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Drift of Space Charge Produced by Glow Corona during Thunderstorms

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Excerpt from the Proceedings of the 2011 COMSOL Conference in Stuttgart

Thunderstorms and discharges
Lightning strike

Taken by: J. Autery, National Geographic (July 1993 Vol.184 No.1)

Thunderstorms and discharges
Glow Corona

Glow corona discharges *(St Elmo's fire) are initiated from grounded objects under thunderclouds (before a lightning strike)*

"the wonderful effects of points, both drawing off and throwing off the electrical fire"

Benjamin Franklin

Glow corona and lightning
Shielding effect

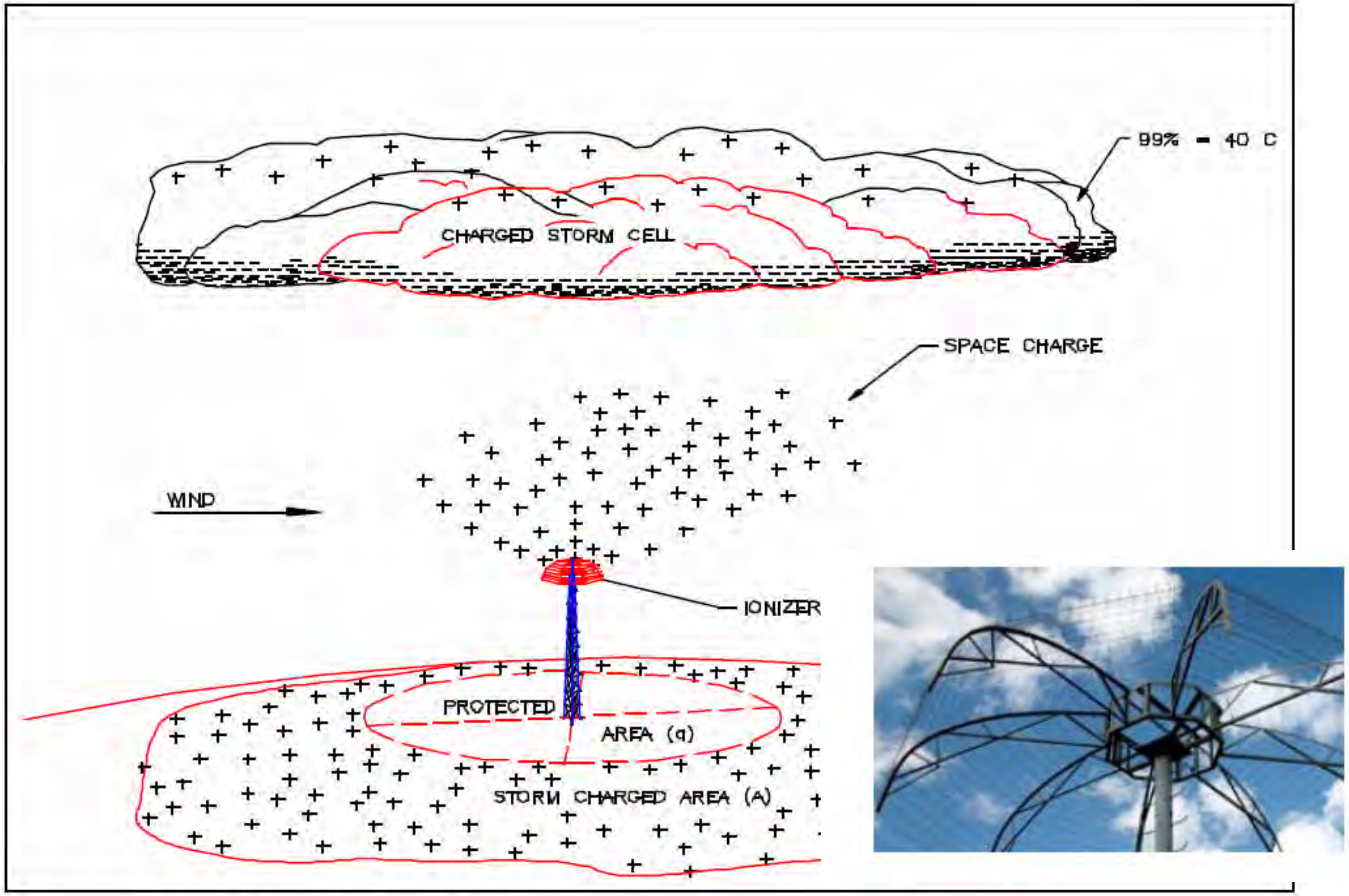
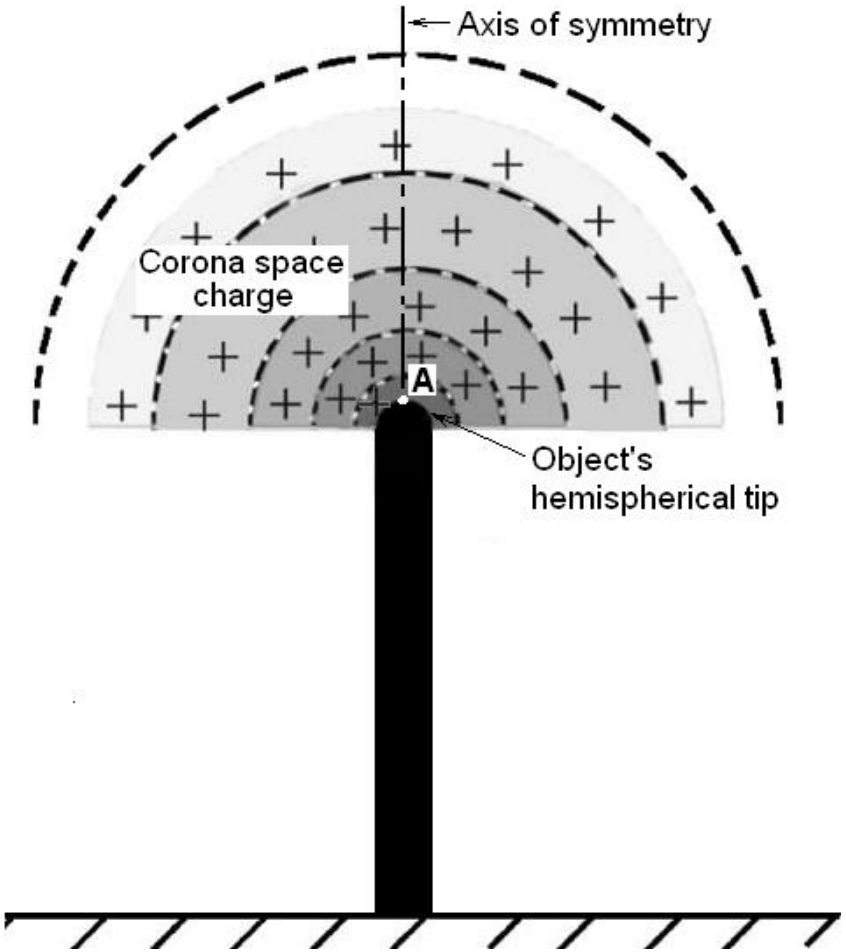


