



European COST Action P18
*Second International Symposium on
Lightning Physics and Effects*

*Electromagnetic Environment at Very Close Range
from a Tower Struck by Lightning*

A. Mosaddeghi, D. Pavanello, F. Rachidi, and M. Rubinstein



Outline

- Introduction
- Computational Parameters and Case Studies
- Simulations
- Theoretical Explanations
- Sensitivity Analysis
- Conclusions



Introduction

- ❑ The presence of a tower may result in a substantial increase (a factor of 3 or so) of the electric and magnetic field peaks and their derivatives for observation points located at distances exceeding the height of the tower.
(e.g. [Baba and Rakov, 2005; Bermudez, et al., 2005; Rachidi, et al., 2001])
- ❑ Interestingly, the effect of the tower at distances of about the height or the tower or less could result in a significant decrease of the electric field
(e.g. [Baba and Rakov, 2005; Miyazaki and Ishii, 2004; Pavanello, et al., 2004]).
- ❑ In this paper, we discuss the signature of electric and magnetic fields **at very close distances**, within the tower height, to a tower struck by lightning.



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Engineering Return-Stroke Models

Current in the lightning channel:

$$i(z', t) = \left[P(z'-h) i_o \left(h, t - \frac{z'-h}{v^*} \right) - \rho_t i_o \left(h, t - \frac{z'-h}{c} \right) + (1 - \rho_t)(1 + \rho_t) \sum_{n=0}^{\infty} \rho_g^{n+1} \rho_t^n i_o \left(h, t - \frac{h+z'}{c} - \frac{2nh}{c} \right) \right] u \left(t - \frac{z'-h}{v} \right)$$

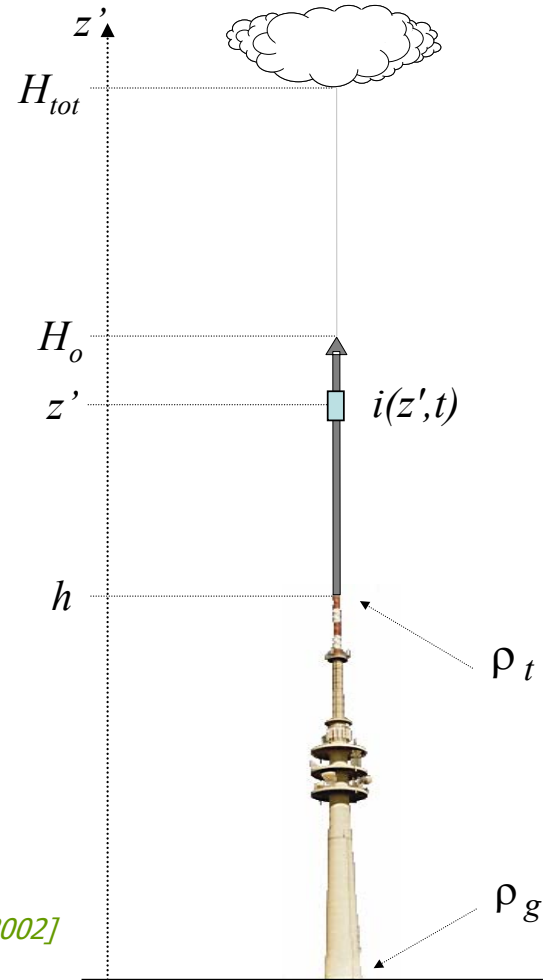
Current in the strike object:

$$i(z', t) = (1 - \rho_t) \sum_{n=0}^{\infty} \left[\rho_t^n \rho_g^n i_o \left(h, t - \frac{h-z'}{c} - \frac{2nh}{c} \right) + \rho_t^n \rho_g^{n+1} i_o \left(h, t - \frac{h+z'}{c} - \frac{2nh}{c} \right) \right] u \left(t - \frac{h+z'}{c} - \frac{2nh}{c} \right)$$

'Undisturbed' current $i_o(t)$:

'ideal' current that would be measured at the tower top if the reflection coefficients at the tower extremities were both equal to zero.

[Rachidi et al., 2002]





Engineering Return-Stroke Models

Current in the lightning channel:

