TLE Modeling: An Overview

A. Luque[1], F. J. Gordillo-Vázquez[1]

[1] *Instituto de Astrofísica de Andalucía, IAA-CSIC, PO Box 3004, 18080 Granada, Spain,*

This is a tutorial talk about the modeling of Transient Luminous Events (TLE). We will take a walk from the micro- to the macro-physics of TLEs and review the most relevant models for each of the processes that take part in them. We start by briefly reviewing the physics of free electrons in a gas and then we move to kinetic models for atmospheric plasmas. Next, we study electromagnetic propagation models for elves, drift-reaction models for sprites and halos and streamer-to-leader transition models for jets. Finally we will talk about large-scale conductor models for fully branched streamer trees in sprites.

1. Transient Luminous Events

Transient Luminous Events are brief light emissions in the upper atmosphere produced by the electrical activity of a thunderstorm. The quasi-electrostatic field created at high altitudes by an uncompensated charge in the cloud is responsible for sprites and halos. Sprites are filamentary discharges composed by tens or hundreds of streamers and spanning altitudes from about 50 to 80 km; halos are diffuse, pancake-like emissions around 80 km of altitude and with diameters of about 100 km. The electromagnetic pulse (EMP) radiated from an impulsive lightning discharge produces elves: expanding, doughnut-shaped emissions at about 90 km. Closer to the ground, a thundercloud sometimes discharges with an upward-propagating jet, sometimes called giant blue jet or simply giant if it reaches all the way up to the ionosphere.

2. Modeling TLEs

The physics of transient luminous events is described by the acceleration and multiplication of free electrons in air at different pressures. These processes are coupled to electromagnetic fields created by space charges inside or close to the TLE and by the remote lightning discharge. In this tutorial talk, we will review the models of TLEs currently in use. Here we offer a few selected examples.

2.1 Sprites and halos

Usually sprite and halos are modelled using drift-reaction models coupled with quasi-static fields [1–3]. Figure 1 provides an example of a drift-reaction simulation used to investigate the origin of the persistent spots of luminosity in a streamer channel called *beads*. Since halos can be considered almost planar, neglecting their convexity leads to simpler, zero-dimensional models that have been suceesfully applied to investigate their chemical impact [4].

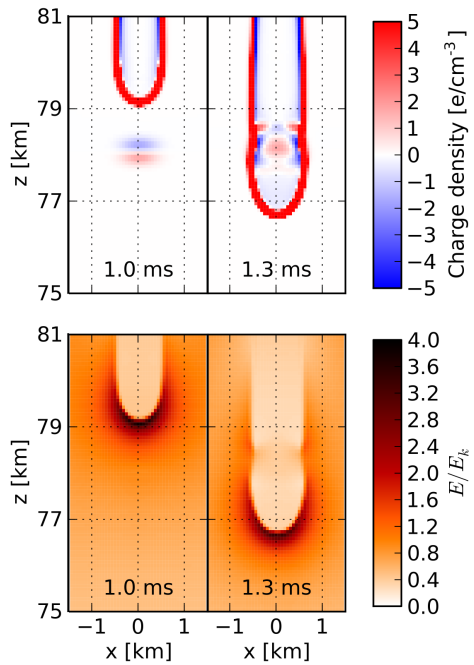

Fig. 1: **Drift-reaction models** are used both for the propagation of individual streamers inside a sprite and for the study of halos. Here a drift-reaction model was used to explain the existence of beads: small, persistent bright dots inside a streamer channel [5].

2.2 Elves

The most widely used tool for the modeling of elves is the solution of the Maxwell equations with a Finite-Differences, Time-Domain solver [6, 7]. The electromagnetic solver is usually coupled with an integrator for the time evolution of species densities. Figure 2 shows a the simulated electromagnetic pulse that produces an elve as it interacts with the lower ionosphere.