Figure 10: The "Space Charge" Effect

The shielding effect of the ions generated by glow corona on lightning strikes is subject of an ***on ongoing debate*** *in the lightning protection scientific community*

Modeling of glow corona under storms

Existing models in literature



Adapted from Aleksandrov et al, 2007

1D FDM solution of the continuity equations along axis of symmetry for **small ions** n_+, **large aerosol ions** N_+ and **aerosol neutrals** N_a :

$$\frac{\partial n_+}{\partial t} = D \cdot \nabla^2 n_+ - \nabla \bullet \left(n_+ \cdot \mu_{n+} \cdot \overline{E}\right) - k_{nN} \cdot n_+ \cdot N_a$$

$$\frac{\partial N_+}{\partial t} = D \cdot \nabla^2 N_+ - \nabla \bullet \left(N_+ \cdot \mu_{N+} \cdot \overline{E}\right) + k_{nN} \cdot n_+ \cdot N_a$$

$$\frac{\partial N_a}{\partial t} = D \cdot \nabla^2 N_a - k_{nN} \cdot n_+ \cdot N_a$$

Poisson equation

$$\nabla \cdot \overline{E} = -\nabla^2 \Phi = \frac{e \cdot \left(n_+ + N_+\right)}{\varepsilon_0}$$

Kaptzov's assumption:

$$n_+^{(tip)} \rightarrow E_{rod} = E_{crit}$$

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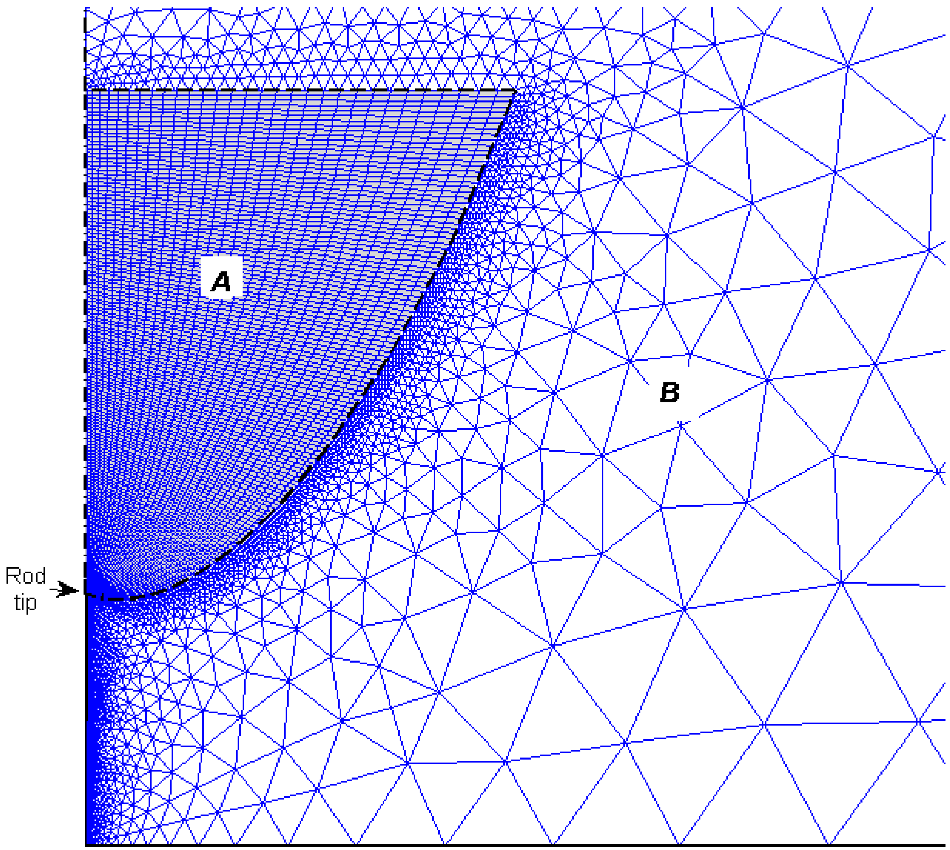
ABB