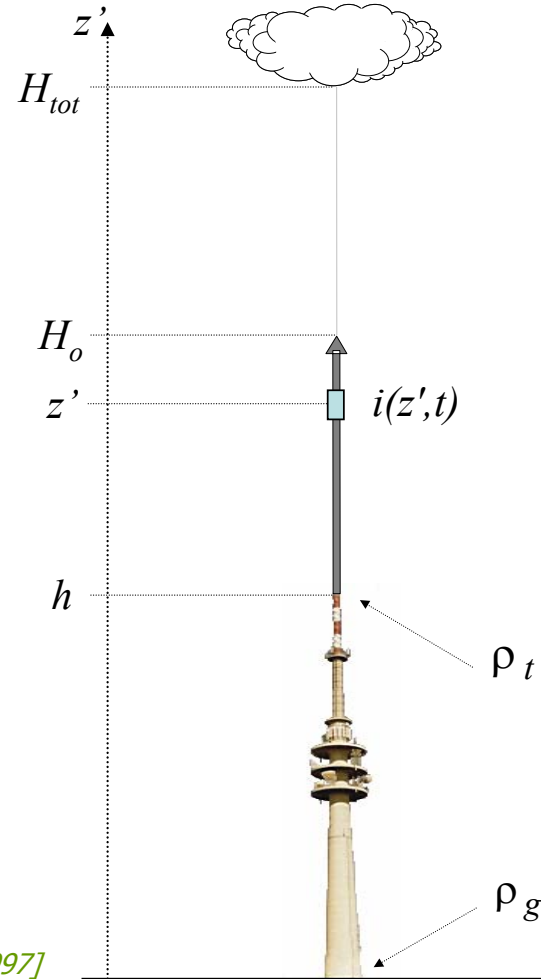
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Model	$P(z')$	v^*
BG	1	∞
TCS	1	$-c$
TL	1	v
MTLL	$1 - z'/H_{tot}$	v
MTLE	$\exp(-z'/\lambda)$	v

[Rakov, 1997]





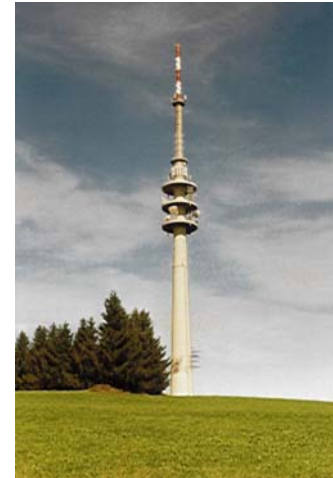
Case Studies



CN Tower
(Canada)

$$\left\{ \begin{array}{l} H = 553\text{m} \\ \rho_t = -0.366 \\ \rho_g = 0.8 \end{array} \right.$$

Peissenberg Tower
(Germany)



$$\left\{ \begin{array}{l} H = 168\text{m} \\ \rho_t = -0.53 \\ \rho_g = 0.7 \end{array} \right.$$



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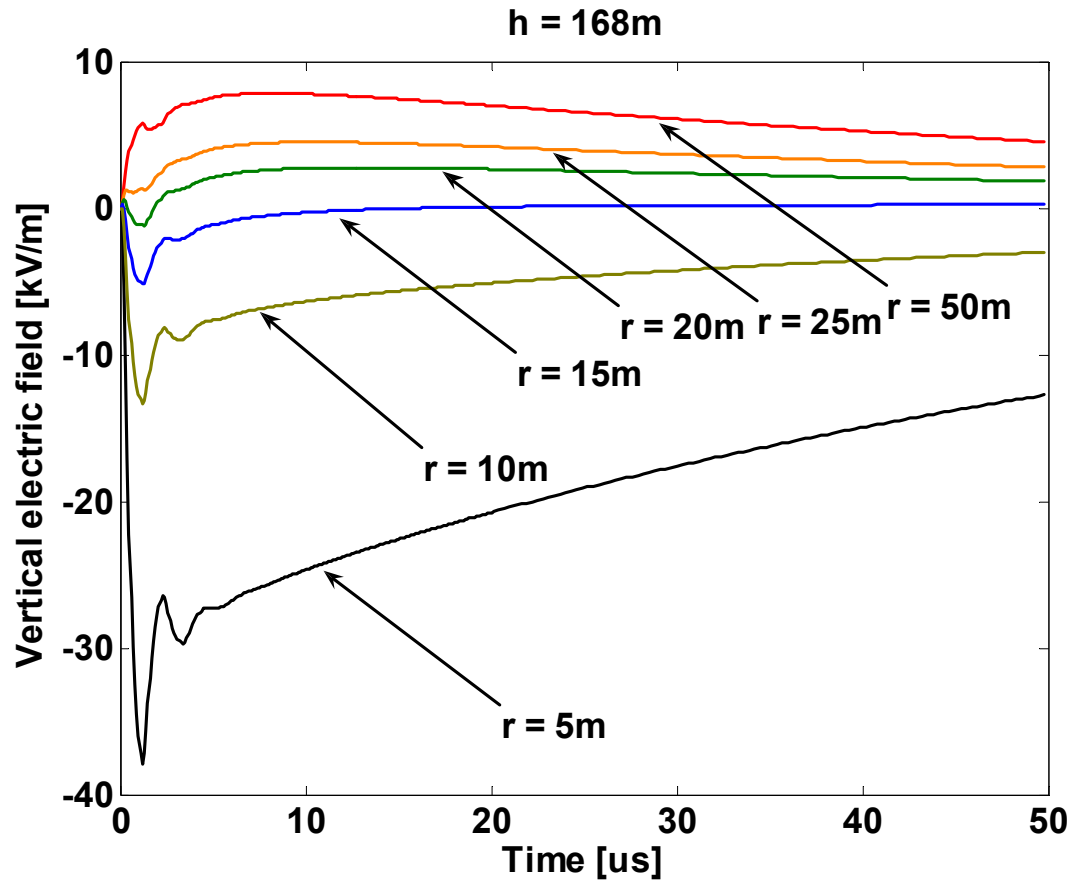
Case Studies

