=1e5 m/s





A 3D illustration of the failure of the electrogeometrical model. Junction with the structure. I=10 kA, Rv=2, W=40 m, H=100 m

A 3D illustration of a protected structure. Junction with the Franklin rod. I=10 kA, Rv=2 W=40 m, H=100 m.

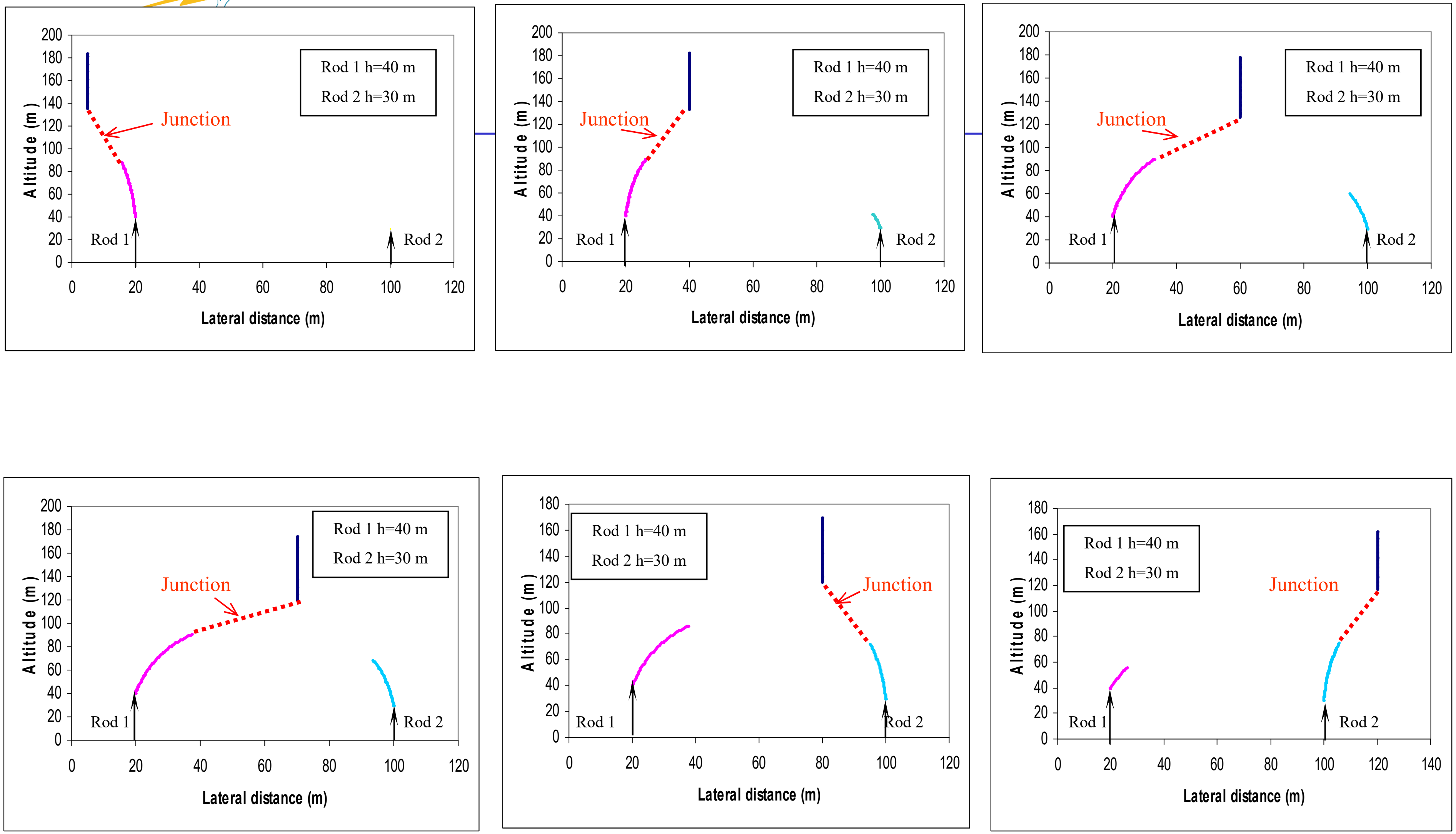


A 3D illustration of a protected structure struck by an oblique downward leader. I=50 kA, Rv=1, lightning rod height h=11 m, structure height H=100 m and width W=40 m.