Modeling of glow corona under storms

Present model



2D FEM *transient* solution of the continuity equations for small ions n_+, large aerosol ions N_+ and aerosol neutrals N_a in COMSOL Multiphysics 3.5a

$$\frac{\partial n_+}{\partial t} + \nabla(-D\nabla n_+) =$$

$$\left(-n_+ \cdot \mu_{n+} \cdot \frac{e\cdot(n_+ + N_+)}{\varepsilon_0} - k_{nN} \cdot n_+ \cdot N_a\right) - (\mu_{n+} \cdot \bar{E}) \bullet \nabla n_+$$

$$\frac{\partial N_+}{\partial t} + \nabla(-D\nabla N_+) =$$

$$\left(-N_+ \cdot \mu_{N+} \cdot \frac{e\cdot(n_+ + N_+)}{\varepsilon_0} + k_{nN} \cdot n_+ \cdot N_a\right) - (\mu_{N+} \cdot \bar{E}) \bullet \nabla N_+$$

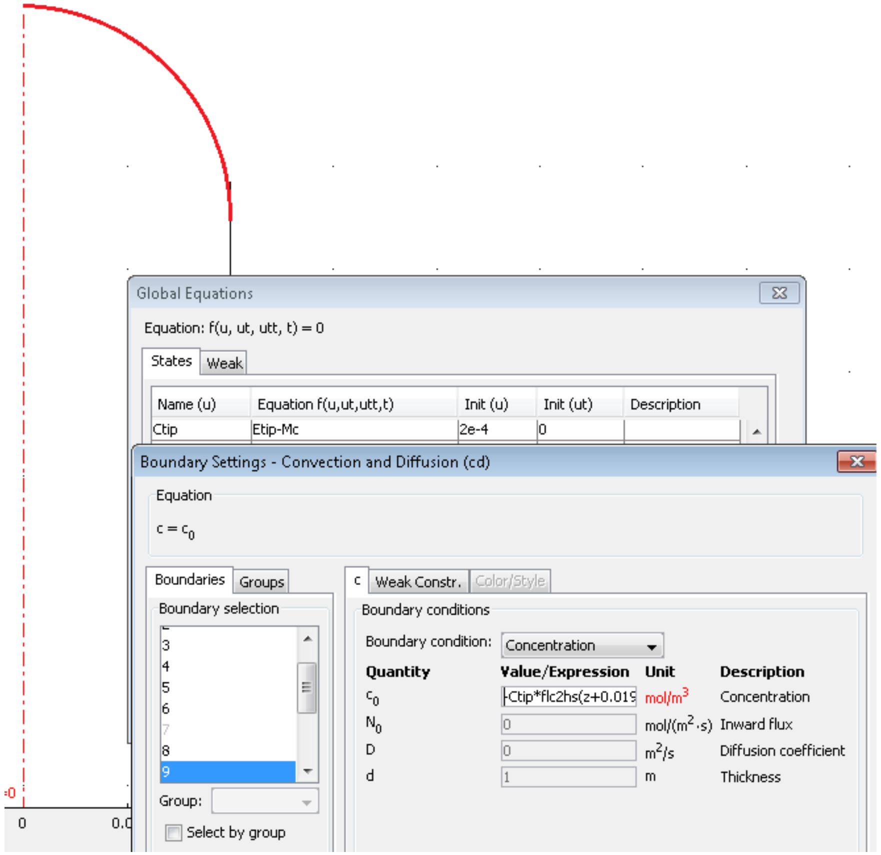
$$\frac{\partial N_a}{\partial t} = D \cdot \nabla^2 N_a - k_{nN} \cdot n_+ \cdot N_a$$

Poisson equation

$$\nabla \cdot \bar{E} = -\nabla^2 \Phi = \frac{e\cdot(n_+ + N_+)}{\varepsilon_0}$$

Modeling of glow corona under storms

Present model



Boundary condition (**Kaptzov's assumption**)

Global expression for n_+ (*Ctip*) such that

$$n_+^{(tip)} \rightarrow E_{rod} = E_{crit}$$

Boundary condition limited to the surface where corona is generated:

$$n_+^{(rod)} = \begin{cases} 0, & E_{rod} < E_{crit} \\ n_+^{(rod)}, & \text{otherwise} \end{cases}$$

