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Towards a fluid model for the streamer-to-leader transition in lightning channels.

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Electric discharges are a very common phenomenon on Earth's atmosphere. However some of their features are still poorly understood. A sufficiently long electric discharge, such as a lightning channel, propagates along two phases. The first phase is known as "streamer phase" and consists in thin filaments of ionized air that advance due to a high electric field at their tip. The dominant process of ionization is impact ionization, involving electrons and the two major components in the air mass, which are nitrogen and oxygen. In the second phase called "leader phase", the electric current of the streamers has increased the air temperature highly enough so the thermal energy of the molecules present in the air is comparable to the ionization potential of nitrogen and oxygen. The underlying mechanism whereby the streamer-to-leader transition occurs is not precisely known. High-speed observations show that in negative discharges, comprising 90% of cloud-to-ground lightning, this transition is not smooth but mediated by the formation of a "space leader", that is, an isolated hot segment within the streamer region. This space leader is connected to the main leader in a sudden jump and therefore one speaks of a "stepped leader". However, the origin of the space leader is so far unknown.

Here we present recent steps in the modeling of the streamer-to-leader transition, which requires coupling fluid mechanics, electromagnetism and air plasma chemistry. We discuss our work towards a model that solves Euler's equations (3 dimensions reduced to 2 by virtue of symmetry) coupled to electron drift using high-resolution finite volume methods for hyperbolic systems [1] implemented in the software package CLAWPACK. The drift of electrons is determined by a self-consistent electric field, which we obtain by solving Poisson's equation by means of off-the-shelf solvers. Our model also includes a selection of chemical reactions that have a relevant effect on the electron density in air, such as impact ionization, attachment and detachment.

Using this model we plan to test the hypothesis that leader stepping results from an attachment instability that creates low-conductivity, high-field regions in a streamer corona, as recently discussed for sprites in [2]. With our detailed model for gas heating and expansion we will investigate whether the attachment instability leads to heating of air to a temperature high enough to develop space stems. A positive answer to this question would elucidate the physical mechanism of leader stepping.

References

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