UUL and UCL phenomena

M. Pecka, Z. Pelíšková

Upward leaders and attachment, Cummins et al



Two rods in competition. I= 50 kA, Rv=1.

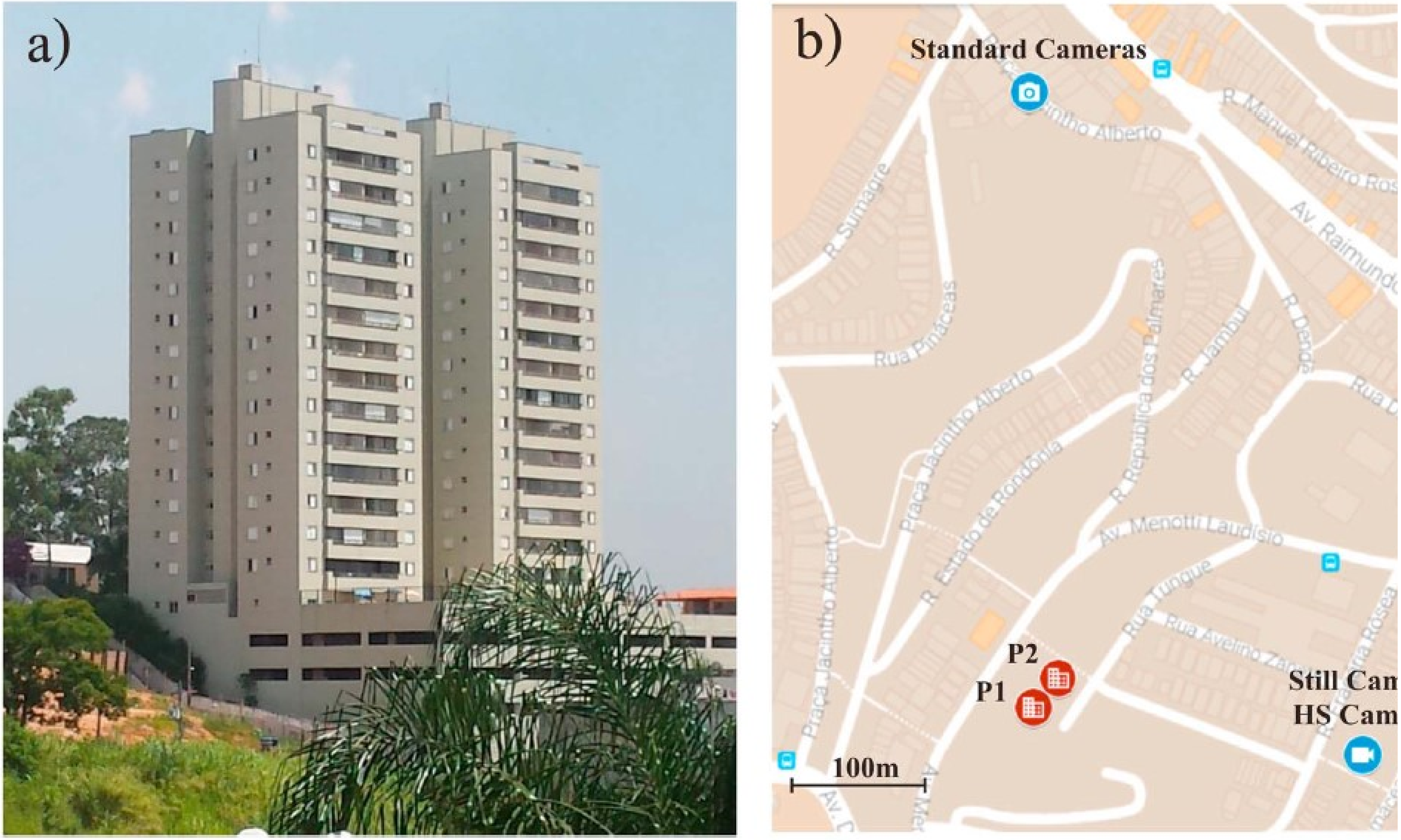
Recent research by Saba et al 2016-2017

Recent outstanding research in natural conditions have been successfully achieved by Saba et al in Brazil and published in 2017. Two identical buildings 52m high equipped with vertical rods have been observed by means of high speed video and still cameras. Flashes around the buildings and the ones hitting the structure were monitored using a lightning detection network.