Peissenberg Tower
(Germany)

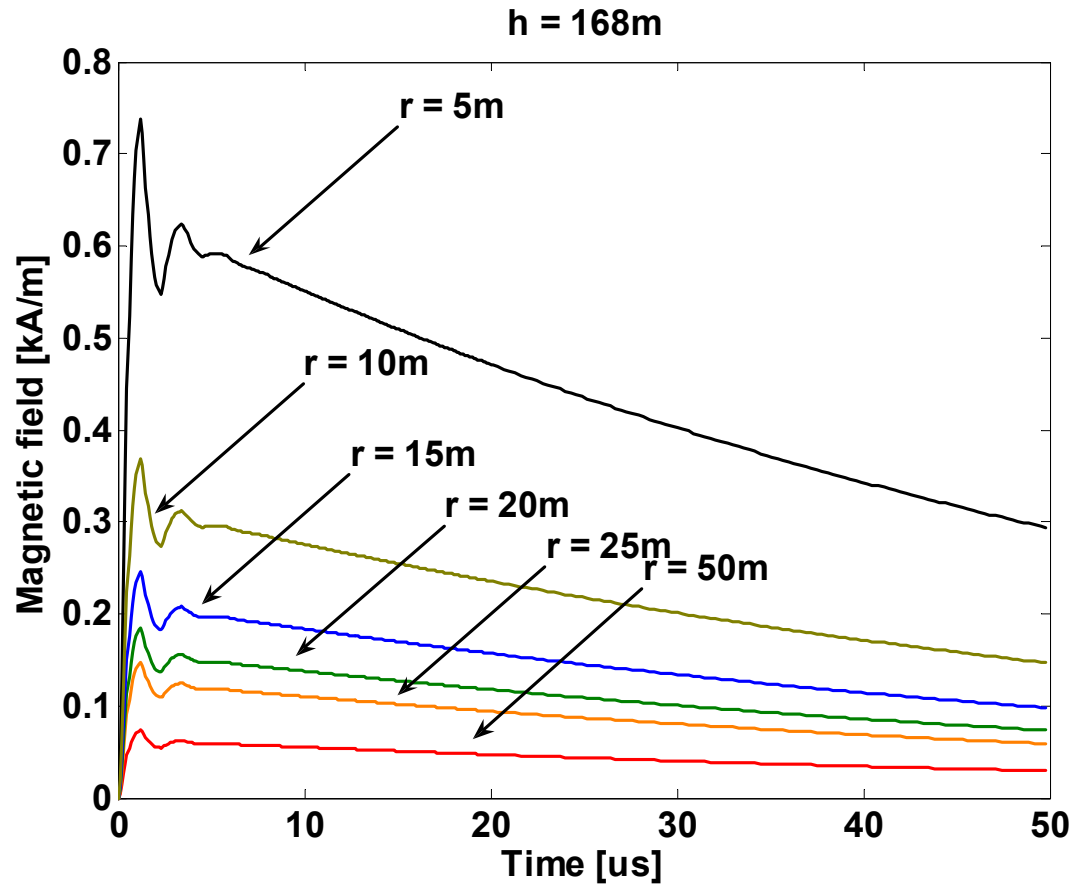


$$\left\{ \begin{array}{l} H = 168\text{m} \\ \rho_t = -0.53 \\ \rho_g = 0.7 \end{array} \right.$$

