Report on TEA-IS Short Visit 4567 – Application of streamer modeling results to large-scale lightning simulations

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Introduction

Despite hundreds of years of study, the fundamental physics behind lightning discharges is poorly understood. The basic physics is known, but how the large-scale (100 km, 1 s) properties of the lightning discharge result from the small-scale fundamental physics (1 mm, 1 ns) is the subject of much debate. Simulations from first principles have been very successful, but can only reach cm-scale. Large-scale processes can be reproduced with approximate simulations, ignoring many of the details, but such simulations can only be applied to limited circumstances.

Purpose of the visit

The proposed short visit is to discuss and attempt to bridge the gap between the small-scale first-principles simulations (Dr. Ebert's area of research) with large-scale approximate simulations (Dr. Carlson's area of research). In particular, Dr. Ebert's small-scale first-principles simulations shed light on the sudden extension of the lightning channel, and therefore provide additional details to better model the step-wise extension of the lightning channel in Dr. Carlson's simulations. Dr. Carlson's work, on the other hand, provides a global context within which to attempt to understand the implications of the small-scale physics.

Description of work and results

The visit consisted largely of discussions between Dr. Carlson, Dr. Ebert, and Dr. Ebert's students. Dr. Ebert has many ideas regarding the formation and extension of the lightning channel, including the fundamental nature of the stepping mechanism, the radial profile of the lightning channel, and the nature of the sheath of change surrounding the channel. Including these ideas in Dr. Carlson's simulations will be

very profitable, and such work was begun during the visit. Two such projects are described as follows

First, the sudden extension of the lightning channel leads to impulsive electromagnetic (EM) wave emission. Such EM waves are routinely detected by radio receivers nearby lightning discharges. Recent work by Dr. Carlson shows that the EM pulses can be well-explained by channel extension only if the channel resistance decreases with a 10 μs timescale and if the migration of the charge away from the conducting channel into the surrounding air is included. These effects cannot fully reproduce the shape of the EM pulses, however, suggesting that more details are needed to fully understand the formation of the EM pulses. This suggests that such EM pulses may also provide information about the smaller-scale plasma physics of the channel and how it extends. As discussed during the visit, Dr. Ebert's ideas about channel extension, implemented in Dr. Carlson's simulations, will predict the behavior of such EM pulses from first principles. This projects is ongoing and will be written into a paper starting early in 2012.

Second, the shape and behavior of the sheath of charge surrounding the lightning channel was also discussed. During the visit, a variety of approaches to understanding this sheath of charge were discussed, in particular with Christoph Koehn, one of Dr. Ebert's students. One particularly promising approach simplifies the behavior of the sheath of charge as a single partial differential equation describing charge density and motion. Appropriate treatment of this partial differential equation will help determine how quickly the sheath forms and how quickly it expands. Such results can be tested by implementation in Dr. Carlson's large-scale simulations. This project is also ongoing and will also be written into a paper starting early 2012.

Future collaboration

These ongoing projects are clear and promising bases for future collaboration. Further opportunities for collaboration will likely arise as these projects continue. Additionally, other projects and experiments were discussed during the visit, also possibly including experiments done in collaboration with Dr. Lex van Deursen at the Technical University of Eindhoven. Dr. van Deursen has the equipment necessary to generate 2 m sparks which provide another means to test predictions made by Dr. Ebert and Dr. Carlson's simulations.

Comments

This was a very interesting and productive visit, and we gratefully thank the TEA-IS program for funding such activities.