Smoothed with a flc1hs function

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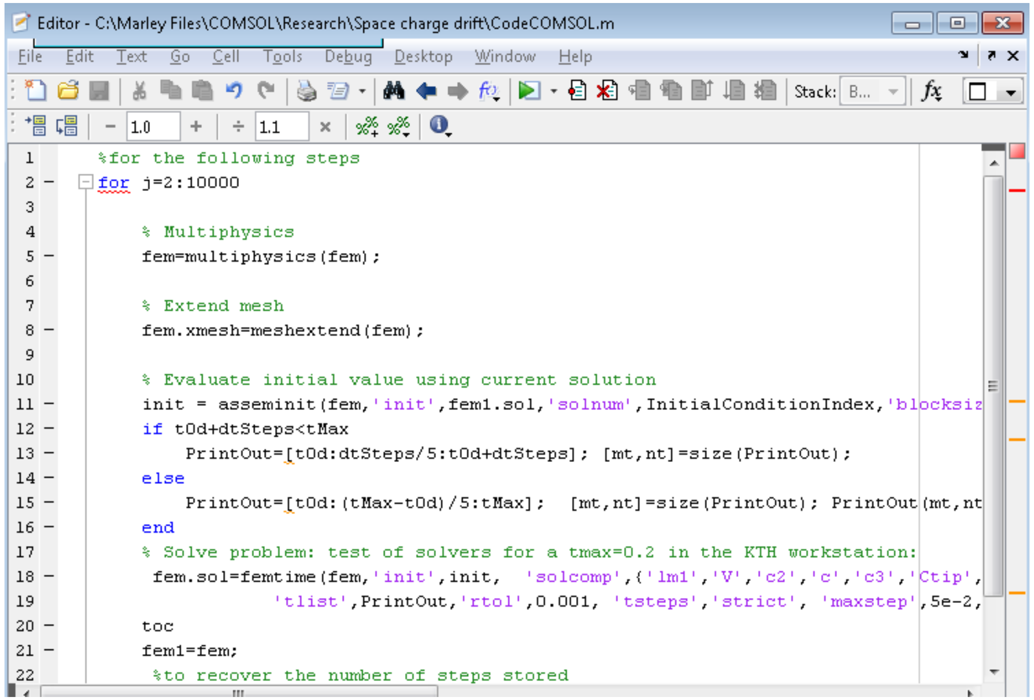
Modeling of glow corona under storms

Present model



Coded with COMSOL

Programming language in Matlab

Solution is **time-splitted** in intervals where the limits for the condition

$$n_+^{(rod)} = \begin{cases} 0, & E_{rod} < E_{crit} \\ n_+^{(rod)}, & \text{otherwise} \end{cases}$$