Lightning attachment process to common buildings

M. M. F. Saba[1], A. R. Paiva[1], C. Schumann[2], M. A. S. Ferro[3], K. P. Naccarato[1], J. C. O. Silva[4], F. V. C. Siqueira[5], and D. M. Custódio[3]

[1]INPE—National Institute for Space Research, São José dos Campos, Brazil, [2]School of Electrical and Information Engineering, University of Witwatersrand, Johannesburg, South Africa, [3]IAE—Institute of Aeronautics and Space, São José dos Campos, Brazil, [4]APTEMC—Analysis, advices and training on EMC, São José dos Campos, Brazil, [5]Electrical Engineering, ITA—Technological Institute of Aeronautics, São José dos Campos, Brazil


a)
b)
Standard Cameras
P2
P1
Still Cam
HS Cam
100m

Main observations of Saba's team

Three cases of lightning striking the buildings are fully reported. In all cases, UCL (Upward Connecting Leader) is always accompanied by an UUL (Upward Unconnected Leader) from the vertical air termination of the other building.

2D and 3D downward leader velocities may be computed in the range 1.4-2.8 10^5 m/s. UCL and UUL average speeds are in the range 4-7 10^4 m/s. Lightning currents are close to 20 kA and the video frame rate is chosen equal to 10,000 or 20,000 images per second.

As expected, during the final jump, the upward positive leader bridges the final gap.

Case A

Table 1. Cases of Attachments

	Case A	Case B	Case C
Date and time of the stroke	9 February 2014 21:28:37.711490	1 March 2014 22:37:38.962550	25 February 2015 20:05:00.76954
Attachment point	Vertical rod of P2	Vertical rod of P2	Vertical rod of P1
Upward leaders from buildings	P1: one UULP2: one UCL	P1: two UULP2: one UCL	P1: one UCL, one UULP2: two UU
Attachment: stroke order and number of strokes in the flash	Fourth stroke of a four-stroke flash	Fourth stroke of a five-stroke flash	Second stroke of an eight-stroke flash
Estimated peak current of attachment stroke from LLS	−17 kA	−21 kA	−14 kA
Video frame rate (images per second)	10,000	10,000	20,000


