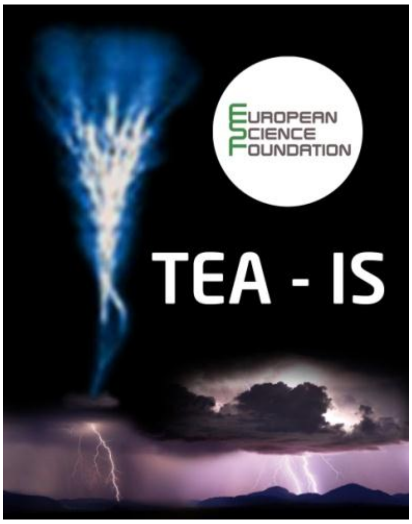
Scientific Report
Investigation of the coupling of fluid and particle model for streamer simulation.



ESF Exchange Grant within the framework of the ESF Activity:
Thunderstorm effects on the atmosphere-ionosphere system (TEA-IS)

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1 Purpose of the visit

1.1 Motivation

The generation of X- and Gamma-rays in electric discharges have been studied intensively since the discovery of Terrestrial Gamma-ray Flashes (TGFs) by the Compton Gamma-ray Observatory in 1994 [Fishman et al., 1994]. Emissions are bremsstrahlung from energetic electrons accelerated in the discharge electric field. Whereas observations now are many, from thunderstorm clouds [Torii et al., 2009], lightning [Moore et al., 2001] and in the laboratory [Dwyer et al., 2005], the phases of the discharge where emissions are generated are still debated and several processes for electron acceleration have been put forward by theorists [Dwyer et al., 2005]. The proposed simulation effort will allow having a reliable numerical tool to experiment with the acceleration of low energy electrons in the enhanced electric field of streamers.

1.2 Aim

The aim is to couple a Drift-Diffusion fluid model from the laboratory EM2C with a Particle in Cell model developed by DTU Space.

Modelling of streamer using the Drift Diffusion equation had been extensively used in the past [Luque, 2012]. It allows simulating streamer propagation solving for electron density and current together with the self-consistent calculation of the electric field. Unfortunately it can't reproduce the acceleration of electron in the runaway regime which is necessary for the generation of X- and Gamma-rays.

Modelling of streamer using a Particle in Cell model have shown to reproduce the generation of runaway electrons from the streamer discharge tip [Chanrion, 2010]. Unfortunately the computational cost to simulate the huge number of electrons of low energy makes it difficult to use for experimentation.

The main interest is to use a drift diffusion fluid model to represent the body of the streamer that contains a huge number of low energy electrons and to use a particle in cell, only when the electron energy gets high.

The visit allowed to have 2 teams expert in the 2 different simulations strategy to meet and collaborate for the realisation of the coupling.

2 Work carried out during the visit.

2.1 Scientists involved.

2.1.1 DTU Space

- Olivier Chanrion, Scientist, DTU Space.

2.1.2 EM2C.

- Anne Bourdon. Senior Scientist, EM2C.
- Tholin Fabien and Pechereau Francois, PhD students, EM2C.
- Zdenek Bonaventura, Scientist, EM2C / Department of Physical Electronics, Faculty of Science, Masaryk University, Czech Republic.

2.2 Preparation

The fluid model has to use some macroscopic parameters to describe the movement of electrons such their mobility and the coefficient of diffusion, ionization and attachment. These coefficients are generally assumed to depend only on the local electric field. In preparation for the coupling, these parameters were pre-computed using full particle simulation for different constant electric fields. Only the contribution of low energy electrons was used in their calculation.

In addition, the particle model needs to receive some source term from fluid model in order to inject electrons from the body of the streamer. The distribution of the electrons were computed and tabulated for different constant electric fields.

2.3 Implementation

2.3.1 Particle model

The particle in cell routines had been adapted or fully rewritten to be included inside the structure of the fluid code. It concerned mainly:

- The particle pusher that makes particle move along the field.
- The particle collider that perform electron-neutral collision
- The particle injector that use the fluid densities and the electric field to create high energy computer electrons.
- The particle weightier that removes computer electrons and ions from the particle part and add up densities to the fluid part.

This work had been carried out for both a 1D model and a 2D model.

2.3.2 Fluid model

The fluid routines had been adapted or fully rewritten to receive input from the particle model. It concerns mainly:

- The use of tabulated macroscopic coefficients.
- A communication routine was written to give access to the plasma densities and electric fields from the fluid simulation.
- A 1.5D model electric field model had been adapted to perform rapid realistic tests.

2.3.3 Main routine

The main routine that loops over the time steps to advance the solution of the simulation in time had been written. The core of it is described below.

- Initialization
- Loop in in time

Calculation of the electric field.

Calculation of the transport parameters.

Inject particles in the particle model.

Perform the fluid model transport.

Perform the fluid model integration of the source (ionization and attachment from low energy particles).

Move the electron in the particle model.

Perform the collision in the particle model.

Calculate densities of particle of low energy from the particle model.

Perform the fluid model integration of the from the particle model.

3 Main results

3.1 Model Development

Resulting from the collaboration, the merging of the 2 models was realized successfully, the 2 groups has now access to 2 codes.

- The first one is a 1.5D model that allows rapid tests of the approach.
- The second is a 2D asymmetrical code.

The first code had been tested successfully. The second works but is not yet validated due to the lack of time.

3.2 Scientific results

The pre-results are yet to be confirmed but so far, we have observed some interesting findings from the work performed.

- The streamer does emit high energy electrons from the discharge. The number of which is low enough to be treated as real particle in the model.
- The emissions of high energy electron have an impact on the streamer propagation. It clearly speeds it up while adding some diffusion in front of the streamer.
- The emission of high energy electron seems to pulse.
- It tends to show by correcting it that the local field approximation is not fully valid for high field.

The code allows now to go deeper into the analysis of the results.

4 Future collaborations

The collaboration went really well.

The 2 resulting codes are distributing among the 2 groups. It has been agreed that any results coming from the study will be shared.

Future collaboration includes study that is planned to be performed in common, the most interesting are:

- The study of the altitude dependence of the emissions of high energy electrons.
- The study of the impact of high energy electron on the streamer propagation.
- The study of the impact of high energy electron on streamer branching.
- The study of the characteristic of the spectrum of hard radiation.

5 Projected publications

The results will be presented at the EGU General Assembly 2013, EGU2013-11588: "Beam-Bulk" streamer modeling for the production of TGFs by Olivier Chanrion et al. The present common work is planned be published in at least a common paper that describes the method and the preliminary results.

6 Other comments.

Non applicable.