is evaluated on the boundary for the solution of the following time interval

Validation

Comparison with experiments

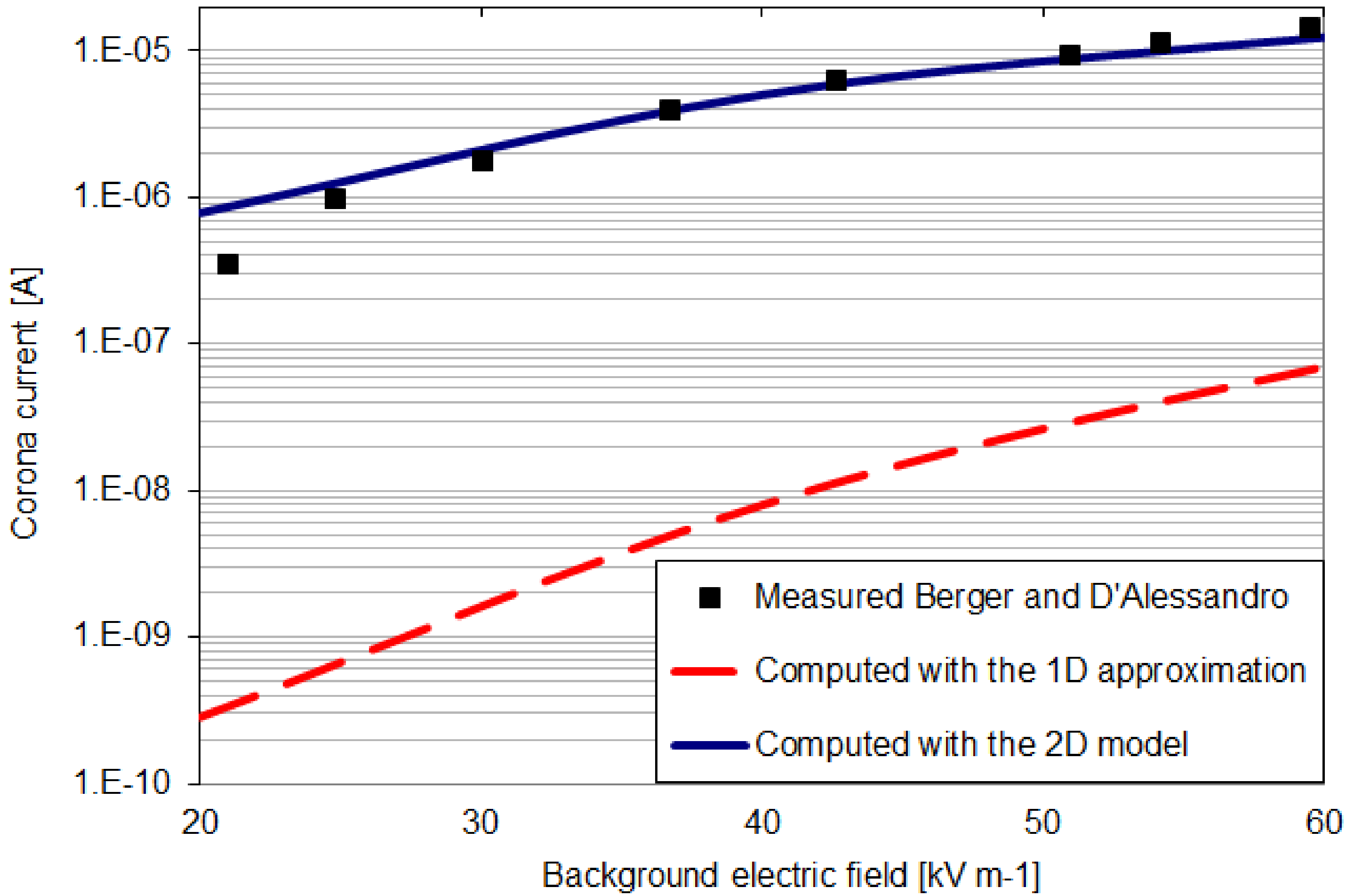
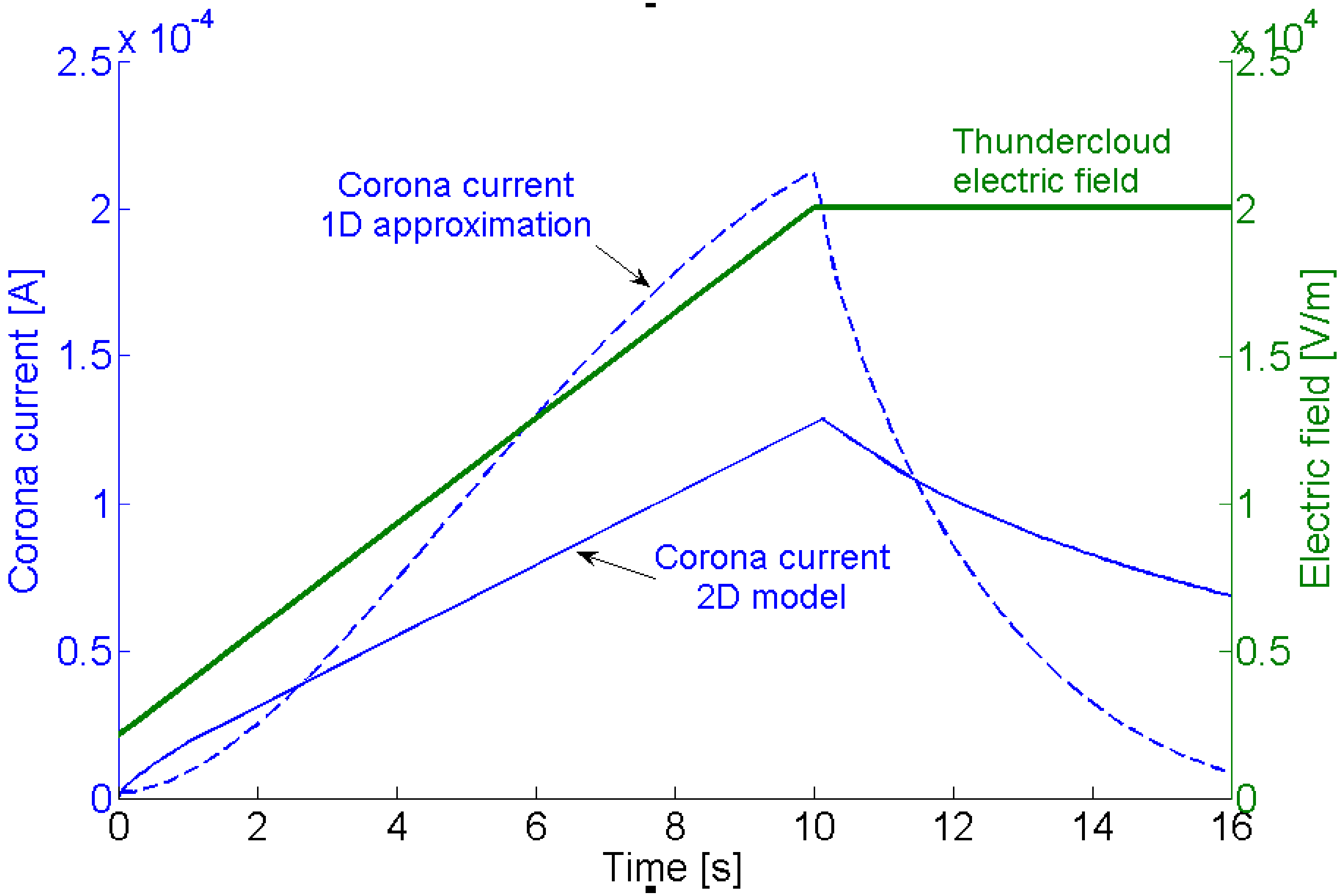