downloaded @ dvdvid


downloaded @ dvdvi
Mail - Internet

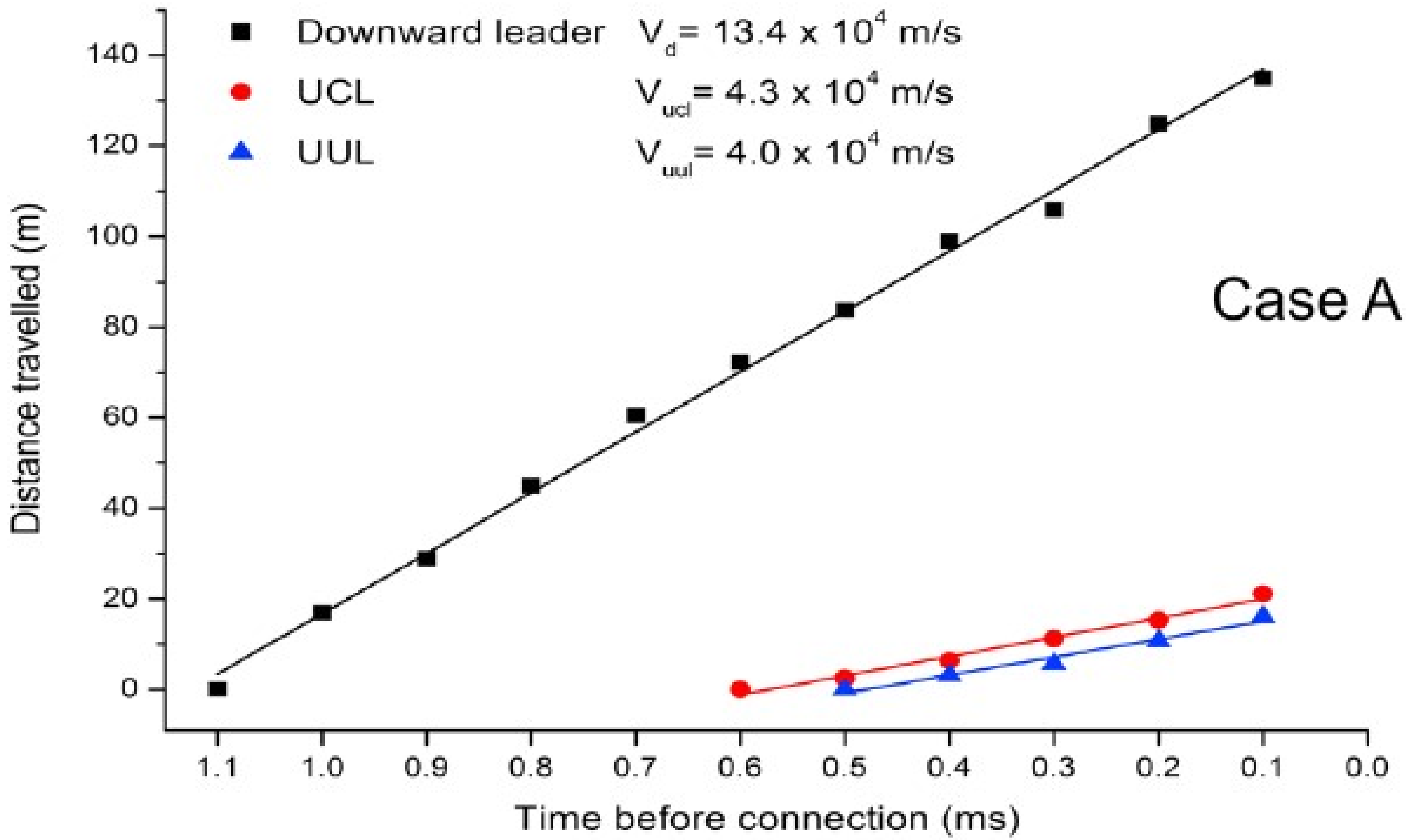

Downward leader V_d= 13.4 x 10^4 m/s
UCL V_{ucl}= 4.3 x 10^4 m/s
UUL V_{uul}= 4.0 x 10^4 m/s
Case A
Distance travelled (m)
Time before connection (ms)
140
120
100
80
60
40
20
0
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

Table 1. Cases of Attachments