Results: E-Field



Results: H-Field





Case Studies



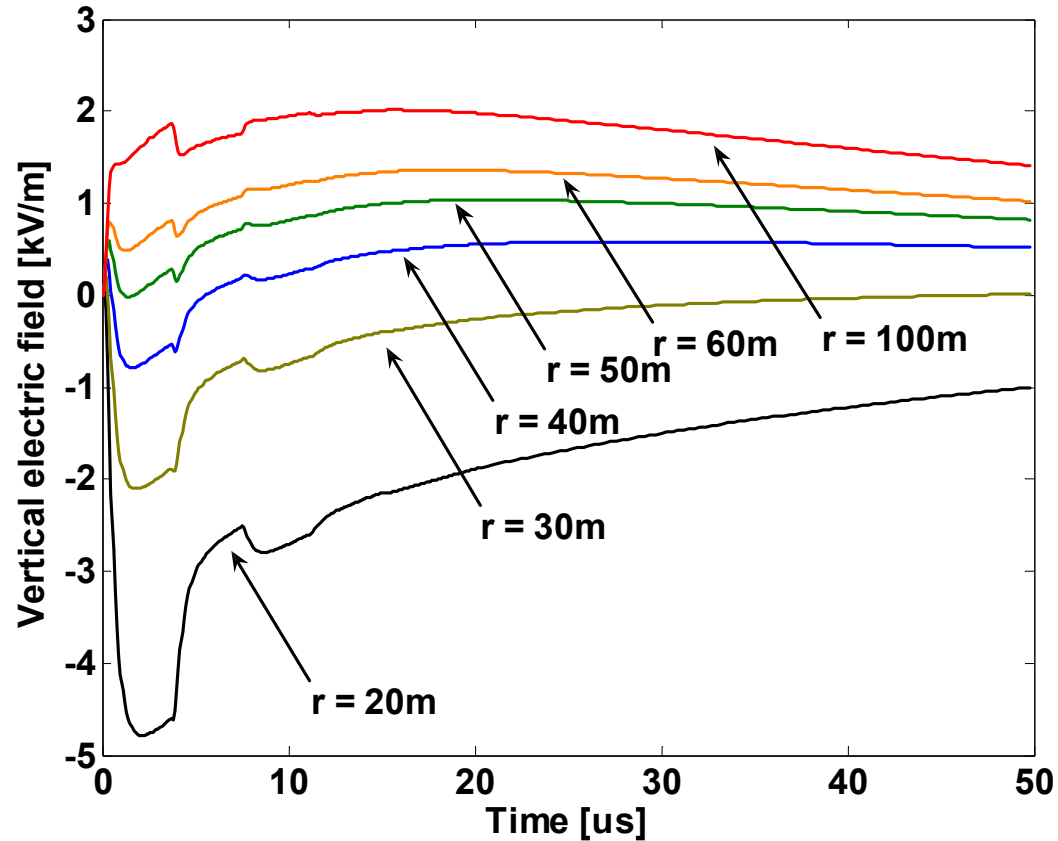
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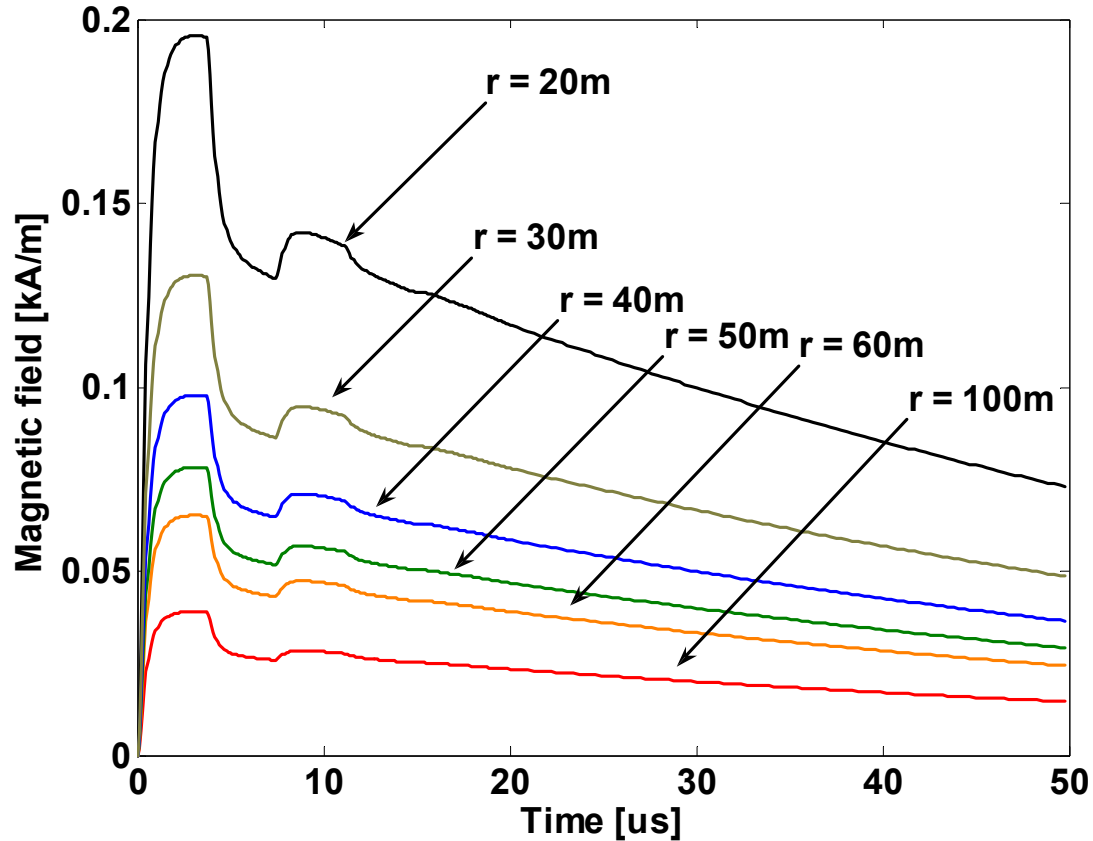
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$h = 553\text{m}$