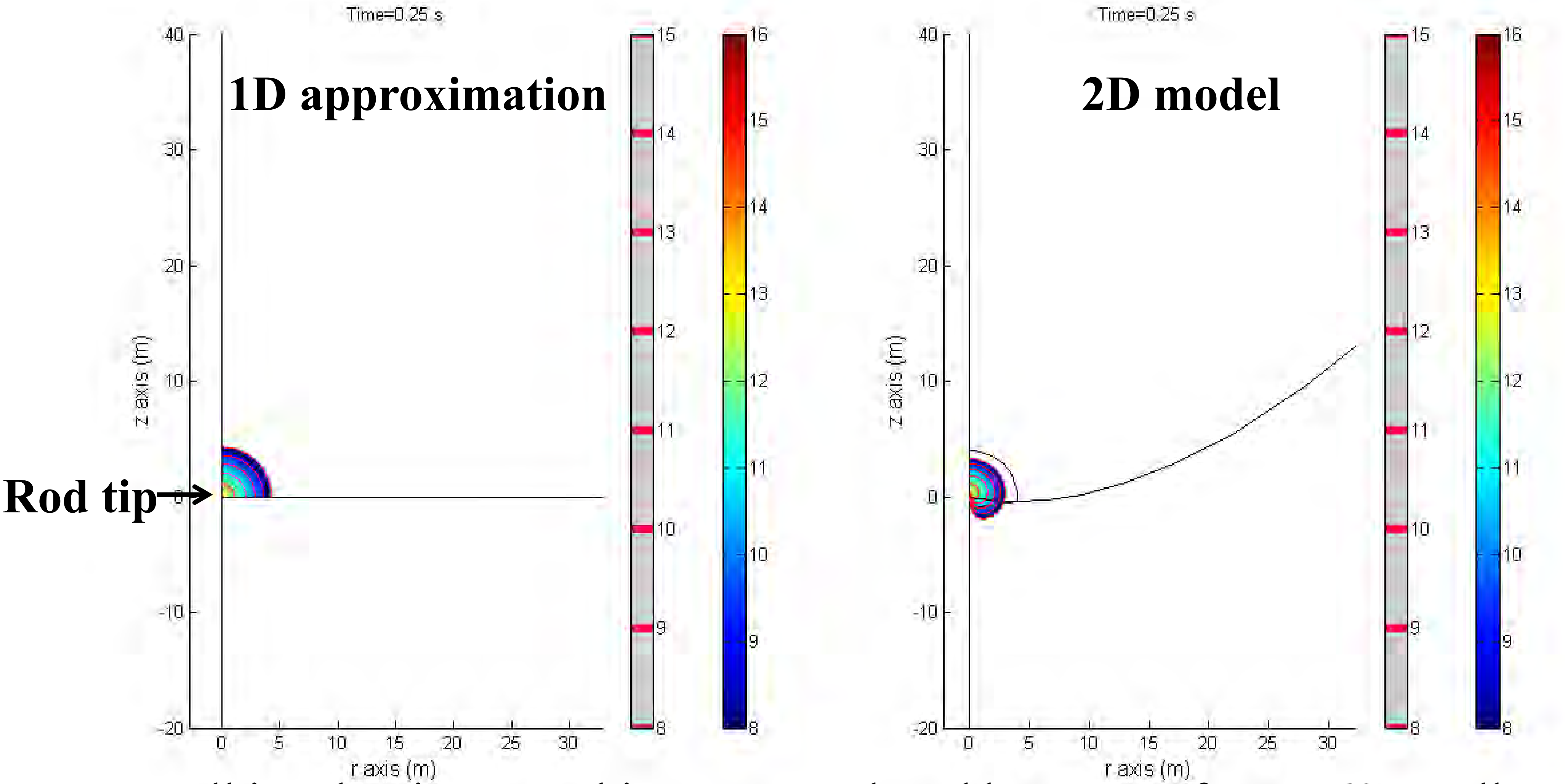
Figure 3. Comparison of the stationary corona current of a 1 m tall pencil-shaped rod computed according to the 1D approximation and with the 2D model. The measured values reported in [18] are also shown.