	Case A	Case B	Case C
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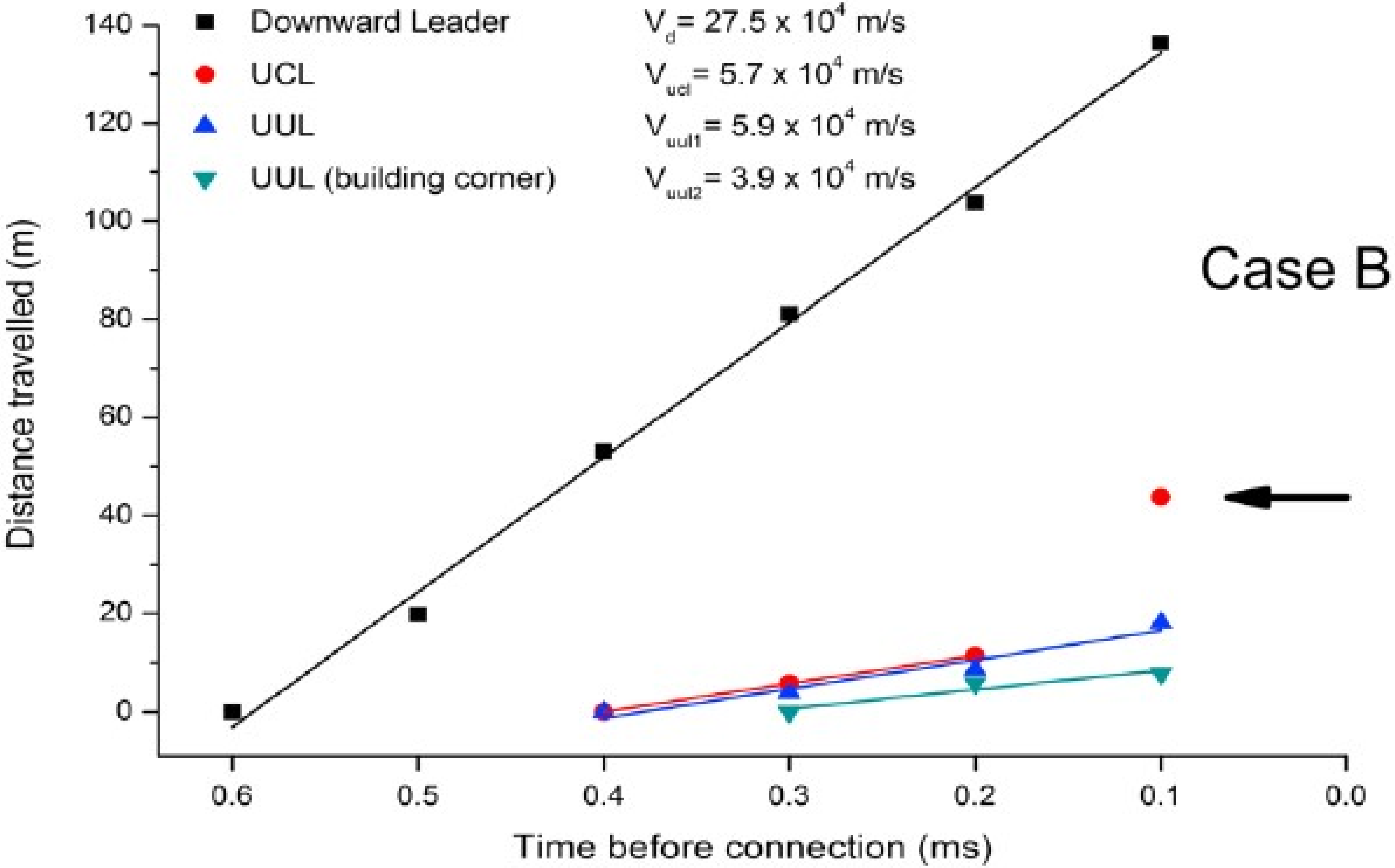
Downward Leader
UCL
UUL
UUL (building corner)
V_d = 27.5 x 10^4 m/s
V_{ucl} = 5.7 x 10^4 m/s
V_{uul1} = 5.9 x 10^4 m/s
V_{uul2} = 3.9 x 10^4 m/s
Case B
Distance travelled (m)
Time before connection (ms)
0
20
40
60
80
100
120
140
0.6
0.5
0.4
0.3
0.2
0.1
0.0