Results: H-Field

$h = 553\text{m}$



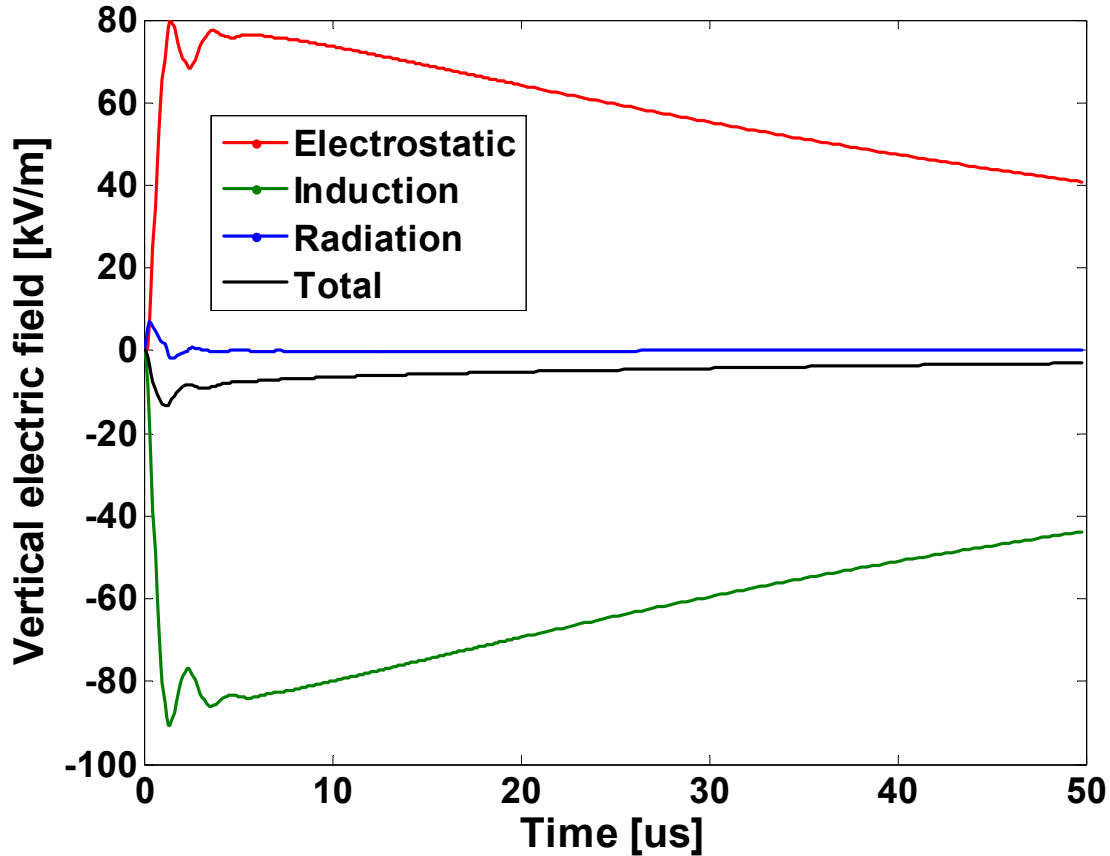


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Explanation 1



Electric field at a distance of 10 m from the 168-m tall struck tower.