Simulation results
During thundercloud charging



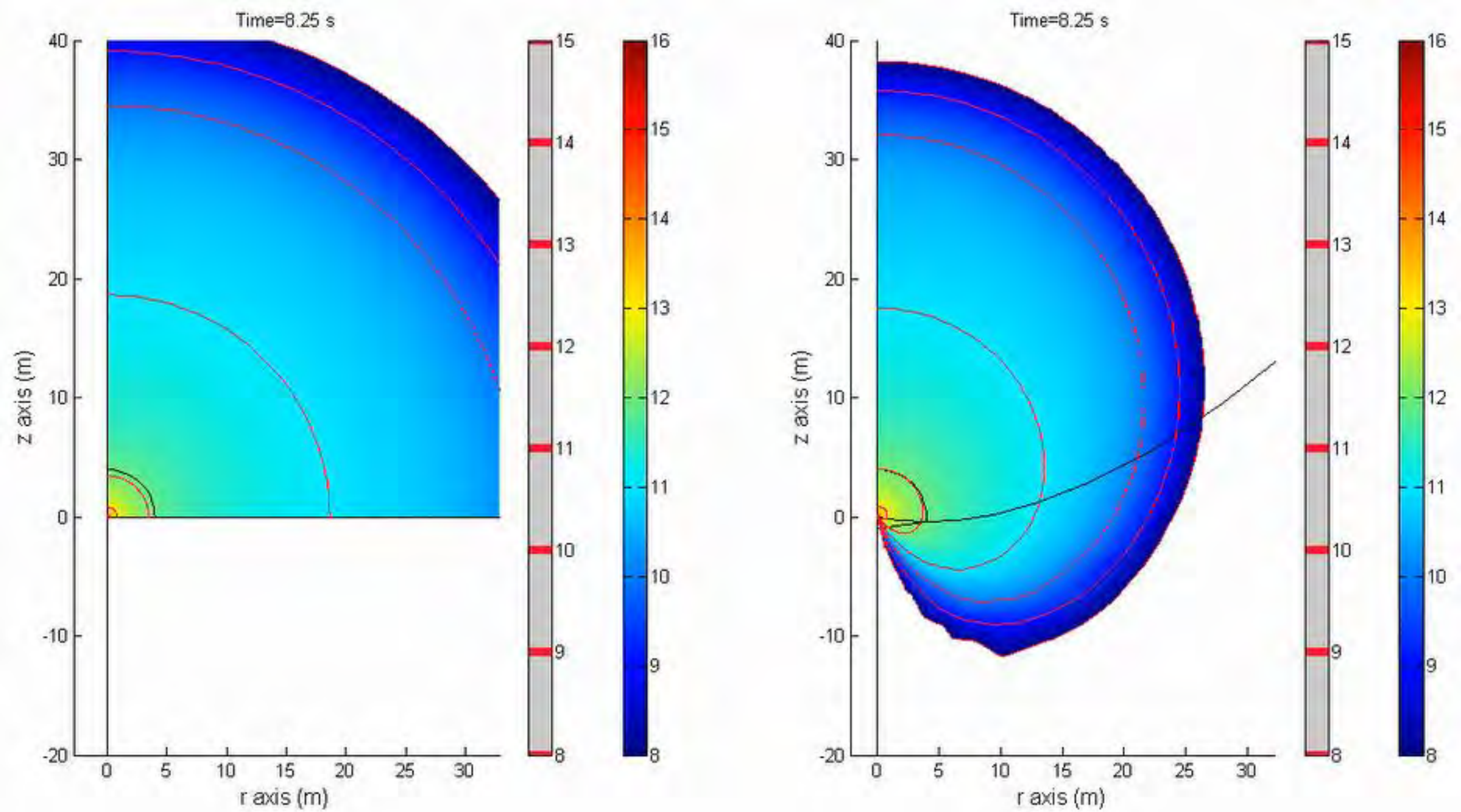
Computed currents *assuming that the thundercloud electric field increases linearly with time until 20 kV/m and then remaining constat*

Simulation results
During thundercloud charging



small ion density per cubic meter produced by corona from a 60 m tall rod

Simulation results
During thundercloud charging



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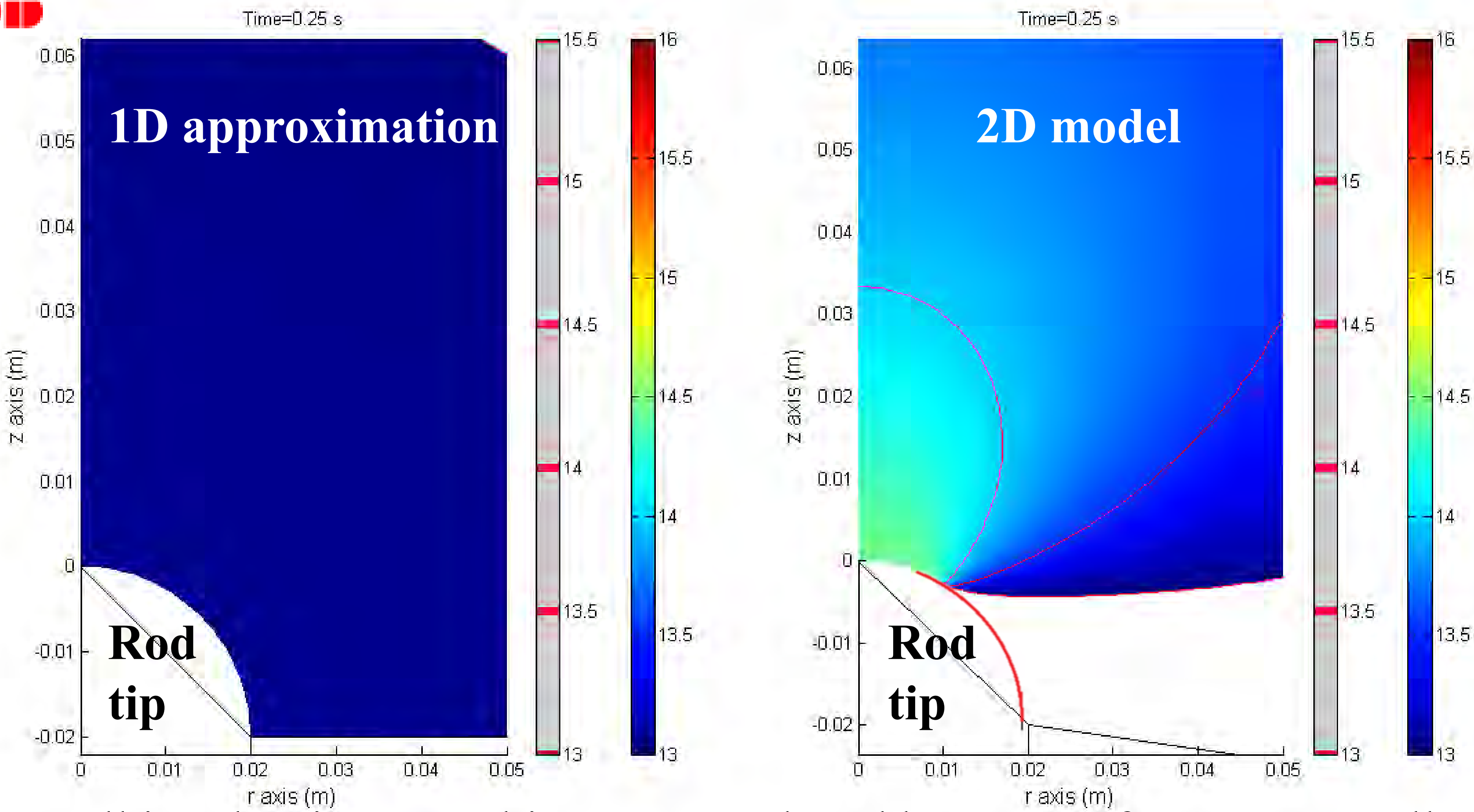
Simulation results