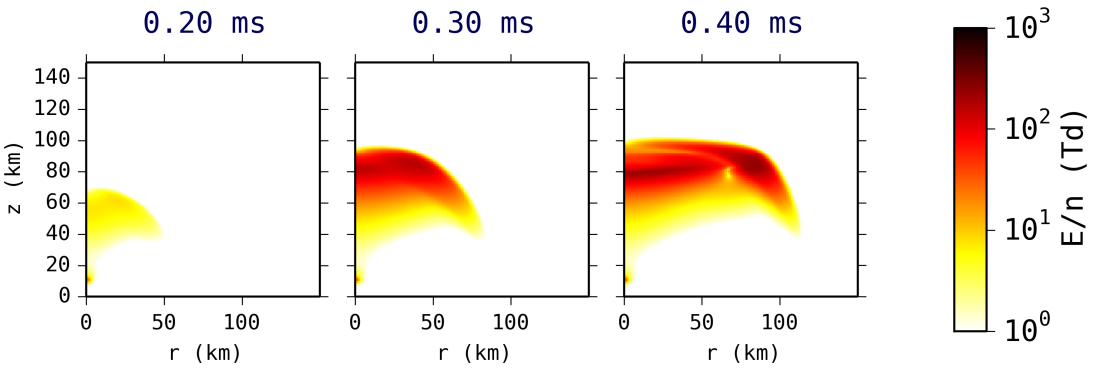

Fig. 2: **FDTD models** are widely used for elves. Here we show the propagation of a lightning-generated electromagnetic pulse (EMP) as it impinges on the ionosphere. This figure was generated using the open-source GREMPY code (GRanada Electro-Magnetic PYthon simulator, `http://www.iaa.es/~aluque/grempy/usage.html`).

2.3 Large-scale charge transport models

The full dynamics of a sprite, including its hundreds or thousands of filaments cannot be realistically captured by drift-diffusion streamer models, which are presently limited to one or at most a few streamer channels. This problem calls for the construction of large-scale models where streamer channels are represented as interacting, one-dimensional objects [8]. We show an example of this kind of model in figure 3.

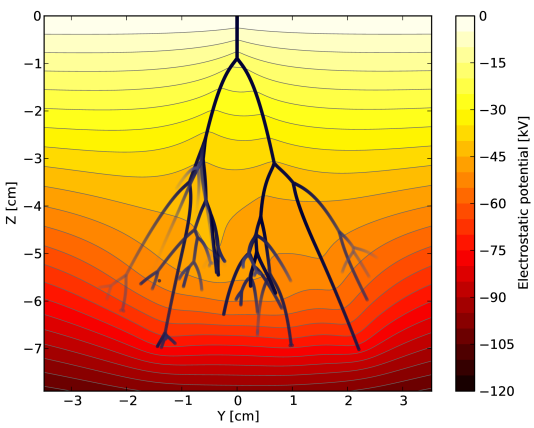

Fig. 3: **Large-scale transport models** represent a streamer tree by a set of interacting 1D conductors. Here we represent the electrostatic potential created by a streamer tree at atmospheric pressure. The simulation was performed with the open-source `strees` code available at `https://github.com/aluque/strees`.

3. Outlook

The final part of the talk will be devoted to a look at the future of TLE simulations. We will discuss issues such as the standarization of computer codes and the coupling between different models.

Acknowledgments: We acknowledge support from Spanish MINECO under project AYA2011-29936-C05-02 and by the Junta de Andalucia, Proyecto de Excelencia FQM-5965.

References

[1] V. P. Pasko, U. S. Inan, T. F. Bell, Y. N. Taranenko, Sprites produced by quasi-electrostatic heating and ionization in the lower ionosphere, J. Geophys. Res.102 (1997) 4529. doi:10.1029/96JA03528.

[2] A. Luque, U. Ebert, Emergence of sprite streamers from screening-ionization waves in the lower ionosphere, Nature Geoscience 2 (2009) 757. doi:10.1038/ngeo662.

[3] N. Liu, Model of sprite luminous trail caused by increasing streamer current, Geophys. Res. Lett. 37 (2010) 4102. doi:10.1029/2009GL042214.

[4] F. C. Parra-Rojas, A. Luque, F. J. Gordillo-Vázquez, Chemical and electrical impact of lightning on the Earth mesosphere: The case of sprite halos, J. Geophys. Res. (Space Phys) 118 (2013) 5190. doi:10.1002/jgra.50449.

[5] A. Luque, F. J. Gordillo-Vázquez, Sprite beads originating from inhomogeneities in the mesospheric electron density, Geophys. Res. Lett. 38 (2011) 4808. doi:10.1029/2010GL046403.

[6] U. Inan, R. Marshall, Numerical Electromagnetics: The FDTD Method, Cambridge University Press, 2011.

[7] R. A. Marshall, An improved model of the lightning electromagnetic field interaction with the D-region ionosphere, J. Geophys. Res. (Space Phys) 117 (2012) 3316. doi:10.1029/2011JA017408.

[8] A. Luque, U. Ebert, Growing discharge trees with self-consistent charge transport: the collective dynamics of streamers, New Journal of Physics 16 (1) (2014) 013039. arXiv:1307.2378, doi:10.1088/1367-2630/16/1/013039.