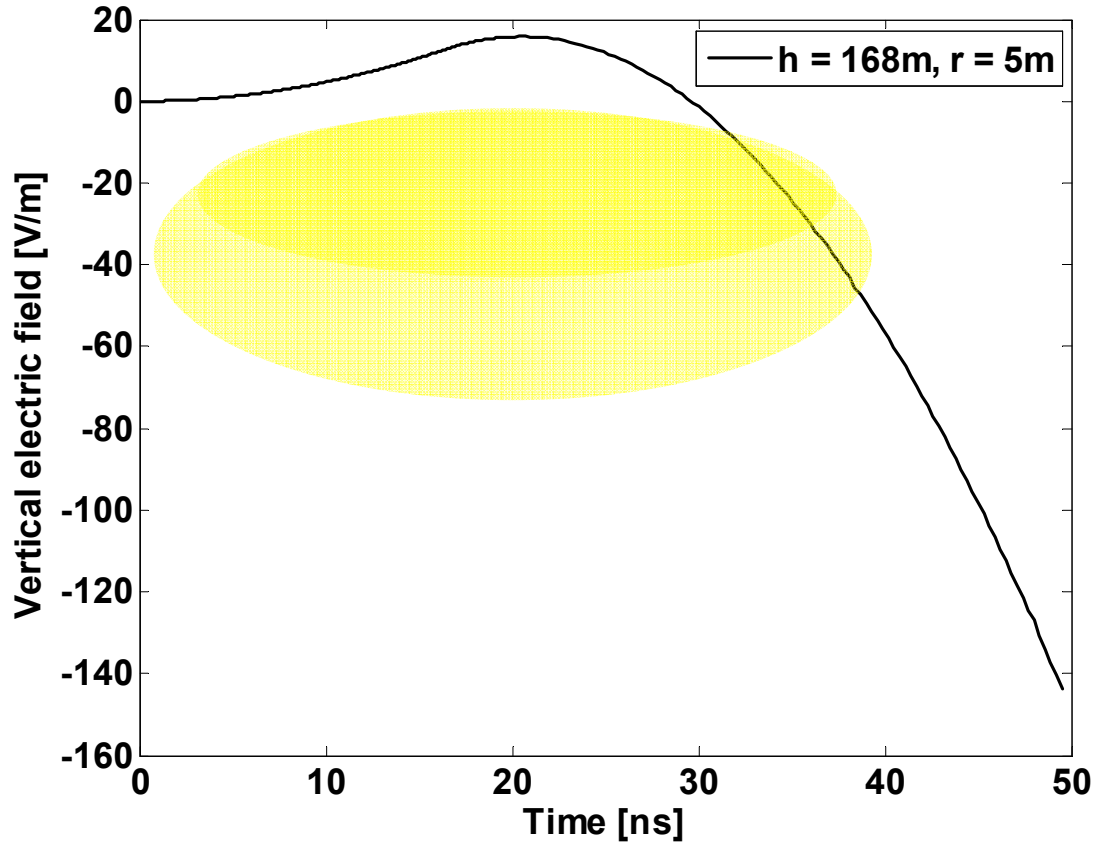
Explanation 2

- Based on the theory developed by Thottappillil et al. (2001), Baba and Rakov (2005) derived the following expression for the special case of a return stroke speed $v = c$ and $\rho_t = 0$ at a horizontal distance r from the tower base:

$$\begin{aligned}
 E_z(r, t) = & \frac{1}{2\pi\epsilon_0 c \sqrt{r^2 + h^2}} i_{SC} \left(h, t - \frac{\sqrt{r^2 + h^2}}{c} \right) \\
 & - \frac{1}{2\pi\epsilon_0 cr} 0.5 i_{SC} \left(h, t - \frac{h}{c} - \frac{r}{c} \right) \\
 & + \frac{1}{2\pi\epsilon_0 cr} 0.5 \rho_g i_{SC} \left(h, t - \frac{h}{c} - \frac{r}{c} \right)
 \end{aligned}$$



Explanation 2



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- How field coe
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would become positive and unipolar.

of the electric field
rms in c field



Explanation 2

- The critical distance up to which the electric field exhibits a negative excursion can be estimated as

$$r_c = (1 - \rho_g) \frac{h}{2}$$

- For the considered 168-m and 553-m tall towers, the estimated values for the critical distance are respectively 25 m and 55 m. These values correspond very well to the simulation results presented previously.