During thundercloud charging



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Simulation results
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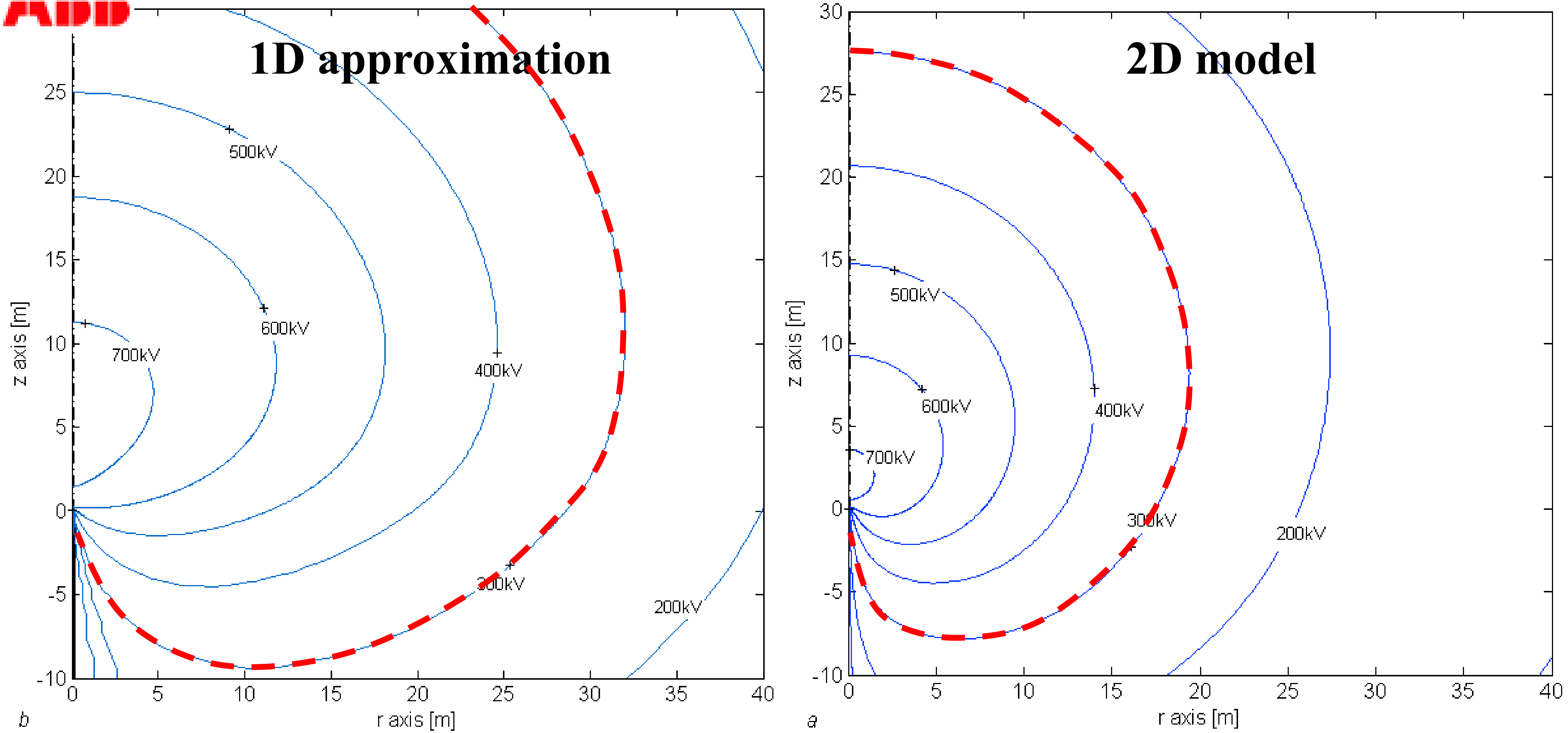

Contour plot of the shielding potential of the generated space charge produced by corona from a 60 m tall rod

Conclusions

- An ion drift **model is successfully implemented** in COMSOL Multiphysics to assess the shielding effect of glow corona generated under thunderstorms.

- The implementation in COMSOL of **boundaries changing in space and time** is a **challenge**

- The obtained results show that **previous estimates** published in the literature (based on a 1D analysis) **exaggerate the shielding effect of glow corona**

Thanks!

"Just between you and me, Roy, I don't know how much longer I can keep doing this company lightning-rod thing."

Further questions?

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