Table 1. Cases of Attachments

	Case A	Case B	Case C
Date and time of the stroke	9 February 2014 21:28:37.711490	1 March 2014 22:37:38.962550	25 February 2015 20:05:00.769540
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Estimated peak current of attachment stroke from LLS	−17 kA	−21 kA	−14 kA
Video frame rate (images per second)	10,000	10,000	20,000


00:25


00:26

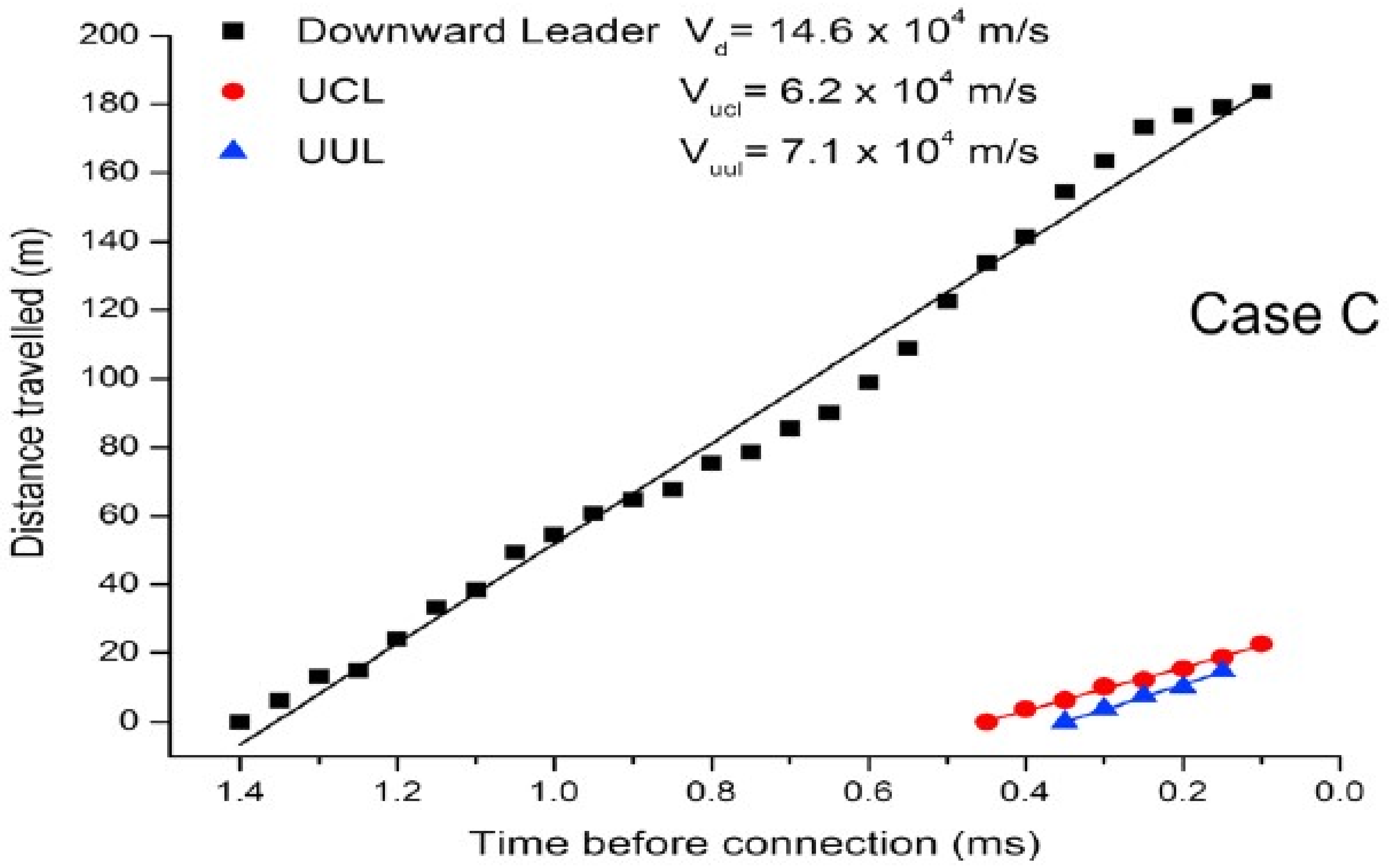
Downward Leader $V_d = 14.6 \times 10^4$ m/s
UCL $V_{ucl} = 6.2 \times 10^4$ m/s
UUL $V_{uul} = 7.1 \times 10^4$ m/s
Case C
Distance travelled (m)
Time before connection (ms)
200
180
160
140
120
100
80
60
40
20
0
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0

Table 2. Characteristics of the Leaders and Striking Distances

	Unit	Case A	Case B	Case C
Downward leader average speed (V_d)	m/s	13.4×10^4	27.5×10^4	14.6×10^4
UCL average speed (V_{ucl})	m/s	4.3×10^4	5.7×10^4	6.2×10^4
Speed ratio (V_d/V_{ucl})		3.1	4.8	2.3
UUL average speed (V_{uul})	m/s	4.0×10^4	$5.9 \times 10^4 3.9 \times 10^4$	7.1×10^4
Time interval between leader inception and return stroke (attachment)	ms	0.54	0.40	0.47
Distance between the down-coming negative leader tip and the tip of the vertical rod at the inception of a stable upward positive leader	m	82	120	62
Distance between the tip of the vertical rod and the negative leader tip at the moment of attachment	m	44	46	40–50

ADVANTAGES OF OUR MODEL

- A 3D numerical model which is based on physical laws and recent studies on the lightning
- Can be used for any LPS
- Open model
- Our numerical model determines quantitatively the conditions for capture of a downward leader by an upward leader emitted by the LPS.
- Our model shows evidences of the competition between upward leaders that determines the real impact point.
- Can be used for an incoming downward leader trajectory
- It explains the striking of some high protected structures.
- Identify the vulnerable points on a complex and elevated structure and improve the lightning protection

Conclusions

- **Comparison between our model and natural observations of Saba are in really good agreement. The general description of lightning attachment is respected.**

- **As expected, we may observe UCL and UUL. Each type of leader can start from a vulnerable point of the structure, a corner, an edge or a roof protrusion (preferentially the lightning rod). Striking distances are inside the expected range.**

Conclusions

- From the theoretical model, it has been shown that rods are in competition when a downward negative leader is incoming to the vicinity of a building. When a rod is in competition with a corner or an edge, situations occur when the corner (or edge) catch the flash, leading to material damages.

- The early launch of a competing leader (becoming UCL) is the key of a successful lightning protection. An important consequence is to reduce the electric field around the other vulnerable points of the structure, so weakening the development of competitive leaders.