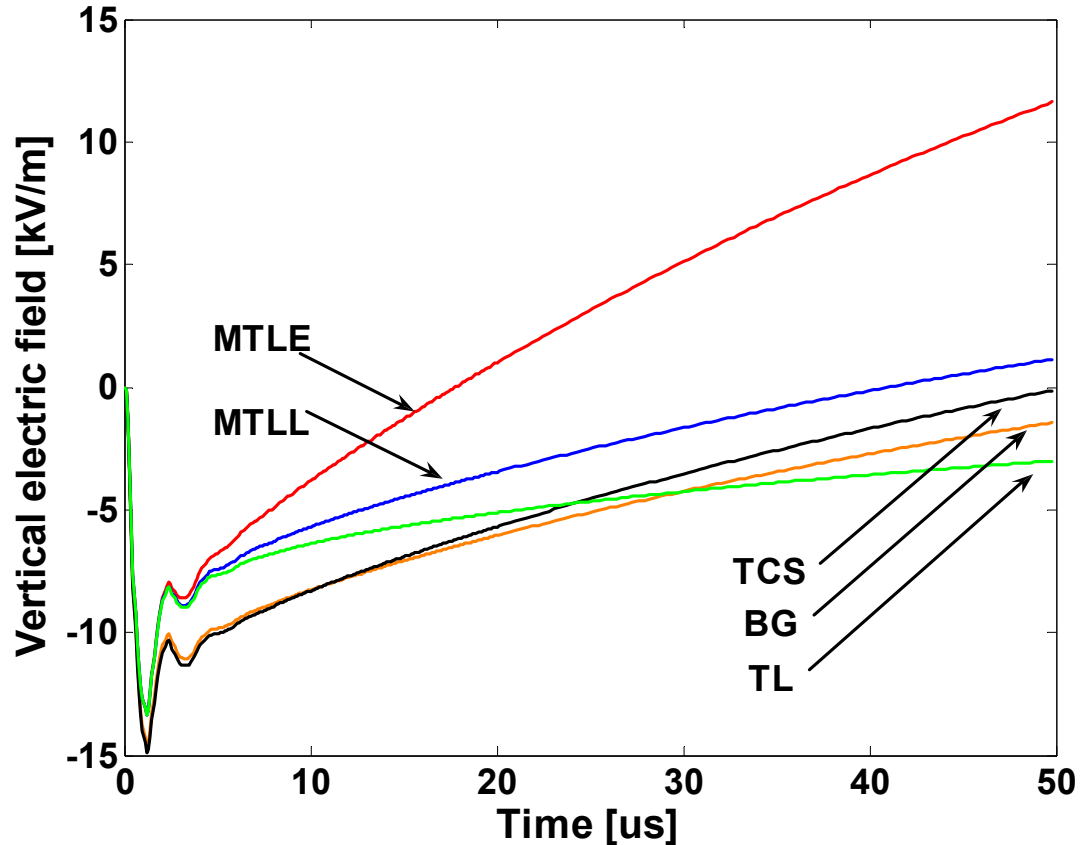


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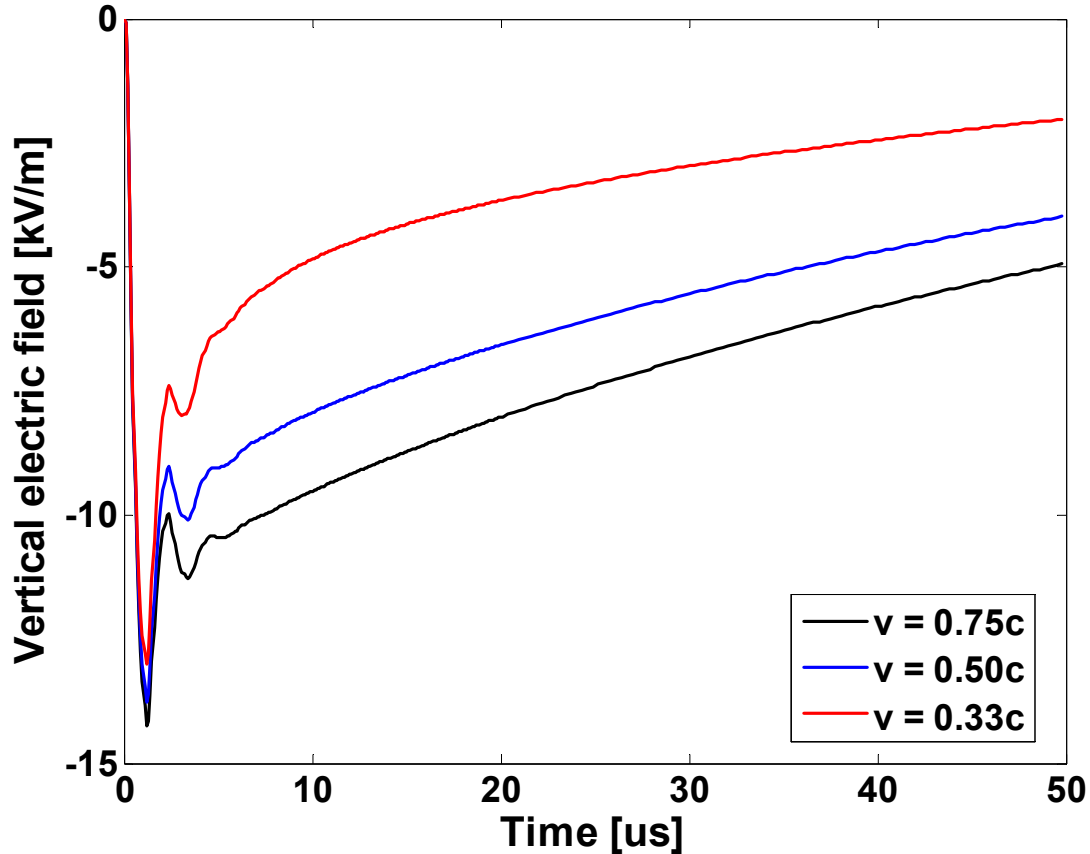
Return Stroke Model



