



Drift of Space Charge Produced by Glow Corona during Thunderstorms

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Thunderstorms and discharges Lightning strike



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



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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



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Glow corona and lightning Shielding 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

Figure 10: The "Space Charge" Effect



Modeling of glow corona under storms Existing models in literature

-Axis of symmetry Corona space charge Object's hemispherical tip

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

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

Kaptzov's assumption:

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

Adapted from Aleksandrov et al, 2007



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

$$\frac{\partial n_{+}}{\partial t} + \nabla (-D\nabla n_{+}) = \left(-n_{+} \cdot \mu_{n+} \cdot \frac{e \cdot (n_{+} + N_{+})}{\varepsilon_{0}} - k_{nN} \cdot n_{+} \cdot N_{a}\right) - (\mu_{n+} \cdot \overline{E}) \bullet \nabla n_{-}$$

$$\begin{split} \frac{\partial N_{+}}{\partial t} + \nabla (-D\nabla N_{+}) &= \\ & \left(-N_{+} \cdot \mu_{N+} \cdot \frac{e \cdot \left(n_{+} + N_{+}\right)}{\varepsilon_{0}} + k_{nN} \cdot n_{+} \cdot N_{a} \right) - (\mu_{N+} \cdot \overline{E}) \bullet \nabla N_{+} \\ & \frac{\partial N_{a}}{\partial t} = D \cdot \nabla^{2} N_{a} - k_{nN} \cdot n_{+} \cdot N_{a} \end{split}$$

Poisson equation

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





Modeling of glow corona under storms Present model

Global Eq	uations : $f(u, ut, utt, t) = 0$					
States Name (Weak (u) Equation f(u,	ut,utt,t)	Init (u)	Init (ut)	Description	
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Boundary condition (Kaptzov's assumption)

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

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

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

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2 - 🕞 for j=2:10000								
3								
% Multiphysics								
fem=multiphysics(fem);								
6								
7 % Extend mesh								
- fem.xmesh=meshextend(fem);								
9								
% Evaluate initial value using current solution								
<pre>init = asseminit(fem,'init',fem1.sol,'solnum',InitialConditionIndex,'blocksiz -</pre>								
if tOd+dtSteps <tmax< td=""></tmax<>								
<pre>PrintOut=[t0d:dtSteps/5:t0d+dtSteps]; [mt,nt]=size(PrintOut);</pre>								
else								
<pre>PrintOut=[t0d:(tMax-t0d)/5:tMax]; [mt,nt]=size(PrintOut); PrintOut(mt,nt</pre>								
16 - end								
17 % Solve problem: test of solvers for a tmax=0.2 in the KTH workstation:								
fem.sol=femtime(fem,'init',init, 'solcomp',{'lm1','V','c2','c','c3','Cti								
19 'tlist', PrintOut, 'rtol', 0.001, 'tsteps', 'strict', 'maxstep', 5e-	2,							
20 - toc								
21 - fem1=fem;								
22 %to recover the number of steps stored	-							

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 **ROYAL INSTITUTE** OF TECHNOLOGY







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





Simulation results During thundercloud charging





Simulation results During thundercloud charging





Simulation results During thundercloud charging



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





- 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!

Further questions? <u>marley@kth.se</u>



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