Electric field at a distance of 10 m from the 168-m tall struck tower



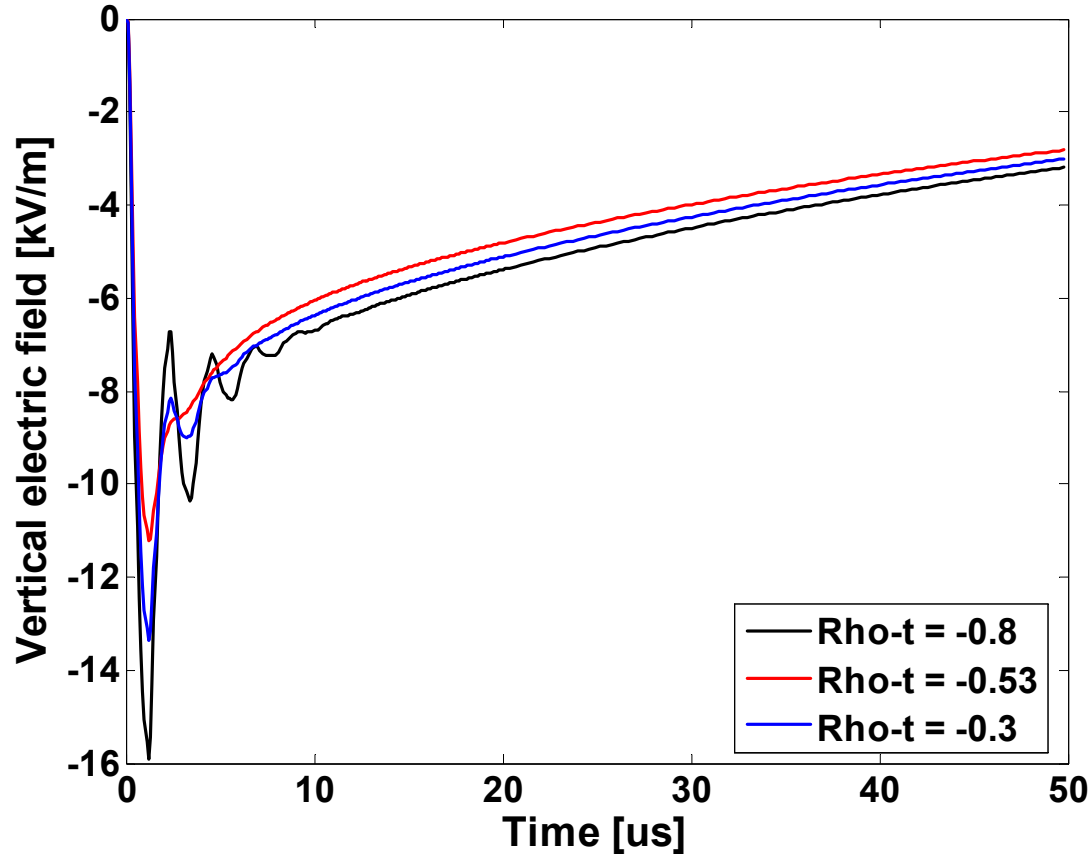
Return Stroke Speed



Electric field at a distance of 10m from the 168-m tall struck tower



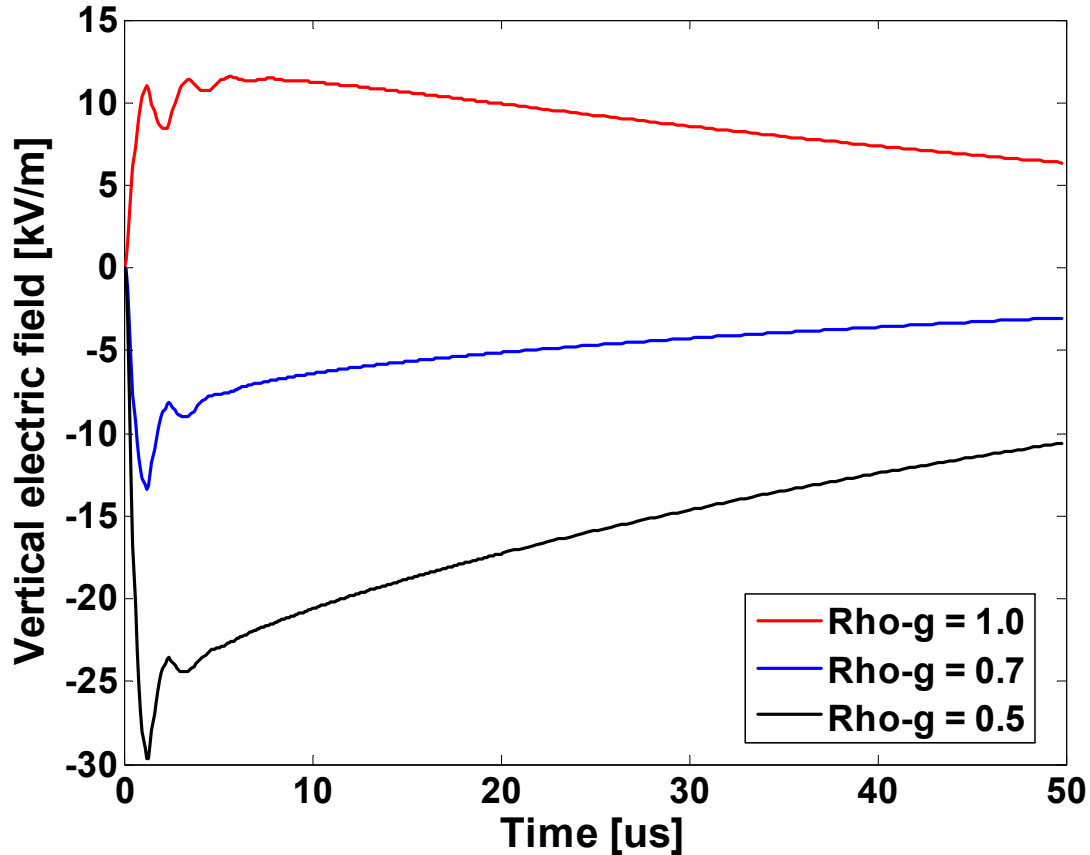
Top Reflection Coefficient



Electric field at a distance of 10 m from the 168-m tall struck tower



Reflection Coefficient at Ground



Electric field at a distance of 10 m from the 168-m tall struck tower



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Conclusions 1

- ❑ Electric field generated by a lightning return stroke to a tall structure can change polarity at very close distance range, typically at distances of about one tenth the height of the struck object or so.
- ❑ This change in the polarity seems to be a specific signature of very close vertical electric fields.
- ❑ Two different theoretical explanations of such an inversion of polarity are given and a simple equation is derived which provides an estimate of the critical distance below which such an inversion of polarity might occur.



Conclusions 2

- ❑ The inversion of polarity depends on the value for the reflection coefficient at the base of the tower and might disappear for reflection coefficients close to 1.
- ❑ Other parameters such as the return stroke speed, the reflection coefficient at the top of the tower, and the adopted return stroke model seem not to have an impact on the inversion of polarity.
- ❑ Experimental data on electromagnetic fields at very close range to a tower struck by lightning are needed in order to confirm the theoretical finding.